The Evolution and Future of Mobile Communication Systems

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1.1. Early Systems

1.1.1. 1921

The Detroit Police Department in 1921 implemented a radio that system allowed the patrol cars to communicate a central control point, although this system has little in common with today's sophisticated modern communications systems, it was the first mobile communications system.

1.1.2. 1939 – 1944 (World War II)

World War II proved that the mass production of VHF radios was possible, by the end of the 1940's there seems to be little standing in the way of the development of mobile communications systems.

1.1.3. 1946

By 1946 in St. Louis it became possible link a vehicle mounted mobile radio unit to a PSTN (Public Switched Telephone Network).

1.1.4. PMR & PAMR (Private Mobile Radio & Private Access Mobile Radio)

These systems were developed by during the 1950's, usually utilising vehicle mounted units. These systems are mainly used by the emergency services, public utilities, road haulage and taxi's. To start with these systems were very basic single site and single channel. However they have developed into much more complex systems, utilising multi site, multi channel, selective calling, connections PABXs/PSTN's and direct calling. (TETRA(Terrestrial Trunked Radio).

1.1.5. TACS (Total Access Communications System)

TACS was the first real mobile communications system*. In 1985 when this system was introduced it was mainly vehicle mounted units, but later developed into mobile units. Unlike the other systems used around the world TACS used the 900 MHz band.

* In the United Kingdom

1.2. GSM (Global System for Mobile Communications)

The concept for GSM started in 1982 when CEPT (Conference for European Post and Telecommunications Administration) formed a committee known as Groupe Speciale Mobile. The main reason for the formation of this committee, was to create a standard for mobile communications within Europe. This would have several distinct advantages, such as the user would be able to use their phone anywhere within Europe, and any manufacturer would be able to produce any part of the overall system. When conceived GSM was not envisaged as being a global standard.

In 1990 the design development of GSM was frozen into a set of standards known as the “GSM Specifications”.

1.2.1. GSM Phase 1

The standardisation of GSM900 was completed in 1990 and of DCS1800 in 1991. These standards are designated as GSM Phase 1, they include all the central requirements for a digital cellular network. Speech transmission (Full Rate Speech) is of central importance. Data transfer is defined with rates of 0.3 up to 9.6 kbit/s. only a few basic Supplementary Services (call forwarding and call baring) are included.

1.2.2. GSM Phase 2

The standardisation of Phase 2 was completed in 1995, the main topics were Supplementary Services comparable with those of a fixed network ISDN (Integrated Services Digital Network). Furthermore, technical enhancements, e.g.

Half Rate Speech, were defined. Of great importance was the decision to enable downward compatibility to the previous phases for all future GSM phases.

1.2.3. GSM Phase 2.5

GSM Phase 2.5 is characterised by a smoother transition as opposed to the previous phase changes. No complete revision of the GSM standard will be carried out but single topics will be handled separately. The standard is being updated in Annual Releases since 1996. The current topics concern new Supplementary Services, IN applications, services for specific user groups and enabling data transmission with high data rates.

1.3. GSM Evolutionary Concepts

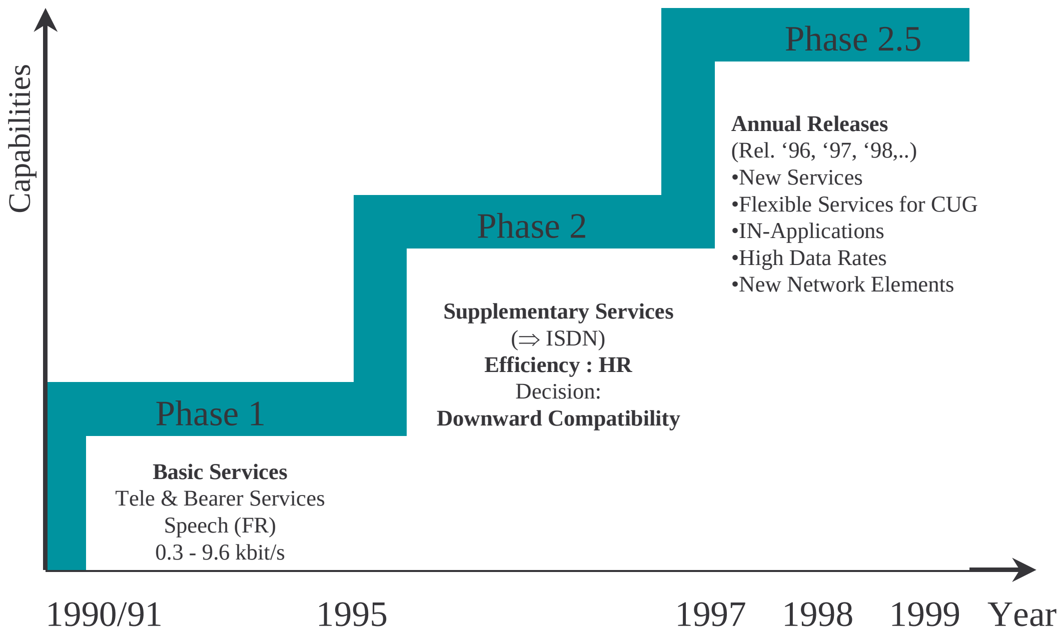


Figure 1 GSM Evolutionary Concepts

(Adapted from Ericsson LZU 108 879)

2.1 Introduction (GSM)

The most successful mobile digital communications system in today's world is GSM, with networks in over 130 countries and more than 100 million users worldwide. Back at the start of the 1980's Europe was facing a big problem, there were many existing analogue mobile networks, which were based on similar standards, for example NMT 450, however they were all running on slightly different carrier frequencies. To avoid this problem in the second generation mobile phone system, the Groupe Spéciale Mobile (GSM) was created in 1982. Now the system developed by this group is known as global system for mobile communications (GSM).

The primary goal of GSM was to provide a mobile phone system that would allow it's users to use their mobile phone in any European country i.e. Roaming. This system would have to provide voice services comparable with ISDN and other PSTN systems. The initial specification details were over 5000 pages, with the new services in particular data services there are even more specification details.

GSM is a typical second generation system, replacing the old analogue first generation system, however it still does not offer worldwide high data rates but will be offered in the new third generation system UMTS. GSM was initially deployed in Europe using the 890 – 915 MHz band for the uplinks and the 935 – 960 MHz band for the downlinks. This version is commonly known as GSM 900, and later version GSM 1800 (1710 – 1785MHz uplink, 1805 – 1880MHz downlink) which commonly known as DCS (Digital Cellular System)

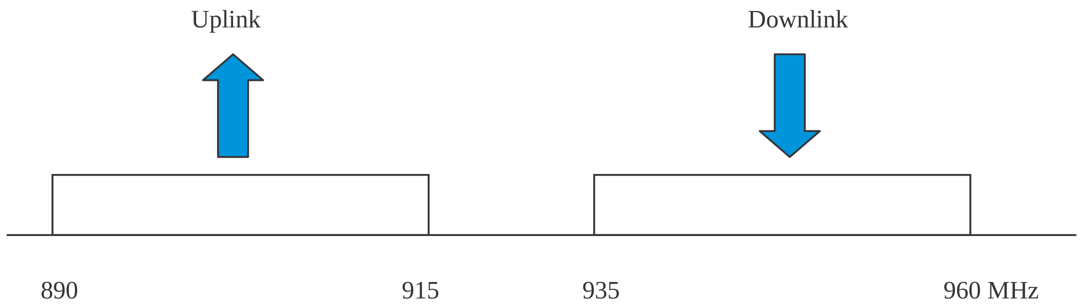


Figure 2 Uplink and Downlink frequencies for original GSM Spectrum

2.1.1 Mobile Services

The GSM system permits the integration of different voice and data services and the inter-working with existing networks. Services make a network flexible to users, i.e. they can choose one network over another. GSM has three different categories of services, bearer, tele and supplementary services And these are described in the following sections. Figure 3 shows a reference model for the GSM services.

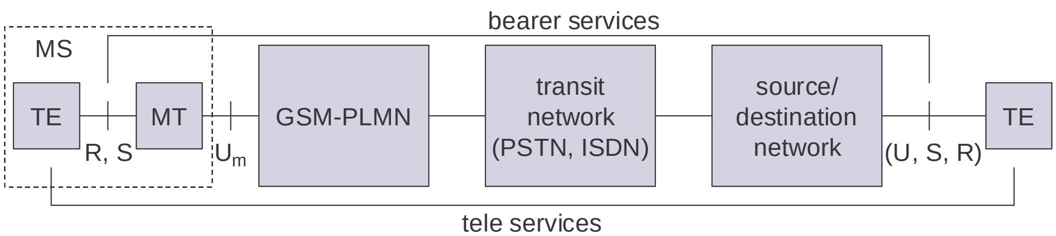


Figure 3 Bearer and tele services reference model

A mobile station (MS) is connected to the GSM Public Land Mobile Network (PLMN) via the Um interface. This network is connected to the Transit network, e.g. Integrated Services Digital Network (ISDN) or the traditional Public Switched Telephone Network (PSTN) though there might also be an additional network, the Source/destination network, before another Terminal (TE) is connected. Bearer services now comprise all services that enable the transparent transmission of data between the interfaces to the network, i.e., S in the case of the MS, and a similar interface for the other terminal. In the original GSM model, bearer services are connection-orientated and circuit or packet switched and these services only need the lower three layers of the ISO/OSI reference model.

Within the mobile station (MS), the mobile terminal (MT) performs all the network specific tasks (such as TDMA, FDMA, coding, etc) and also offers the interface for data transmission (S) to the terminal (TE), which can then be independent of the network. Depending on the capabilities of the TE, more interfaces may be needed, such as R, according to ISDN reference model (Halsall, 1996). Tele services are application specific and may need all seven layers of the ISO/OSI reference model, these services are specified end-to-end, i.e. from one terminal (TE) to another terminal.

2.1.1.1 Bearer Services

GSM specifies different mechanisms for data transmission for data transmission for the original GSM allowed for data rates up 9600 bit/s for non-voice services. Bearer services allow for both transparent and non-transparent, synchronous or asynchronous data transmission.

Transparent bearer services use only the functions of the physical layer (layer 1 ISO/OSI reference model) to transmit data; data transmission consequently has a constant delay and throughput, that is if no errors occur. The only mechanism of any use to try and increase the quality of the transmission is forward error correction (FEC). This mechanism codes redundancy into the data-stream and Depending on the FEC, data rate of 2.4, 4.8, or 9.6 kbit/s are possible.

Non-Transparent bearer services use protocols of the layers two and three to implement error correction and flow control. Non-transparent bearer services use the transparent bearer services, while adding a radio link protocol (RLP). This protocol uses mechanisms of high-level data link control (HDLC) (Halsall, 1996), and special selective-reject mechanisms to trigger retransmission of erroneous data. The achieved bit error rate is less than 10-7, but now throughput may vary, this depending on the transmission quality.

2.1.1.2. Tele Services

GSM is mainly focused on voice tele services and these comprise of encrypted voice transmission, message services, and basic data communication with terminals as known from the PSTN or ISDN (e.g. fax). However as the main service is telephony, the primary goal of GSM was to provide high-quality digital voice transmission, offering at least the typical audio bandwidth of 3.1 kHz (which was what the old analogue systems offered). Special codecs (coder/decoder) are used for voice transmission. Different codecs are used for the transmission of data for communication with traditional computer modems, e.g. fax machines or the internet.

Another tele service is the emergency number and this is the same number all over the GSM network in Europe and is also the same as the national emergency number. This is a mandatory service that all the network operators have to provide and is free of charge to the user. Another feature is that this service has the highest priority when connecting, possibly pre-empting other connections. Also, the network operators co-operate allowing users of any digital network to use any network to connect and furthermore this service will automatically put the user through to the nearest emergency centre.

A useful additional service that is offered is the short message service (SMS), which is a simple text message transfer service, offering transmission of messages up to about 160 characters. SMS messages do not use the data channels, but instead uses the unused capacity in the signalling channel. The use of the signaling channel means that the user can send and receive SMS messages during a voice or data transmission.

2.1.1.3. Supplementary Services

Further to bearer and tele services, GSM network operators can also offer supplementary services. These services offer enhancements to the standard telephony service and may differ from operator to operator, though typical services available to the user are caller location identifier (CLI), call forwarding, or redirection.

2.1.2 System Architecture

As with all telecommunications systems, GSM has a hierarchical and complex system architecture comprising of many entities, interfaces and acronyms figure 4 shows a simplified overview of the GSM system as specified in the ETSI (TS 101.622). GSM systems consist of three subsystems, the radio subsystem (RSS), the network and switching subsystem (NSS), and the operation subsystem (OSS). Generally a GSM user will only notice a very small portion of the whole network, commonly the mobile stations (MS) and some antenna masts of the base transceiver stations (BTS).

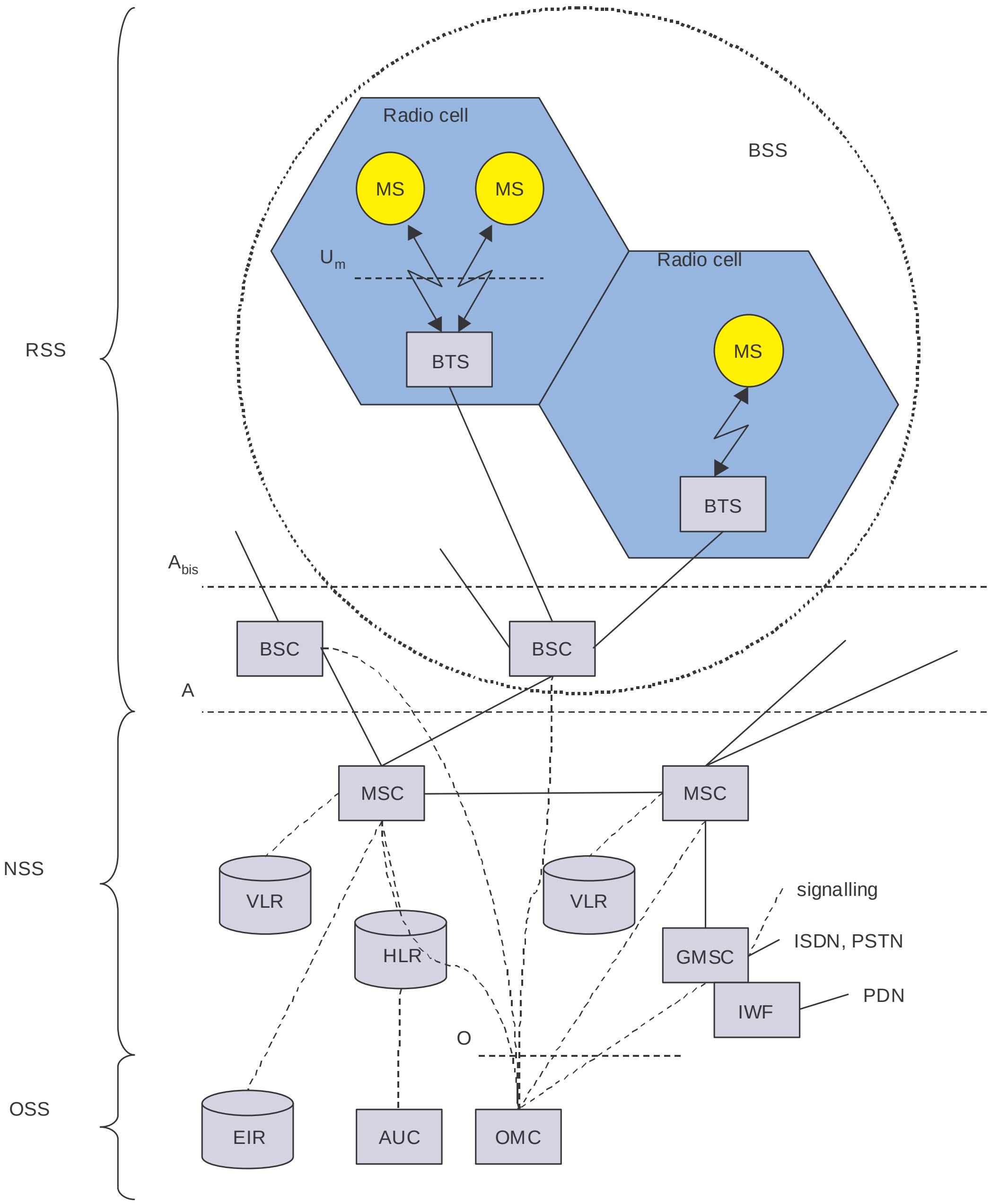


Figure 4 Functional Architecture of a GSM system

2.1.2.1 Radio Subsystem (RSS)

As suggested by the name, the radio subsystem is comprised of all the radio specific elements, i.e. the mobile stations (MS) and the base station subsystem (BSS). The connection between the RSS and the NSS (shown in figure x.ii) via the A interface (solid lines) and the connection to the OSS via the O interface (dashed lines). The A interface is generally based on a circuit-switched PCM-30 system (2.048 Mbit/s), carrying up to 30 X 64 kbit/s connections, whereas the O interface uses the Signalling System No. 7 (SS7) based on X.25 carrying system management data to/from the RSS.

Base Station Subsystem (BSS): A GSM network is made up of many BSSs, each one being controlled by a base station controller (BSC). The main function of the BSS is to maintain the radio connections to an MS, however, it does have several other functions such as the coding/decoding of voice, and rate adaptation to/from the wireless network part. As well as a BSC, the BSS contains several BTSs.

Base Transceiver Station (BTS): A BTS contains all the radio equipment (antennas, signal processing, amplifiers) necessary for radio transmission. A BTS can be used to form a radio cell, or if sectored antennas are used, several cells. The BTS is connected to the MS by the Um interface, and the BSC by the A_{bis} interface. The Um interface comprises of all the mechanisms necessary for wireless transmission (TDMA, FDMA). A_{bis} interface consists of 16 or 64 kbit/s connections. The area coverage from a GSM cell can vary from 100m and 35km depending on the expected traffic and the location environment.

Base Station Controller (BSC): Basically, the BSC controls the BTS The functions of the BSC include reserving radio frequencies, handling handovers from one BTS to another and performing the paging of the MS. The BSC also multiplexes the radio channels onto the fixed network connections at the A interface.

Function	BTS	BSC
Management of radio channels		X
Frequency hopping	X	X
Management of terrestrial channels		X
Mapping of terrestrial onto radio channels		X
Channel coding and decoding	X	
Rate adaptation	X	
Encryption/decryption	X	X
Paging	X	X
Uplink Signal measurement	X	
Traffic measurement		X
Authentication		X
Location registry, location update		X
Handover management		X

Mobile Station (MS) : The MS is the user equipment which contains the software required for communication with the GSM network. The MS consists of user independent hard/software and the subscriber identity module (SIM), which stores the user specific data. While an MS can be identified via the international mobile equipment identity (IMEI). Users can personalize their MS, by making use of the SIM.

2.1.2.2 Network and switching subsystem

At the centre of any GSM system there is the network and switching subsystem (NSS) that connects the GSM network with the public land network (i.e. a PSTN), performs the handovers between BSS's, comprises functions for worldwide localization of users and supports charging, accounting and roaming of users between different networks and in different countries. The NSS is comprised of the following switches and databases:

Mobile services switching centre (MSC): High-performance digital ISDN switches, that set up the connections between other MSC's and the BSC's, using the A interface. Hence the MSC's are the backbone of any GSM network. Normally one MSC will manage many BSC's in a geographical area. Some MSC's are gateway MSC (GMSC) that provide connections to other fixed networks (e.g. PSTN). Using additional functions such as the interworking functions (IWF) an MSC can also connect to public data networks (PDN) such as X.25.

Home Location Register (HLR): The most important database in a GSM network is the HLR as it stores all the relevant information about the users. Information such as the mobile station ISDN number (MSISDN), services subscribed to, and the authentication key Ki. Furthermore the HLR stores dynamic information like the LA (Location Area) of the MS. As the MS moves geographically around the GSM network, the HLR stores the location of the MS from the LA. This information is used to localize the user within the worldwide GSM network. All of these user specific information elements only exist once for each user in a single HLR. The HLR also supports charging and accounting.

Visitor Location Register (VLR): The VLR associated to each MSC is a very dynamic database which stores all important information needed for the MS users currently in the LA that is associated to the MSC. If a new MS comes into the LA then the VLR is responsible for it. The VLR copies all the relevant information for the MS from the HLR. The structure of the VLR and HLR avoids frequent updates and long-distance signaling of user information.

2.1.2.3 Operation Subsystem

The GSM system is broken up in to three parts, the first two parts have already been discussed, the third part of the GSM system is the operational subsystem (OSS). The OSS contains all the functions necessary for network operation and maintenance. The OSS possesses network entities of its own and accesses other entities via SS7 signaling. The following section describes the entities:

Operation and Maintenance Centre (OMC): The OMC monitors and controls all other GSM network entities via the O interface (SS7 with X.25), typically the OMC functions are Traffic Monitoring, Status reports of the network entities, subscribers and security management, or accounting and billing.

Authentication Centre (AuC): The Radio Air interface and the MS's are particularly vulnerable, therefore a separate AuC has been defined to protect user identity and data transmission. The AuC contains the algorithms for authentication, the keys for encryption and generates the values needed for user authentication for the HLR.

Equipment Identity Register (EIR): EIR is a database for all IMEIs that stores all the device identifications registered for the GSM network. As MSs are mobile they can be stolen easily. If a user has a valid SIM of their own, then they can use any stolen MS. Hence the EIR has a 'black list' of stolen or locked devices so the MS on this list is useless as soon as the owner of the MS has reported it as stolen. Furthermore the EIR holds a list of valid IMEIs, and a list of malfunctioning devices.

2.1.3 Radio Air Interface

One of the most interesting interfaces in the GSM network is the Um, the Radio Air Interface because it comprises many of the mechanisms used for multiplexing and media access. GSM utilises SDMA (Space Division Multiple Access) using cells with BTS and assigns an MS to a BTS. What's more, FDD (Frequency Division Duplex) is used to separate the downlink and uplink as shown in Figure 5.

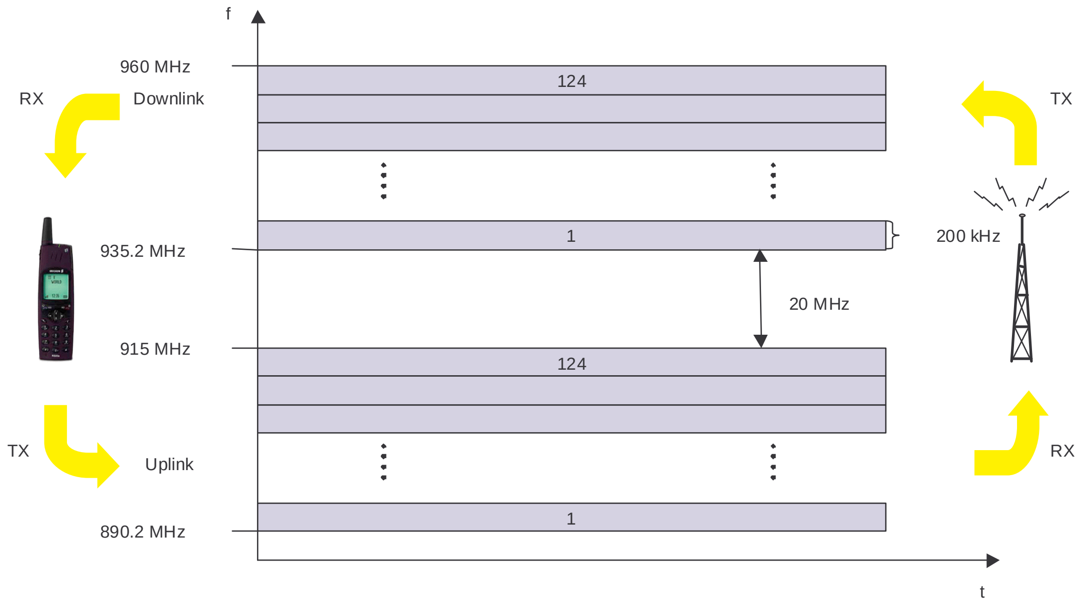


Figure 5 Frequency division multiplexing for multiple access and duplex

(NB. Figure 5, only show the frequency used by GSM as envisaged in GSM Phase 2)

Media access combines TDMA and FDMA. In GSM 900 there are 124 channels, each 200KHz wide and are used for FDMA, however in GSM 1800, there are 374 channels used. The following is an example based on the GSM 900 system, while figure x.iii shows the FDM in GSM. Figure 6 shows TDM in use. Each if the 248 channels is additionally separated in time by using a TDM GSM frame. i.e. each 200 kHz carrier is subdivided into frames that repeated continuously. The duration of a frame is 4.615 ms which is subdivided into 8 GSM time-slots, where each slot represents a TDM channel and lasts for 577 µs. Hence each TDM channel occupies the 200 kHz carrier for 577 µs every 4.615 ms.

Data is transmitted in small sections known as a 'burst' figure 6 shows a normal burst as used for data transmission inside a time slot. In this example (Figure 6) the burst is only 546.5 μs long and contains 148 bits of data. The remaining 30.5 μs is used as guard space which is done to prevent overlapping with other bursts due to the different path delays and to leave the transmitter time to turn on and off. However, if the full slot if filled with data that would allow the transmission of 148 bits within the 546.5 μs. So each physical TDM channel has a data rate of around 38.8 kbit/s, but each radio carrier transmits around 270 kbit/s over the Um interface.

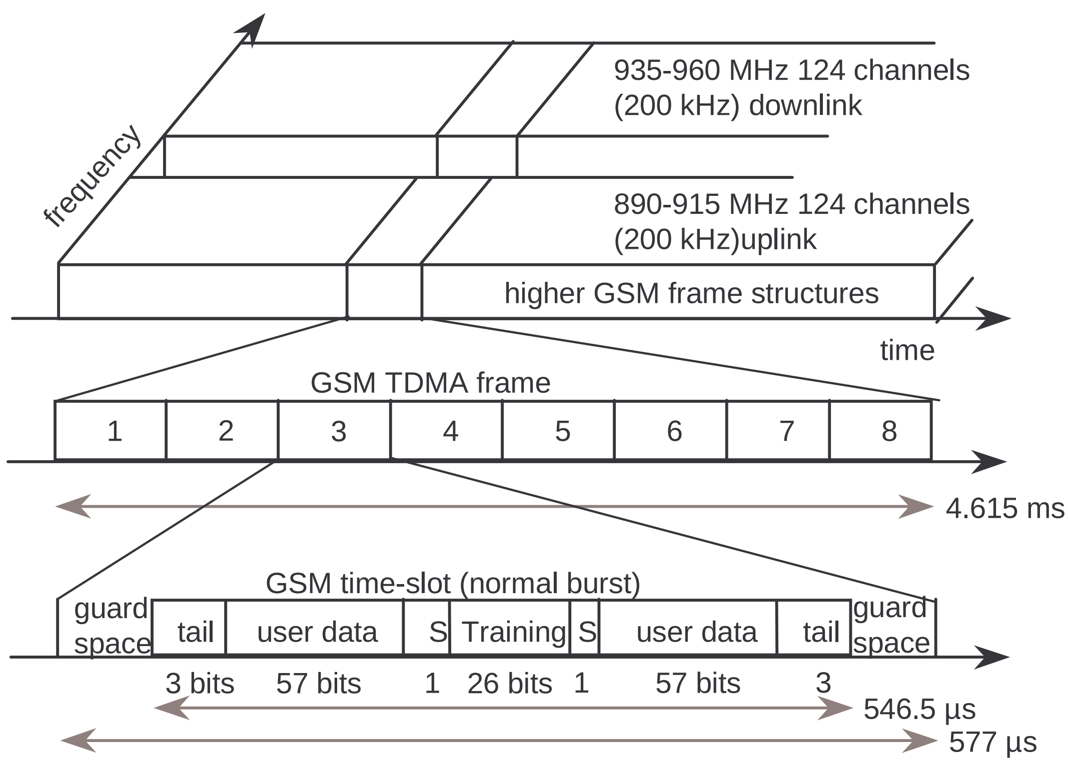


Figure 6 GSM TDMA frame, slots, and bursts

There are three bits at the start and finish of each burst these are known as the 'tail' and are set to 0 so they can be used to enhance the receiver performance. The training sequence in the middle of the burst is used to adapt the parameters of the receiver to the current path propagation characteristics and to select the strongest signal in the case of multi-path propagation (check this). The 'S' flag indicates whether the data field contains user or network control data.

Two factors allow for the use of simple transmitter hardware: on the one hand, the slots for uplink and downlink of a physical TDM channel are separated in frequency (45 MHz for GSM 900 and 95 MHz for GSM 1800 using FDD). On the other hand, the TDMA frames are shifted in time for three slots. i.e., if the BTS sends data at time t0 in slot one on the downlink, the MS access slot one on the uplink at time t0+3.577µs. An MS thus does not need a full-duplex transmitter, a simpler half-duplex transmitter switching between receiving and sending is enough. In order to avoid frequency selective fading, GSM specifies an optional slow frequency hopping mechanism. MS and BTS may change the carrier frequency after each frame, based on a common hopping sequence. An MS changes its frequency between up and downlink slots respectively.

2.1.3.1. Logical Channels and Frame Hierarchy

GSM specifies two basic groups of logical channel, they are the Traffic Channels and the Control Channels :

Traffic Channels (TCH): The GSM network uses a TCH to transmit user data (e.g. Voice). There are two basic TCHs and they are defined as Full Rate TCH (TCH/F) and Half Rate TCH (TCH/H). A TCH/F has a data rate of 28.8 kbit/s, whereas the data rate for TCH/H is 14.4 kbit/s. At the beginning of GSM standardisation the voice codecs only required 13 kbit/s, whereas the remaining capacity of TCH/H was used for error correction (TCH/FS). However, newer codecs allow for better voice coding and can make use of TCH/H. Making use of these TCH/Hs doubles the capacity of the GSM system for voice transmission, but reduces speech quality. For data transmission there are many different traffic channels, for example TCH/F4.8 for 4.8 kbit/s, TCH/F9.6 for 9.6 kbit/s, and in the newer specifications TCH/F14.4 for 14.4 kbit/s. It should be noted that that these logical channels differ in their coding and their level of error correction. However data throughput is < 2Kb/s.

Control Channels (CCH): The GSM network makes use of many different CCHs, for they control medium access, allocation of traffic channels or the mobility management. Three main groups of CCHs have been defined, each has their own sub-channels.

Broadcast Control Channel (BCCH): The BCCH is used by the BTS to signal all MSs within a cell. The sort of information transmitted in this channel is such as the cell identification, options available within this cell (frequency hopping), and the available frequencies within the cell and in neighbouring cells, known as the neighbour list. In addition to this, the BTS sends information about frequency correction using the FCCH (Frequency Correction Channel), and also information about the time synchronisation via the SCH (Synchronisation Channel). Both of these channels, the FCCH and the SCH are sub channels of the BCCH.

Common Control Channel (CCCH): The CCCH is the channel where all information about connection set up between the MS and the BS is exchanged. For calls toward the MS, the BS uses the PCH (Paging Channel). However if a MS wants to set up a call, it uses the RACH (Random Access Channel) to send data to the BTS. The RACH implements multiple access to all MSs within a cell, and all MSs may access this channel. This however is where collisions may occur between MSs in the GSM system, so the BTS uses the AGCH (Access Grant Channel) to signal an MS that it can use the TCH or SDCCH for further connection set up.

Dedicated Control Channel (DCCH) : The previous two channels (BCCH and CCCH) are unidirectional, the DCCH and it's sub channels are bi-directional. As long as an MS has not established a TCH with the BTS, it uses the SDCCH (Stand-alone Dedicated Control Channel) with a low data rate (782 bit/s) for signaling. The signaling is generally made up of authentication, registration and/or other data needed to set up the TCH. Each TCH and SDCCH has a SACCH (Slow Associated Dedicated Control Channel) associated with it. This channel is used to exchange system information such as the Channel Quality and the signal power level. Finally, if more signaling information needs to be transmitted and a TCH is already existing, GSM uses a FACCH (Fast Associated Dedicated Control Channel). The FACCH uses the time slots which are otherwise used by the TCH and is necessary, especially in the case of handovers where the BTS and the MS have to exchange larger amounts of data, in a smaller amount of time, known as layer 3 messages (not ISO/OSI reference model).

2.1.4 Protocols

Figure 7 shows the architecture of protocols used within the GSM system, with signaling protocols, interfaces as well as the entities already shown in Figure 5.

Again the main area of focus is in the Um interface, this is because the other interfaces occur between entities in a fixed network. The physical layer, Layer 1 handles all the radio specific functions. This layer includes the creation of bursts according to the five different formats, the multiplexing of bursts into TDMA frames, synchronisation with the BTS, detection of the idle channels and the measurement of the channel quality on the downlink. At Um, the physical layer uses GSMK (Gaussian Shift Minimum Keying) for the digital modulation and performs encryption/decryption of data This means that encryption is not performed end-to-end, but only between MS and BTS over the air interface.

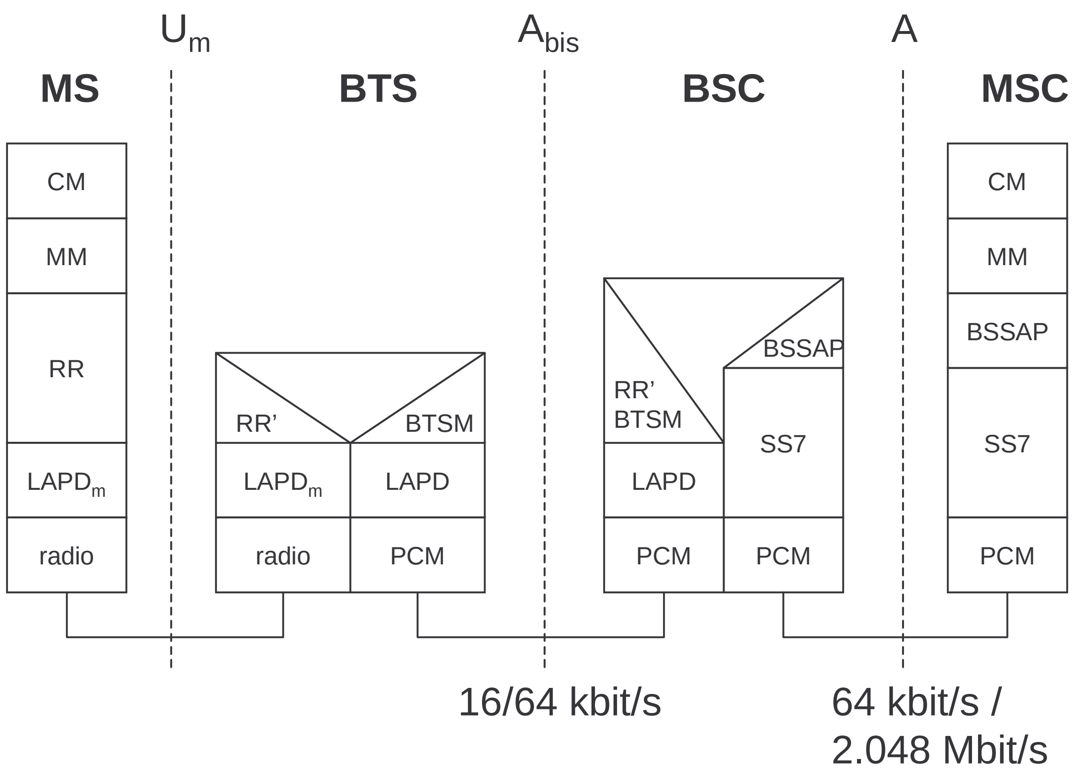


Figure 7 Protocol Architecture for signaling

The synchronisation also includes the correction of the individual path delay between the MS and the BTS, all MSs within a cell can use the same BTS and hence must be synchronised to the BTS. This is due to the fact that the BTS generated the time-structure of the frames and slots etc. This can be problematic since in this context there are different RTTs (Round Trip Time). *An MS that is close to the BTS has a very short RTT whereas an MS that is 35 km away has a RTT of around 0.23 ms.. If the MS 35 km away used the slot structure without correction, a large guard spaces would be required as 0.23 ms. are already 40% of the 0.577 ms available for each time slot.* (Wray Castle, GSM Appreciation, 1998.). Therefore the BTS sends the current RTT to MS, which then adjusts its access time so that all bursts reach the BTS within their limits. This mechanism ensures that the guard space is reduced to only 30.5 μs or 5%. See Figure 7. This means the adjustment of the access is controlled via the variable timing advance, where a burst can be shifted up to 63 bit times earlier, with the resulting bits having a duration of 3.69 μs, thus will result in the 0.23 ms needed.

The physical layer has several main tasks that comprise the channel coding, error detection/correction; this is directly combined with the coding mechanisms. FEC (Forward Error Correction) is used extensively in the coding channel, FEC adds redundancy to the user data, thus allowing for the detection and correction of selected errors. The power of the FEC scheme depends on the amount of redundancy, coding algorithm, and any further interleaving of data to minimise the effects of burst errors. Whatsmore the FEC is the reason that error detection/correction occurs in the physical layer. This differs to the ISO/OSI reference model where it occurs in layer two. The GSM physical layer tries to correct errors, however it does not deliver erroneous data to the higher layers.
GSM logical channels use different coding schemes with different correction capabilities, for example speech channels need the additional coding of voice data after analogue to digital conversion. This is in order to reach a data rate of 22.8

kbit/s (using the 13 kbit/s from the voice codec plus redundancy, CRC bits, and interleaving (Goodman, 1997). When GSM was envisaged it was assumed that voice would be the main service so the physical also contains special functions, for instance VAD (Voice Activity Detection), which transmits voice data only when there is a voice signal. In the duration between voice activity, the physical layer generates a comfort noise to fake a connection, however no actual transmission takes place.

All the interleaving in the voice channel is to minimise interference due to burst errors and the recurrence pattern of a logical channel generates a delay for transmission, although this delay is only about 60 ms for TCH/FS and about 100 ms for TCH/F9.6. These times have to be added to the transmission delay if the BTS is communicating with an MS rather than a standard fixed station (for example a stationary computer etc.) and this in turn may influence the performance of any of higher layer protocols, e.g.. for computer data transmission.

Signaling between the entities within the GSM network requires the use of the higher layers (see Figure 7). For this, the LAPDm (Link Access Procedure for the D-Channel) protocol has been defined at the Um interface for layer two. As the name already implies, it has been derived from link access procedure for the D-Channel (LAPD) in the ISDN system, which is a version of HDLC (Goodman, 1997), LAPDm is a lightweight version of LAPD, in that it does not require synchronisation flags or check summing for error detection, these are not needed as these functions are already performed in the physical layer of the GSM network. LAPDm, however offers reliable data transfer over connections, re-sequencing of data frames and flow control (ETSI, 1993, ETS 300 937), (ETSI, 1999) TS 100 938. Due to the fact that there is no buffering between layer one and two, the LAPDm has to obey the frame structures, recurrence patterns etc defined for the reassembly of data and acknowledged/unacknowledged data transfer.

Layer three in the GSM network is made up of several sublayers as shown in Figure 7, the lowest sublayer is the RR (Radio Resource Management). Only part of this layer the RR', is implemented in the BTS, the remainder of the RR is situated in the BSC. The BSC via the BTSM (Base Transceiver Station Management) are responsible for the functions of the RR'. The RR' has the function of setting up, maintenance and release of the radio channels. Also the RR' has direct access to the physical layer for radio information and offers a reliable connection to next higher layer.

MM (Mobility Management) encompasses the functions for registration, authentication, identification, location updating and the provision of TMSI (Temporary Mobile Subscriber Identity) that replaces the IMSI (International Mobile Subscriber Identity) and is needed to obscure the true identity of the MS over the radio air interface. Although the IMSI identifies the user, the TMSI is only valid within the location area of a VLR. MM also offers a reliable connection to the next higher layer.

Finally the CM (call management) layer contains three entities : CC (Call Control), SMS (Short Message Service) and SS (Supplementary Services). SMS allows for short messages transfer using the control channels SDCCH and SACCH, while SS offers the services described in section 2.1.1.3. CC provides a point-to-point connection between two terminals, the higher layers for call management use this, call clearing and change of call parameters. This layer also contains functions to send in-band tones, called DTMF (Dual Tone Multiple Frequency), over the GSM network.

Additional protocols are used at the A_{bis} and the A interfaces. Data transmission at the physical layer is typically done using PCM (Pulse Code Modulation) systems. Although PCM systems offer transparent 64 kbit/s channels, GSM allows for the sub-multiplexing of four 16 kbit/s channels into single 64 kbit/s (while remembering that 16kbit/s are enough for user data from an MS). At the physical layer, the A interface typically includes leased lines with a capacity of 2.048 Mbit/s. LAPD is used for layer two at A_{bis}, BTSM for the BTS management.

For signaling between the MSC and a BSC, the SS7 (Signaling System No, 7) is used. This protocol also transfers all the management information between MSC's, HLR, VLR's and OMC. Additionally, and MSC can control a BSS via the BSSAP (Base Station [Sub] System Application Part).

2.1.5 Localisation and Calling

One of the main features of GSM system is the automatic, worldwide localisation of it's users. The GSM system always knows where a user is currently located, and the same phone number is valid worldwide. To have this ability the GSM system performs periodic location updates, even if the user does not use the MS, provided that the MS is still logged on to the GSM network and is not completely switched off. The HLR contains information about the current location, and the VLR that is currently responsible for the MS informs the HLR about the location of the MS when it changes. Changing VLRs with uninterrupted availability of all services is also called roaming. Roaming can take place within the context of one GSM service provider or between two providers in one country, however this does not normally happen but also between different service providers in different countries, known as international roaming.

To locate an MS and to address the MS, several numbers are needed:

MSISDN (Mobile Station International ISDN Number)16. The only important number for the user of GSM is the phone number, due to the fact that the phone number is only associated with the SIM, rather than a certain MS. The MSISDN follows the E.164, this standard is also used in fixed ISDN networks.

IMSI (International Mobile Subscriber Identity). GSM uses the IMSI for internal unique identification of a subscriber.

TMSI (Temporary Mobile Subscriber Identity). To disguise the IMSI that would give the exact identity of the user which is signaling over the radio air interface, GSM uses the 4 byte TMSI for local subscriber identification. The TMSI is selected by the VLR and only has temporary validity within the location area of the VLR. In addition to that the VLR will change the TMSI periodically.

MSRN (Mobile Station [Subscriber] Roaming Number)17. This is another temporary address that disguises the identity and location of the subscriber. The VLR generates this address upon request from the MSC and the address is also stored in the HLR. The MSRN is comprised of the current VCC (Visitor Country Code), the VNDC (Visitor National Destination Code) and the identification of the current MSC together with the subscriber number, hence the MSRN is essential to help the HLR to find a subscriber for an incoming call.

All the numbers described above are needed to find a user within the GSM system, and to maintain the connection with a mobile station. The following scenarios below shows a MTC (Mobile Terminate Call) and a MOC (Mobile Originated Call).

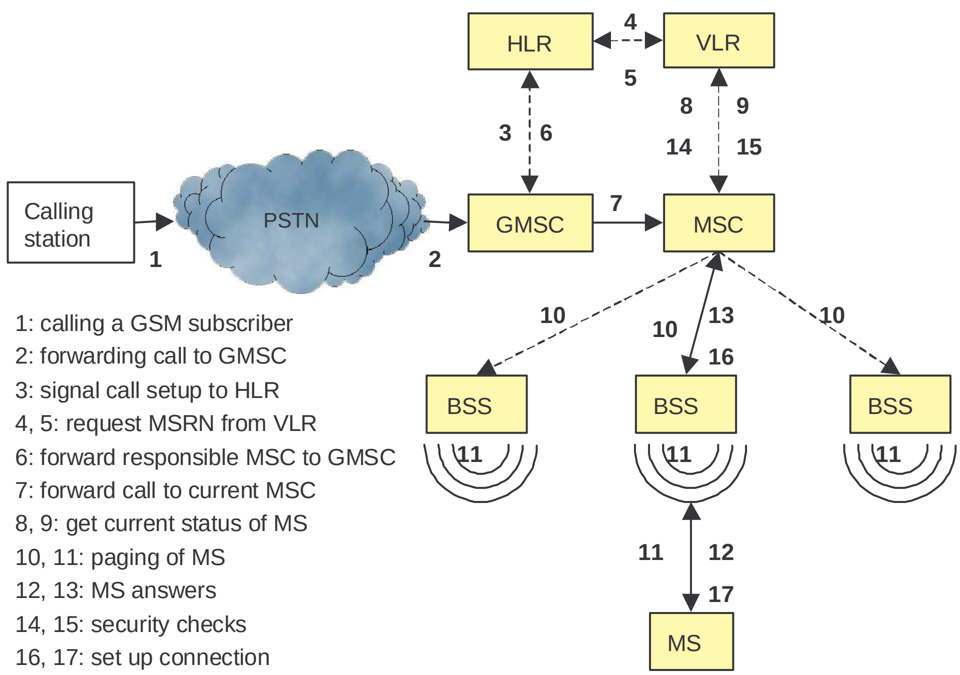


Figure 8 Mobile Terminated Call

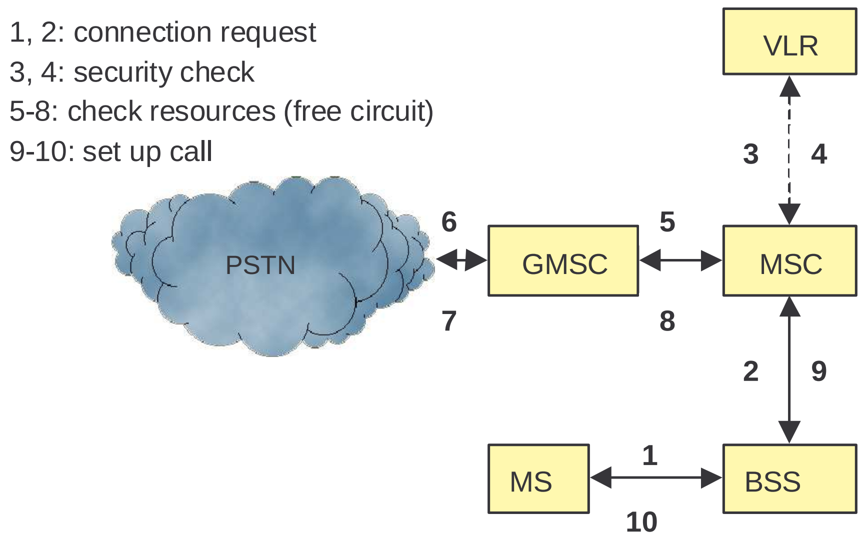


Figure 9 Mobile Originated Call

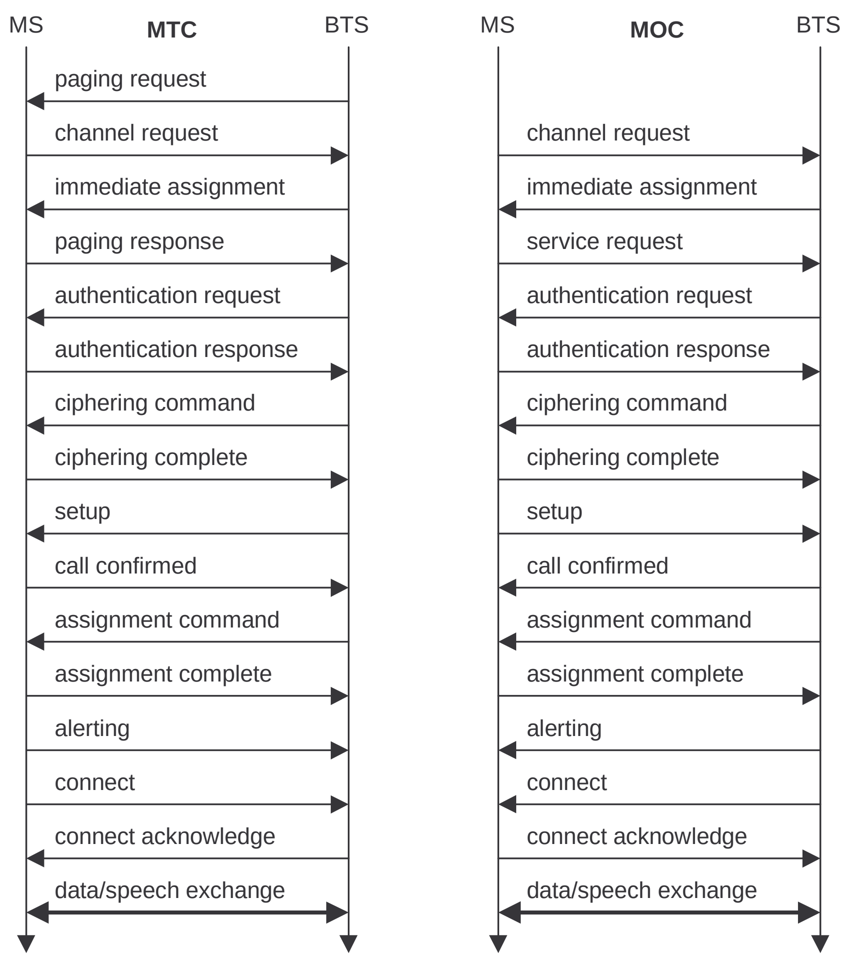


Figure 10 Message Flow for MTC and MOC

2.1.6 Handover

GSM systems require a procedure known as a Handover to maintain the continuity of the call. This is because a single cell does not cover the whole service area e.g. a whole city or country. However a single cell has a maximum service area of approximately 23 miles (35 km) for each antenna (Tripathi, et al. 1998). The smaller the size of the cell and the faster the movement of the MS through the cells (Up to 155 mph (250 kph) for GSM), the more handovers of ongoing calls are required, but a handover should not cause the a call drop. Basically there are two main reasons for handovers, however the GSM Specification identifies 40 reasons.

The MS moves out of coverage of the serving BTS thus the signal level becomes lower continuously until it falls beneath the minimal requirements for communications. Or the error rate may grow due to interference, the distance to the BTS may be do high. All these effects may diminish the quality of the radio link and make transmission impossible in the near future.

The wired infrastructure i.e. the MSC, BSC may decide that the traffic in one cell is too high thus introducing congestion and hence decides to shift some MSs to other cells with a lower level of traffic, if that is possible. Thus, handovers can be used as a method of controlling traffic through load balancing to relieve localised congestion.

Figure 11 shows four possible handover scenarios with in the GSM system.

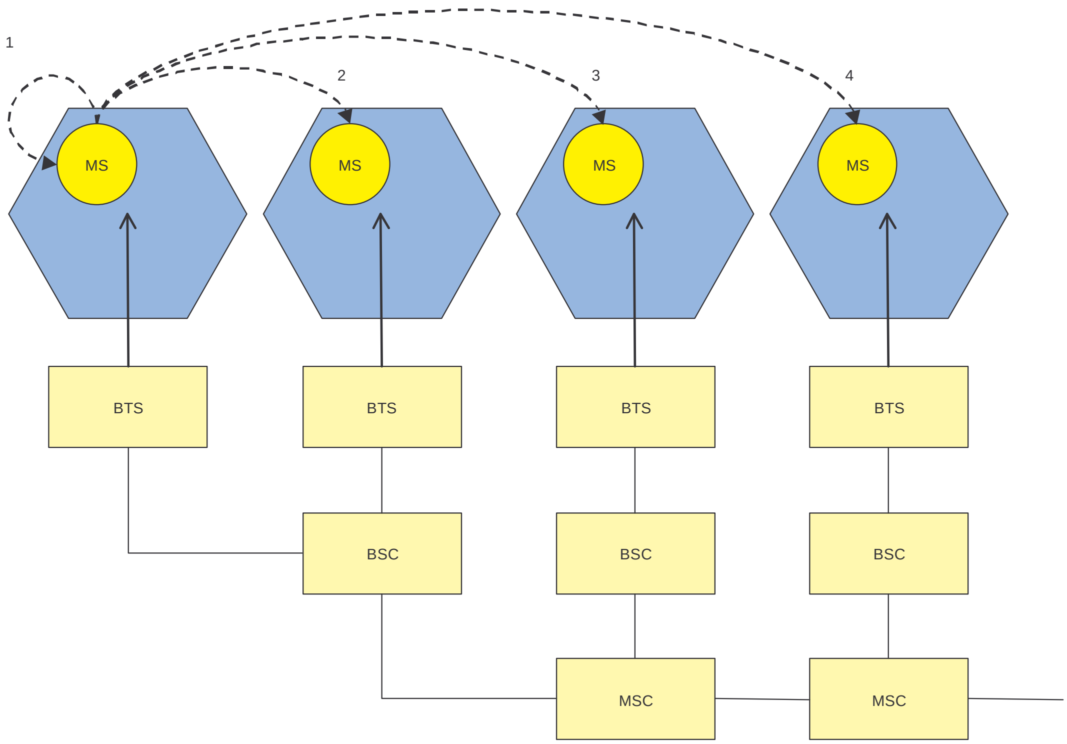


Figure 11 Types of handover within a GSM system

1. Intra Cell Handover : This happens when within a cell, when narrowband interference could make transmission at a certain frequency impossible. The BSC could then decide to change the carrier frequency. (1)
2. Inter Cell, intra BSC handover : This type of handover is a typical handover within the GSM system and occurs when the MS moves from one BTS to another but stays within the control of same BSC. The BSC performs the handover and assigns a new radio channel in the new BTS, then releases the old BTS. (2)
3. Inter BSC, Intra MSC handover : Since a BSC controls a limited number of BTSs, the GSM system has to perform handovers between BSCs. This form of handover is controlled by the MSC. (3)
4. Inter MSC handover : A handover could also be required between two BTSs that belong to two different MSCs, now both MSCs perform the handover together. (4)

In order to provide all the information necessary for a handover due to a weak link, the MS and the BSC both perform periodic measurements of the downlink and the uplink quality respectively. The link quality measurement is made up from receive signal level (RxLev) and the bit error rate (BER) and form part of the layer 3 messaging function. Measurement reports are sent by the MS about every 0.5 seconds and these contain the quality of the current link used for transmission as well as the quality of certain channels in neighbouring cells (the BCCHs).

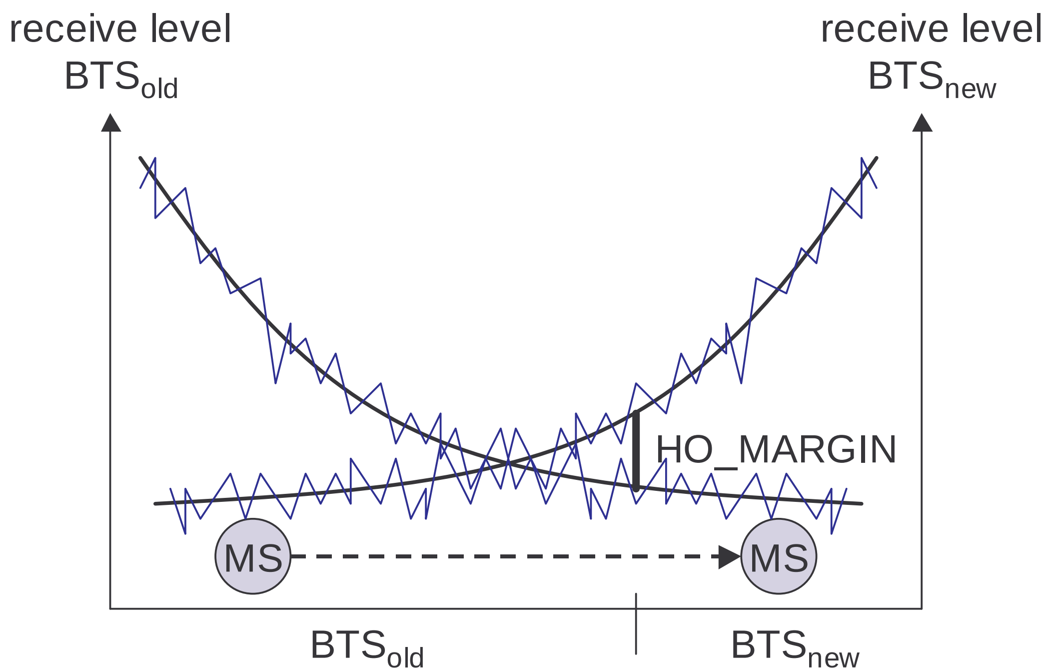


Figure 12 A Typical Handover decision, made depending on the RxLev

Figure 12 shows a handover decision, using the RxLev as the MS moves away from the BTS_{old} (BTS_{old} is the serving cell) towards another BTS (BTS_{new}). In the handover decision shown in figure 12, the handover decision is made not purely on the instantanious value of the receive signal level, but on the average value.

So what's happening. The BTS collects all the values (RxLev and BER from the uplink and downlink) from the BTS and MS, then calculates the average values. These values are then compared to the Handover Margin (HO Margin). The HO Margin includes a hysteresis level to avoid the "*ping-pong*" effect (Wong, 1997).

(*Without hysteresis, even short-term interference, e.g. shadowing due to a building, could cause a handover*). However, even with the HO Margin some ping-pong can still occur. If the HO Margin is set to high then this could cause dropped calls due to low RxLev, and if it is set to low then there will be many handovers in a short period, hence the ping-pong effect and a significant reduction in the quality of the service.

The HO Margin will change between rural and urban areas, but typically will be set at –8db.

The following three figures shows the typical measurement reports, and cell details for a handover. These measurements were taken using TEMS Investigation 2.02, supplied by Ericcson.

Typical Measurement reports for a Handover

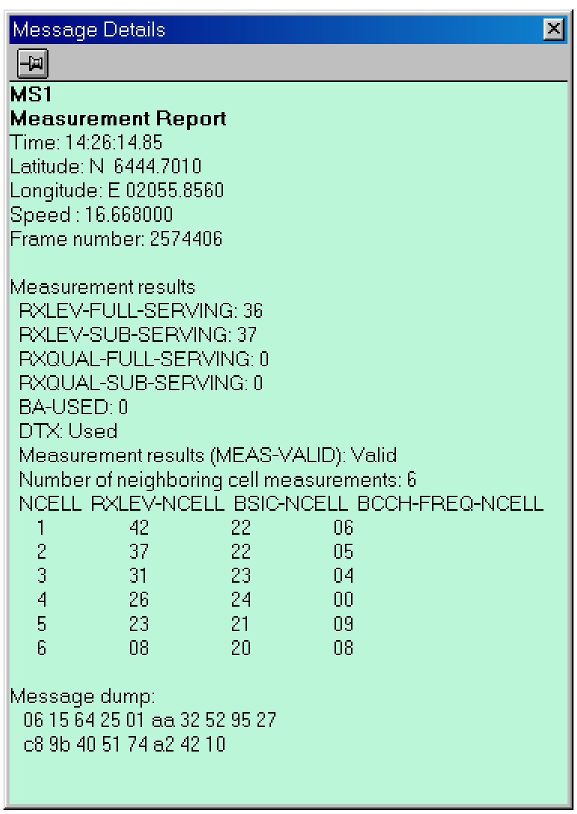


Figure 13 Measurement Reports Before Handover

(Source Ericsson Network Optimization Solutions, TEMS Investigation 2.02)

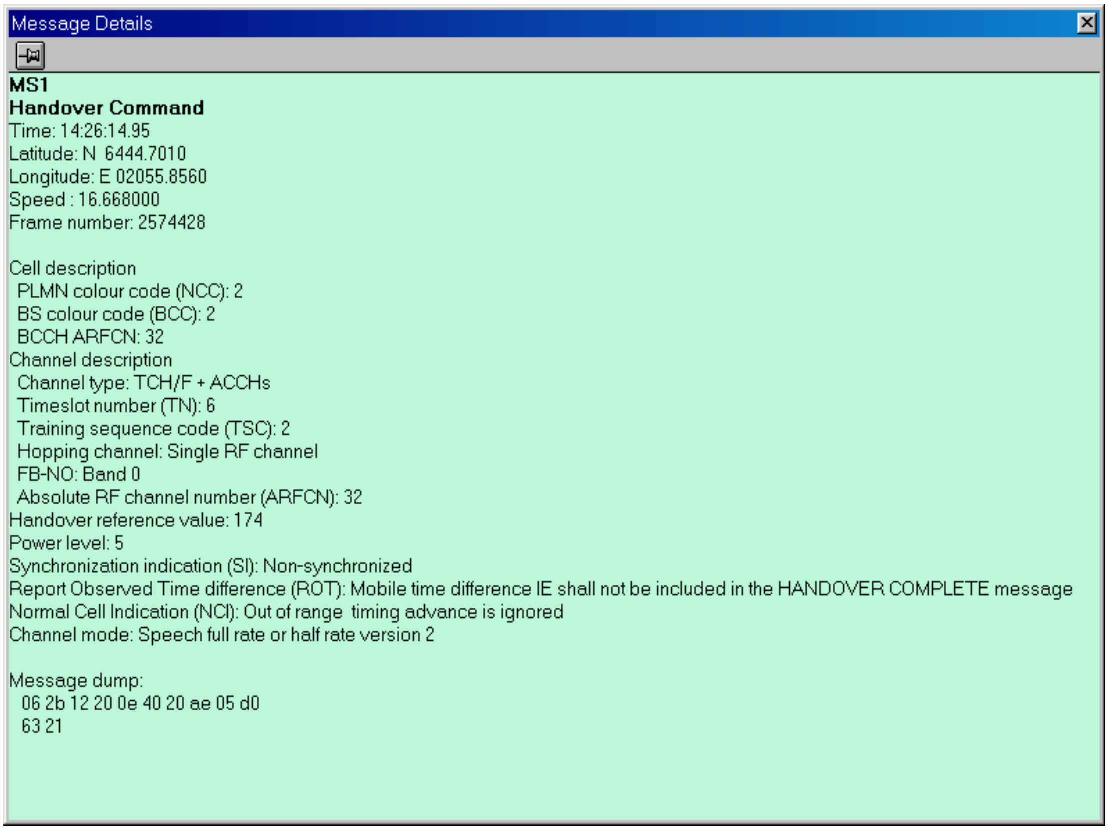
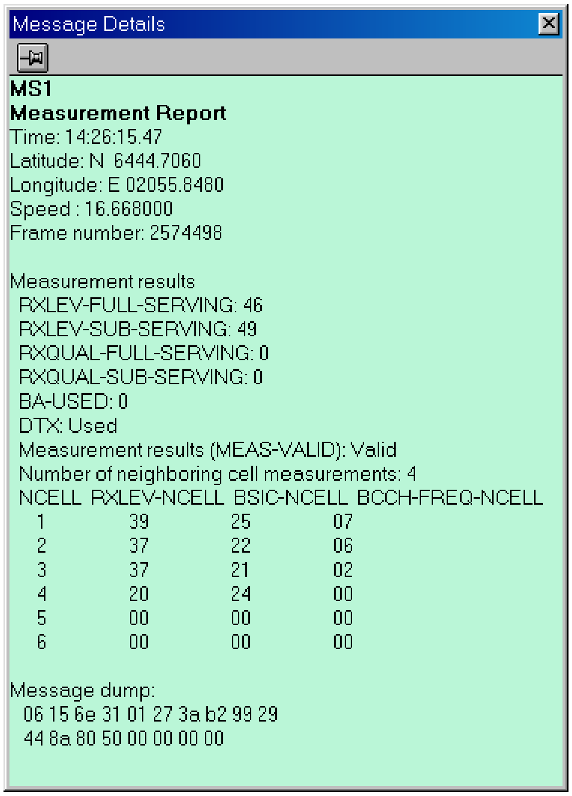


Figure 14 Handover Command

(Source Ericsson Network Optimization Solutions, TEMS Investigation 2.02)


Message Details

MS1
Measurement Report
Time: 14:26:15.47
Latitude: N 6444.7060
Longitude: E 02055.8480
Speed : 16.668000
Frame number: 2574498

Measurement results
RXLEV-FULL-SERVING: 46
RXLEV-SUB-SERVING: 49
RXQUAL-FULL-SERVING: 0
RXQUAL-SUB-SERVING: 0
BA-USED: 0
DTX: Used
Measurement results (MEAS-VALID): Valid
Number of neighboring cell measurements: 4

NCELL	RXLEV-NCELL	BSIC-NCELL	BCCH-FREQ-NCELL
1	39	25	07
2	37	22	06
3	37	21	02
4	20	24	00
5	00	00	00
6	00	00	00

Message dump:
06 15 6e 31 01 27 3a b2 99 29
44 8a 80 50 00 00 00 00

Figure 15 Measurement Report after Handover

(Source Ericsson Network Optimization Solutions, TEMS Investigation 2.02)

2.1.7 Security

The GSM system has several security services for security, these security services use confidential information that is stored in the AuC and in the customers SIM (Subscriber Identity Module) chip. The SIM chip may be plugged into any MS, however for the SIM chip to allow access to the MS the user must enter a PIN (Personal Identification Number), the SIM chip contain personal, secret data. The following are the security services offered by GSM:

Authentication and Access Control : For any MS to be used on the GSM network a number of events have to take place, the first event includes the authentication of a valid user for the SIM, the user enters their secret PIN to access the SIM. Then the MS contacts the AuC (See Figure 16 (Authentication Request)).

Confidentiality : All data that is related to the user is encrypted, after authentication the BTS and MS apply encryption to data, voice and signaling. This confidentiality only exist between the BTS and MS, however it does not exist end-to-end or within the whole fixed GSM/telephone network.

Anonymity : The GSM system also provides a level of anonymity, all of the data is encrypted before transmission, and user identifiers that would show the identity of a user are not used over the air. Instead the GSM system uses a temporary identitfier (TMSI), this is newly assigned by the VLR after each location update. Further more the VLR can change the TMSI at any time.

The GSM system uses three different algorithms to provide security services, the A3 algorithm is used primarily for authentication, A5 is used for the encryption/decryption and A8 which is used for the generation of a cipher key. Out of the three algorithms A5 was the only one that was publicly available, where as A3 and A8 were secret, but standard with open interfaces. However that change in 1998 when A3 and A8 were published on the internet.

2.1.7.1 Authentication

As I have already stated before any user can access the GSM system they must be authenticated as a valid user and this authentication is done by use of the PIN on the SIM. The SIM stores the users Individual Authentication Key K_i, the user identification IMSI and used the A3 algorithm for identification.

The authentication method that is used is challenge – response : the access control will generate a random number RAND as a challenge, and the SIM within the MS has to answer with a signed responses SRES as response. The AuC performs the basic generation of the RAND, signed responses SRES, and cipher key K_c for each IMSI, then forward this information to the HLR, then current VLR then requests the suitable values for the RAND, SRES and the K_c from the HLR.

For authentication the VLR sends the random value RAND to the SIM. Each side, the GSM network and the subscriber module, must perform the same operation with the RAND and the K_i. The MS sends back the SRES generated by the SIM, the VLR can now compare both values. If the value produced by the SIM and the VLR match then the user is granted to access the GSM network, however if they do not match then the subscriber is refused access to the network. This process is shown in Figure 16

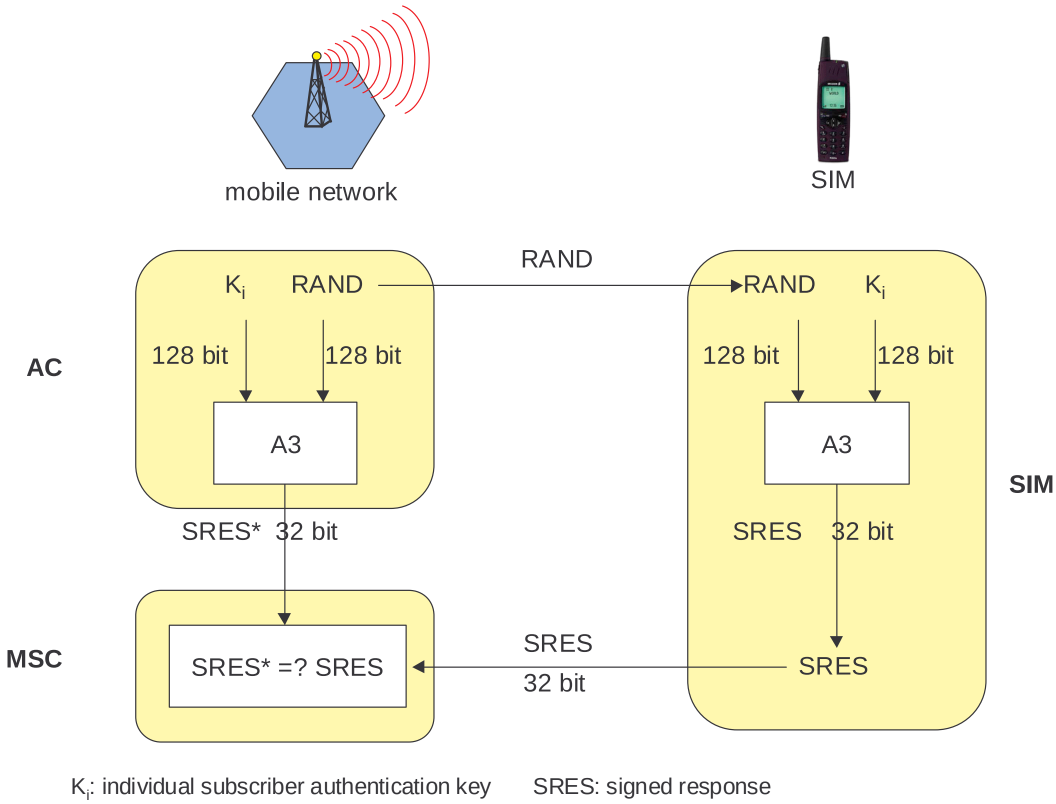


Figure 16 Subscriber Authentication

2.1.7.2 Encryption.

In the GSM system there is a large amount of user related information transmitted over the air interface and since this is the weakest part of GSM system it uses encryption to ensure privacy. After the user has been authenticated, the MS and the BTS can start using encryption by applying the cipher key K_c. K_c is generated using the individual key K_i and a RAND by applying the A8 algorithm. However it should be noted that that the SIM in the MS and the network both create the same value K_c based on the RAND. The K_c itself is not transmitted over the air interface.

The MS and the BTS can now encrypt and decrypt data using the A5 algorithm and the K_c. You can see the encryption and decryption process in Figure 17, K_c should be a 64 bit key – this however this level of encryption is not very strong, but provides enough protection to stop simple eavesdropping.

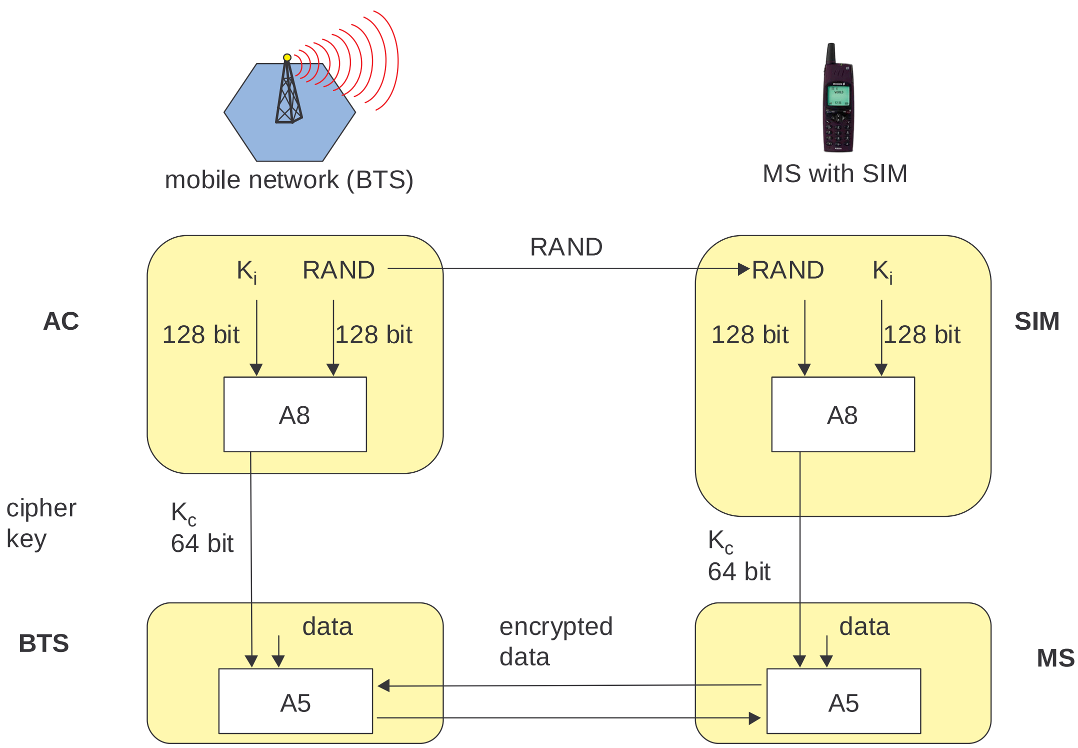


Figure 17 Data Encryption

Since the publication of the algorithm's A3 and A8 on the Internet, it has show that there are certain limitations for example 10 of the 64bits are always set to 0, hence the real length of the key is only 54 bits. The consequence of this is that the encryption is much weaker.

Chapter Summary and key Points

With the increase in demand for the need for communications whist away from a fixed line, GSM specifications were developed in order to provide greater capacity, improved quality and significantly greater security. Also the need to be able to use your mobile phone in other countries became of paramount importance.

GSM provided significantly greater capacity by the use of a combination of FDMA and TDMA. Whereas in previous technologies such as TACS and MTN the modulation technique was analogue and thus not very secure, GSM utilizes digital encoded modulation (See section 2.1.7.2), thus making it virtually impossible for interception by the casual eaves dropper. As a result of this certain Government agencies found it impossible to intercept calls and decode them in real time (DEA, See Appendix 2). However, in recent years details of the encryption algorithms have been made available to these agencies, and then leaked on the internet, thus reducing the security of the GSM system.

A further security improvement brought about by GSM was the use of SIM cards. The SIM card holds data relating to the user, authentication codes, and billing details.

The GSM radio air interface (Abis) is split into two levels, Physical Channels which are the radio bearers and Logical Channels which contain all the control and speech information in data streams. These logical channels are described in GSM Section 2.1.3.1. The net outcome is that speech only occupies a small amount of these data streams, hence the use of TDMA on the FDMA radio bearers.

Mobility means that the MS is moving from one location to another. Thus the system has to know where the MS is in order to direct calls. The MS continually provides a location update so that the network knows where to find the MS. Also because the MS is moving the network has to handover from BSC to another BSC, or another sector in the BSC. Consequently the MS has to continually measure the signal levels and quality in order to know which BSC has the appropriate availability in terms of capacity and quality. In this way the network is able to maintain connectivity and quality of service to the user.

With this increased mobility, users started to demand the ability to send data from their PCs and thus the mobile internet was born. In earlier technologies data transmission was achieved by the use of an analogue modems, but with GSM digital modems are now incorporated into the some MSs, thus providing greater data throughput.

The success of GSM data transmissions has meant that users require faster and faster speeds. On fixed lines the technique known as packet switched data transmission was available, but this was no use for GSM as the human ear cannot tolerate the delays introduced by such a technology. Initially data on the GSM network used a technique known as circuit switched (GSM-CS), which meant that the MS was permanently connected to a specific circuit, which was necessary for speech transmission. In order to increase the data rate a new technology based around packet switching had to be developed and thus the evolution of the GSM network continues into EDGE.

3.1 The Evolution of the GSM Network

The existing mobile digital communications network continues to develop, in order to increase capacity, coverage, quality and data transmission rates. There have been a series of developments that are now starting to be deployed with the aim of enhancing the GSM network functionality.

Figure 3.1 shows the enhancements planned for the next few years, starting off with High Speed Circuit Switched Data (HSCD). The next development is General Packet Radio Services (GPRS), this is a packet-switched service that allows full mobility and wide-area coverage. Enhanced Data rates for GSM Evolution (EDGE) will use enhanced modulation and related techniques, further improving local mobility. Universal Mobile Telecommunications System (UMTS) will include second and third generation services.

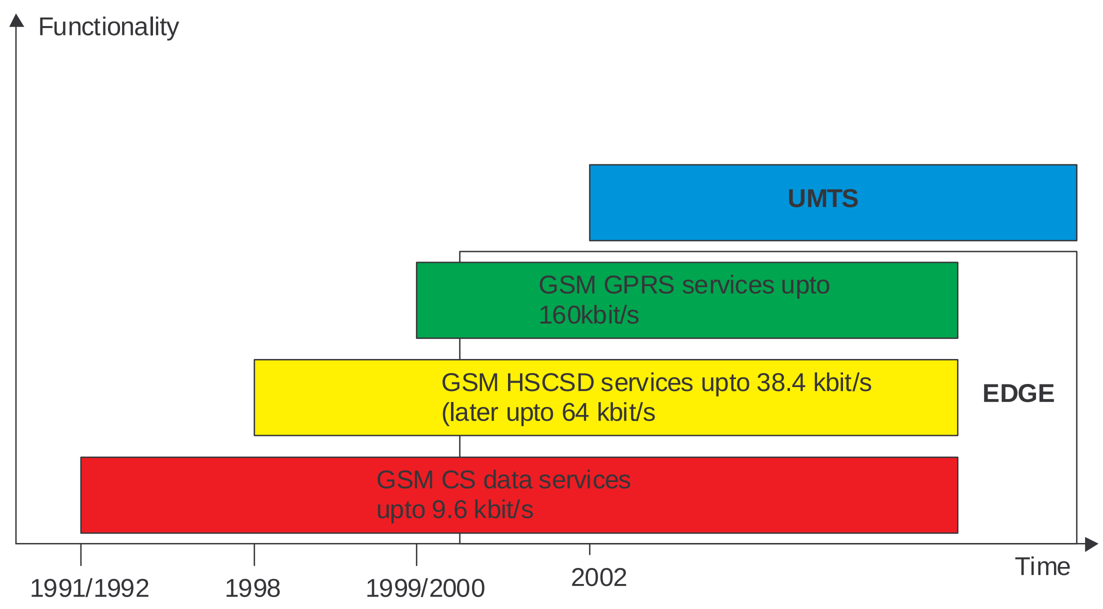


Figure 18 Evolution of GSM Data Service

(Adapted from Ericsson Document EN/LZT 123 5374 R1B)

3.2 High Speed Circuit Switched Data (HSCSD)

HSCSD is basically an upgrade of the original GSM CS data transmission system, by using HSCSD the speed at which data is transmitted is greatly improved. The higher data transmission rates are achieved by making use of bundled Traffic Channels (TCH). The way that this works is the MS requests one or more TCHs from the GSM network, in other words the MSC will allocate TDMA slots within a TDMA frame. This allocations do not need to be asymmetrical i.e. more slots can allocated downlink than the uplink, this fit the behavior of most users, typically the user will download more than they will upload. HSCSD requires software upgrades in an MS and MSC, this is because both have to be able to split a single traffic stream into several traffic streams, each using a TCH, and then to combine the streams again.

In theory a single MS could use all eight time slots within a TDMA frame to achieve an Air Interface User Rate (AIUR), for example 8 TCH/F14.4 channels or 115.2 kbit/s (ETSI 1998) TR 101 186. One major problem with this configuration is that the MS is required to send and receive at the same time. However standard GSM does not support this, uplinks and down links are always shifted for three slots. ESTI, (1997) EN 301 344, specifies that the AIUR available at 57.6 kbit/s (duplex) using four time slots and four time slots for the downlink, the table on the next page shows the allowable combinations of TCHs and allocated slots for non-transparent services.

AIUR	TCH/F4.8	TCH/9.6	TCH/14.4
4.8 kbit/s	1	-	-
9.6 kbit/s	2	1	-
14.4 kbit/s	3	-	1
19.2 kbit/s	4	2	-
28.8 kbit/s	-	3	2
38.4 kbit/s	-	4	-
43.2 kbit/s	-	-	3
57.6 kbit/s	-	-	4

Table 4.1(Available Data Rates for HSCSD)

(Adapted from Ericsson Document EN/LZT 123 5374 R1B)

Although HSCSD delivers major advantages in data transmission over GSM CS it does have several major disadvantages, it still uses a connection-orientated mechanisms of GSM, these mechanisms are not very efficient when it comes to computer data traffic, which typically uses bursts of data. If a large file is being downloaded HSCSD may require all channels to be reserved, where as typical web browsing would leave the channels idle most of the time. The allocation of channels is reflected directly in the service cost, as once the channels have been reserved by one HSCSD user other users can not use them, even if they are idle.

HSCSD was not used by any of the UK operators, this was because of the disadvantages stated above and the fact that GPRS came along so fast.

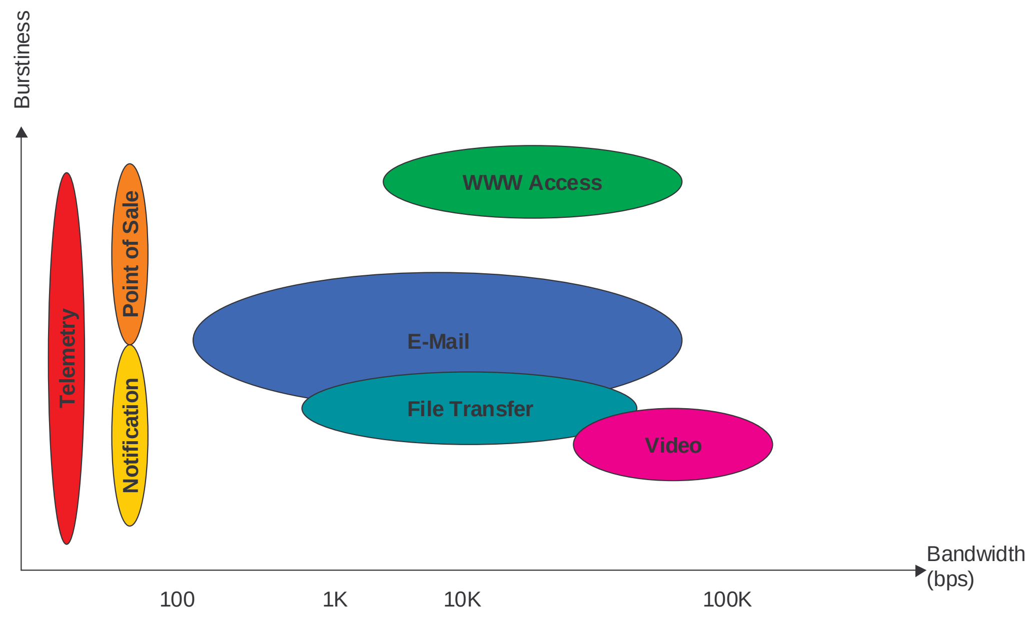


Figure 19 Areas of Bursty and/or bandwidth consuming communications

(Adapted from Ericsson Document EN/LZT 123 5374 R1B)

There are two main ways of transmitting data, Circuit-Switched (CS) and Packet-Switched (PS) communication, this is sometimes referred to packet data communication).

Figure 19 illustrates areas of bursty and/or bandwidth consuming communications. Burstiness and bandwidth requirements affect the type of communication chosen – circuit-switched, packet-switched, or e.g. SMS (Short Message Service) communication. However it should be noted that when choosing the manner of communication for an application the cost should be considered.

3.3 General Packet Radio Service (GPRS)

3.3.1 System Overview

The parts of the GPRS system that carry out the switch of packet data are called the Serving GPRS Support Node (SGSN) and the Gateway GPRS Node (GGSN). The SGSN provides a packet routing to and from the geographical SGSN service area. The GGSN makes up the interface towards the external IP packet networks, the SGSN.GGSN is physically separated from the circuit-switched part of the GSM system. The other parts of the GPRS architecture utilize the current GSM network elements.

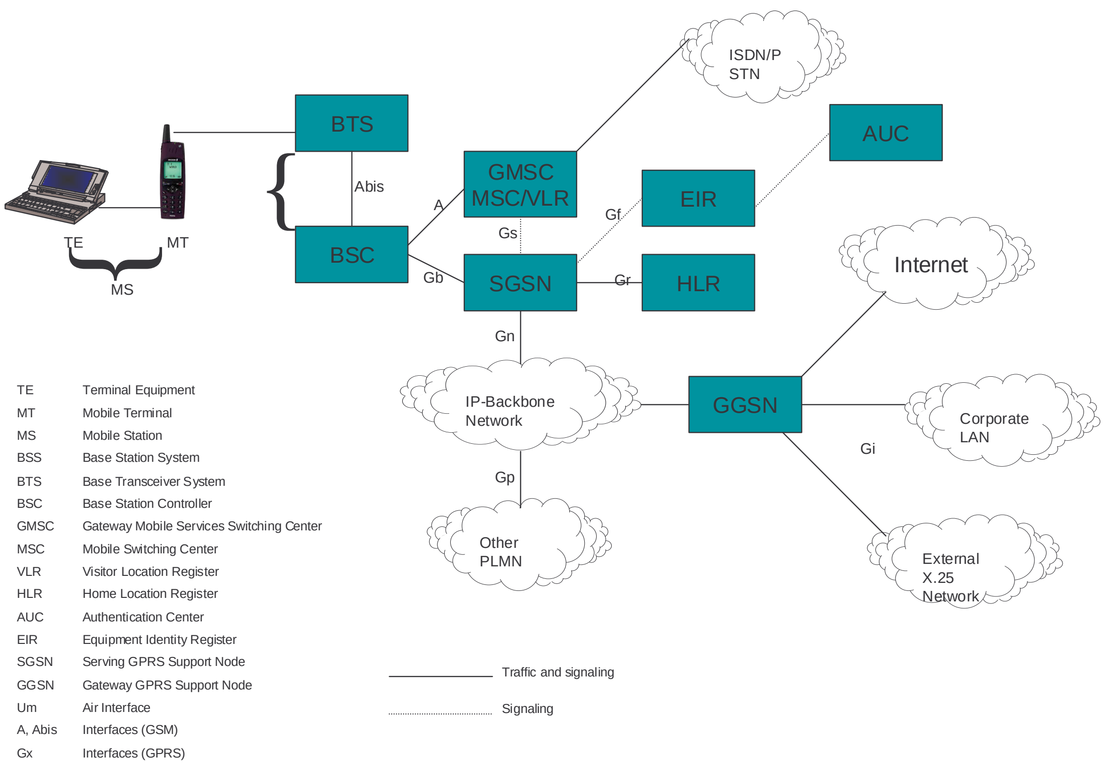


Figure 20 GPRS Logical Architecture

(Adapted from ETIS 1998 EN 301 344)

Terminal Equipment (TE)

The TE is the computer terminal that the end user uses. This is the component used for the GPRS system to transmit and receive end user packet data. For example, the TE could be a laptop computer. The GPRS system provides for IP connectivity between the TE and an Internet Service Provider (ISP), or a Corporate Local Area Network (LAN) connected to the GPRS system. From the users point of view the MT could be compared to a conventional modem.

Mobile Terminal (MT)

The MT communicates with a TE, and over the air with the BTS, the MT must be equipped with software for GPRS functionality when used in conjunction with the GPRS system. The MT is associated with a subscriber in the GSM system, the MT established SGSN. Channel reselection is provided at the radio link between the MT and the SGSN, the IP connection is static from the TE point of view, that is, the TE does not know it is mobile and retains its assigned IP address until the MT detached.

Base Station System (BSS)

The BSS consists of a Base Station Controller (BSC) and a Base Transceiver Station (BTS). The BTS is the radio equipment, that transmits and receives information over the air to let the BSC communicate with MSs in the BSCs service area. A group of BTSs is controlled by the BSC, however for GPRS to work on the BTS it must have the GPRS specific software.

The BSC provides all the radio related functions. The BSC can set up, supervise and disconnect circuit switched and packet switched calls, it has a high capacity switch, this provides function such as handover decisions, cell configuration data and channel assignment. The BSC must also be equipped with both the GPRS hardware and software when used for GPRS, one or several BSCs are served by an MSC, and a number of BSCs are served by an SGSN.

The BTS separates the MS originated circuit switched calls from the packet switched data communications, before the BSC forwards a circuit switched calls to the MSC/VLR, and packet switched data to the SGSN.

The standard GSM protocols are used with the BSC to achieve the desired compatibility.

Mobile Services Switching Center (MSC)

The MSC performs the telephony switching functions of the GSM circuit switched system, like the SGSN switches the GSM packet switched traffic, it controls calls to and from other telephony and data systems, such as the PSTN, ISDN, PLMN, Public Data Networks and possibility some private networks.

The SGSN Routing Area (RA)

The SGSN Routing Area (RA) is a subset of the MSC (CS) Location Area (LA). An MSC Location Area is a group of BSS cells, the system uses the Las to search for subscribers in the active state. An LA is the part of the network in which an MS may move around with out reporting its location to the network.

One MSC/VLR Service Area (SA) is made up of a number of LAs, the SA is the part of the network that is covered by one MSC. However there can be more than one MSC corresponding to one SGSN, one MSC can also be connected to several SGSNs.

Gateway Mobile Services Switching Center (GMSC)

The GMSC switches the circuit switched calls between GSM circuit switched network and the PSTN which is the fixed telephony network, hence it serves the function of routing incoming calls to the MSC where the mobile subscriber is currently registered, it is normally integrated in the same node as the MSC/VLR. The GMSC does not need any upgrading for GPRS.

The Home Location Register (HLR)

As stated in the section about the GSM Network the HLR is the database that holds all the subscription information for every person who has bought a from the GSM operator. The HLR stores information for the CS and PS communication, information stored the HLR includes, for example supplementary services, authentication parameters, Access Point Name (APN) such as subscribers ISP, and whether a static IP address is allocated to the MS. In addition, the HLR also includes information about the location of the MS. The main difference between this and the GSM system is that the information from the HLR is exchanged between the HLR and the SGSN.

The information that is exchanged between the HLR and the SGSN has been set up by the operator for the user, this information transfer is done when the operator changes the subscriber information, or when a new SGSN needs to have data for a subscriber after the MS has connected or in roaming, the old SGSN is also informed if the MS is roaming. The information that is going from the HLR to the SGSN is basically the routing information that is transferred upon an MS action, e.g. attach or roaming. For a roaming MS, the HLR may be in a different PLMN that the SGSN that is serving the MS.

Visitor Location Register (VLR)

The VLR database contains all the information about all MSs that are currently located in the MSC LA or the SGSN routing area respectively. The SGSN actually contains the VLR functionality for packet-switched communications, similarly, the circuit-switched VLR is an integrated component of the MSC. Another function of the VLR is that it contains the temporary subscriber information needed by the MSC or SGSN to provide services for visiting subscribers.

For MSs that support GPRS (PS) and GSM (CS), both the SGSN and the MSC will obtain location information from the HLR when the MS is combined-attached, i.e. both GPRS- and IMSI/CS-attached.

The GPRS VLR consists of software in a serving GRPS Support Node, the VLR contains information about the SGSN that is used.

The MSC/VLR is connected to the SGSN directly using the Gs interface, and indirectly via the BBS using the A and the Gb interfaces.

Serving GPRS Support Node (SGSN)

For the upgrading of the GSM network to cope with GPRS the SGSN is the primary component, and the SGSN is a new component in GSM. The SGSN forwards all incoming and outgoing IP packets addressed to/from an MS that is attached within the SGSN service area. The SGSN provides packet routing and transfer to and from the SGSN service area. SGSN serves all GPRS subscribers that are physically located within the geographical SGSN service area. A GPRS subscriber may be served by any SGSN in the network, all depending on the geographical location. The traffic is routed from the SGSN to the BSC, via the BTS to the MS. Also the SGSN provides:

Ciphering and Authentication

Session Management

Mobility Management

Logical Link Management toward the MS

Connecting to HLR, MSC, BSC, GGSN and other nodes

Output of billing data

Gateway GPRS Support Node (GGSN)

As with the SGSN the GGSN is a new primary component in the GSM network when using GPRS. The GGSN provides the following functions:

The interface toward the external IP packet networks, the GGSN therefore contains access functionality that interfaces with an external ISP, functions such as, routers and RADIUS (Remote Dial-In User Services) servers. From and external IP networks point of view the GGSN is acting as a router for the IP addresses of all subscribers served by the GPRS network. So the GGSN exchanges routing information with the external network.

GPRS session management, communication setup toward external network.

Functionality for associating the subscribers with the right SGSN.

Output billing data, the GGSN collects information for each MS, related to the external data network usage. Both the GGSN and the SGSN collect billing information on the usage of the GPRS network resources.

Equipment Identity Register (EIR)

See GSM section 2.1.2.3 (Page 25)

Authentication Center (AUC)

The AUC is a GSM component that provide triplets to the authentication and ciphering process used within GSM, the authentication for GPRS is the same as for GSM users, the only change is in the security for GPRS is related to ciphering, however this change does not require any change in software or hardware.

3.4 Traffic Cases

3.4.1 IMSI attach

In order to make or receive calls on the GSM system an MS needs to perform one procedure, an IMSI attach. The IMSI attach is shown in Figure 21, at IMSI attach a connection between the MS and the GSM network is established. The end user does not need to specify which fixed networks he wants to use because all fixed networks follow the same numbering plan (E 164), it should be noted that the MSISDN is always the same no matter which country and to whom it calls.

Figure 21 IMSI Attach

3.4.2 GPRS Attach

In order for the GPRS MS to receive or transmit data the end user needs to perform a two-step procedure, GPRS attach (Figure 21) ND PDP context activation (Figure 22)

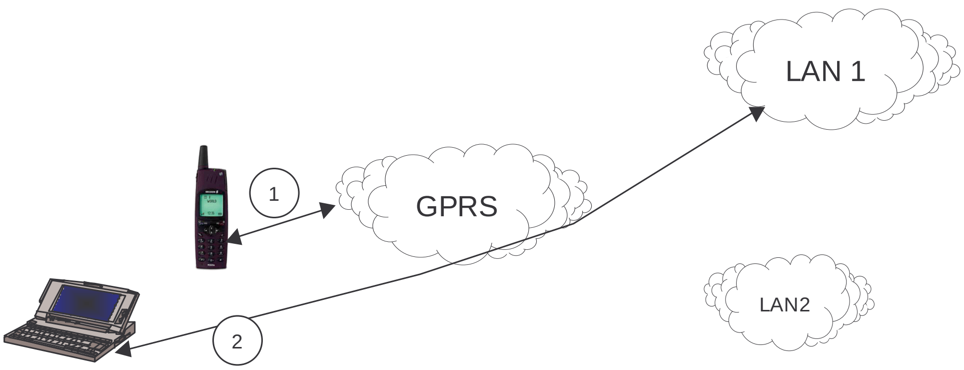


Figure 22 GPRS attach (1) and PDP context activation (2)

At GPRS attach a logical link is established between MS and SGSN, the GPRS attachment procedure in Figure 23.

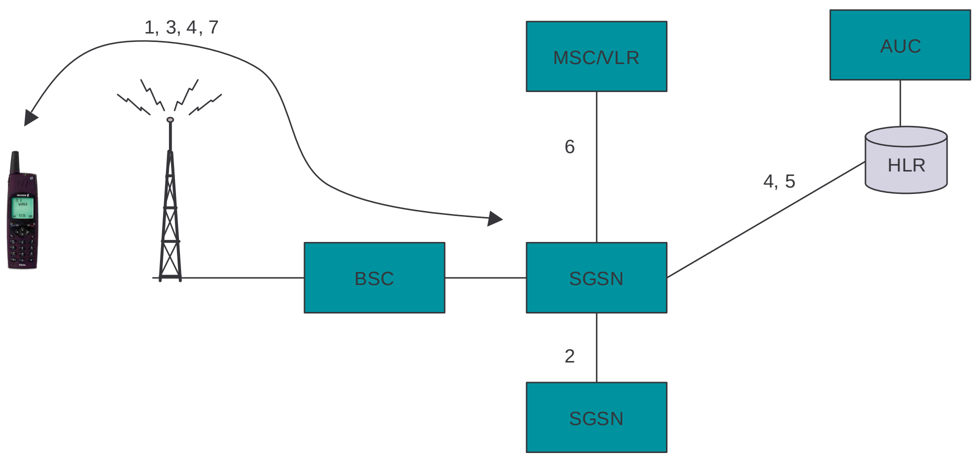


Figure 23 GPRS Attach

MS sends message to SGSN: “attach request”.

If the MS is not known by the SGSN it asks the old SGSN about the IMSI and triplets.

If the MS is not known by the old SGSN it sends an error message to the new SGSN and the new SGSN asks MS about IMSI.

SGSN authenticates MS.

Update HLR (if new SGSN service area).

Update MSC/VLR (only necessary if new LA).

SGSN tell the MS about new TLLI (Temporary Location Link ID).

3.4.3 Combined GPRS/IMSI Attach

In a combined GPRS/IMSI attach, both of the previous procedures are carried out simultaneously, shown in Figure 24.

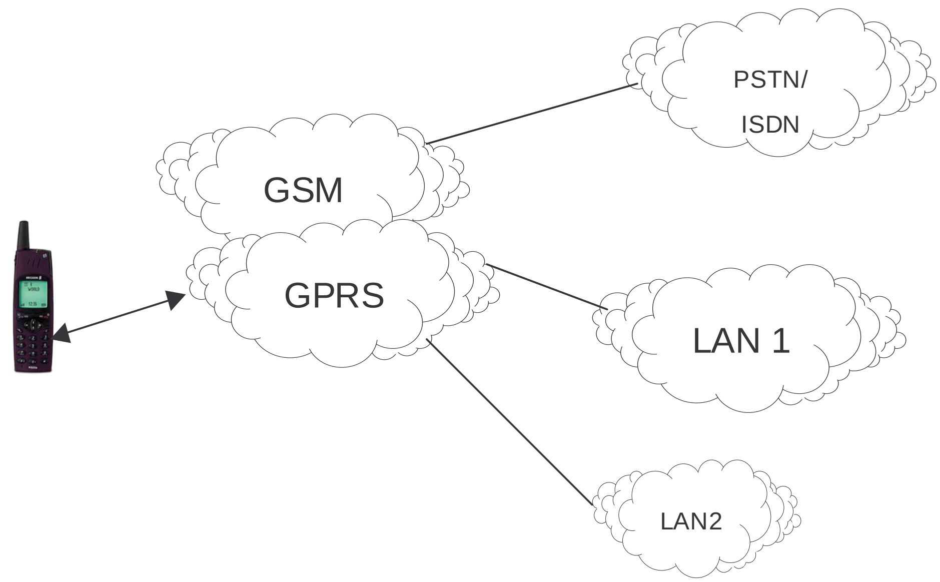


Figure 24 Combined GPRS/IMSI attach

3.4.4 PDP Context Activation and Deactivation

In order for the MS to send and receive GPRS data the MS must perform a PDP context activation after the GPRS attach (Shown in Figure 23). The PDP context activation makes the MS known in the concerned GGSN and communication to external networks is made possible.

The PDP context activation corresponds from the end users perspective to “Logging On” to an external network.

The difference from using a dial-up connection over circuit switched is that in GPRS the end user can have several PDP contexts activated simultaneously if the terminal supports several IP addresses.

3.5 GPRS Air Interface

The air interface (Um) is the logical link between the MS and the BSS. Figure 25 shows the GPRS Protocol Stack from the perspective of the BSS

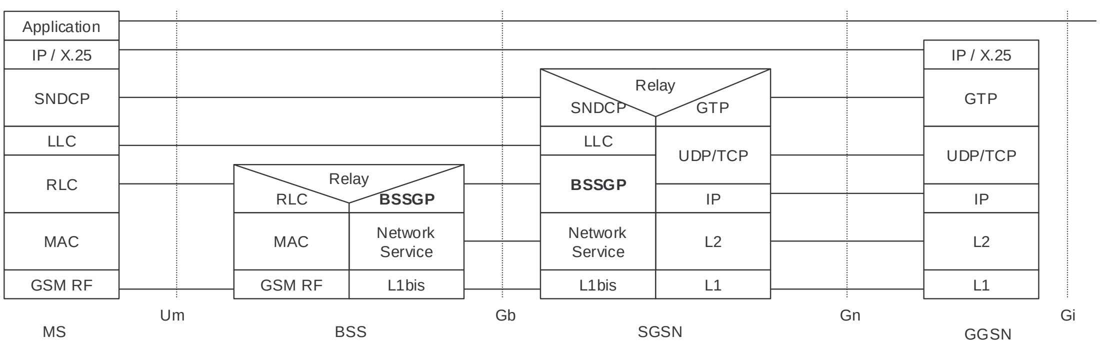


Figure 25 GPRS Protocol Stack

(Thomas, R, et al, 1999, France Telecom)

The Layers are described in Appendix 1.

3.6 Logical Channels

Within GPRS there are a number of new logical channels, similar to the existing ones, but these are only for GPRS. (NB These logical channels have been standardized.) The new logical channels have been mapped onto the physical channels that have been assigned for packet data, the physical channels denoted as Packet Data Channels (PDCH), the logical channels that are mapped onto these are :

Packet Common Control Channels

PRACH : Packet Random Access Channel (Uplink)

PPCH : Packet Paging Channel (Downlink)

PAGCH : Packet Access Grant Channel (Downlink)

PTCCH : Packet Timing advance Control Channel (Up/downlink)

PNCH : Packet Notification Channel (Downlink)

Broadcast Channel

PBCCH : Packet Broadcast Control Channel (Downlink)

Packet Traffic Channels

PDTCH : Packet Data Traffic Channel (Up/downlink)

PACCH : Packet Associated Control Channel (Up/downlink)

3.7 PDCH Allocation

The following section will explain how the PDCH is allocated. Traffic Channels and packet data channels basically create a common pool of resources, utilizing the existing resources in an efficient way. See Figure 26

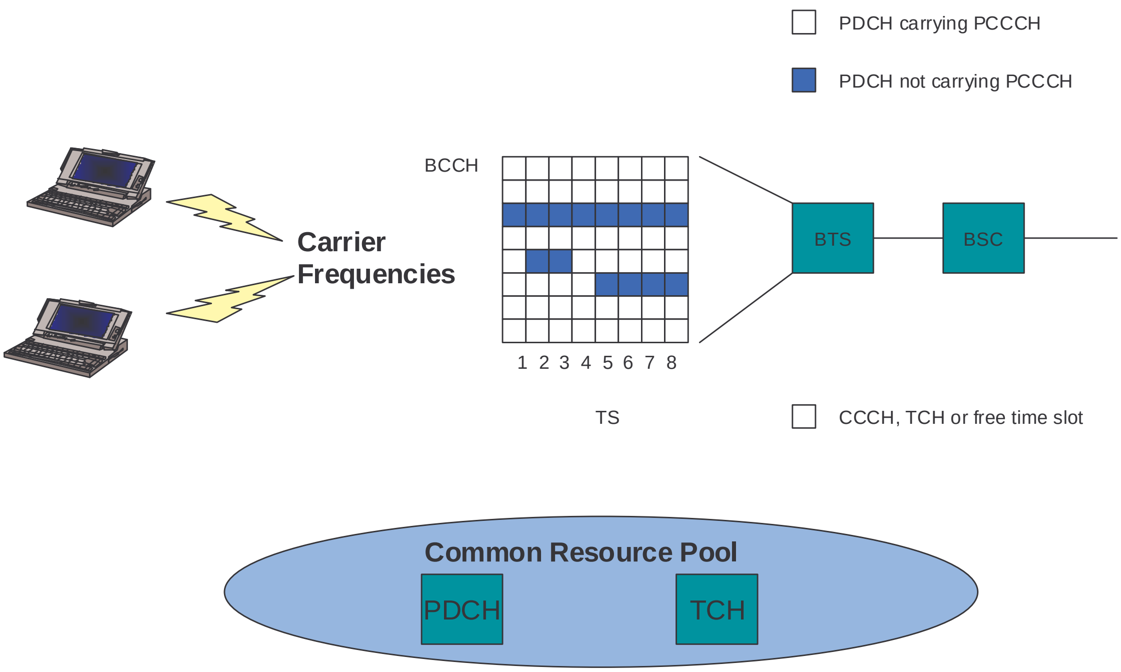


Figure 26 Common Recourse Pool

The PDCHs are allocated to the PCU, the PCU is responsible for assigning channels to different GPRS MSs. The PDCHs can be allocated in different ways:

Dedicated PDCHs are allocated and released by operator command.

On-demand PDCHs, serving as temporary dynamic GPRS recourses, are allocated and released depending on GPRS traffic demand.

The channels that are allocated for GPRS (PDCH) are allocated in sets of maximum four consecutive time slots, such a set is called a PEST (Shown in Figure 27), a PEST can consist of both dedicated and on demand PDCH. All PESTS are on the same frequency or hop the same frequency hopping set. An MS can only be assigned PDCHs from one PEST, at present this limits the maximum number of assigned time slots to four, there is no additional limit on the number of PDCHs that can be allocated in a cell, except the number of available TCHs.

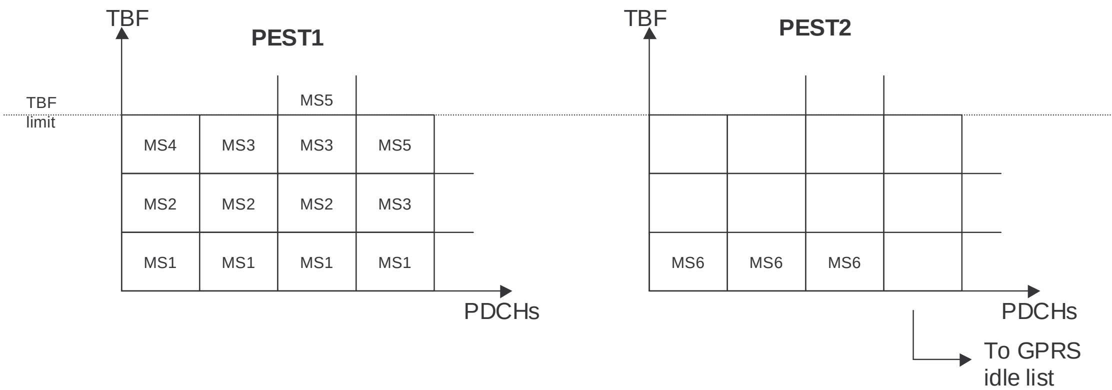


Figure 27 Channel Reservation (PESTs)

3.7.1 Dedicated PDCH

Dedicated PDCHs can only be used for GPRS, the operator can specify between zero and eight dedicated PDCHs per cell, the reason for dedicated PDCHs is to ensure that there is always the GPRS resources in a cell. To some extent the operators can specify to where they dedicated PDCH(s) to be located. However from a radio point of view, non hopping channels on the BCCH carrier are generally not equivalent to traffic channels on other frequencies. The operator can decide if the PDCH shall be allocated on the non-hopping BCCH frequency as primary or secondary choice, or with no preference.

3.7.2 On-demand PDCH

On-demand PDCH can be pre-empted by incoming circuit switched calls in congested cells, it should be noted that in a HSCSD, a user can never get more than a single channel through the pre-emption procedure.

There is no physical limit on how many on-demand PDCHs there can be in a cell. However the number of on-demand PDCHs depends on how much packet switched traffic there is, upto the limit where circuit switched traffic starts

3.7.3 Master PDCH

A master PDCH (MPDCH), is a PDCH carrying a PBCCH and PCCCH, as well as GPRS traffic. The PCCCH carries all the necessary control signaling to initiate packet traffic. In the standard, the MPDCH is called “the PDCH carrying the PBCCH”. NB the abbreviation MPDCH is only used within Ericsson systems.

The first directed PDCH that is allocated according to the operator’s preferences regarding non-hopping BCCH will be configured as an MPDCH. The following PDCHs that are allocated will only carry GPRS traffic and associated signaling. However in a cell with no MPDCH (i.e. no dedicated PDCH allocated) the ordinary control channels such as the BCCH, RACH etc, will handle the broadcasting and signaling to the GPRS mobiles.

3.8 Cell Selection and Reselection

Comparing GPRS with circuit switched

In a GSM network the BSC governs the cell selection behavior of the MS when in idle and active mode by different methods. Idle mode MSs autonomously performs cell reselection by using the C1/C2 criteria.

In active mode, non-GPRS MSs are steered by the locating functionality implemented in the BSC. So this means that the BSC initiates the handovers to other cells. With GPRS, the MS determines the base station with which it will communicate, Figure 28 shows the handover procedures for both Circuit Switched and Packet Switched. The GPRS MS manages both the idle packet and transfer packet mode behaviors.

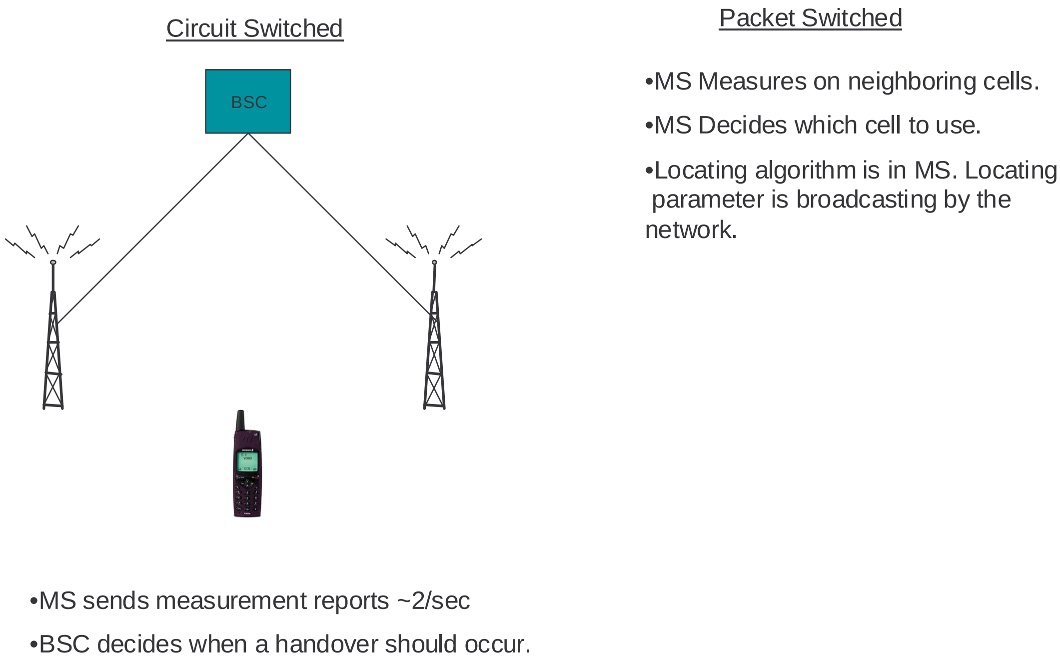


Figure 28 Handover, comparison between CS and PS

The cell selection and reselection algorithm used for controlling the idle/transfer mode behaviors are governed by the GPRS cell selection and reselection parameter setting broadcast in the packet system information on the PBCCH in each GPRS capable cell with an allocated PBCCH (MPDCH). If no PBCCH has been allocated in a cell, the GPRS MS will read the system information broadcast on BCCH and use the C1/C2 criteria for cell selection and reselection as in the circuit switched idle mode case.

So as you can see the GPRS cell selection and reselection algorithms are governed by parameter settings. These parameters C31 and C32 are different to the corresponding parameters for the circuit switched system. However with some GPRS systems GPRS cell section parameters are automatically mapped on those for cell selection/locating known from the circuit switched case. The reason for this is to achieve the same cell selection behavior for GPRS, as with GSM, this will enable an easy rollout of GPRS in the network.

The GPRS standard allow the network to take over cell reselection for a specific MS or for all MSs. This is called Network Controlled Cell Reselection and have not yet been implemented in any UK or European GPRS systems.

3.8.1 GPRS Support Node (GSN)

The GSN is a general purpose, high-performance packet switching platform, the GSN combines features usually more associated with data communications (features such as compactness and high functionality) with features from telecommunications such as robustness and scalability. The GSN is designed for non-stop operation, the platform incorporates 1+n redundant hardware, and also the software is of a modular design enabling individual modules to be upgraded with out causing any interference to the traffic.

3.9 Interconnection Principles.

In this section the connection between GSNs and their operating environment, the interfaces used in the GPRSN network and the GSNs, and their contexts are shown in Figure 29, the interface names are part of the ETSI GSM standard for GPRS.

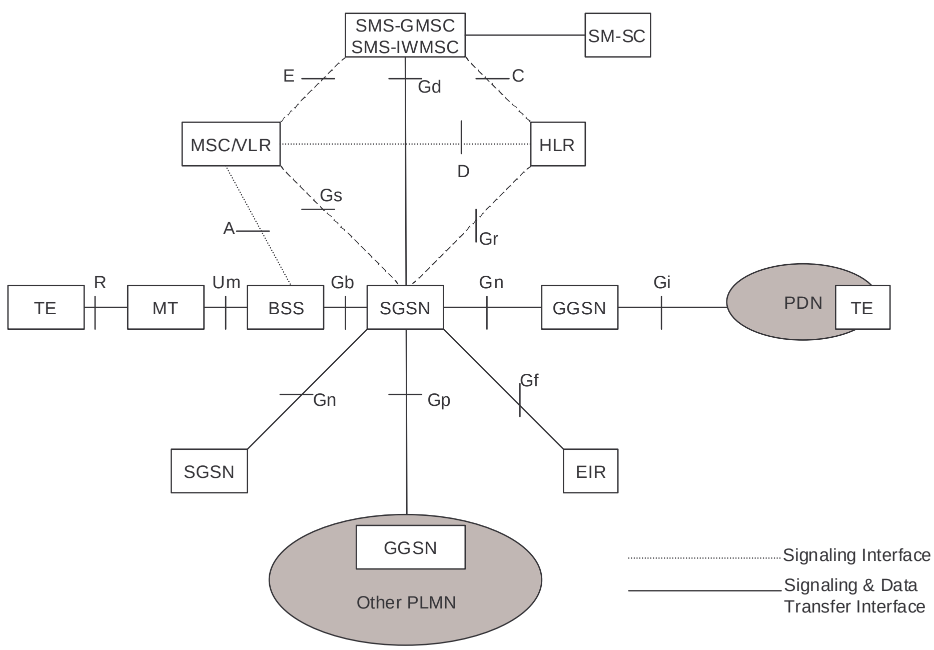


Figure 29 GPRS Logical Architecture

(Adapted from ESTI 301 344 V6.3.2 (1999))

3.10 GPRS IP Connectivity

One of the main advantages of GPRS is that it provides IP connectivity, this means that communication between the different parts of the operators GPRS system, the GGSN, administrative hosts and hosts providing Internet Services. Further more the IP connectivity enables easy communication with the Internet. However is should be noted that GPRS has two different types of communications, represented with two different levels of IP communication:

The IP communications within the GPRS network. This is for signaling, management etc.

3.11 The users IP communication.

The latter is the communication between a GPRS MS and an ISP, for example. The GPRS system provides IP connectivity between MS and ISPs, using the GSM standard, data transfer is based on the common internet protocol (IP), which means that packet data transmission is carried out on an end-to-end basis (including the air interface). From the users point of view a modem connection to the internet is provided when using an GPRS MS.

An interface that communicates using the IP protocol must have an IP address and identifier, now since the GPRS system uses the IP protocol for both the end-user traffic and the system user traffic, both MSs and system components need IP addresses.

The IP addresses used in the GPRS system, for system and for end-user communication, can be public, dynamic or static.

Chapter Summary and Key Points

In GSM Circuit switched data, the typical maximum data rate of data throughput was officially 9.6 kbit/s, however when the overhead of control, guard data, encryption keys and error correction, are taken into account the typically user data throughput was only 1 – 1.5 kbit/s.

The first phase of the GSM evolution to higher speed data was the introduction of High Speed Circuit Switched Data (HSCSD). This gave the user the potential of data rates up to 38.4 kbit/s, which after the overhead was accounted for allowed a user data rate of 14 kbit/s. This improvement in data throughput was achieved by the use of multiple time slots, but was at the expense of the main revenue earning service (speech).

Due to the fact that data is tolerant to delays in transmission, as opposed to speech a new technique utilizing packet switching was developed (GPRS)

GPRS differs significantly from HSCSD in that it is not permanently connected to a single physical channel. Like HSCSD, GPRS utilizes multiple time slots, but the network has the ability to reduce the number of time slots used so that speech traffic is given priority. The disadvantage to the data user is that during peak hour traffic data throughput will be significantly reduced by the network in order to accommodate the higher revenue potential of speech traffic.

To the network operator the introduction of GPRS has meant a significant modification of the existing GSM network infrastructure. The advantage to the network operator is that they can now use a packet switched network for data transmission instead of dedicated circuit switched network. This has major economic advantages for the network operator. During speech transmissions, there are many instances of no information being transmitted but with data, transmission is continuous. It is for this reason that data does not need to be permanently connected as the data can always be re-arranged at the terminal end.

With users requiring faster and faster data speeds and even the ability to download multimedia applications, a new technology had to be developed due to the fact that GSM had reached it's maximum data throughput. Also the network had to consider whether it was connected to a data or speech call. So the next step in the evolution was the development of Wideband CDMA, leading to UMTS.

4.1 WCDMA

WCDMA of 3G potentially will offer the user significantly increased data throughput rates. Speeds of up to 2mbit/s and higher are being predicted but it will be sometime before these are achieved. New techniques such as voice over IP are being developed for use on the Transport Infrastructure and will bring significant advantages to the operator especially in terms of data compression techniques used in such transmission modes as ATM. Increased data throughput means greater capacity for a given amount of frequency spectrum and thus lower costs for both Infrastructure and spectrum licences. Potentially the benefits of WCDMA to the user and operator are massive with greater data rates for the user and reduced costs for the operator.

4.2 Carrier Spacing and Deployment Scenarios

The carrier spacing has a range of 200 kHz and can differ from 4.2 to 5.4 MHz, the different carrier spacing can be used to obtain suitable adjacent channel protections depending on the interference scenario. Figure 30 shows an example, where the bandwidth of 15 MHz with three cell layers. Larger carrier spacing can be applied between operators, than within one operators band in order to avoid inter-operator interference. Interfrequency measurements and handovers are supported by WCDMA to make use of three cell layers and carriers.

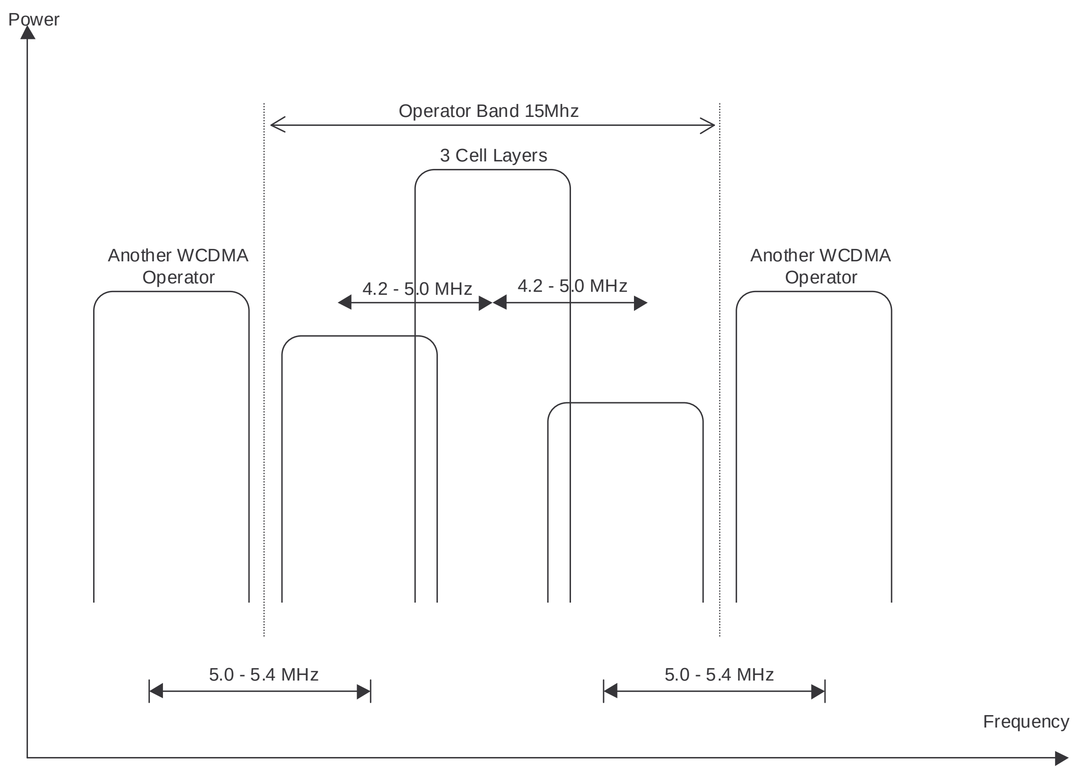


Figure 30 Frequency utilization with WCDMA

(Adapted from Holma, H. et al 2000)

4.3 Logical Channels

WCDMA mainly follows the ITU Recommendation M.1035 in the definitions of logical channels. The following logical channels are defined for WCDMA.

4.4 Control Channels

BCCH : Broadcast Control Channel carries system and cell specific channels;
PCH : Paging Channel for messages to the mobiles in the paging area;
FACH : Forward Access Channel for messages from the base station to the mobile in one cell.

In addition to the two Control Channels there are also two Dedicated Channels;

DCCH : Dedicated Control Channel, this covers two channels : stand-alone dedicated control channel (SDCCH), and the Associated Control Channel (ACCH);
DTCH : Dedicated Traffic Channel for point to point data transmission in the uplink and downlink.

4.5 Uplink Physical Channels

There are two dedicated channels and one common channel for the uplink. User data is transmitted on one of these channels, the Dedicated Physical Data Channel (DPDCH), as is the control information. The Random Access Channel is a common access channel.

The Dedicated Physical Control Channel (DPCCH) is needed to transmit pilot symbols for coherent reception, power signaling bits, and rate information for rate detection. The two basic solutions for multiplexing physical control and data channels are time multiplexing and code multiplexing. A combined IQ and code multiplexing solution (dual-channel QPSK) is used in the WCDMA uplink and to avoid Electromagnetic Compatibility (EMC) problems with Discontinuous Transmission (DTX).

There is a major drawback of a time multiplexed control channel, that is where there are EMC problems that arise when DTX is used for data transmission. Figure 31 shows an example of DTX during normal speech transmission. During periods when there is silence there is no need for information bits to be transmitted. This results in pulsed transmission of the of the control data that has to be transmitted.

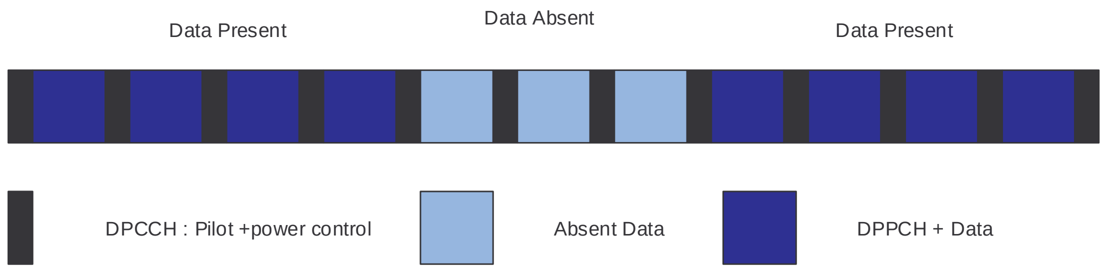


Figure 31 Pulsed Transmission when time multiplexed control channel

(Adapted from Holma, H. et al 2000)

The Random Access Burst is made up of two parts; a preamble which is made up of 16c256 chip (1ms) and a data part but data parts length is not a fixed length and this is what gives WCDMA its variable data rates. The random access system is based on slotted ALOHA technique; Figure 32 shows the structure of the random access burst.

Before the transmission happens the Mobile Station (MS) has to carry out a number of tasks:

Achieve chip, slot, and frame synchronization to target BSS from the SCH;

Retrieve information from the BCCH about the random access code used in the target cell/sector;

Estimate the downlink path loss, which is used together with a signal strength target to calculate the required transmit power of the random access request.

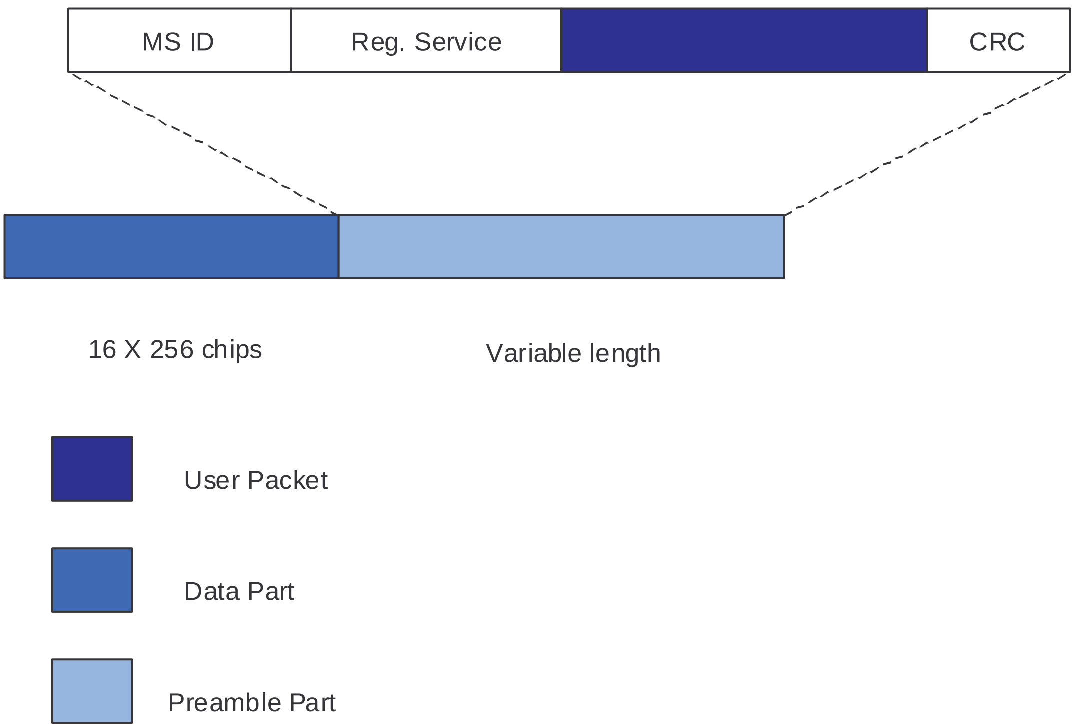


Figure 32 The structure of a Random Access Burst in a WCDMA System

4.6 Downlink Physical Channels

There are three physical channels in the downlink; the primary and secondary Common Control Physical Channels (CCPCH) carry the downlink for the common control logical channels (BCCH, PCH and FACH); the SCH provides timing information and in WCDMA is used for handover measurements by the Mobile Station (MS).

The dedicated channels (DPDCH and DPCCH) are multiplexed, however this means that there is an EMC problem caused by discontinuous transmission, but this is not considered a significant problem to the downlink, for two reasons :

There are signals to several users transmitted in parallel and at the same time.

Base Stations are not so close to other electrical equipment.

4.7 Packet Data

There are two very different types of packet data transmission within the WCDMA system. Short data packets can be added to the random access bursts and this method is called Common Channel Packet Transmission (CCPT). CCPT is most commonly used for short infrequent packets, where link maintenance needed for a dedicated channel would lead to an unacceptable overhead. Another factor for the use of CCPT cuts out the delay that can be associated with a dedicated channel. It should also be noted that for common channel packet transmission only open loop power control is in operation (Open Loop Power control measures the interference conditions from the channel, and adjusts the transmission power adoringly to meet the desired frame error rate (Ojanpera, T etal. 1998)). CCPT should therefore be limited to short packets that only use a limited capacity. This is shown in Figure 33.

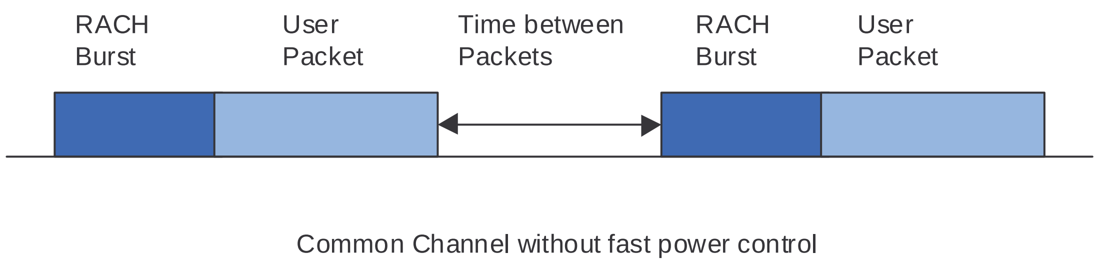


Figure 33 Packet Transmission on the Common Channel

For larger or more frequent packets transmitted on a dedicated channel, a large single packet is transmitted using a single packet system, where a dedicated channel is released immediately after the packet has been transmitted. In a multipacket system the dedicate channel is maintained by transmitting power control and synchronization information between subsequent packets.

4.8 Handovers

The WCDMA system's base stations do not need to be synchronized, and hence, there is no need for an external source of synchronization such as GPS. Asynchronous base stations have to be considered, especially when designing soft handover algorithms and when implementing position location services.

Before a soft handover happens, the MS measures observed timing differences of the downlink SCHs from the two base stations. The timing of a new downlink soft handover connection is adjusted with a resolution of one symbol. For example, dedicated downlink signals from the two base stations that are synchronized with an accuracy of one symbol. This enables the mobile RAKE receiver to collect the micro diversity energy from the two base stations. From this the timing adjustments of dedicated downlink channels can be carried out with a resolution of one symbol without losing orthogonality of downlink codes.

4.8.1 Soft Handovers

Soft handovers with WCDMA are very different to the handovers used in the GSM system and this basic principle stems from the US system CDMA. Basically the MS is connected to more than one BTS (Base Station Transceiver) at a time. The reason for this is to reduce interference into other cells (BTSs). It also has the advantage of improving performance through macro diversity.

Figure 34 illustrates a soft handover principle. The uplink signal fro the MS is received by both BTSs, which, after demodulation and combining, pass the signal forward to the combining point, typically this is the BSC. From a downlink point of view the same information is transmitted via both BTSs, and the MS receives the information from both of the BTSs as a separate multipath signals and can therefore combine them.

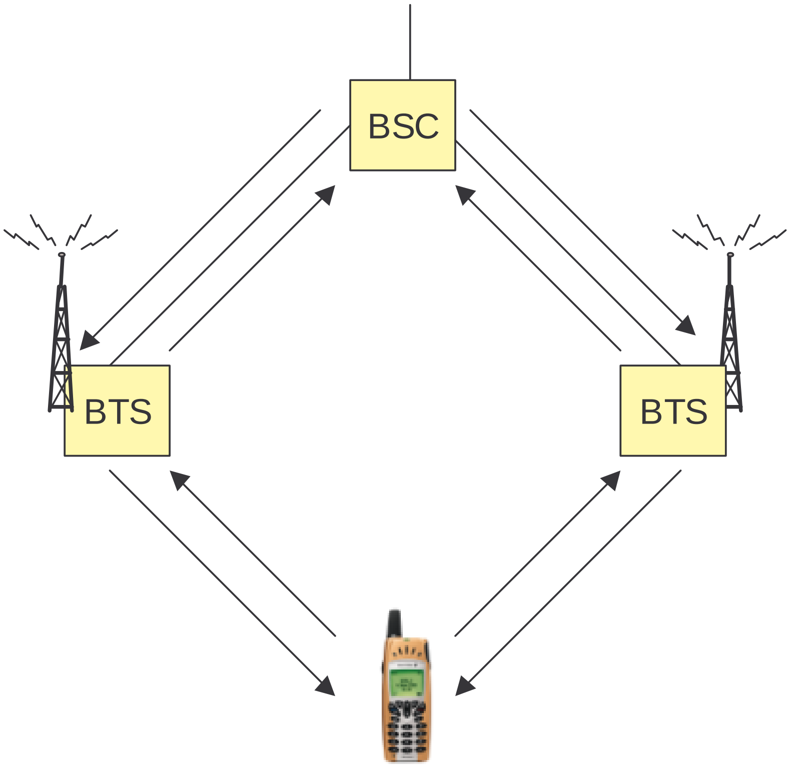


Figure 34 Principle of soft handover with two base station transceivers (BTS)

Infrequent handovers are needed for utilizations of a hierarchical call structures; macro, micro and indoor cells. Several carriers and inter-frequency handovers may also be used for taking care of high capacity needs in hot spots. Infrequent Handovers will be needed also for handovers to the 2G systems (See UMTS). There are two methods that are being considered for WCDMA, (1) Dual Receiver and, (2) Slotted Mode.

Chapter Summary and Key points

GPRS saw the realization of the maximum data rate that can be attained using the GSM system. So there was a need for Wideband CDMA (WCDMA), this is an enhanced version of the mobile communication system that is used in the United States. The main use for WCDMA in the UK will be for mobile data communications, this is because the UK already has an effective voice system in the GSM system.

It should be noted that WCDMA has several major drawbacks, the biggest being that with WCDMA used a form of DTX, this DTX causes EMC (Electromagnetic Compatibility) problems. The DTX is used in both Voice and Data transmission, but the problem only occurs when the MS is in Data transmission mode.

WCDMA is not envisaged to by applied in the UK for the next 3-4 years, this will probably be around the same time that UMTS is made available, however the potential benefits of WCDMA to the user and operator are massive with greater data rates for the user and reduced costs for the operator.

WCDMA is an integral part of UMTS (Universal Mobile Telecommunications System). UMTS is an integration of communications systems, and will hopefully provide a solid base for mobile communications in the future.

Some information contained in this chapter is based on Commercially confidential documents supplied by Ericsson. This section may not be passed on to any persons other that the primary and secondary markers.

This document must not be placed in the University Library!

5.1 UMTS Introduction

This chapter provides an overview of the GSM/UMTS core network, as specified by the 3GPP release 99 standards. There is still no strict formal definition of the core network, but the position of the core network for the purpose of this chapter and how it relates to other parts of the PLMN (Public Land Mobile Network) and co-operating networks.

Originally decided by the ETSI SMG, the 3GPP release 99, the UMTS core network standard is evolved from the earlier GSM standards releases. The core network forms the central part of a PLMN and accommodates important functions for intra and inter PLMN roaming, the provision of IP-connectivity and internet access, ISDN services and interworking with other networks.

The core network may be looked upon as consisting of two different parts :

Managing Circuit Switched mode communication services. (ISDN type services)

Managing Packet Switched mode communication services. (GPRS type services)

Although logically very different the two parts share certain core network functionality, such as the HLR, Auc, EIR etc, and may also run over a common transport infrastructure.

5.2 Horizontal Layering

Today's modern telecommunications and data communications environment consists of a variety of networks. Most of these networks are highly specialized and optimized to serve a specific purpose such as PLMN, ISDN/PSDT and Data/IP Network. To a larger extent these networks are all vertically integrated in a sense they combine functionality in one and the same network element.

Due to the fact that most networks are vertical in structure, they have evolved separately and therefore differ in many respects. However, this has the effect of limiting the network operators ability to create synergies among their networks.

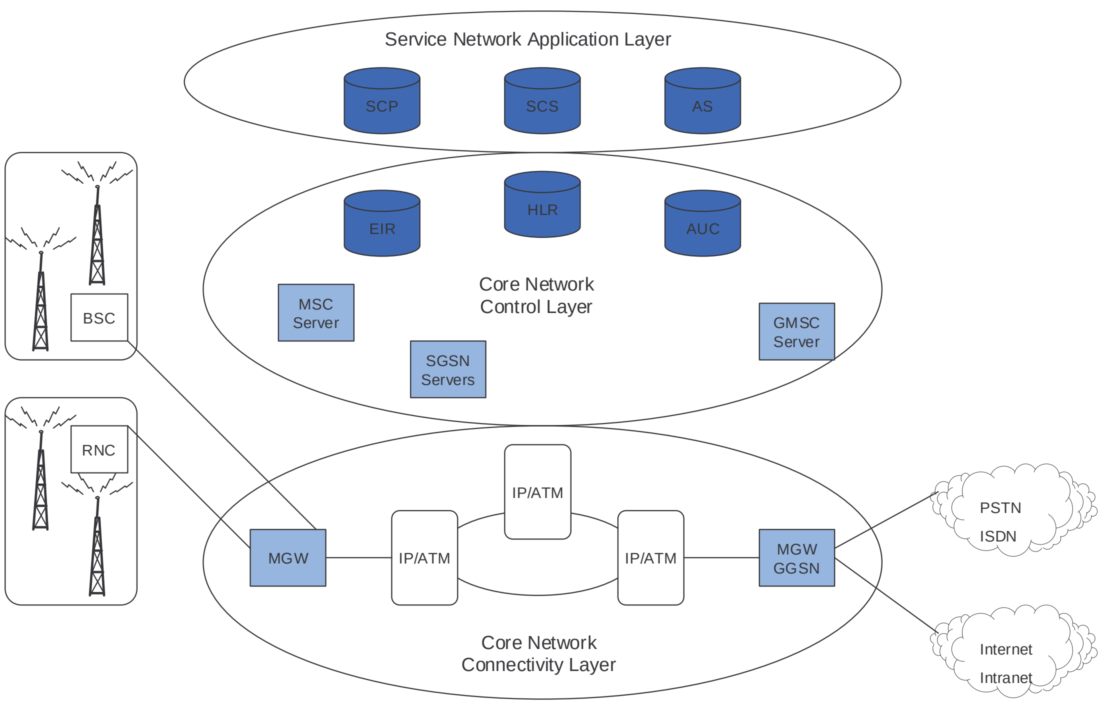


Figure 35 Three Layered UMTS Core Network Architecture

(Adapted Edlin, B 2001)

The architecture of the core network for UMTS is shown is Figure 35, this illustrates the way to evolve this multi-network situation in order to overcome some of the existing defects. In short the UMTS solution is based on a horizontalisation of the core network into a number of independent networks.

Basically UMTS is a “*Network of Networks”* (Personal Comment). Special Media Gateways (MGW), controlled by specific network servers, adapt and connect different access types to a common backbone network. End user applications are provided by a specific service layer, common to different access types.

5.3 General Principles

The layered core network architecture is derived from the current standards reference model by separating the control plane functions, thus turning these nodes into Servers and Media Gateways.

5.3.1 User Plane

The user plane, sometimes referred to as the connectivity layer (see Figure 35), could be seen as a layer of distributed resources managing user data (and signaling) flows. The user plane’s functions are primarily handled by the GGSNs and the MGWs, located at the edges of the core network. The MGW carries out the processing of end user data such as speech coding and also acts as an access switch/router to the backbone network. The MGW also sets up the bearer connections carrying the user data flows in the user plane.

The MGWs are controlled by the MSC and SGSN servers via the H.248 gateway control protocol. The resources needed for a call/session may be distributed over multiple MGWs. For Circuit mode communications the user data processing is primarily allocated to the MGW on the boarder of the ISDN/PSTN.

For interconnecting the network elements in the user plane, different transport technologies may be used.

5.3.2 Control Plane

The control plane houses a number of network servers and databases of different types (MSC Server, SGSN Server, HLR, Auc, EIR etc). These servers are responsible for handling subscriber data, security, mobility management, setup and release of calls and sessions, requested by the end users, circuit mode supplementary services and similar functions. The network servers communicate among themselves and with other network elements by means of standard layer 3 protocols such as the following, Iu "Mobility Management", Iu "Call/Session control", ISUP, MAP etc. The MSC and the SGSN servers can also determine which MGW functions and resources are required by the call/session and control these functions and resources in the MGW by means of the H.248 gateway protocol.

5.3.3 Application Layer

The application layer is a simplified abstraction of the layer where most of the end-user applications reside. To a large extent these applications are implemented partly in the terminals and partly in the specific application servers, which reside within the network*. Applications exist in a broad variety, from the simple end-to-end client server solutions to complex applications involving multiple interactive end-systems, networks, media communication models etc.

* Some services handled by the network elements in the control plane, particularly the more traditional supplementary services for circuit mode communication.

5.4 Core Network Standards and Interfaces

(This section refers to the Ericsson UMTS Core Model)

The Ericsson core network architecture fully aligns with the 3GPP release 99 standards and complies with the interfaces worked out by the 3GPP. The separation of the control and user plane functions can be seen as an enhancement to the release 99 reference model and aligns with a number of important standardization initiatives in IETF, ETSI, IT-U and other different industry forums.

As a result of the various control plane/user plane separation initiatives in different standardization forums, a gateway control protocol (H.248) has now been standardized by ITU-T.

5.5 Key Benefits of the Layered Architecture

The key principle of modern networking is the separation of network functionality into independent layers; this is also true in the tele and datacoms industry. The 'layered' thinking is also a very fundamental and visible aspect in a number of standardization initiatives and industry forums, such as Multiservice Switching Forum, led by several of the largest operators and manufactures.

3G mobile communication systems are designed with these principles in mind, and hence offer a number of advantages and possibilities. Special attention needs to be put on meeting the requirements for time-to-market, low cost of ownership, openness and future evolution towards an "all-IP" solution.

Key characteristics :

Offers an open and versatile architecture capable of meeting the current and future demand in a fast changing telecommunications enviroment.

Provides and inherent flexibility for coping with growth and/or changing traffic patterns and traffic mixes.

Independence between layers allows each layer to evolve independently.

Provides great transport flexibility and allows different transport technologies, both existing and new. To be deployed without impacting the control or services/application layers.

Allows common transport arrangements for multi-services network.

Allows access independent and seamless services through a common service/applications layer.

Provides efficient use of network resources.

Relies on proven and stable protocols and design.

Allow a very flexible re-use of investments in the GSM infrastructure.

5.6 Core UMTS Network Elements

The following section sets out the elements of the GSM/UMTS core network, and some of the reasoning behind it. Figure 36 shows how these core elements fit together and how they fit into the overall system picture. However Figure 36 is not a true physical representation of the core network, nor does it show all the interfaces. As the core network has not been standardized there still exist other possibilities for bundling different functions into physical network elements.

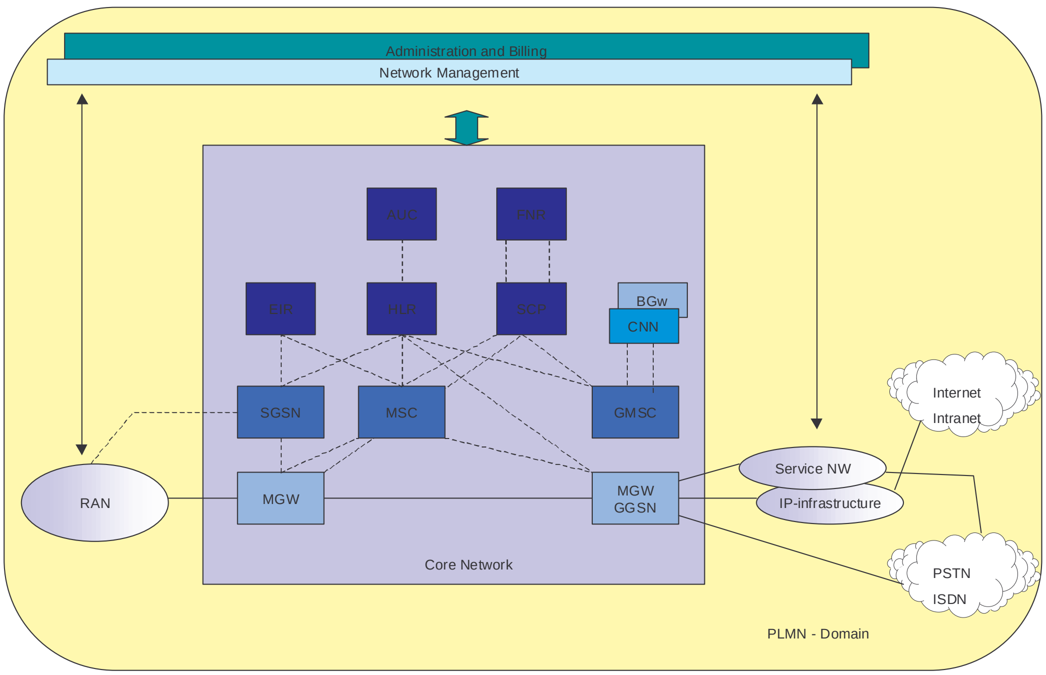


Figure 36 UMTS Core Network Elements

(Adapted from Ericsson Document EN/LZT 123 5374 R1B)

MSC Server

The MSC Server handles control layer functions related to circuit mode communication services at the UTRAN and PSTN/ISDN borders and performs among others the following functions:

- Media gateway control
- ISDN services control
- Mobility management
- Authentication
- Charging data collection/output
- Services switching function (5SF)
- Internet dial-in services (RAS)
- Element management

In addition to these functions the MSC Server also houses the interworking and gateway functionality necessary to act as an SMS-IWMSC and SMS-GMSC for the Short Message Service.

Serving GPRS Support Node Server (SGSN Server)

The SGSN Server handles control layer functions related to packet mode communication services at the border between UTRAN and the basic core network and performs among others the following functions:

- Media gateway control
- Session management
- Mobility management
- Authentication
- Charging control
- Relaying of SMS
- Element management

Media Gateway (MGW)

The MGW handles transport and user plane functions for both packet and circuit mode communication at the borders between networks/network segments. These lower layer functions primarily concern the user data handling and includes e.g.:

- Media processing (speech coding. conference call bridging etc)
- Media generation (tones etc)
- Setup/release of user data bearers
- Provision of traffic/charging info for packet mode communication
- Security management
- Routing and switching QoS management
- Element management

Most MGW resources are shared between packet and circuit communication services or can easily be re-configured from one communication mode to the other. This offers a very cost efficient and flexible solution for managing future changes in the circuit and packet mode traffic balance.

Gateway GPRS Support Node (GGSN)

The GGSN constitutes the tunnel end-point for the GPRS specific GTP-tunnel for packet mode communication and is situated on the border between the basic UMTS core network and the ISP-POP". The GGSN is (indirectly) selected by the end-user at setup of the PDP-context. From an addressing point of view the GGSN represents the point of presence for 'logged on' end-users, i.e. end-users with an established PDP-context. Addresses can be dynamically assigned (fetched from an external server or a pool of own addresses) or statically assigned (fetched from the HLR). In order to fulfill its role in the network the GGSN performs the following functions among others:

- Tunnel management
- IP-address management

- Charging data collection/output
- Security management
- Packet filtering
- Packet routing/tunneling
- QoS management
- Element management

Optionally, a GGSN may also include certain non-GPRS specific functions such as a Foreign Agent (FA).

Home Location Register (HLR)

The Home Location Register is a network database for mobile telecommunications. The HLR holds all mobile specific subscriber data and contains a number of functions for managing these data, controlling services and enabling subscribers to access and receive their services when roaming within and outside their home PLMN. The HLR communicates with the GSNs, MSCs and other network element via the MAP-protocol.

The Authentication Centre (AUC) contains functions for secure storage of individual subscriber identifiers and keys. AUC also includes algorithms necessary for generating authentication and ciphering data based on the subscriber keys. The authentication and ciphering data, provided by the AUC upon request, are used by different network elements to protect the network, users and operators against unauthorized use of the system.

Service Control Point (SCP)

The SCP is a part of the IN concept and contains the service logic and its execution environment. The SCP works in close co-operation with the service switching functions in the MSCs and provides IN-services such as Virtual Private Network (VPN), Number Portability etc.

Flexible Number Register (FNR)

The FNR accommodates translation functions necessary to de-couple end-user identities from the actual network databases holding end-user data. These translation functions are essential in order to be able to e.g.:

Easily reconfigure some of the network databases, e.g. as a result of a growing number of end-users.

Allow end-users to keep their identities when changing from one administration to another.

Equipment Identity Register (EIR)

The Equipment Identity Register is a network database holding status information on mobile station equipment. The EIR is interrogated by means of the MAP-protocol from e.g. network elements providing access into the PLMN (MSC and SGSN servers), in order to ensure that the mobile station equipment is not black-listed for any reason.

Cost Control Node (CCN)

The Cost Control Node is a central part of the 3G charging environment. CCN contains centralized rating functions and constitutes the charging determination point for services provided to subscribers at both into and inter PLMN roaming. CCN also handles credit limits for accumulated subscriber charges. These on-line charging mechanism are used for provision of features such as credit control (e.g. pre-paid), user cost information (advice of charge), fraud control etc.

CCN receives traffic information on-line and off-line from the different traffic handling/service nodes and instructs these nodes to proceed with the calls/services according to the outcome of the operator defined cost control analyses. CCN also has the ability to receive CDR’s deriving from the Serving network providing near-real-time revenue charging.

Billing Gateway (BGw)

The Billing Gateway is a key component for the off-line (CDR based) charging in UMTS. The BGw collects information from the different traffic handling/service nodes (GSN, MSC. SMS-C. voice mail, application servers. etc) and forwards it to the operator’s administrative systems for off-line billing, accounting. traffic analyses and similar functions. The BGw also acts as an intermediate storage and pre-processor for formatting the CDR-information into the specific formats used by the operator.

The BGw also provides an interface to CCN and can be used to relay information for online charging from the traffic handling/service nodes not having direct interfaces to CCN.

BGw also acts as an accounting/settlement broker by providing the ability to distribute CDR's from the Serving network to the Home environment BGw or CCN in near real time.

5.8 Routers/Switches

For routing and switching of user data and signalling flows in the core network connectivity layer, standard switches and routers are used. Most infrastructures offer a wide range of routers and switches with different functions and performance characteristics for most transport needs in all segments of the network (access, aggregation, core) when undertaking total or turnkey contracts.

5.9 Traffic Handling in a Layered Architecture

In order to facilitate the understanding of call/session handling in a Server/Media Gateway architecture, with separated control and user plane functions there are four traffic cases in the following sections. Please note that these traffic cases have been simplified.

5.9.1 Traffic Cases

5.9.1.1 Mobile Originated Call

An AAL2-switche core network has been assumed.

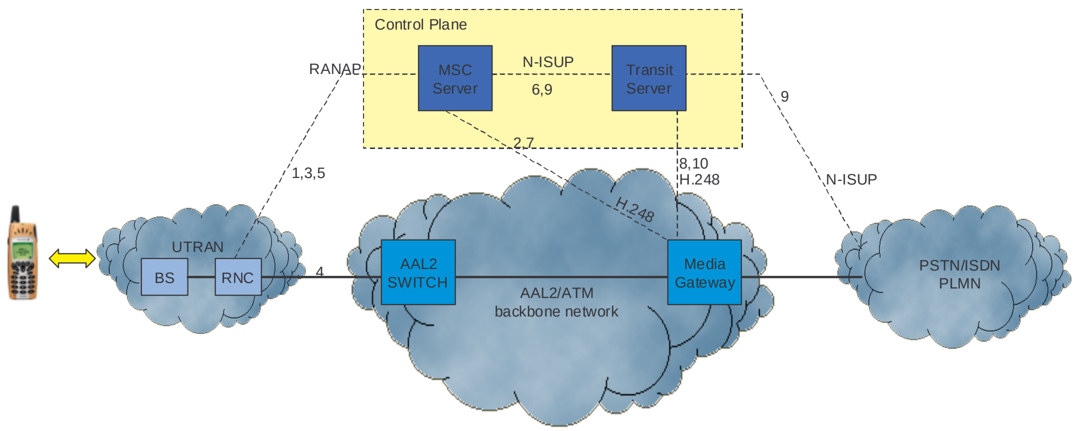


Figure 37 Mobile Originated Call (Traffic Case)

1 A request for call setup is received from the UE. Selection of an applicable MGW

2 Resources controlled by the MSC-server are reserved in the selected MGW

3 The MSC-server orders the RNC to setup a radio access bearer

4 The User plane is setup from the RNC to the MGW

5 The MSC server is informed that the user plane setup to the MGW has been completed

6 The call setup to the transit server is initiated by the MSC

7 Backward through connection of the equipment controlled by the MSC server is ordered in the MGW

8 Resources controlled by the transit server are requested from the MGW

9 Call setup to the selected PSTN switch is initiated by the transit server

10 Through connection of the transit server controlled path in the MGW is ordered

5.9.1.2 Mobile Terminated Call

A simplified procedure for a mobile terminated call

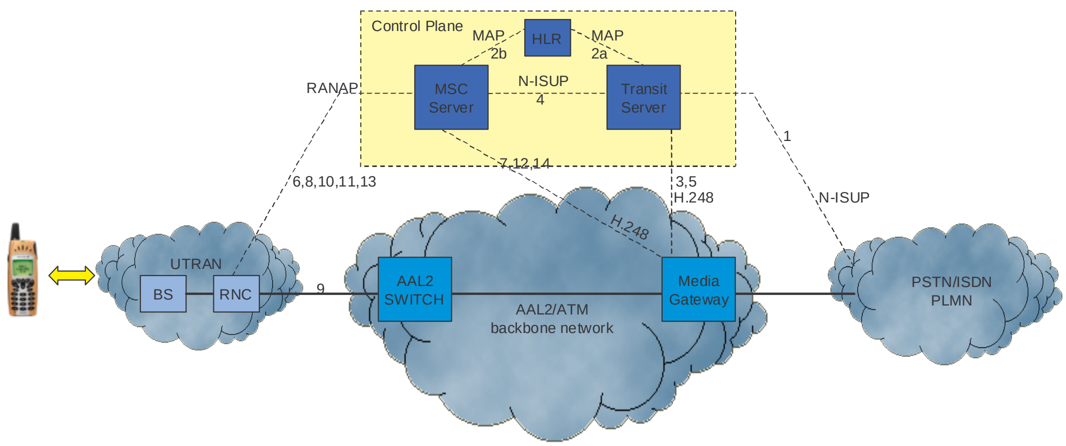


Figure 38 Mobile Terminated Call (Traffic Case)

1 An incoming call is received in the GMSC server

2 Routing data is obtained from the MSC server (VLR) via the HLR

3 Resources controlled by the GMSC server are reserved in the MGW

4 The call setup towards the visited MSC server is initiated by the GMSC server

5 Through connection of the MGW resources is ordered by the GSMC server

6 Paging of the called party is ordered by the MSC server, the call setup is confirmed by the UE.

7 Resources controlled by the MSC server are reserved in the MGW

8 The MSC server orders the RNC to setup a radio access bearer

9 The user plane is setup from the RNC to the MGW

10 The RNC informs the MSC server that the user pane setup to the MGW has been completed

11 The MSC server is informed by the UE that altering of the called party has started

12 The MSC server orders the MGW to start sending ringing tone towards the calling party

13 Answer is received from the called party

14 Through connection of the MGW is ordered by the MSC server

5.9.1.3 PDP-context Activation

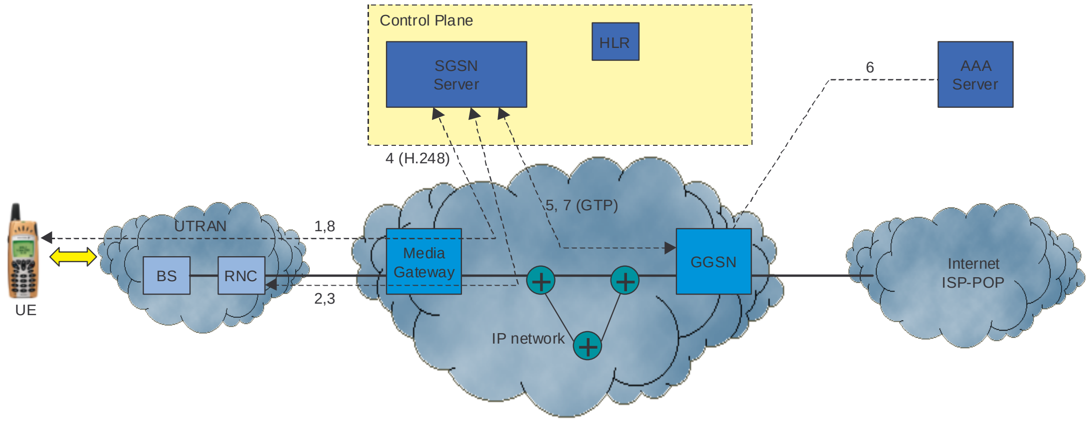


Figure 39 PDP-context Activation (Traffic Case)

1 An "active PDP context request" is sent by the UE to the SGSN server

2 The SGSN server requests the UTRAN to setup a radio access bearer (RAB)

3 The request for a RAB is acknowledged by UTRAN

4 The SGSN server requests the MGW to create a GTP tunnel transfer point

5 A "create PDP context request" is sent from the SGSN server to the GGSN

6 The GGSN server requests an IP address fro the AAA server (or similar)

7 GGSN sends a "create PDP context response" back to the SGSN server

8 An "active PDP context response" is sent back to the UE from the SGSN server

5.9.1.4 Packet Forwarding

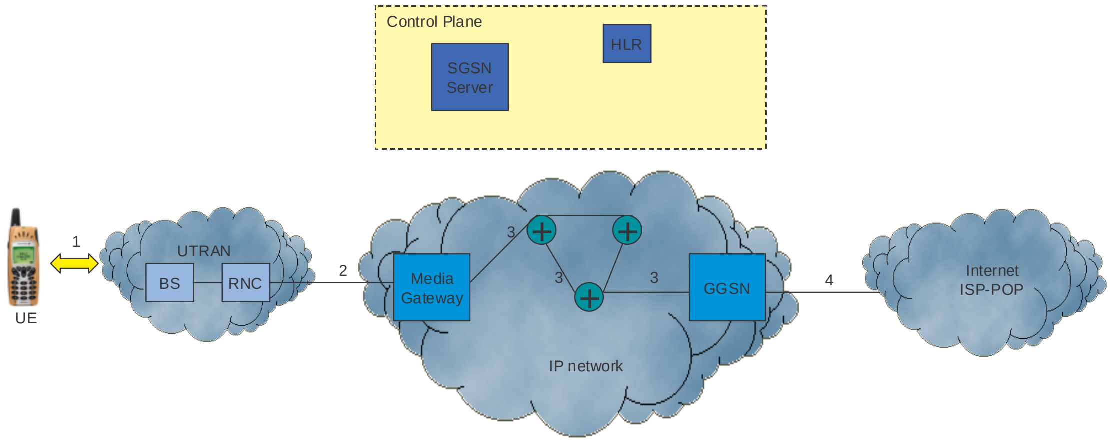


Figure 40Packet Forwarding (Traffic Case)

1 A PDU is sent from the UE

2 The PDU is forwarded over the GTP-U tunnel between the RNC and the MGW

3 The PDU is forwarded over the core network GTP-U tunnel to the GGSN

4 The PDU is forwarded to the Internet/ISP-POP

Chapter Summary and Key points

As technology stands at this time UMTS is the best solution for modern mobile communications. This chapter on UMTS is mainly based on the Ericsson view of what UMTS will be, this is down to the fact that there have been no standards agreed.

One of the main advantages of UMTS is that it has a layered architecture, this is different to other existing systems for mobile communications which are vertical is structure.

The great advantage of UMTS is that it uses the existing systems for mobile communication, UMTS is not necessarily a speaking a new technology, but rather the application of existing technology. Eventually the UMTS system will be able to detect what service the user requires be it Voice or Data communication.

The mobile phone industry is already starting to work on new phones which combine the functionality of a personal computer and the size of a mobile phone.

6.1 The Future

UMTS is seen by most operators as the panacea for a total and seamless cellular system. MSs will not only have to be tri or even quad band but also multi mode (GSM & WCDMA) thus the complexity will staggering. Initially, the user will probably have to select which type of service they require (Speech or Data) but ultimately this service detection will be done by the network. MSs will become smaller but as the size of the human finger will not alter so there is a limitation in this parameter. Voice control will be the order of day and the user may only have one button to press, the on/off button. Eventually this may even disappear as this function could be achieved simply tapping the MS as is portrayed in the Sci Fi series Star Trek.

What is going to happen to the network is anybody's guess. Already, there as plans for the use of WANs in buildings where this acts as yet another layer below the pico cell. This is already being trialed as an extension to WCDMA.

Speech, will still for the foreseeable future be the main revenue earner for the operator and combining this with video is likely to be the next major advance. Perhaps, the speech will be handled on GSM and the video on WCDMA but this will pose some interesting problems on timing and synchronization. At the moment, everyone is concentrating on getting UMTS right and compatible between countries and manufacturers.

7.1 Final Thoughts

Since the introduction of Cellular Mobile Communications in late 80s early 90s, the number of users and the amount of traffic have multiplied beyond all belief. To keep pace with the increase, both the Telcoms Manufacturers and the operators have had to invest enormous amounts of effort and money in developing and installing new systems and technologies.

Initially, speech was the only service provided but with the advent of the Laptop PC and the massive increase in the use of email, data transmission started to become a significant proportion of the traffic. The need for the mobile Internet is now the main driver for the introduction of new services and consequently the development of new technologies.

So what does this all mean to the User, the Operator and the Manufacturer. In the following paragraphs, I will look into just some of the important aspects of each of these categories.

7.2 The User:

Users have become use to relatively fast connections to the Internet and Intranet using fixed lines from the office or their homes. Business people on the move want to be able to connect to their company email system from remote locations such as airport lounges and usually do not have a lot of time in which to do it thus speed is of the essence.

GSM offered a solution but only at an effective data throughput of about 1.5 kbit/s. Using such programmes as Microsoft Outlook, this meant that you could spend up to half an hour downloading your emails and this quite often was insufficient and did not allow any time to actually send any emails, just collect incoming mails.

Edge was the next evolution to be developed and that is projected to give the user a download throughput of up to 160 kbit/s. However, once take off the transmission system overhead and the error correction function, the effective rate reduced significantly but ended up at about the same as you could expect from a 56 kbit/s modem on a fixed network. For most business people this would show an enormous improvement but was still not considered fast enough. GSM/EDGE had reached it's limit as far as speed for data transmission was concerned and thus the development of WCDMA or 3G

WCDMA or 3G as it is commonly known, is projected to offer the user data speed up to 2 mbit/s but those speeds are still sometime away.

Will this be enough for the user, I doubt it. However, it will be cost that determines how fast the user will be able to go and what service packages are offered for with operators changing the charging principles from time to data throughput it could become extremely expensive for the ordinary, non business user who will be the numerical majority.

7.3 The Operator:

Users will want faster and faster data speed and more specialist services. The Manufacturer wanting to sell new technology and having to recover all their development costs in as short a time as possible to satisfy their shareholders. Finally the Government charging exorbitant amounts of money for new licences and the use different parts of the radio spectrum.

The recent sales of 3G licences in the UK gave the Governments something in excess of £6B which the operators have to pay in advance. On top of that, they will have to install a totally new infrastructure which means not only new Hardware & Software but also the acquisition of new cell site locations, for WDCMA will require more not less sites in order to offer good coverage at high speed. For many years to come, the existing GSM service and infrastructure will provide the main revenue for operators and this why they need to go for UMTS. This will allow the operator to determine what service the user needs, speech, text messaging, low, medium or high speed data transmission and then allocate the user to the appropriate technology for the service they require (GSM/EDGE/WDCMA).

7.4 The Manufacturer:

The cost of developing new technologies is enormous, both in cash and time. Once developed they have to be tested so not only does the manufacturer have to develop the infrastructure but also the MS. The MS market is extremely competitive so the potential for profits from this market are not going to be as great as one would expect so the to cross subsidisation of profits will be less.

Another problem faced by most of the major Manufacturers is that when they try to sell their systems to operators, they find that they have to finance the deal as well. This is because the operators are cash limited due to the large amounts of money spent on acquiring the new licences and spectrum. Some operators have negotiated deals where the manufacturers will only start to get paid once the new service starts to make a profit and that could be many years. The high cost of licences and frequency spectrum is being sited as one of the major causes in the current downturn in the Hi Tech shares.

7.5 The Winner:

So who is the real winner. I would say the Governments for they are in a win, win situation. They made money on the licences, they make money of the operators profits and they make money by fining operators who do not provide the contracted quality of service required by the Regulator. (*Personal Comment*)

List of Figures

8.0 Critique

Original Aims

To show that I have a good understanding of future of the Digital Mobile Communications field.

- To show that I have a good understanding of not only the technology being applied, but also the driving forces pushing cellular operators adopt new technologies.

Original Objectives

To produce an informative document that will provide the reader with an insight into the fundamentals of the existing mobile communication systems, and the future of Digital Mobile Communications.

To apply the research in such a way to come to my own conclusions about the future of mobile communications.

I believe that in this document I have shown a fair knowledge of the digital mobile communications field. Even so, this document has only scratched the surface of mobile communications, the area that I have tended to focus on is the air interface and the actual mobile network, as this is the area that holds the most interest for me. Even though the development of the MSs (Mobile Stations), more commonly known as Mobile or Cell Phones, is important, they are useless without the air interface and the network.

The reason that the GSM section is so large and comprehensive is that to understand the later technologies you first have to understand GSM. The only technology that is radically different, or does not use the GSM core technology is Wideband CDMA.

After GPRS (General Packet Radio Service), information became harder to obtain, this is because the systems are still in development and there have been no standards agreed. However I was granted access to the Ericsson intranet, this gave me access to privileged information, which is confidential. Hence the reason why this document can not be distributed beyond the primary and second marker.

I feel that this document is informative in that it introduces the subject of mobile communication from the very beginning. If I had had more time and the word limit was greater I would have been able to explore the driving forces behind the development of the new communications technologies in more detail.

On the subject of time management, I have never been described as one of life's greatest time keepers, but on this dissertation I have tried my best to keep to my original plan, as outlined in Assignment 1. However I experienced a some communications problems with my original supervisor, Mike Ferriday. Even with the communication problems, I have managed to complete the dissertation. Since March and the assignment of a new supervisor I have completed most of my dissertation according to plan.

I know now that the subject area that I chose for this dissertation was far to complex, and the way that this dissertation has turned out to be not so much about the Future of the Mobile Communications but the Evolution and Future of communications. This is due to the fact that everything after GPRS in this dissertation is in the future, in the UK GPRS will not become active until mid May early June 2001, WCDMA another two to three years, and UMTS about six to 12 months after WCDMA.

As for the real future of mobile communications after UMTS there is no real way of telling, one idea from a source whom will remain nameless is that after UMTS the next step will be smoke signals and semaphore.

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