NOKIA

GSM Architecture

Training Document

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1 Introduction

A connection between two people – a caller and the called person – is the basic service of all telephone networks. To provide this service, the network must be able to set up and maintain a call, which involves a number of tasks: identifying the called person, determining the location, routing the call, and ensuring that the connection is sustained as long as the conversation lasts. After the transaction, the connection is terminated and (normally) the calling user is charged for the service he has used.

In a fixed telephone network, providing and managing connections is a relatively easy process, because telephones are connected by wires to the network and their location is permanent from the networks' point of view. In a mobile network, however, the establishment of a call is a far more complex task, as the wireless (radio) connection enables the users to move at their own free will – providing they stay within the network's service area. In practice, the network has to find solutions to three problems before it can even set up a call:

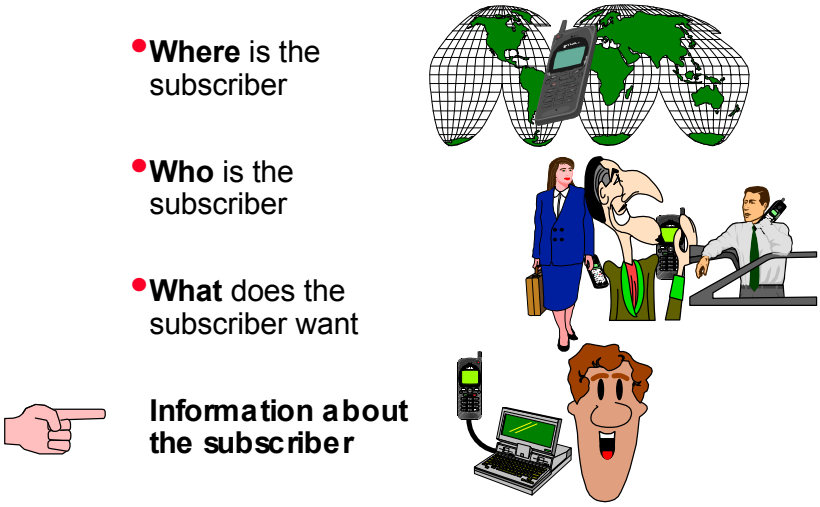

Figure 1. Information required by a mobile communications network

In other words, the subscriber has to be **located** and **identified** to provide him/her with the requested **services**. In order to understand how we are able to serve the subscribers, it is necessary to identify the main interfaces, the subsystems and network elements in the GSM network, as well as their functions.

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2 Open interfaces of GSM

One of the main purposes behind the GSM specifications is to define several *open interfaces*, which then limit certain parts of the GSM system. Because of this interface openness, the operator maintaining the network may obtain different parts of the network from different GSM network suppliers. When an interface is open, it also strictly defines what is happening *through* the interface, and this in turn strictly defines what kind of actions/procedures/functions must be implemented *between* the interfaces.

The GSM specifications define two truly open interfaces within the GSM network. The first one is between the Mobile Station (MS) and the Base Station (BS). This open-air interface is appropriately named the **"air interface".** It is relatively easy to imagine the need for this interface to be open, as mobile phones of all different brands must be able to communicate with GSM networks from all different suppliers.

The second interface is located between the Mobile services Switching Centre, MSC, (which is the switching exchange in GSM) and the Base Station Controller (BSC). This interface is called the **"A-interface"**. These two network elements will be discussed in greater detail in later chapters. The system includes more than the two defined interfaces, but they are not totally open, as the system specifications had not been completed when the commercial systems were launched.

When operating analogue mobile networks, experience has shown that centralised intelligence generates excessive load in the system, thus decreasing the capacity. For this reason, the GSM specification, in principle, provides the means to distribute intelligence throughout the network. Referring to the interfaces, the more complicated the interfaces in use, the more intelligence is required between the interfaces in order to implement all the functions required. In a GSM network, this decentralised intelligence is implemented by dividing the whole network into three separate subsystems:

- **N**etwork **S**witching **S**ubsystem (**NSS**)
- **B**ase **S**tation **S**ubsystem (**BSS**)
- **N**etwork **M**anagement **S**ubsystem (**NMS**)

The actual network needed for establishing calls is composed of the NSS and the BSS. The **BSS** is responsible for radio path control and every call is connected through the BSS. The NSS takes care of call control functions. Calls are always connected by and through the **NSS**.

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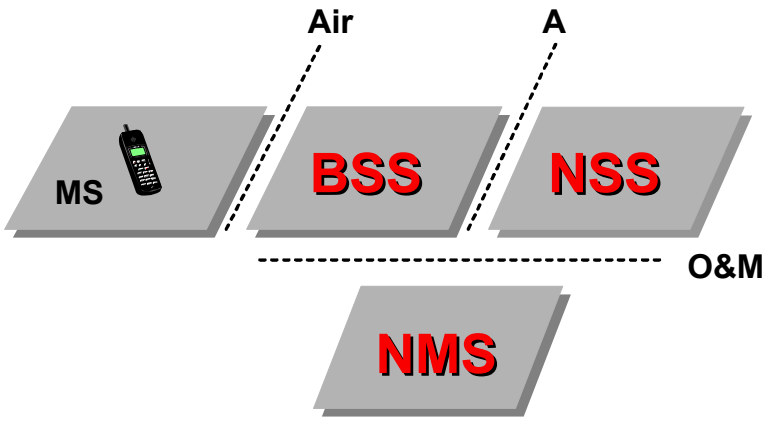

Figure 2. The three subsystems of GSM and their interfaces

The **NMS** is the operation and maintenance related part of the network and it is needed for the control of the whole GSM network. The network operator observes and maintains network quality and service offered through the NMS. The three subsystems in a GSM network are linked by the air-, A-, and O&M interfaces as shown in Figure 2.

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2.1 Mobile Station (MS)

The **MS** (**M**obile **S**tation) is a combination of terminal equipment and subscriber data. The terminal equipment as such is called **ME** (**M**obile **E**quipment) and the subscriber's data is stored in a separate module called **SIM** (**S**ubscriber **I**dentity **M**odule).

Therefore, ME + SIM = MS.

Figure 3. Inserting a SIM card in a mobile phone

From the user's point of view, the SIM is certainly the best-known database used in a GSM network. The SIM is a small memory device mounted on a card and contains user-specific identification. The SIM card can be taken out of one mobile equipment and inserted into another. In the GSM network, the SIM card identifies the user – just like a traveller uses a passport to identify himself.

The SIM card contains the identification numbers of the user and a list of available networks. The SIM card also contains tools needed for authentication and ciphering. Depending on the type of the card, there is also storage space for messages, such as phone numbers. A home operator issues a SIM card when the user joins the network by making a service subscription. The home operator of the subscriber can be anywhere in the world, but for practical reasons the subscriber chooses one of the operators in the country where he/she spends most of the time.

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3 Subsystems and network elements in GSM

The GSM network is divided into three subsystems: Network Switching Subsystem (NSS), Base Station Subsystem (BSS), and Network Management Subsystem (NMS). The three subsystems, different network elements, and their respective tasks are presented in the following.

3.1 Network Switching Subsystem (NSS)

The Network Switching Subsystem (NSS) contains the network elements MSC, VLR, HLR, AC and EIR.

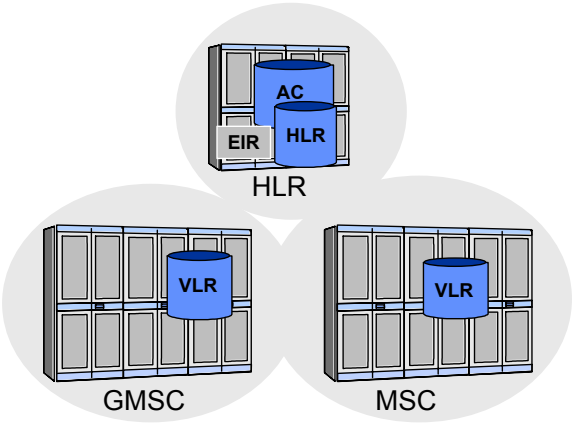

Figure 4. The Network Switching Subsystem (NSS)

The main functions of NSS are:

Call control

This identifies the subscriber, establishes a call, and clears the connection after the conversation is over.

Charging

This collects the charging information about a call (the numbers of the caller and the called subscriber, the time and type of the transaction, etc.) and transfers it to the Billing Centre.

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Mobility management

This maintains information about the subscriber's location.

Signalling

This applies to interfaces with the BSS and PSTN.

Subscriber data handling

This is the permanent data storage in the HLR and temporary storage of relevant data in the VLR.

3.1.1 Mobile services Switching Centre (MSC)

The MSC is responsible for controlling calls in the mobile network. It identifies the origin and destination of a call (mobile station or fixed telephone), as well as the type of a call. An MSC acting as a bridge between a mobile network and a fixed network is called a Gateway MSC.

The MSC is responsible for several important tasks, such as the following.

Call control

MSC identifies the type of call, the destination, and the origin of a call. It also sets up, supervises, and clears connections.

Initiation of paging

Paging is the process of locating a particular mobile station in case of a mobile terminated call (a call to a mobile station).

Charging data collection

(Charging will be covered later in this material.)

3.1.2 Visitor Location Register (VLR)

In the Nokia implementation, Visitor Location Register (VLR) is integrated with the MSC. VLR is a database which contains information about subscribers currently being in the service area of the MSC/VLR, such as:

- Identification numbers of the subscribers
- Security information for authentication of the SIM card and for ciphering
- Services that the subscriber can use

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The VLR carries out location registrations and updates. It means that when a mobile station comes to a new MSC/VLR serving area, it must register itself in the VLR, in other words perform a location update. Please note that a mobile subscriber must always be registered in a VLR in order to use the services of the network. Also the mobile stations located in the own network is always registered in a VLR.

The VLR database is temporary, in the sense that the data is held as long as the subscriber is within its service area. It also contains the address to every subscriber's Home Location Register, which is the next network element to be discussed.

3.1.3 Home Location Register (HLR)

HLR maintains a permanent register of the subscribers, for instance subscriber identity numbers and the subscribed services. In addition to the fixed data, the HLR also keeps track of the current location of its customers. As you will see later, the MSC asks for routing information from the HLR if a call is to be set up to a mobile station (mobile terminated call). In the Nokia implementation, the two network elements, Authentication Centre (AC) and Equipment Identity Register (EIR), are located in the HLR.

3.1.4 Authentication Centre (AC)

The Authentication Centre provides security information to the network, so that we can verify the SIM cards (authentication between the mobile station and the VLR, and cipher the information transmitted in the air interface (between the MS and the Base Transceiver Station). The Authentication Centre supports the VLR's work by issuing so-called authentication triplets upon request. Later we will discuss more about the Authentication Centre's role, and how the authentication triplets are used.

3.1.5 Equipment Identity Register (EIR)

As for AC, the Equipment Identity Register is used for security reasons. But while the AC provides information for verifying the SIM cards, the EIR is responsible for IMEI checking (checking the validity of the mobile equipment).

When performed, the mobile station is requested to provide the **International Mobile Equipment Identity** (**IMEI**) number. This number consists of type approval code, final assembly code and serial number of the mobile station.

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The EIR contains three lists:

- A mobile equipment in the **white list** is allowed to operate normally.
- If we suspect that a mobile equipment is faulty, we can monitor the use of it. It is then placed in the **grey list**.
- If the mobile equipment is reported stolen, or it is otherwise not allowed to operate in the network, it is placed in the **black list**.

Note that IMEI checking is an optional procedure, so it is up to the operator to define if and when IMEI checking is performed. (Some operators do not even implement the EIR at all.)

3.2 Base Station Subsystem (BSS)

The Base Station Subsystem is responsible for managing the radio network, and it is controlled by an MSC. Typically, one MSC contains several BSSs. A BSS itself may cover a considerably large geographical area consisting of many cells (a cell refers to an area covered by one or more frequency resources). The BSS consists of the following elements:

- BSC Base Station Controller
- BTS Base Transceiver Station
- TC Transcoder

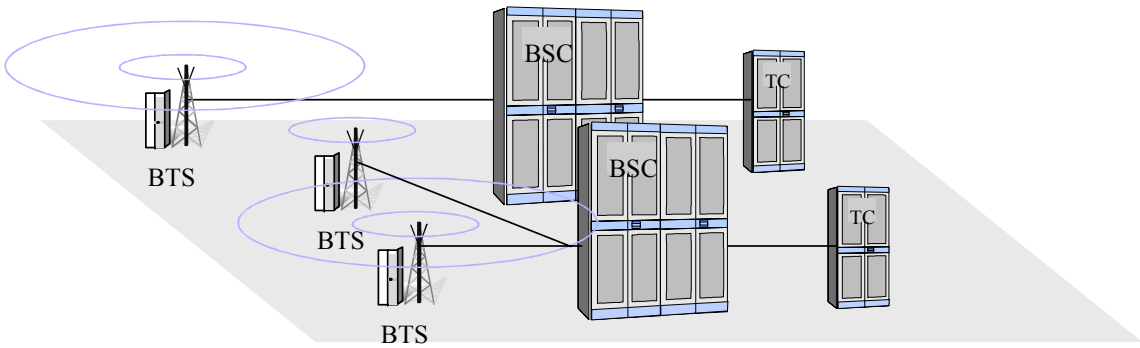

Figure 5. The Base Station Subsystem (BSS)

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Some of the most important BSS tasks are listed in the following:

Radio path control

In the GSM network, the Base Station Subsystem (BSS) is the part of the network taking care of radio resources, that is, radio channel allocation and quality of the radio connection.

Synchronisation

The BSS uses hierarchical synchronisation, which means that the MSC synchronises the BSC, and the BSC further synchronises the BTSs associated with that particular BSC. Inside the BSS, synchronisation is controlled by the BSC. Synchronisation is a critical issue in the GSM network due to the nature of the information transferred. If the synchronisation chain is not working correctly, calls may be cut or the call quality may not be the best possible. Ultimately, it may even be impossible to establish a call.

Air- and A-interface signalling

In order to establish a call, the MS must have a connection through he the BSS.

Connection establishment between the MS and the NSS

The BSS is located between two interfaces, the air- and the A-interface. The MS **must** have a connection through these two interfaces before a call can be established. Generally speaking, this connection may be either a **signalling** connection or a **traffic** (speech, data) connection.

Mobility management and speech transcoding

BSS mobility management mainly covers the different cases of handovers. These handovers and speech transcoding are explained in later sections.

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Let us now have a closer look at each of the individual network elements (BSC, BTS, and Transcoder.

3.2.1 Base Station Controller (BSC)

The BSC is the central network element of the BSS and it controls the radio network. It has several important tasks, some of which are presented in the following:

Connection establishment between the MS and the NSS

All calls to and from the MS are connected through the group switch of the BSC (GSWB).

Mobility management

The BSC is responsible for initiating the vast majority of all handovers, and it makes the handover decision based on, among others, measurement reports sent by the MS during a call.

Statistical raw data collection

Information from the Base Transceiver Stations, Transcoders, and BSC are collected in the BSC and forwarded via the DCN (Data Communications Network) to the NMS (Network Management Subsystem), where they are post-processed into statistical views, from which the network quality and status is obtained.

Air- and A-interface signalling support

In the A-interface, SS#7 (Common Channel Signalling System No. 7) is used as the signalling language, while the environment in the air interface allows the usage of a protocol adapted from ISDN standards, namely LAP-Dm (Link Access Protocol on the ISDN D Channel, modified version). Between the Base Transceiver Station and the BSC (Abis interface), a more standardised LAP-D protocol is used. The BCSU (Base Station Controller Signalling Unit) in the BSC will therefore need to convert from LAP-D to SS#7 and vice versa in the uplink/downlink directions. The BSC also enables the virtual signalling connection needed between the MSC/VLR and the MS.

BTS and TC control

Inside the BSS, all the BTSs and TCs are connected to the BSC(s). The BSC maintains the BTSs. In other words, the BSC is capable of separating (barring) a BTS from the network and collecting alarm information. Transcoders are also maintained by the BSC, that is, the BSC collects alarms related to the transcoders.

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3.2.2 Base Transceiver Station (BTS)

The BTS is the network element responsible for maintaining the air interface and minimising the transmission problems (the air interface is very sensitive for disturbances). This task is accomplished with the help of some 120 parameters. These parameters define exactly what kind of BTS is in question and how MSs may "see" the network when moving in this BTS area.

The BTS parameters handle the following major items: what kind of handovers (when and why), paging organisation, radio power level control, and BTS identification. The BTS has several very important tasks, some of which are presented in the following.

Figure 6. Nokia MetroSite Base Transceiver Station

Air interface signalling

A lot of both call and non-call related signalling must be performed in order for the system to work. One example is that when the MS is switched on for the very first time, it needs to send and receive a lot of information with the network (more precisely with the VLR) before we can start to receive and make phone calls. Another example is the signalling required to set up both mobile originated and mobile terminated calls. A third very important signalling in mobile networks is the need to inform the MS when a handover is to be performed (and later when the MS sends a message in the uplink direction telling the network that the handover is completed. Later in this chapter, we will have a closer look at all of these different cases.

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Ciphering

Both the BTS and the MS must be able to cipher and decipher information in order to protect the transmitted speech and data in the air interface.

Speech processing

Speech processing refers to all the functions the BTS performs in order to guarantee an error-free connection between the MS and the BTS. This includes tasks like speech coding (digital to analogue in the downlink direction and vice versa), channel coding (for error protection), interleaving (to enable a secure transmission), and burst formatting (adding information to the coded speech / data in order to achieve a well-organised and safe transmission).

The base station can contain several TRXs (Transceivers), each supporting one pair of frequencies for transmitting and receiving information. The BTS also has one or more antennas, which are capable of transmitting and receiving information to/from one or more TRXs. The antennas are either *omnidirectional* or *sectorised.* It also has control functions for Operation and Maintenance (O&M), synchronisation and external alarms, etc.

3.2.3 TC(SM) – Transcoder (SubMultiplexer)

In the air interface (between MS and BTS), the media carrying the traffic is a radio frequency. To enable an efficient transmission of digital speech information over the air interface, the digital speech signal is compressed. We must however also be able to communicate with and through the fixed network, where the speech compression format is different. Somewhere between the BTS and the fixed network, we therefore have to convert from one speech compression format to another, and this is where the Transcoder comes in.

For transmission over the air interface, the speech signal is compressed by the mobile station to **13 Kbits/s (Full Rate and Enhanced Full Rate) or 5.6 Kbits/s (Half Rate).** The compression algorithm for Full Rate is known as **"Regular Pulse Excitation** with **Long Term Prediction" (RPE-LTP).** For Enhanced Full Rate, speech coding is based on the algorithm **"Algebraic Code Excited Linear Prediction" (ACELP). "Vector Sum Excited Linear Prediction" (VSELP)** is used in the case of Half Rate. However, the standard bit rate for speech in the PSTN is **64 Kbits/s**. The modulation technique is called **"Pulse Code Modulation" (PCM)**.

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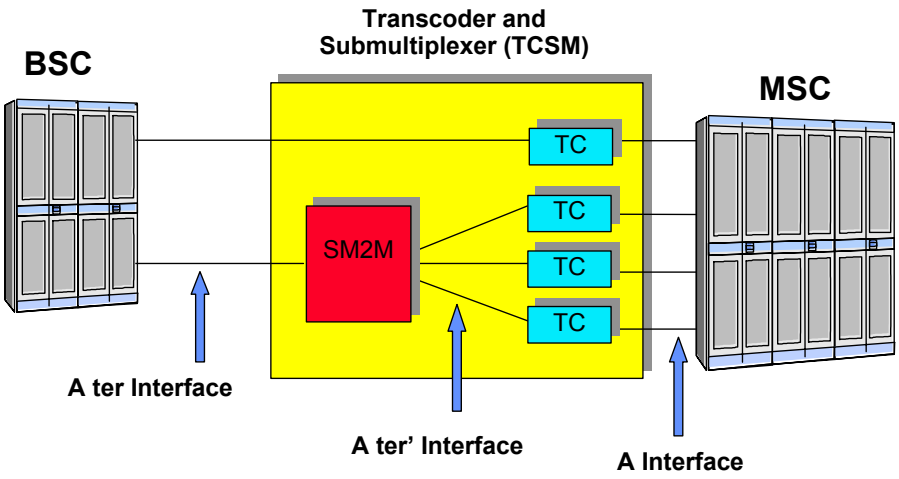

Figure 7. Location of Transcoder and Submultiplexer

The Transcoder (TC) thus takes care of the change from one bit rate to another. If the TC is located as close as possible to the MSC with standard PCM lines connecting the network elements, we can, in theory, multiplex four traffic channels in one PCM channel. This increases the efficiency of the PCM lines, and thus lowers the costs for the operator. When we connect to the MSC, the multiplexed lines have to be de-multiplexed. In this case the unit is called **Transcoder and Submultiplexer (TCSM)**.

Another task for the TC is to enable DTX (Discontinuous transmission), which is used during a call when there is nothing to transmit (no conversation). It is activated in order to reduce interference and to save MS battery.

In the Nokia solution, the submultiplexing and transcoding functions are combined in one equipment called TCSM2E (European version) or TCSM2A (American version).

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3.3 Network Management Subsystem (NMS)

The **Network Management Subsystem (NMS)** is the third subsystem of the GSM network in addition to the Network Switching Subsystem (NSS) and Base Station Subsystem (BSS), which we have already discussed. The purpose of the NMS is to monitor various functions and elements of the network. In the Nokia implementation, these tasks are carried out by the **NMS/2000,** which consists of a number of workstations, servers, and a router, which connects to a Data Communications Network (DCN).

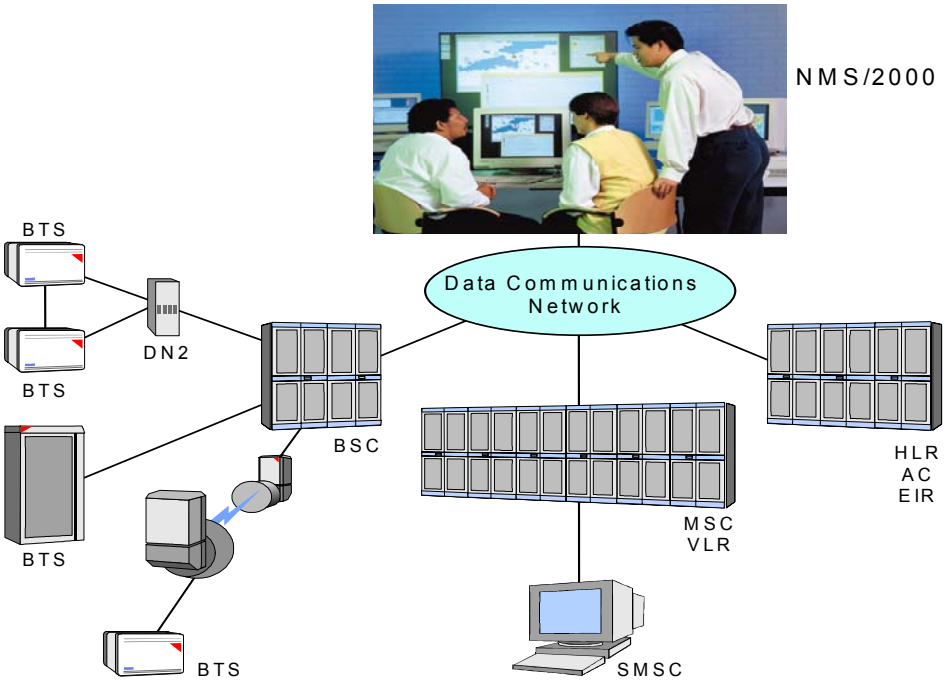

Figure 8. The NMS and the GSM network

The operator workstations are connected to the database and communication servers via a Local Area Network (LAN). The database server stores the management information about the network. The communications server takes care of the data communications between the NMS and the equipment in the GSM network known as “network elements”. These communications are carried over a Data Communications Network (DCN), which connects to the NMS via a router. The DCN is normally implemented using an X.25 Packet Switching Network.

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The functions of the NMS can be divided into three categories:

- Fault management
- Configuration management
- Performance management

These functions cover the whole of the GSM network elements from the level of individual BTSs, up to MSCs and HLRs.

Fault management

The purpose of fault management is to ensure the smooth operation of the network and rapid correction of any kind of problems that are detected. Fault management provides the network operator with information about the current status of alarm events and maintains a history database of alarms.

The alarms are stored in the NMS database and this database can be searched according to criteria specified by the network operator.

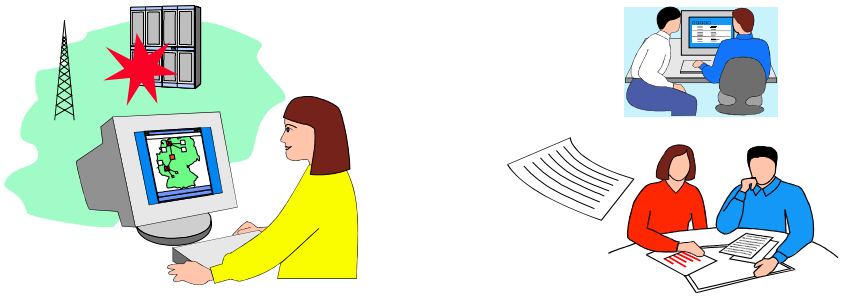

Figure 9. Fault management

Configuration management

The purpose of configuration management is to maintain up-to-date information about the operation and configuration status of network elements. Specific configuration functions include the management of the radio network, software and hardware management of the network elements, time synchronisation, and security operations.

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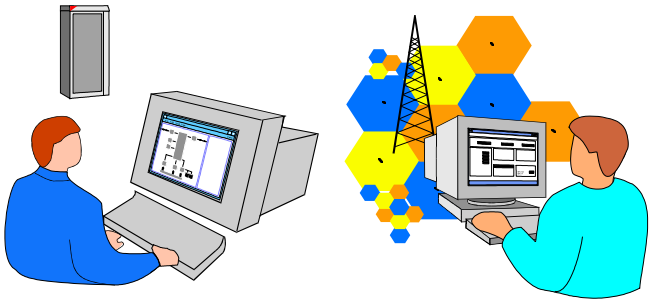

Figure 10. Configuration management

Performance management

In performance management, the NMS collects measurement data from individual network elements and stores it in a database. On the basis of these data, the network operator is able to compare the actual performance of the network with the planned performance and detect both good and bad performance areas within the network.

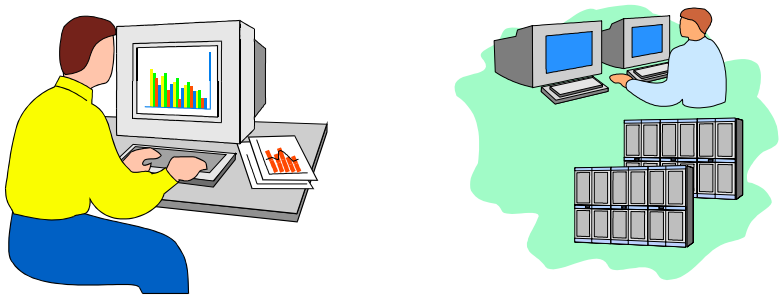

Figure 11. Performance management

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4 Network elements and connections – Nokia implementation

In the previous sections we have discussed all subsystems and network elements thoroughly. The picture below shows an overall picture of the GSM network, where you can also see some of the connections to external elements, such as SMSC and Billing Centre. Note that the network picture below contains equipment from a typical GSM network, some of which is not included in the GSM specifications. Furthermore the picture exemplifies how Nokia implements the network.

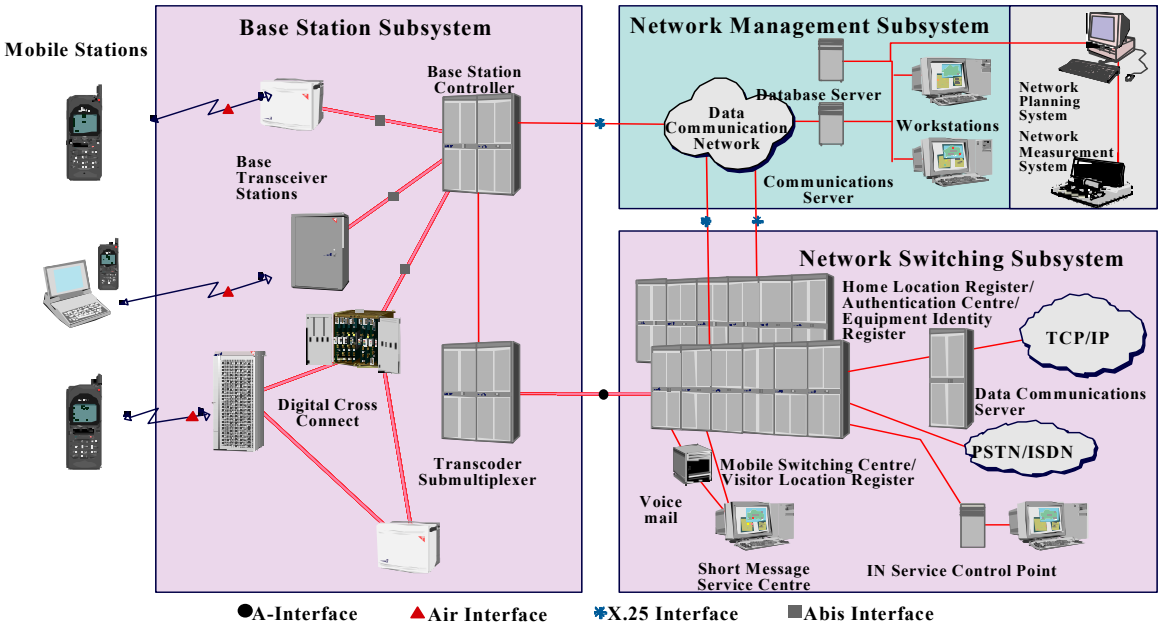

Figure 12. GSM network architecture – Nokia implementation

Up until now, we have covered the history of GSM, the subsystems, and interfaces. Step by step, we have also built a (virtual) GSM network by describing the different network elements and their respective tasks. Now it is finally time to start to use this network, in other words to make calls, receive calls, and use the different services offered by the network. However, before it is possible to use the network, we must tell the system that we are there and that we are authorised users. These will be covered in the following modules.

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