Cellular wireless networks

Cellular wireless networks

- Introduction
- NMT (Nordiska Mobiltelefonsystemet)
- GSM (Group Special Mobile)
- GPRS
- UMTS

Introduction

- Cellular telephone systems (cellular networks) are the segment of the telecommunication market that have and will continue to grow rapidly.
- Cellular telephone systems are extensions of traditional PSTN[1] and ISDN[2] networks, which allow for seamless roaming with the same mobile phone nation or even world wide.
- Today and historically these systems are mainly used for voice traffic, i.e., they originate from the telephone system and not from computer networks (Ethernet, TCP/IP etc..)
- However the data traffic is continuously growing and will probably become the most important task for the cellular system in the future.

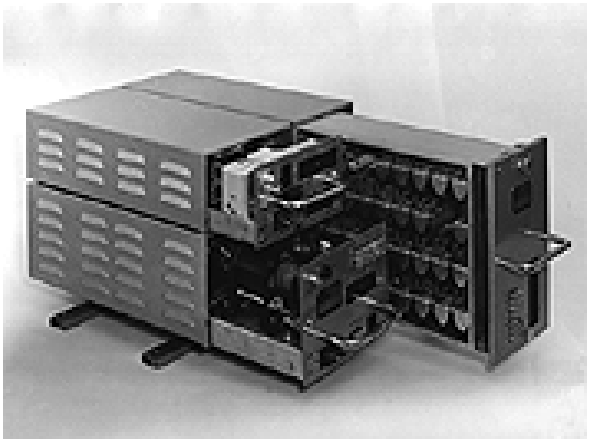
[1] Public Switched Telephone Network
[2] Integrated Services Digital Network

Mobile telephone system Laurén MTA (1956-1967)

- The first public automatic mobile telephone system in the world.
- Coverage: 30 km, base stations established in Stockholm and Gothenburg.
- Frequency: 160 MHz
- Channels: 4 (full duplex)
- In total 26 subscribers (1956).
- In the mid 60's the number of subscribers had increased to 125.

Mobile telephone system *Laurén* MTA (1956-1967)

Mobile radio and relay unit



40 kilo

5 A standby

18 A transmission

12 V

Mobile telephone system *Laurén* MTA (1956-1967)

- The base continuously transmitted a carrier on each channel.
- ***At call from the mobile station***, the mobile unit automatically searched for a channel with free carrier and made a call to the base station.
- The base station provided the car with a channel number which it then switched to.
- ***At call from the base station*** to the mobile unit a call was made on all channels without interfering with ongoing traffic.
- When a connection was established the mobile unit was directed to a free channel.
- All subscribers where given a group number which started with 95 which was common for both Stockholm and Gothenburg.
- Could handle 1000 subscribers in total.

Mobile telephone system *Berglund* MTB (1962-1983)

- Second generation automatic mobile phone system established in Stockholm, Gothenburg and Malmö.
- Coverage: 30 km from base station.
- Channels: 12 (Stockholm), 8 (Gothenburg) and 4 (Malmö).
- Frequency: 76-77.5 MHz and 81-82.5 MHz
- 1983 there were about 600 subscribers.
- Based on transistor technology (not vacuum tubes as previously have been used, much more energy efficient)

Mobile telephone system *Berglund* MTB (1962-1983)

- The Berglund system is based on an innovation called the “tone code principle”, i.e., a ***selection tone*** is used to identify the mobile unit.
- The ***selection tone*** (5000-7000 Hz) is transmitted during all the time that the call is up.
- Two crystals with the same frequency was used one in the mobile unit and one in the subscriber card in the base station.
- These crystals were used to decide the frequency of the identification tone and in tone selective circuit.
- The ID tone, selection tone, was transmitted from the car, influencing the specific tone selective subscriber card in the base station.
- By letting the tone sent back to the car at the used channel the mobile unit got an acknowledge on the identification.
- The mobile unit automatically choose a free channel.

Mobile telephone system *Berglund* MTB (1962-1983)

- The dialling in the car was made with a dial which generated tone pulses, these were converted to time pulses, at the base station, that responded to the system used in the present telephone system.
- When a call to the car occurred the subscriber card was activated by the incoming call from a telephone switching center then a selection tone was broadcasted and when the selection tone was identified by the mobile unit it rang.

Mobile telephone system MTD (1971-1987)

- Actually a step backward because this system was manually served by telephone operators, but it ***covered all the Nordic countries***.
- It was a temporary solution before the NMT system roll out.

Mobile telephone system MTD (1971-1987)

- A manual system based on operator centrals.
- Frequency: 450 MHz.
- 20000 subscribers (1980).

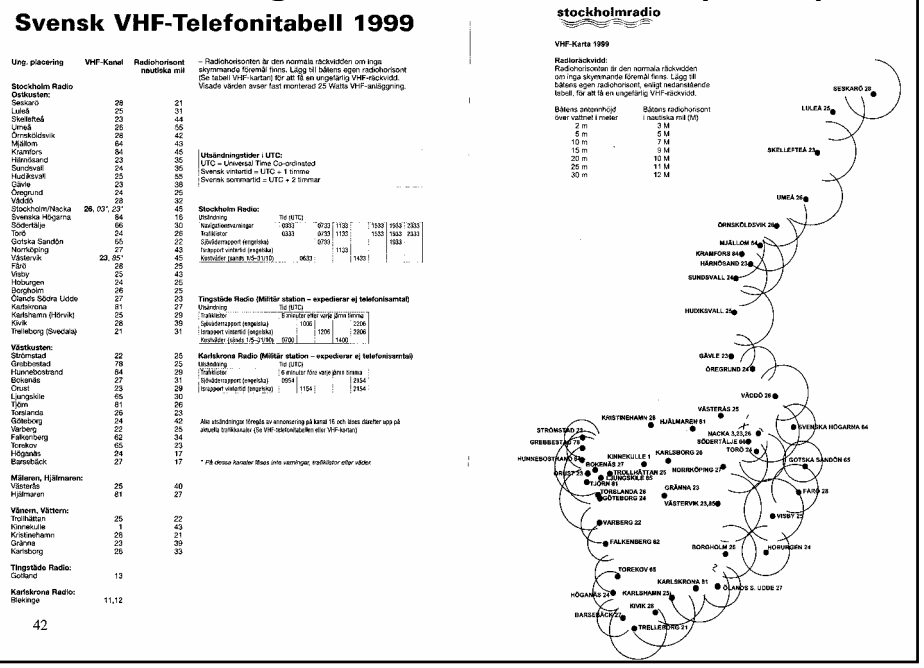
Mobile telephone system MTD (1971-1987)

- In a manual system the operator connected the calls from the telephone network to the radio system and the opposite.
- To each operator central a number of base stations were connected.
- Each base station was equipped with a number of frequency channels.
- One channel was used as call channel and used to call the operator central.
- This kind of system is still used for short range maritime (VHF) radio in Sweden (Stockholm radio).

Short range maritime radio (VHF)

- Frequency: 155.5 -162.025 MHz
- Call channel 16 (156.8 MHz)
- 55 channels
- 20000 users in Sweden
- Simplex and duplex channels

Short range maritime radio (VHF)



Svensk VHF-Telefonitabell 1999

Ung. placering	VHF-Kanal	Radiohorisont nautiska mil
Stockholm Radio Östkusten:		
Seskarö	28	21
Luleå	25	31
Skellefteå	23	44
Umeå	26	55
Örnsköldsvik	26	42
Mjällom	64	43
Kramfors	84	45
Hälnäsand	23	35
Sundsvall	24	35
Hudiksvall	25	35
Gävle	23	38
Öregrund	24	26
Väddö	28	32
Stockholm/Nacka	26, 03*, 23*	45
Svenska Högarna	84	16
Södertälje	66	30
Torö	24	28
Gotska Sandön	65	22
Norrköping	27	43
Västervik	23, 85*	45
Fårö	28	25
Visby	23	43
Hoburgen	24	25
Borgholm	26	25
Ölands Södra Udde	27	23
Karlskrona	81	27
Karlshamn (Hörvik)	25	29
Kivik	28	39
Trelleborg (Svedala)	21	31
Västkusten:		
Strömstad	22	25
Grebbestad	78	25
Hunnebostrand	84	29
Bokenäs	27	31
Orust	23	29
Långsiele	65	30
Tjörn	81	26
Torslanda	26	23
Göteborg	24	40
Varberg	22	25
Falkenberg	62	34
Torekov	65	23
Höganäs	24	17
Barsebäck	27	17
Mälaren, Hjälmaren:		
Västerås	25	40
Hjälmaren	81	27
Vänern, Vättern:		
Trollhättan	25	22
Kinnekulle	1	43
Kristinehamn	26	21
Gränna	23	39
Karlsborg	26	33
Tingstäde Radio:		
Gotland	13	
Karlskrona Radio:		
Blekinge	11,12	

– Radiohorisonten är den normala räckvidden om inga skymmande föremål finns. Lägg till båtens egen radiohorisont (Se tabell VHF-kartan) för att få en ungefärlig VHF-räckvidd. Visade värden avser fast monterad 25 Watts VHF-anläggning.

Utsändningstider i UTC:
UTC = Universal Time Co-ordinated
Svensk vintertid = UTC + 1 timme
Svensk sommartid = UTC + 2 timmar

Stockholm Radio:

Utsändning	Tid (UTC)					
Navigationsvarningar	0333	0733	1133	1533	1933	2333
Trafikläster	0333	0733	1133	1533	1933	2333
Sjövädersrapport (engelska)		0733		1533		
Israpport vintertid (engelska)			1123			
Kantvåder (sänds 1/5–31/10)	0633			1433		

Tingstäde Radio (Militär station – expedierar ej telefonisamtal)

Utsändning	Tid (UTC)					
Trafikläster	5 minuter efter varje jämn timma					
Sjövädersrapport (engelska)		1006			2206	
Israpport vintertid (engelska)			1206			2006
Kantvåder (sänds 1/5–31/10)	0700			1400		

Karlskrona Radio (Militär station – expedierar ej telefonisamtal)

Utsändning	Tid (UTC)			
Trafikläster	5 minuter före varje jämn timma			
Sjövädersrapport (engelska)	0954			2154
Israpport vintertid (engelska)		1154		2154

Alla utsändningar föregås av annonsering på kanal 16 och läses därefter upp på arbetsfig kanal/kanaler (Se VHF-telefonitabellen eller VHF-kartan)

* På dessa kanaler läses inte varningar, trafikläster eller väder.

stockholmradio

VHF-Karta 1999

Radieräckvidd:
Radiohorisonten är den normala räckvidden om inga skymmande föremål finns. Lägg till båtens egen radiohorisont, enligt nedanstående tabell, för att få en ungefärlig VHF-räckvidd.

Båtens antennhöjd över vattnet i meter	Båtens radiohorisont i nautiska mil (M)
2 m	3 M
5 m	5 M
10 m	7 M
15 m	9 M
20 m	10 M
25 m	11 M
30 m	12 M

Short range maritime radio (VHF)

A manual set up for a telephone call outside Jamaica (channel 16)

- Jamaica radio, Jamaica radio, this is Swedish yacht Tornado II, (8SY3456) Eight Sierra Yankee Three, Four Five Six, Eight Sierra Yankee Three Four Five Six, calling for a phone call.

- Eight Sierra Yankee Three Four Five Six this is Jamaica radio, what is your position please.

- My position is just outside Montego bay.

- Channel 25

- Channel 25

(***You change manually to channel 25 and call Jamaicaradio again***)

- Jamaica radio this is Swedish Yacht Tornado II Eight Sierra Yankee Three Four Five Six.

- Yes, Eight Sierra Yankee Three Four Five Six, this is Jamaica radio what can I do for you.

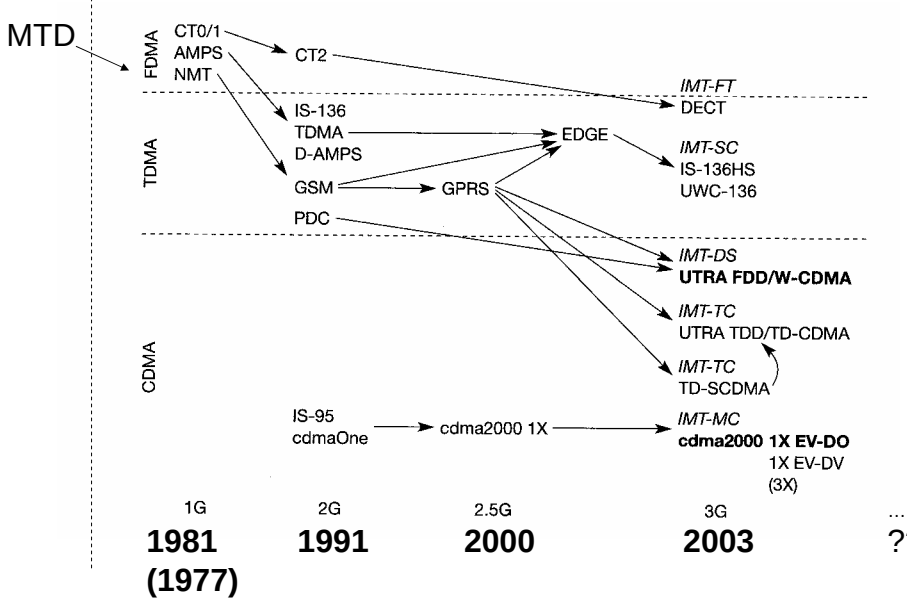
- I want a phone call to Sweden, area code 31, and phone number 123456.

- OK, Tornado II what is your accounting code.

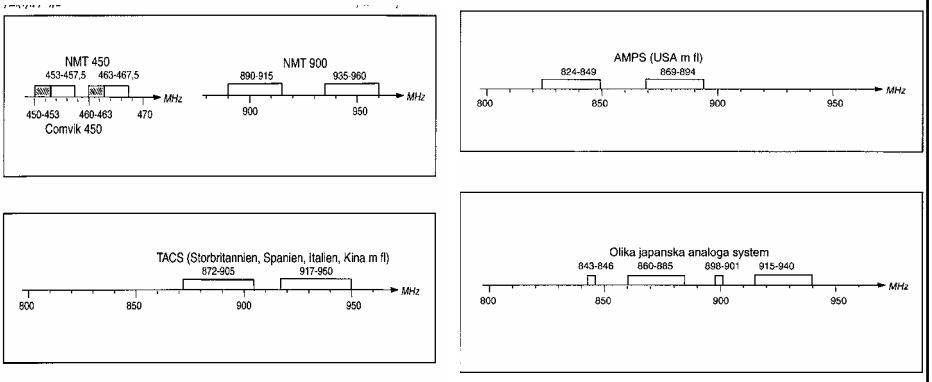
- My accounting code is Sierra Whiskey Zero One

- OK stand by

Introduction



Introduction



Advanced mobile phone service (AMPS)

Nordiska Mobiltelefonsystemet (NMT)

(TACS)

AMPS

- Early 80’s
- Frequency 869 – 894 MHz, 824-849 MHz
- 25 KHz per channel (12,5 kHz in each direction)
- Channel spacing 30 MHz
- 416 channels (21 control and 395 traffic channels)
- FM for traffic and FSK for control digital data

NMT

- FM modulated
- Frequency 450 (900) MHz
- Nr of base stations 250 (Sweden)
- Channels 180
- Channel bandwidth 25 kHz
- Duplex separation 10 MHz
- Digital Control data FSK 1200 baud

NMT

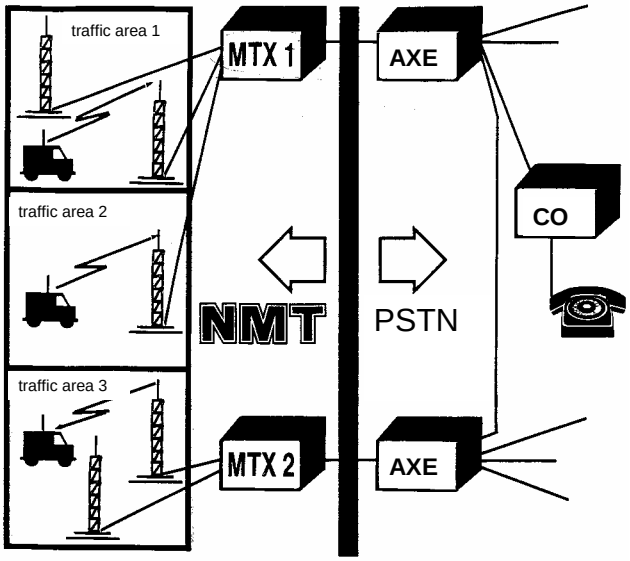
- Analogue mobile telephone system (1G).
- 1969 a group started to plan the first automatic mobile phone system in the Nordic countries.
- First test system in Stockholm 1977.
- The first NMT networks was actually deployed in Saudi Arabia (Ericsson lighted a NMT system in Saudi Arabia a couple of months earlier).
- Televerket (October 1981 -) NMT450.
- Comvik (August 1981- Mars 1996) NMT450.
- Televerket (December 1986 – 31 December 2000) NMT 900 (channel allocated for GSM).

NMT

Three fundamental building blocks

- ***Mobile telephone exchange*** (MTX). The heart of the NMT system is the MTX, which is the interface to the PSTN. In the beginning 2-4 MTX in Sweden.
- ***Base stations***, provide the wireless interface.
- ***Mobile units.***

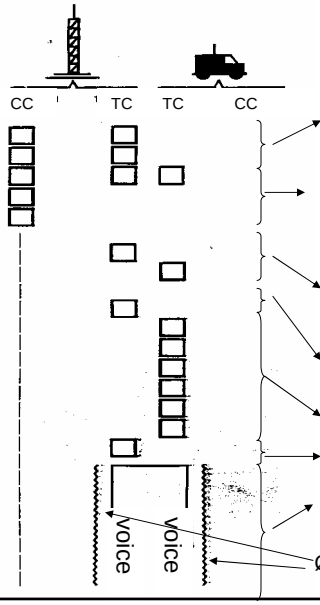
NMT – System



NMT connection setup

- A call from a subscriber in PSTN is setup on the basis of first numbers in the mobile subscriber's phone number, i.e., it identifies the subscribers home MTX.
- The home MTX stores the position of the mobile unit.
- When an incoming call from the PSTN occurs a broadcast over all base stations in the traffic area where the mobile unit is registered to be in.
- If the mobile unit is not in the home MTX traffic area the home MTX connects the call over PSTN to the MTX where the mobile unit is present in.

NMT connection setup – call from mobile unit



In standby the mobile unit listens to the control channel (CC). The MTX transmits free TC over CC.

When the subscriber dials the number and hook of the horn, the mobile units looks for a free TC and transmits an occupation signal, when received by the MTX, it mark the TC as occupied and transmits an OK.

The MTX asks for a repeated handshake (identification from the mobile unit).

When the MTX is ready to receive the dialled number it transmits a send number.

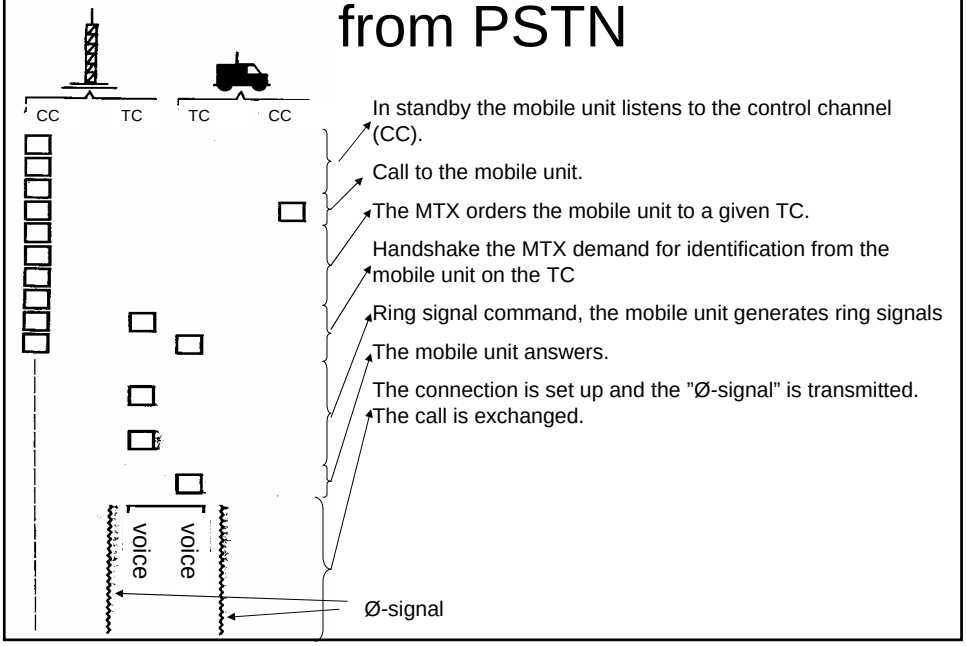
The number that was stored in the mobile unit is transmitted.

The MTX replies the number received.

The connection is set up and the "Ø-signal" is transmitted. The call is exchanged.

Ø-signal

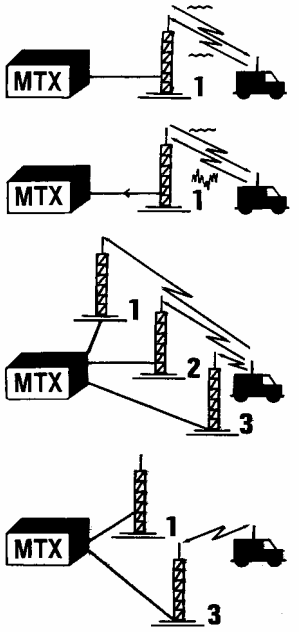
NMT connection setup – call from PSTN



NMT hand off

- The signal quality is supervision by a signal that is continuously transmitted from the base station during a call (Ø-signal).
- It is a tone at 4 KHz outside the voice frequency spectra (300-3400 KHz).
- The base station transmits the Ø-signal signal to the mobile unit which echoes it back to the base station.
- Which measures the signal quality SNR.
- If the quality is bad the MTX orders all base stations in area to listen to the signal.
- If another base station has a better signal quality the MTX orders it to take over the call.

NMT hand off



During a call the base station transmits the supervision signal (Ø-signal) that is echoed back by the mobile unit. (the SNR is measured).

When the mobile unit moves the SNR decreases. When a threshold is reached the bases station sends an alarm message to the MTX.

The MTX orders the base stations in the area to measure the SNR for the specific channel. The base stations return the result to the MTX and chooses the one with the strongest signal (3 in this case).

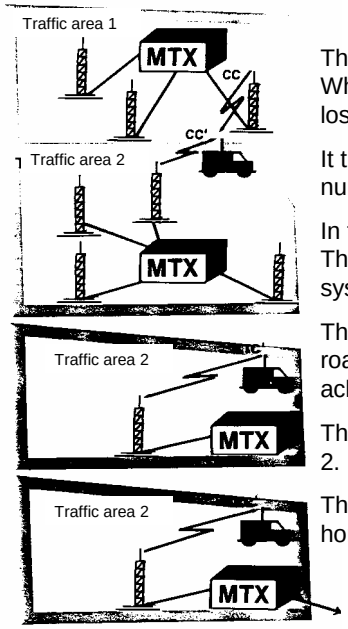
The MTX decides to switch the call present at base station 1 to base station 3 (the mobile unit is order to change to a new TC).

In the mobile unit the hand off will be detected as a very short interrupt of the call.

NMT - Roaming

- Roaming, you can call a specific mobile unit without knowing where it is positioned.
- This is possible by the fact that a mobile unit that leaves one traffic area for another messages that to the MTX.
- The information about where the mobile unit is positioned is stored in the MTX.

NMT - Roaming



The mobile unit is listening on the CC in traffic area 1. When the mobile unit is moving out from the traffic area it loses the contact with the CC in traffic area 1.

It then tries to find a new CC with the same traffic area number if this fails it starts to look for any traffic area CC.

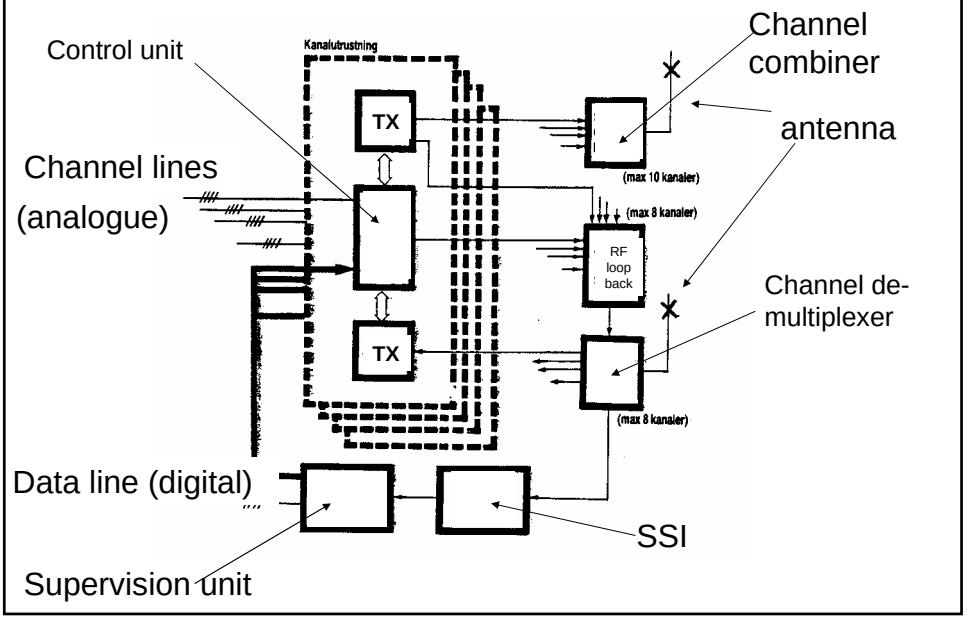
In this case the mobile unit finds a CC' for traffic area 2. The mobile unit then sends a update message to tell the system that it is positioned in a new traffic area.

The mobile unit looks up a free TC and sends a special roaming update frame. The base station answers with an acknowledge.

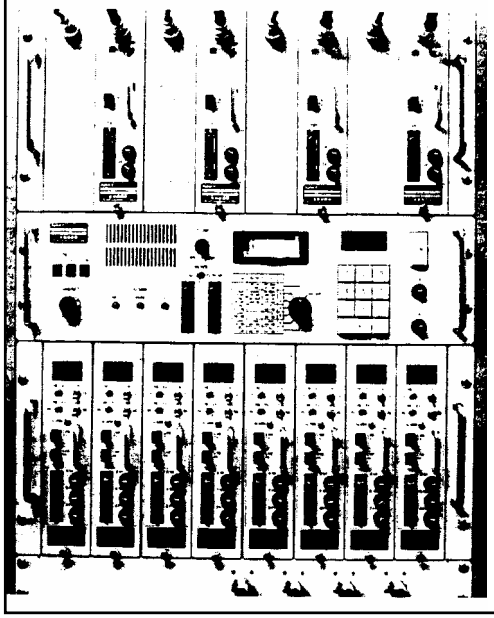
The mobile unit locks its CC to the CC used by traffic area 2.

The MTX sends an update message to the mobile unit's home MTX.

NMT – base station



NMT – base station



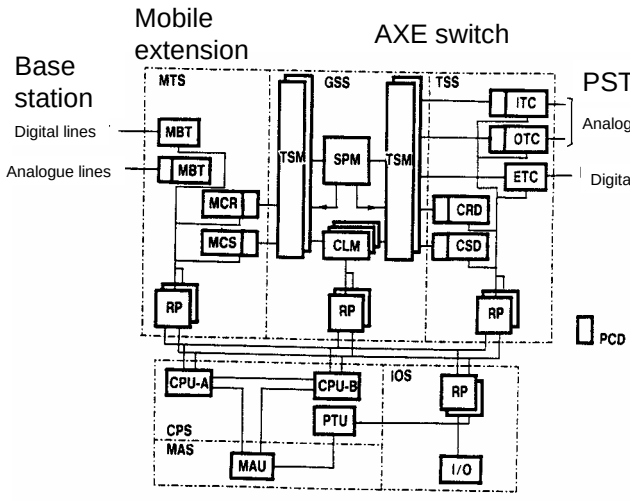
8 Channel NMT transmitter rack

Transmitters

Test units (RF loop back test)

Control units

NMT – MTX



GSS Group sub system

TSS Trunc and signalling system

MTS Mobile telephone subsystem

CPS Central processor system

MAS Maintenance subsystem

IOS Input output subsystem

TSM Time switch module
SPM Space switch module
CLM clock module
CRD code receiver modulator
CSD code sender modulator
PCD pulse code modulator
RP regional processor
CPU central processor
PTU processor test unit
MAU maintenance unit
MCR Mobile code receiver

MBT mobile double trunc
I/O input output unit
MCS mobile code sender

OTC outgoing trunc circuit
ETC exchange terminal circuit

Global System for Mobile communication (GSM)

GSM

- The primary goal with GSM was to provide a mobile phone system that allow users to roam throughout Europe and provide voice services compatible to ISDN and PSTN systems.
- GSM 900
- GSM 1800, Digital cellular system (DCS)
- GSM 1900, personal communication service (PCS).
- GSM 400
- GSM-R (GSM-Rail)

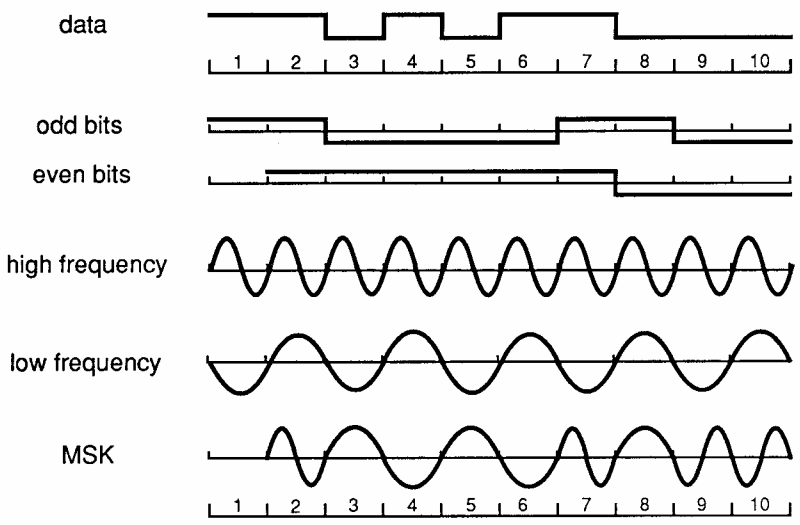
GSM

- Frequency:
  - GSM 900 uplink 890-950 MHz downlink 935-960 MHz.
  - GSM 1800 uplink 1710-1785 MHz downlink 1805-1880 MHz.
  - GSM 1900 uplink 1850-1910 MHz downlink 1930-1990 MHz.
  - GSM 450 uplink 450.4-457.6/478.8-486.0 MHz downlink 460.4-467.6/488.8-496 MHz.

GSM – Modulation

- Gaussian Minimum Shift Keying (GMSK), a form of constant-envelope FSK.
- A successor to minimum shift keying (MSK).
- Each channel has a bit rate of 270.833 kbps.
- Bandwidth 200 kHz/channel.
- We start by dividing the data stream into odd and even bits.
- We hold each alternate odd and even bit in data for two bit times.
- Apply these two waveforms to a quadrature modulator, we have Offset Quadrature Phase Shift Keying (OQPSK), the staggering of odd and even bits helps us creating a wave form with minimal AM.

GSM – Modulation



GSM – Modulation

- We make odd and even bits by taking the value 1 and -1.
- In the GSM case the staggered odd bits and even bits waveform will have half the rate 135.4 kpbs.
- The fourth and fifth waveforms are the high frequency (HF) and low frequency versions (LF), respectively of the carrier frequency. The result is a form of FSK.
- We shift between these two carriers to create a MSK signal.

GSM – Modulation

Digital Input		MSK Output	
Bit Value		Frequency	Sense
Odd Bit	Even Bit	High or Low	+ or −
1	1	High	+
−1	1	Low	−
1	−1	Low	+
−1	−1	High	−

We create the MSK signal. We regard the odd bits and the even bits values and look them up in the table.

Pick either the low frequency or the high frequency version of the carrier.

Turn the version of the carrier upside down or not, according to the “sense” +/-.

The resulting MSK waveform fifth wave form.

Note the relative smooth phase transitions (frequency) from one frequency to another.

GSM – Modulation

- There is a last step we must consider when building a MSK waveform, the two carrier frequencies HF and LF we shift between should be as close as possible in the frequency domain and still remain orthogonal over bit time T_{bit}.
- The term, orthogonal, comes from the fact that any vector can be described by its three orthogonal components X, Y , and Z directions[1].
- In the GSM case the two frequencies HF and LF, differs from each other by the data rate of the modulating waveform.
- This is one half of 270.833 kbps, or maximum 135.4 kHz. The two carrier versions then appear 67.7 kHz above or below the assigned frequency channel.
- Thus, the modulation index becomes 67.7/135.4 KHz = 0.5

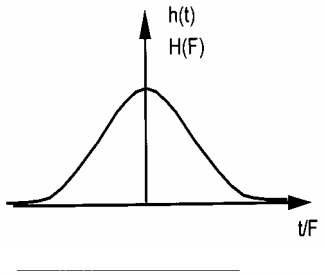
[1] In radio work, orthogonal can mean: “Easily distinguished one from another” or “not easily confused with each other”.

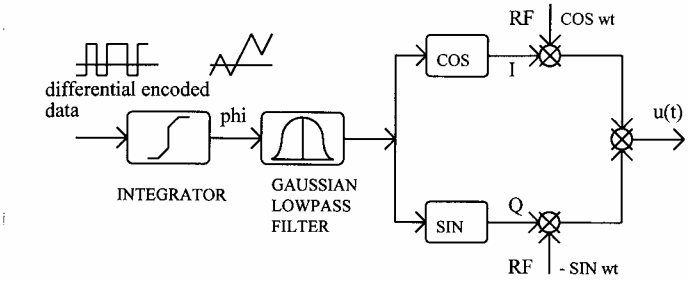
GSM – FDM

- SDM, TDM, FDM.
- Frequency Channels:
  - 124 duplex channels (248 simplex, 200 kHz), GSM 900.
  - 374 duplex channels (748 simplex, 200 kHz), GSM 1800.
- Typically 32 channels are control channels and 90 channels are traffic channels (GSM 900).
- A typical base station has one control channel and up to 10 traffic channels.

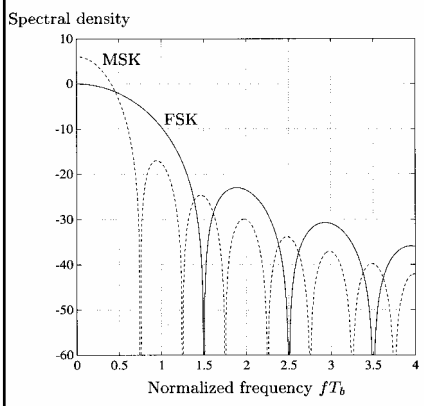
GSM – Modulation

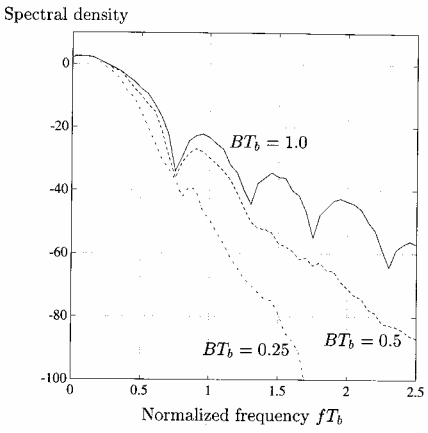
- To make a GMSK signal out of a MSK signal, we need only to filter the stretched data waveforms with a Gaussian filter of an appropriate bandwidth, i.e., a BT product.
- In GSM BT is 0.3, B 81.3 KHz and T =3.7 μs (T=1/270.833).



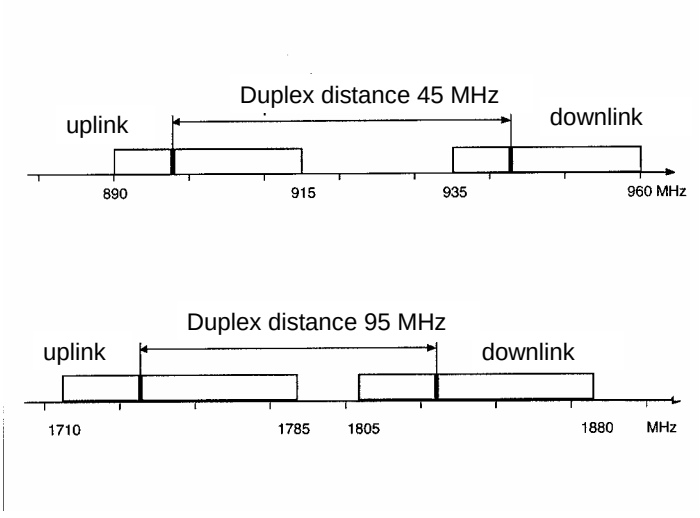


GSM – Modulation – spectral density





GSM – FDM

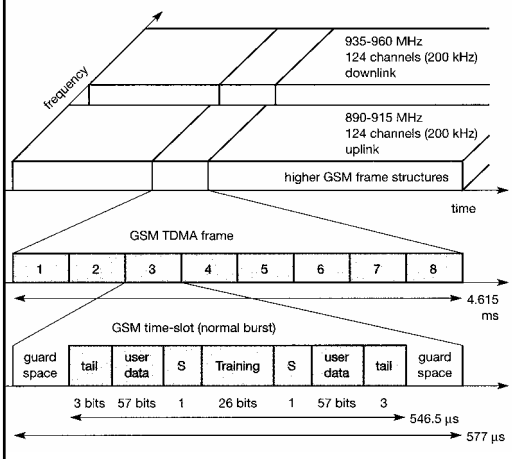


One of the factors that allows for simple transmitter hardware is that uplink and downlink are separated in frequency, large separation 45, 95 MHz.

GSM - TDM

- Each of the 248 frequency channels is additionally separated into a TDMA frame.
- The duration of a frame is 4.615 ms, these are subdivided into 8 time slots (577 μs each).
- The data is transmitted in small bursts, 546.5 μs long containing 148 bits.
- The remaining 30.5 μs is guard space for avoiding overlapping between bursts.

GSM – FDM/TDM



A flag bit **S** indicates if the slot contains user or network data.

- Each physical TDM channel has a raw data rate of 33.8 kbps.
- The first and last three bits (***tailbits***) are set to '0', can be used to enhance the performance of the receiver.
- The ***training sequence*** in the middle of a slot is used to adapt the parameters of the receiver to the current path propagation characteristics and to select the strongest signal in case of multipath propagation.

GSM

- Apart from the normal burst four more bursts are defined.
- ***Frequency correction burst***, allows the mobile station to correct the local oscillator to avoid adjacent channel interference with neighbouring channels.
- ***Synchronization burst***, an extended training sequence to synchronize the mobile station with the base station in time.
- ***Access burst***, used for the initial connection setup between the mobile station and the base station.
- ***Dummy burst***, used if no user data is available for the slot.
- The TDM slots are shifted in time for three slots, i.e., if the base station sends data at time t_0 (in slot one) for the down link, the mobile station accesses on the uplink at time t_0+3*577 μs (shifted 3 slots).

GSM – Logical channels and frame hierarchy

- The physical separation of the medium is into 8*124 duplex channels (GSM 900).
- A physical channel consists of a slot repeated every 4.615 ms.
- GSM specifies two basic groups of logical channels, i.e., ***traffic channels*** (TCH) and ***control channels*** (CCH).

GSM – TCH

- GSM uses TCH to transmit user data.
- Two basic categories of TCH has been defined; full-rate TCH (TCH/F) and half-rate TCH (TCH/H).
- A TCH/F has a data rate of 22.8 kbps whereas TCH/H only has 11.4 kbps.
- With the voice codec available at the beginning of the GSM standardization, 13 kbps was required, whereas the remaining capacity of the TCH/F was used for error correction.
- Improved codecs allow for better voice coding and the use of TCH/H, i.e., a 5.6 kbps data stream from the codec.

GSM – TCH

- Data transmission in GSM is possible at many different data rates:
  - TCH/F2.4 2.4 kpbs (convolution 1/6 rate)
  - TCH/F4.8 4.8 kbps (convolution 1/3 rate)
  - TCH/F9.6 9.6 kbps (convolution ½ rate)
  - TCH/F14.4 14.4 kbps
- These logical channels differ in terms of their coding schemes and error correction capabilities.

GSM – CCH

- Many different CCHs are defined in the GSM system. They are used to control medium access, allocation of traffic channels and mobile management.
- The three main groups of controls channels are:
  - ***Broadcast Control Channel*** (BCCH)
  - ***Common Control Channel*** (CCCH)
  - ***Dedicated Control Channel*** (DCCH)

GSM – CCH – BCCH

- A base station uses this channel to signal information to all mobile stations within a cell.
- Information transmitted in this channel is cell identifier, options available in the cell and frequencies available in the cell and in neighbouring cells.
- The base station sends information for frequency correction via the ***Frequency Correction Channel*** (FCCH) and information about time synchronization via the ***Synchronization Channel*** (SCH), where both channels are sub-channels of BCCH.

GSM – CCH – CCCH

- All information regarding connection setup between base station and mobile station is exchanged via the CCCH.
- For calls towards the mobile station, the base station uses the ***paging channel*** (PCH), for paging the appropriate mobile station. If a mobile station wants to setup a call, it uses the ***random access channel*** (RACH) to send data to the base station.
- The RACH implements multiple access by using slotted aloha (this is where collisions may occur with other mobile stations in the GSM system).
- The base station uses the ***access grant channel*** (AGCH) to signal a mobile station that it can use TCH or SDCCH for further connection setup.