

Motorola Ltd

**INTRODUCTION
TO
DIGITAL CELLULAR**

The information
contained in this document
is not intended to replace that contained
in the relevant equipment manuals and is
for training purposes only.

THIS MANUAL WILL NOT BE UPDATED

INTRODUCTION TO DIGITAL CELLULAR

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INTRODUCTION TO DIGITAL CELLULAR

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Principles of Cellular Telecommunications

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Name the main components of a cellular network and describe their functionality.

- . Name the two different cell types and understand why and when each would be used.

- . State the GSM, EGSM and DCS1800 frequency bands.



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Introduction to Digital Cellular

Section 1

Principles of Cellular Telecommunications

PRINCIPLES OF CELLULAR TELECOMMUNICATIONS

OVERVIEW

A cellular telephone system links mobile station (MS) subscribers into the public telephone system or to another cellular system's MS subscriber.

Information sent between the MS subscriber and the cellular network uses radio communication. This removes the necessity for the fixed wiring used in a traditional telephone installation.

Due to this, the MS subscriber is able to move around and become fully mobile, perhaps travelling in a vehicle or on foot.

ADVANTAGES OF CELLULAR COMMUNICATIONS

Cellular networks have many advantages over the existing "land" telephone networks. There are advantages for the network provider as well as the mobile subscriber.

Overview

Advantages to Mobile Subscriber

- **Mobility**
- **Flexibility**
- **Convenience**

Advantages to Network Provider

- **Network Expansion Flexibility**
- **Revenue/Profit Margins**
- **Efficiency**
- **Easier Re-Configuration**

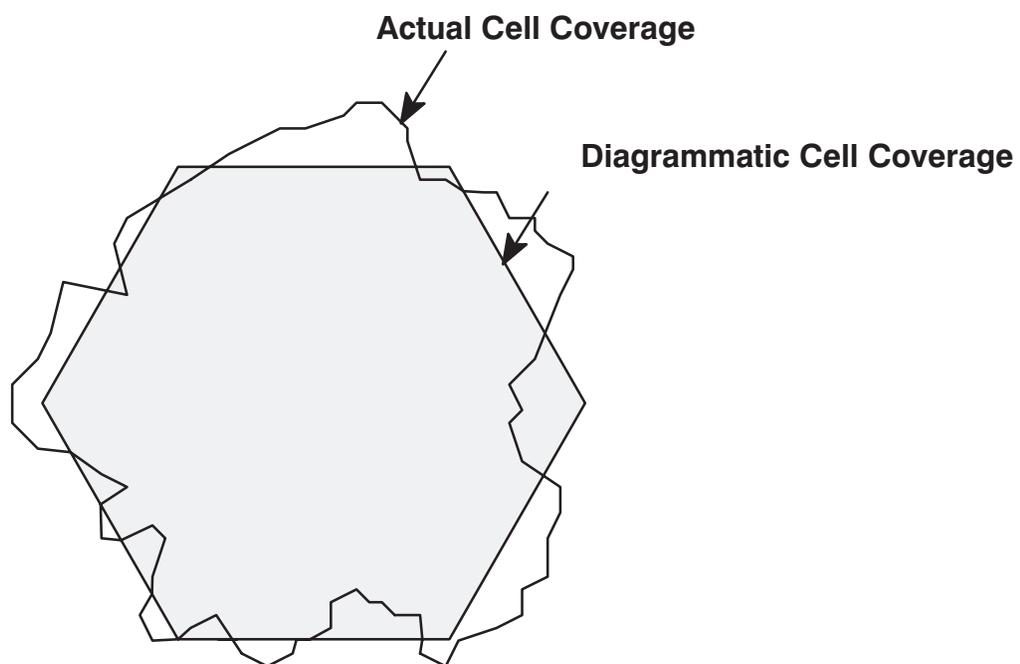
NETWORK COMPONENTS

GSM networks are made up of Mobile services Switching Centres (MSC), Base Station Systems (BSS) and Mobile Stations (MS). These three entities can be broken down further into smaller entities; such as, within the BSS we have Base Station Controllers, Base Transceiver Stations and Transcoders. These smaller network elements, as they are referred to, will be discussed later in the course. For now we will use the three major entities.

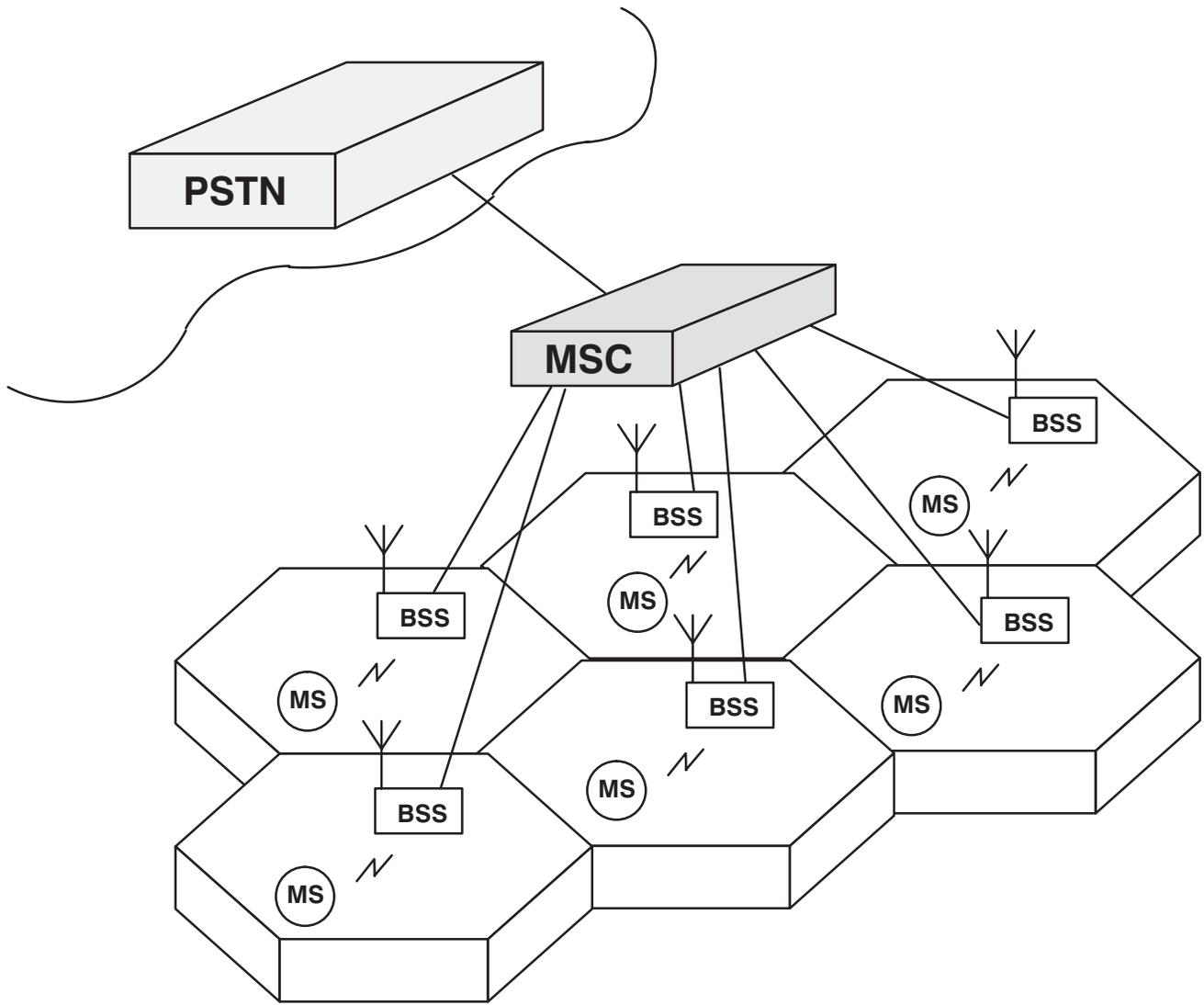
With the MSC, BSS and MS we can make calls, receive calls, perform billing etc, as any normal PSTN network would be able to do. The only problem for the MS is that all the calls made or received are from other MSs. Therefore, it is also necessary to connect the GSM network to the PSTN.

Mobile Stations within the cellular network are located in "cells", these cells are provided by the BSSs. Each BSS can provide one or more cells, dependent on the manufacturers equipment.

The cells are normally drawn as hexagonal, but in practice they are irregularly shaped, this is as a result of the influence of the surrounding terrain, or of design by the network planners.



Network Components



-  **PSTN (Public Switched Telephone Network)**
-  **MSC (Mobile service Switching Centre)**
-  **BSS (Base Station System)**
-  **MS (Mobile Station)**
-  **(Cell Coverage Area)**

FREQUENCY SPECTRUM

INTRODUCTION

The frequency spectrum is very congested, with only narrow slots of bandwidth allocated for cellular communications. The list opposite shows the number of frequencies and spectrum allocated for GSM, Extended GSM (EGSM) and DCS1800.

A single Absolute Radio Frequency Channel Number (ARFCN) or RF carrier is actually a pair of frequencies, one used in each direction (transmit and receive). This allows information to be passed in both directions. For GSM and EGSM the paired frequencies are separated by 45 MHz and for DCS1800 the separation is 75 MHz.

For each cell in a GSM network (GSM, EGSM or DCS1800) at least one ARFCN must be allocated, and more may be allocated to provide greater capacity.

The RF carrier in GSM can support up to eight Time Division Multiple Access (TDMA) timeslots. That is, in theory, each RF carrier is capable of supporting up to eight simultaneous telephone calls, but as we will see later in this course although this is possible, network signalling and messaging may reduce the overall number from eight timeslots per RF carrier to six or seven timeslots per RF carrier, therefore reducing the number of mobiles that can be supported.

Unlike a PSTN network, where every telephone is linked to the land network by a pair of fixed wires, each MS only connects to the network over the radio interface when required. Therefore, it is possible for a single RF carrier to support many more mobile stations than its eight TDMA timeslots would lead us to believe. Using statistics, it has been found that a typical RF carrier can support up to 15, 20 or even 25 MSs. Obviously, not all of these MS subscribers could make a call at the same time, but it is also unlikely that all the MS subscribers would want to make a call at the same time. Therefore, without knowing it, MSs share the same physical resources, but at different times.

Frequency Range

GSM

- Receive (uplink) 890–915 MHz
- Transmit (downlink) 935–960 MHz
- 124 Absolute Radio Frequency Channels (ARFCN)

EGSM

- Receive (uplink) 880–915 MHz
- Transmit (downlink) 925–960 MHz
- 175 Absolute Radio Frequency Channels (ARFCN)

DCS1800

- Receive (uplink) 1710–1785 MHz
- Transmit (downlink) 1805–1880 MHz
- 374 Absolute Radio Frequency Channels (ARFCN)

ARFCN

- Bandwidth = 200 kHz
- 8 TDMA timeslots

CELL SIZE

The number of cells in any geographic area is determined by the number of MS subscribers who will be operating in that area, and the geographic layout of the area (hills, lakes, buildings etc).

LARGE CELLS

The maximum cell size for GSM is approximately 80 km in diameter, but this is dependent on the terrain the cell is covering and the power class of the MS. In GSM, the MS can be transmitting anything up to 8 Watts; obviously, the higher the power output of the MS the larger the cell size. If the cell site is on top of a hill, with no obstructions for miles, then the radio waves will travel much further than if the cell site was in the middle of a city, with many high-rise buildings blocking the path of the radio waves.

Generally large cells are employed in:

- Remote areas.
- Coastal regions.
- Areas with few subscribers.
- Large areas which need to be covered with the minimum number of cell sites.

SMALL CELLS

Small cells are used where there is a requirement to support a large number of MSs, in a small geographic region, or where a low transmission power may be required to reduce the effects of interference. Small cells currently cover 200 m and upwards.

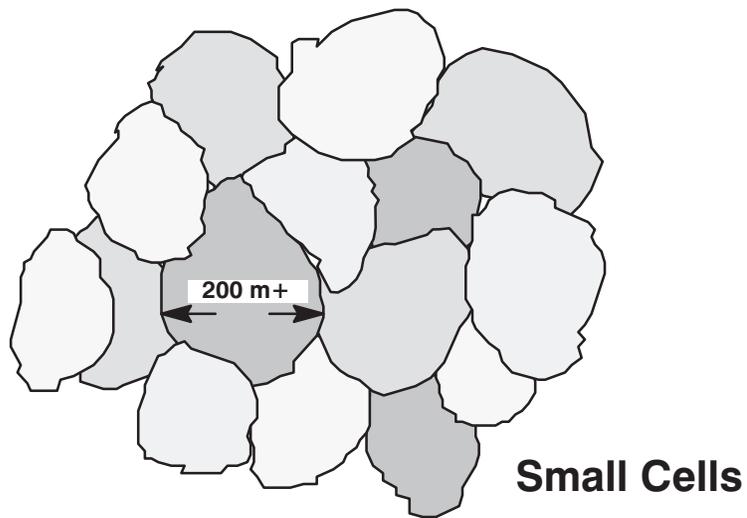
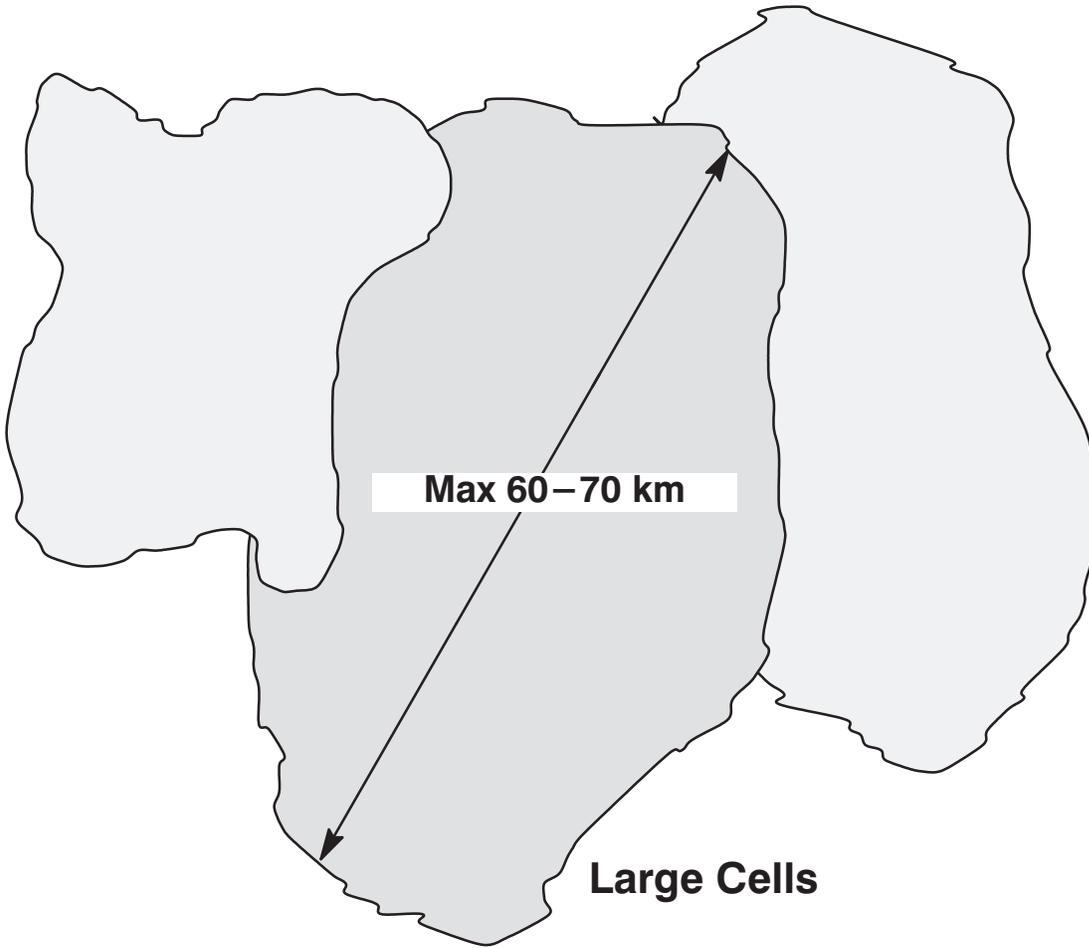
Typical uses of small cells:

- Urban areas.
- Low transmission power required.
- High number of MSs.

THE TRADE OFF – LARGE V SMALL

There is no right answer when choosing the type of cell to use. Network providers would like to use large cells to reduce installation and maintenance cost, but realize that to provide a quality service to their customers, they have to consider many factors, such as terrain, transmission power required, number of MSs etc. This inevitably leads to a mixture of both large and small cells.

Cell Size



FREQUENCY RE-USE

Standard GSM has a total of 124 frequencies available for use in a network. Most network providers are unlikely to be able to use all of these frequencies and are generally allocated a small subset of the 124.

Example:

A network provider has been allocated 48 frequencies to provide coverage over a large area, let us take for example Great Britain.

As we have already seen, the maximum cell size is approximately 70 km in diameter, thus our 48 frequencies would not be able to cover the whole of Britain.

To overcome this limitation the network provider must re-use the same frequencies over and over again, in what is termed a “frequency re-use pattern”.

When planning the frequency re-use pattern the network planner must take into account how often to use the same frequencies and determine how close together the cells are, otherwise co-channel and/or adjacent channel interference may occur. The network provider will also take into account the nature of the area to be covered. This may range from a densely populated city (high frequency re-use, small cells, high capacity) to a sparsely populated rural expanse (large omni cells, low re-use, low capacity).

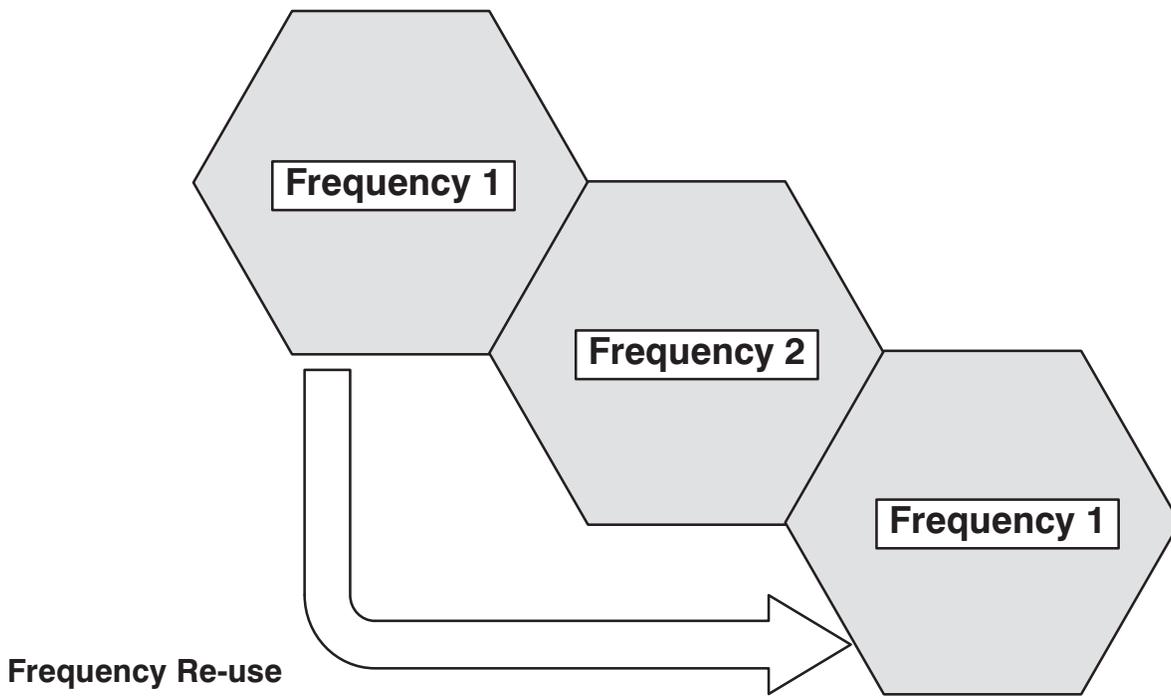
CO-CHANNEL INTERFERENCE

This occurs when RF carriers of the same frequency are transmitting in close proximity to each other, the transmission from one RF carrier interferes with the other RF carrier.

ADJACENT CHANNEL INTERFERENCE

This occurs when an RF source of a nearby frequency interferes with the RF carrier.

Frequency Re-use



SECTORIZATION

The cells we have looked at up to now are called omni-directional cells. That is each site has a single cell and that cell has a single transmit antenna which radiates the radio waves to 360 degrees.

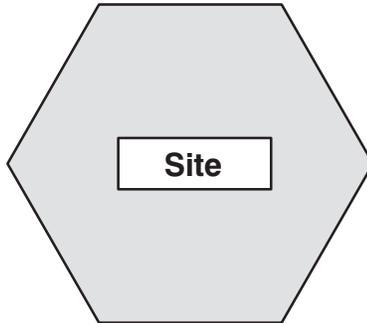
The problem with employing omni-directional cells is that as the number of MSs increases in the same geographical region, we have to increase the number of cells to meet the demand. To do this, as we have seen, we have to decrease the size of the cell and fit more cells into this geographical area. Using omni-directional cells we can only go so far before we start introducing co-channel and adjacent channel interference, both of which degrade the cellular network's performance.

To gain a further increase in capacity within the geographic area we can employ a technique called "sectorization". Sectorization splits a single site into a number of cells, each cell has transmit and receive antennas and behaves as an independent cell.

Each cell uses special directional antennas to ensure that the radio propagation from one cell is concentrated in a particular direction. This has a number of advantages: firstly, as we are now concentrating all the energy from the cell in a smaller area 60, 120, 180 degrees instead of 360 degrees, we get a much stronger signal, which is beneficial in locations such as "in-building coverage". Secondly, we can now use the same frequencies in a much closer re-use pattern, thus allowing more cells in our geographic region which allows us to support more MSs.

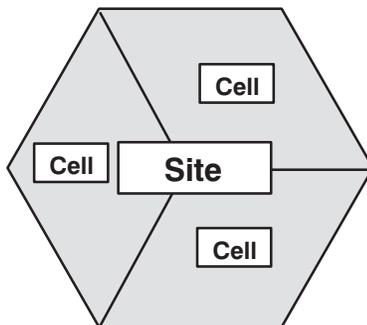
Site Sectorization

360 Degree cells



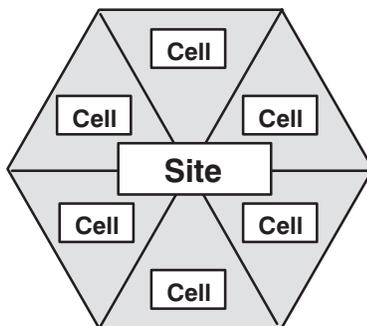
Omni Cell Site
1 Transmit/Receive
Antenna

120 Degree Sectors/cells



3 cell site
3 transmit/Receive
Antenna

60 Degree Sectors/cells



6 cell site
6 Transmit/Receive
Antenna

USING SECTORED SITES

The distribution of RF carriers, and the size of the cells, is selected to achieve a balance between avoiding co-channel interference by geographically separating cells using the same RF frequencies, and achieving a channel density sufficient to satisfy the anticipated demand.

The diagram opposite illustrates how, by sectoring a site we can fit more cells into the same geographical area, thus increasing the number of MS subscribers who can gain access and use the cellular network.

This sectorization of sites typically occurs in densely populated areas, or where a high demand of MSs is anticipated, such as conference centres/business premises.

4 SITE/3 CELL

A typical re-use pattern used in GSM planning is the 4 site/3 cell.

For example, the network provider has 36 frequencies available, and wishes to use the 4 site/3 cell re-use pattern he may split the frequencies up as follows:

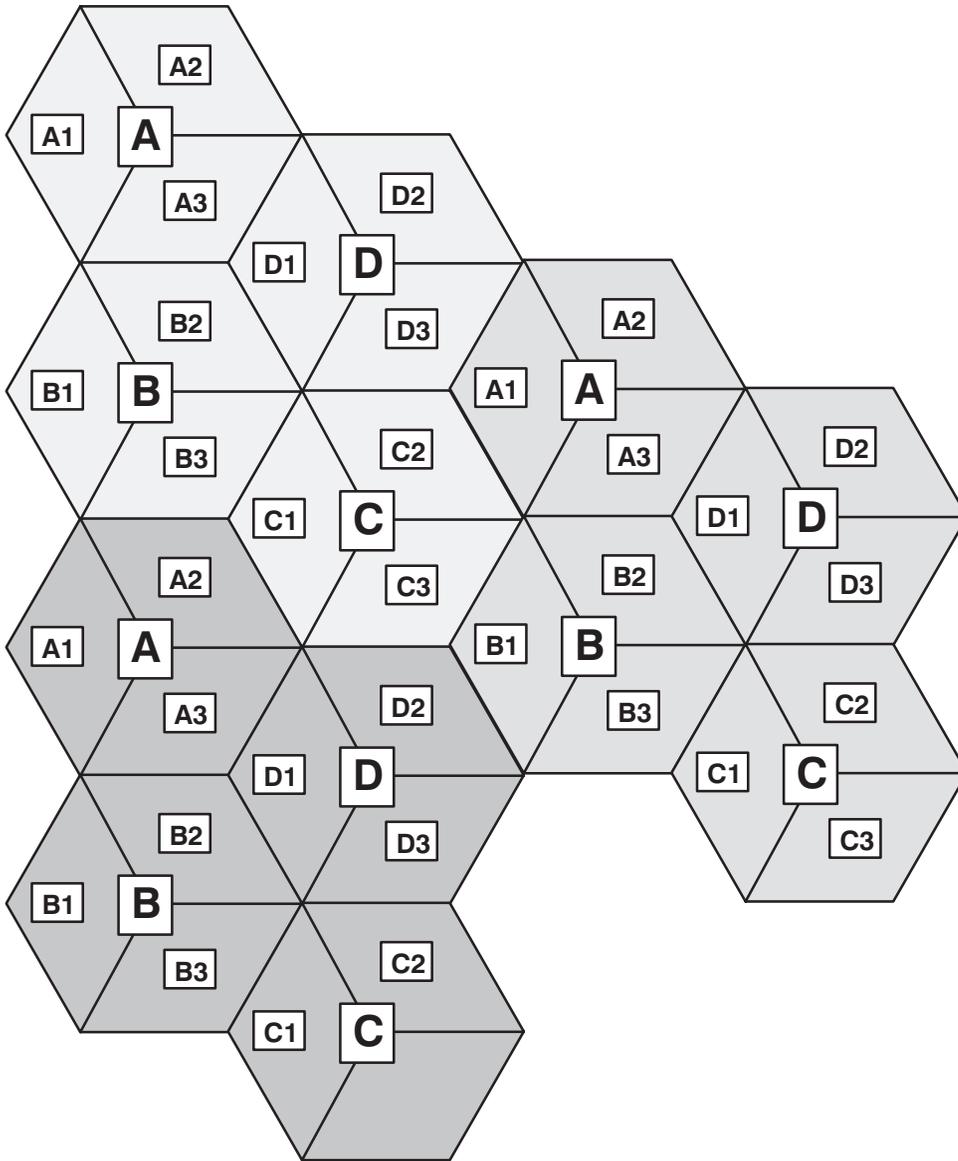
Cell A1	Cell A2	Cell A3	Cell B1	Cell B2	Cell B3	Cell C1	Cell C2	Cell C3	Cell D1	Cell D2	Cell D3
1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32	33	34	35	36

In this configuration each cell has a total of 9 carriers and each site has a total of 9 carriers. If the provider wished to reconfigure to a 3 site/3 cell then the result would be:

Cell A1	Cell A2	Cell A3	Cell B1	Cell B2	Cell B3	Cell C1	Cell C2	Cell C3
1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25	26	27
28	29	30	31	32	33	34	35	36

As can be seen from the table, each cell now has 4 carriers and each site has 12 carriers. This has the benefit of supporting more subscribers in the same geographic region, but problems could arise with co-channel and adjacent channel interference.

4 Site/3 Cell



SWITCHING AND CONTROL

Having established radio coverage through the use of cells, both omni-directional and directional (sectored sites), now consider what happens when the MS is in motion (as MSs tend to be).

At some point the MS will have to move from one cell's coverage area to another cell's coverage area. Handovers from one cell to another could be for a number of reasons in GSM (e.g. the signal strength of the "serving cell" is less than the signal strength of a "neighbour cell", or the MS is suffering a quality problem in the serving cell) and by handing over to one of its neighbours this may stop the quality problem.

Regardless of the reason for a "handover" it has to be controlled by some entity, and in GSM that entity is the Mobile services Switching Centre (MSC).

To perform a handover, the network must know which neighbour cell to hand the MS over to. To ensure that we handover to the best possible candidate the MS performs measurements of its surrounding neighbour cells and reports its findings to the network. These are then analyzed together with the measurements that the network performs and a decision is made on a regular basis as to the need for a handover. If a handover is required then the relevant signal protocols are established and the handover is controlled by the MSC.

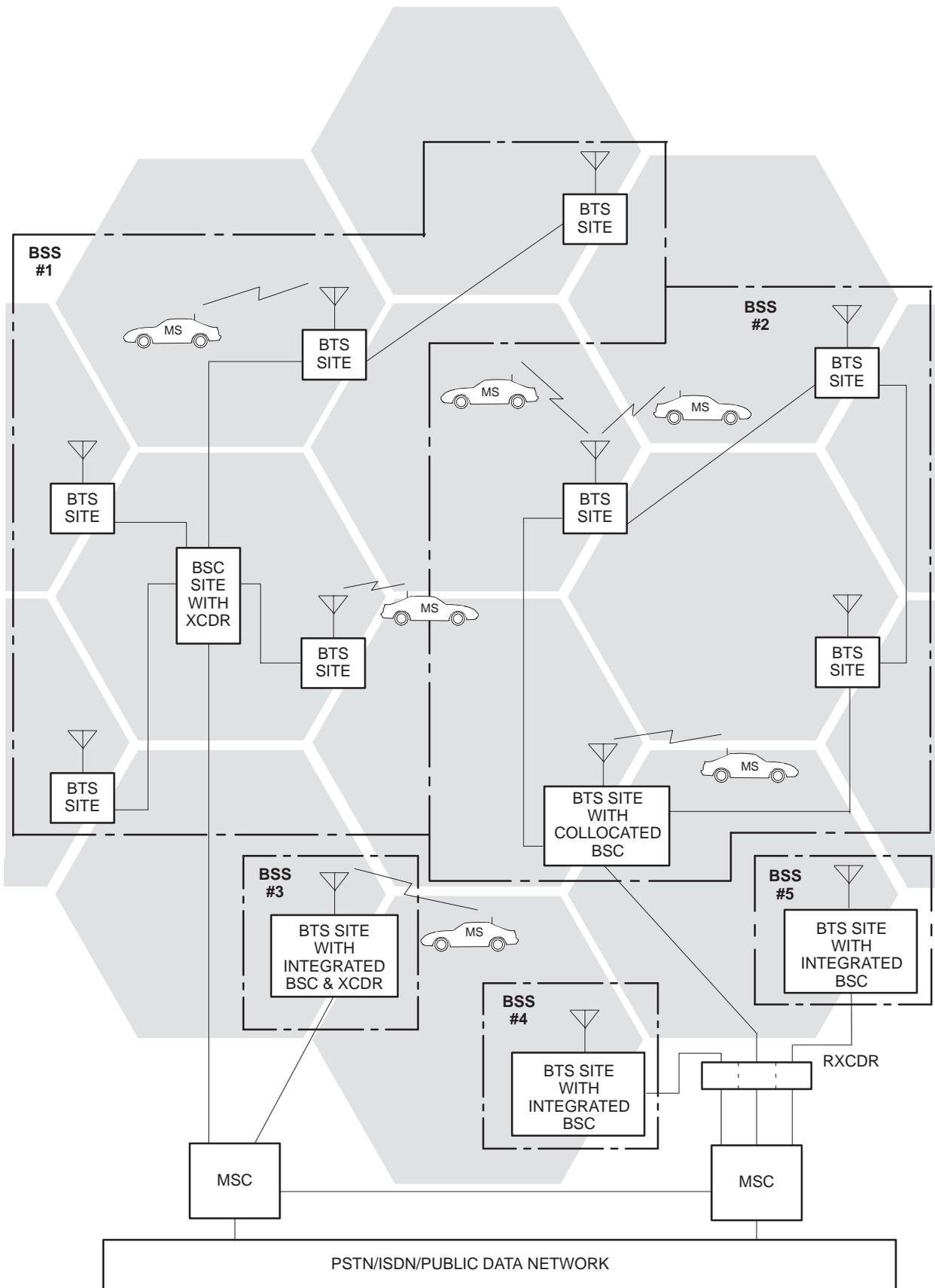
Handovers must be transparent to the MS subscriber. That is the subscriber should be unaware that a handover has occurred.

As we will see later in this course, handovers are just one of the functions of the MSC, many more are performed by the MSC and its associated entities (e.g. such as authentication of MS, ciphering control, location updating, gateway to PSTN).

Note:

Some networks may allow certain handovers to be performed at the BSS level. This would be dependent on the manufacturer's equipment.

Switching and Control





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INTRODUCTION TO DIGITAL CELLULAR

Section 2

Features of GSM

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Name eight features which set GSM apart from other existing cellular systems.



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Introduction to Digital Cellular

Section 2

Features of GSM

FEATURES OF GSM

Our current cellular telephone systems provide the MS subscriber and network provider with many advantages over a standard telephone network, but there are still many drawbacks.

COMPATIBILITY

Due to the rapid development of cellular, there are now many different cellular systems which are incompatible with one another.

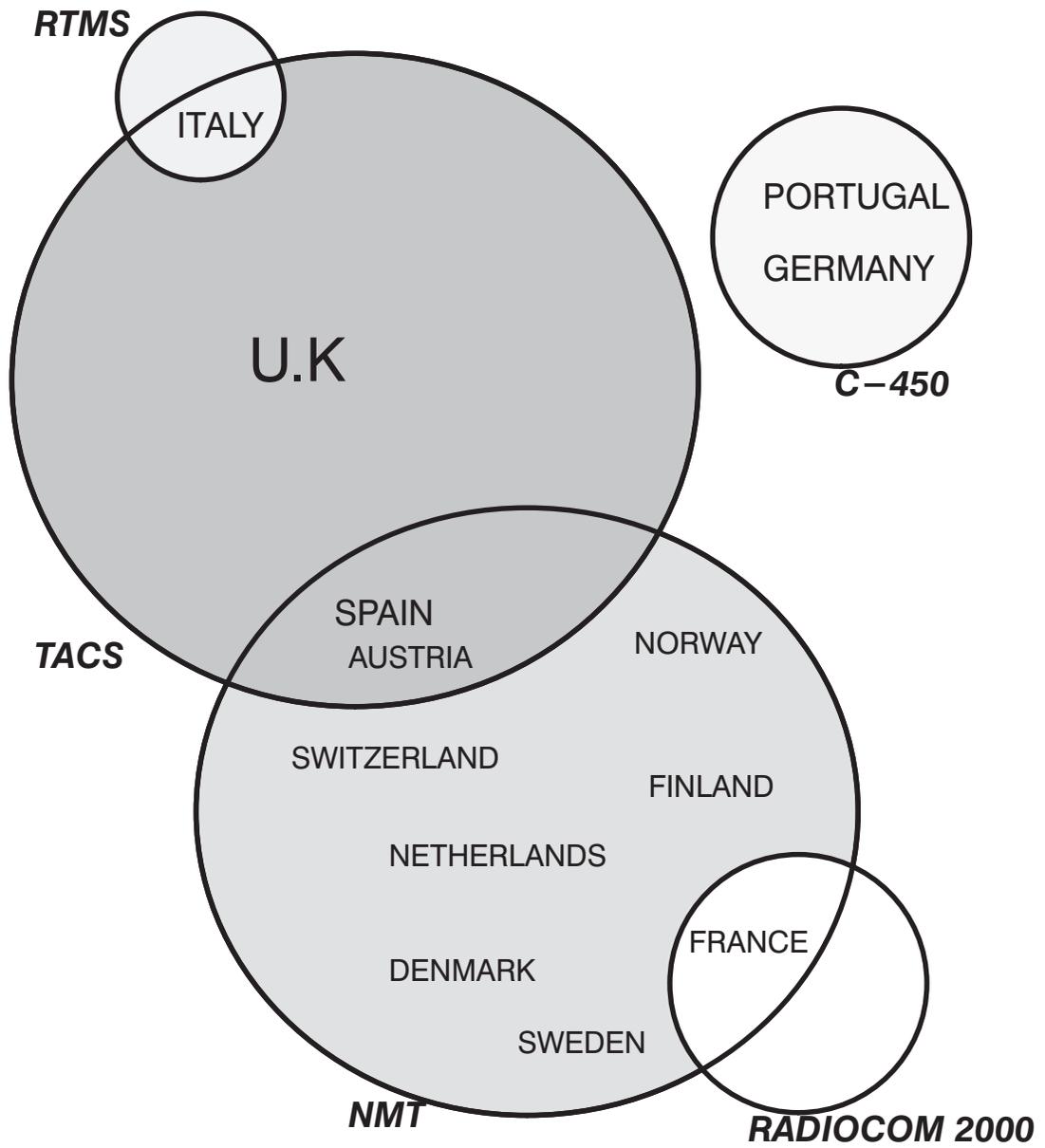
The need for a common standard for mobile telecommunications is therefore obvious. An executive body was set up to co-ordinate the complicated task of specifying the new standardized network.

GSM has been specified and developed by many European countries working in co-operation with each other. The result is a cellular system which will be implemented throughout Europe. Eventually you will be able to drive from Germany to Spain without dropping your telephone call.

Due to GSMs standardization and features, it has now been accepted not only in Europe but throughout the world.

An additional advantage resulting from this is that there will be a large market for GSM equipment. This means that manufacturers will produce equipment in higher quantities and of better quality, and also, due to the number of manufacturers, a competitive and aggressive pricing structure will exist. This will result in lower costs for the MS subscriber.

Compatibility



NOISE ROBUST

In the current cellular telephone systems the MS communicates with the cell site by means of analogue radio signals. Although this technique can provide an excellent audio quality (it is widely used for stereo radio broadcasting, for example), it is vulnerable to noise, as anyone who has tried to receive broadcast stereo with a poor aerial will testify!

The noise which interferes with the current system may be produced by any of the following sources:

- A powerful or nearby external source (a vehicle ignition system or a lightning bolt, perhaps);
- Another transmission on the same frequency (co-channel interference);
- Another transmission “breaking through” from a nearby frequency (adjacent channel interference);
- Background radio noise intruding because the required signal is too weak to exclude it.

In order to combat the problems caused by noise, GSM uses digital technology instead of analogue.

By using digital signals, we can manipulate the data and include sophisticated error protection, detection and correction software. The overall result is that the signals passed across the GSM air interface can withstand more errors (that is, we can locate and correct more errors than current analogue systems). Due to this feature, the GSM air interface in harsh RF environments can produce a usable signal, where analogue systems would be unable to.

Sources of Noise

- **Vehicle ignition systems**
- **Lightning**
- **Co-channel interference**
- **Adjacent channel interference**
- **Background spurious noise**

GSM Answers

- **Digital interface**
- **Interleaving**
- **Error detection**
- **Error correction**

FLEXIBILITY AND INCREASED CAPACITY

The success of the current analogue cellular systems means that there is a requirement for increased cellular phone capacity and also ease of expansion. Current cellular networks have to some extent become the victims of their own success. So many subscribers have registered on these systems so quickly that it has been difficult to expand their capacity fast enough to satisfy call demand.

With the analogue air interface, every connection between a MS and a cell site requires a separate RF carrier and that, in turn, requires a separate set of RF hardware at the cell site. Therefore, to expand the capacity of a cell site by a given number of channels, an equivalent quantity of RF hardware must be added to the cell site equipment. System expansion, therefore, is time-consuming, expensive and labour intensive.

With GSM, the equipment is typically much smaller in size due to the latest technology being implemented in its design. This offers significant cost savings to the network provider as well as allowing quick installation and reconfiguration of existing networks.

A future enhancement of GSM is "half rate speech". This in its simplest terms will reduce the transmission rate over the air interface of a traffic channel by 50%, thus will effectively doubling the number of traffic channels on a single carrier.

GSM also offers the increased flexibility of international roaming. This allows the MS user to travel from one country to another, use their SIM card in any GSM phone and use the visited countries GSM network to make and receive calls. The advantage for the MS user is that no matter where they are (any country with supported GSM network) the GSM network will ensure that they receive all their calls from their home network; not only that, all call billing is done on the home network, so the MS user only receives the one bill.

GSM is highly software dependent. Although this makes it very complex, it also allows a high degree of flexibility when changes need to be implemented. GSM suppliers are constantly revising their software and adding new features to compete in the GSM market.

Flexibility/Increased Capacity

- **Latest technology**
- **Small 'Footprint' (size)**
- **Easily (RF) configured (software driven)**
- **Half rate**
- **International roaming**
- **Extended frequency spectrum**

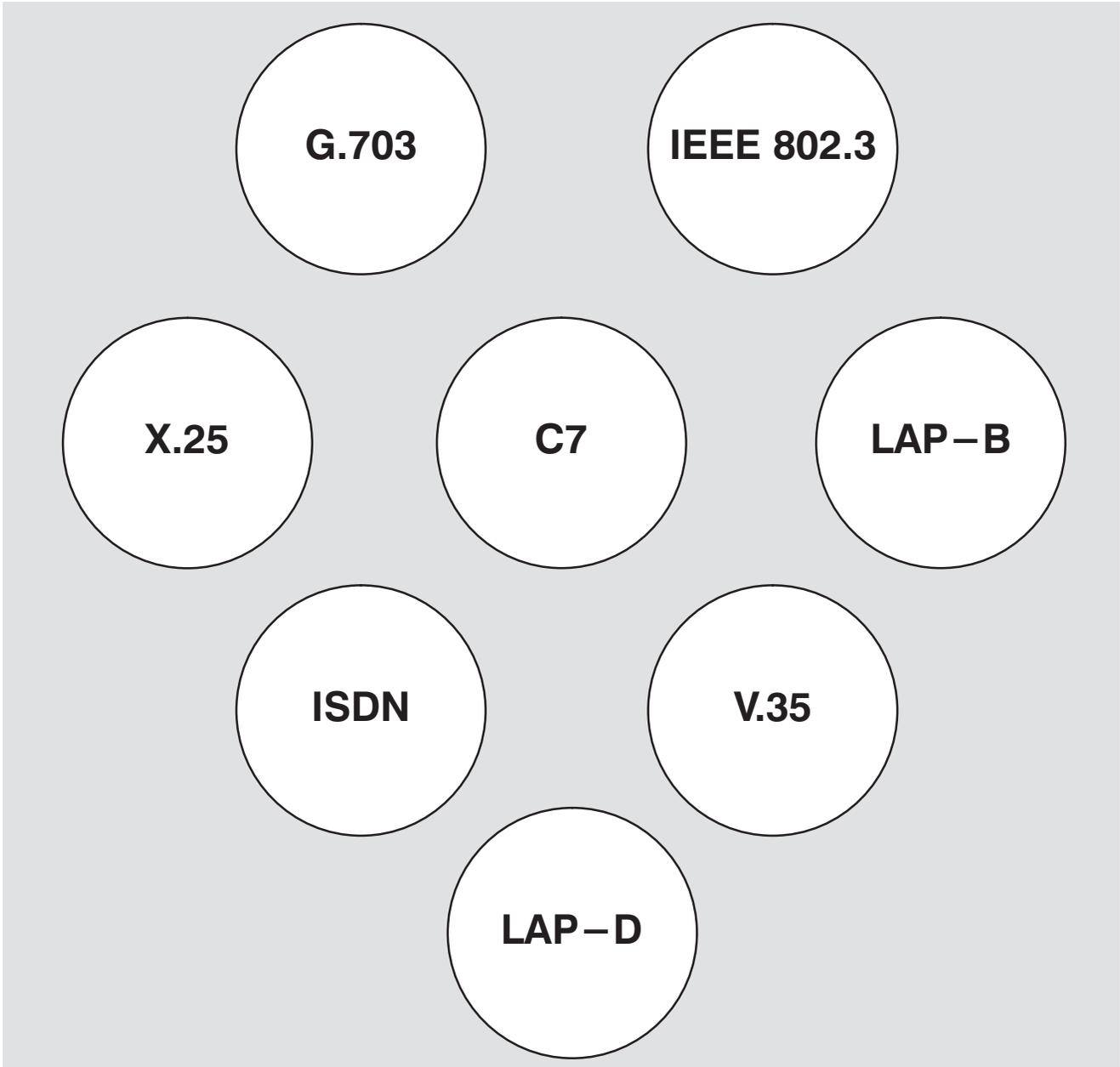
USE OF STANDARDISED OPEN INTERFACES

The equipment in each of the analogue cellular networks tends to be produced by one manufacturer. This is because the equipment is only designed to communicate with other equipment made by that manufacturer. This situation is very profitable for the manufacturers as they have a great deal of influence over the pricing of their product. Unfortunately for the MS user and the network provider, this means high prices.

The situation is very different with GSM, where standard interfaces such as **C7** and **X.25** are used throughout the network. This means that network planners can select different manufacturers for different pieces of hardware. Competition between manufacturers will therefore increase and prices should fall.

In addition, network planners have a great deal of flexibility in where the network components are situated. This means that they can make the most efficient use of the terrestrial links which they operate.

Use of Standardized Open Interfaces



IMPROVED SECURITY AND CONFIDENTIALITY

Security figures high on the list of problems encountered by some operators of analogue systems. In some systems, it is virtually non-existent and the unscrupulous were quick to recognize this. With some of the "first generation" systems, it has been estimated that up to 20% of cellular phone calls are stolen.

Extensive measures have been taken, when specifying the GSM system, to substantially increase security with regard to both call theft and equipment theft.

With GSM, both the Mobile Equipment (ME) and Mobile Subscriber are identified. The ME has a unique number coded into it when it is manufactured. This can be checked against a database every time the mobile makes a call to validate the actual equipment. The subscriber is authenticated by use of a smart card known as a Subscriber Identity Module (SIM), again this allows the network to check a MS subscriber against a database for authentication.

GSM also offers the capability to encrypt all signalling over the air interface. Different levels of encryption are available to meet different subscriber/country requirements.

With the authentication processes for both the ME and subscriber, together with the encryption and the digital encoding of the air interface signals, it makes it very difficult for the casual "hacker" to listen-in to personal calls.

In addition to this, the GSM air interface supports frequency hopping; this entails each "burst" of information being transmitted to/from the MS/base site on a different frequency, again making it very difficult for an observer (hacker) to follow/listen to a specific call.

Improved Security and Confidentiality



GSM Offers:

Encryption

ME Authentication

Subscriber Authentication (SIM)

Frequency Hopping

FLEXIBLE HANDOVER PROCESSOR

Handovers take place as the MS moves between cells, gradually losing the RF signal of one and gaining that of the other.

The MS switches from channel to channel and cell to cell as it moves to maintain call continuity. With analogue systems, handovers are frequently a problem area and the subscriber is only too well aware that a handover has occurred!

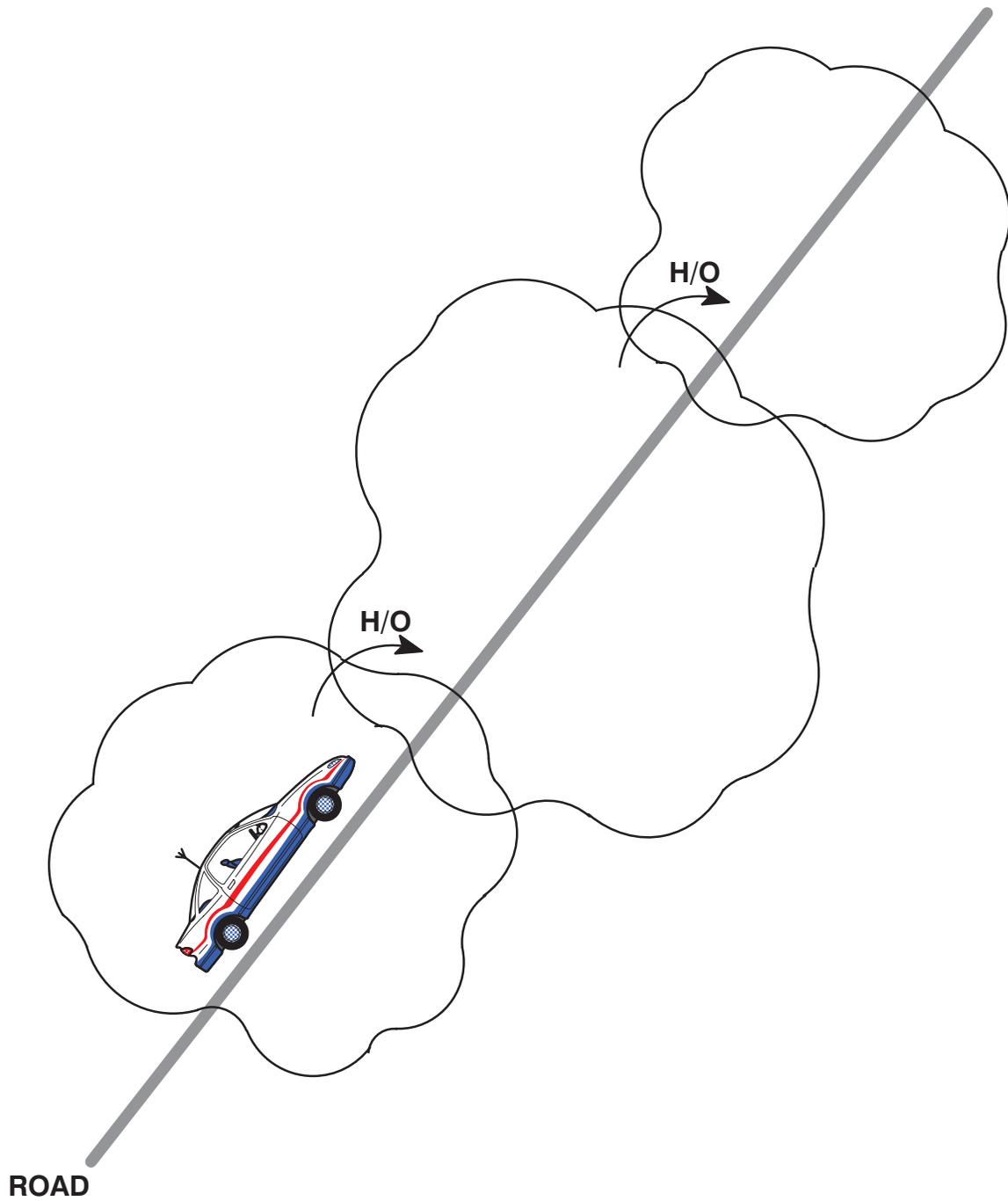
When GSM was specified a great deal of thought went into the design and implementation of handovers. Although the GSM system is more complicated than analogue in this area, the flexibility of the GSM handover processes offer significant improvements which provide a much better quality of service to the subscriber.

GSM provides handover processes for the following:

- Quality (uplink/downlink).
- Interface (uplink/downlink).
- RF level (uplink/downlink).
- MS distance.
- Power budget.

More handover algorithms have been developed for specific applications, such as microcellular, and are currently being implemented.

Flexible Handover Processes



ISDN COMPATIBILITY

Integrated Services Digital Network (ISDN) is a standard that most developed countries are committed to implement. This is a new and advanced telecommunications network designed to carry voice and user data over standard telephone lines.

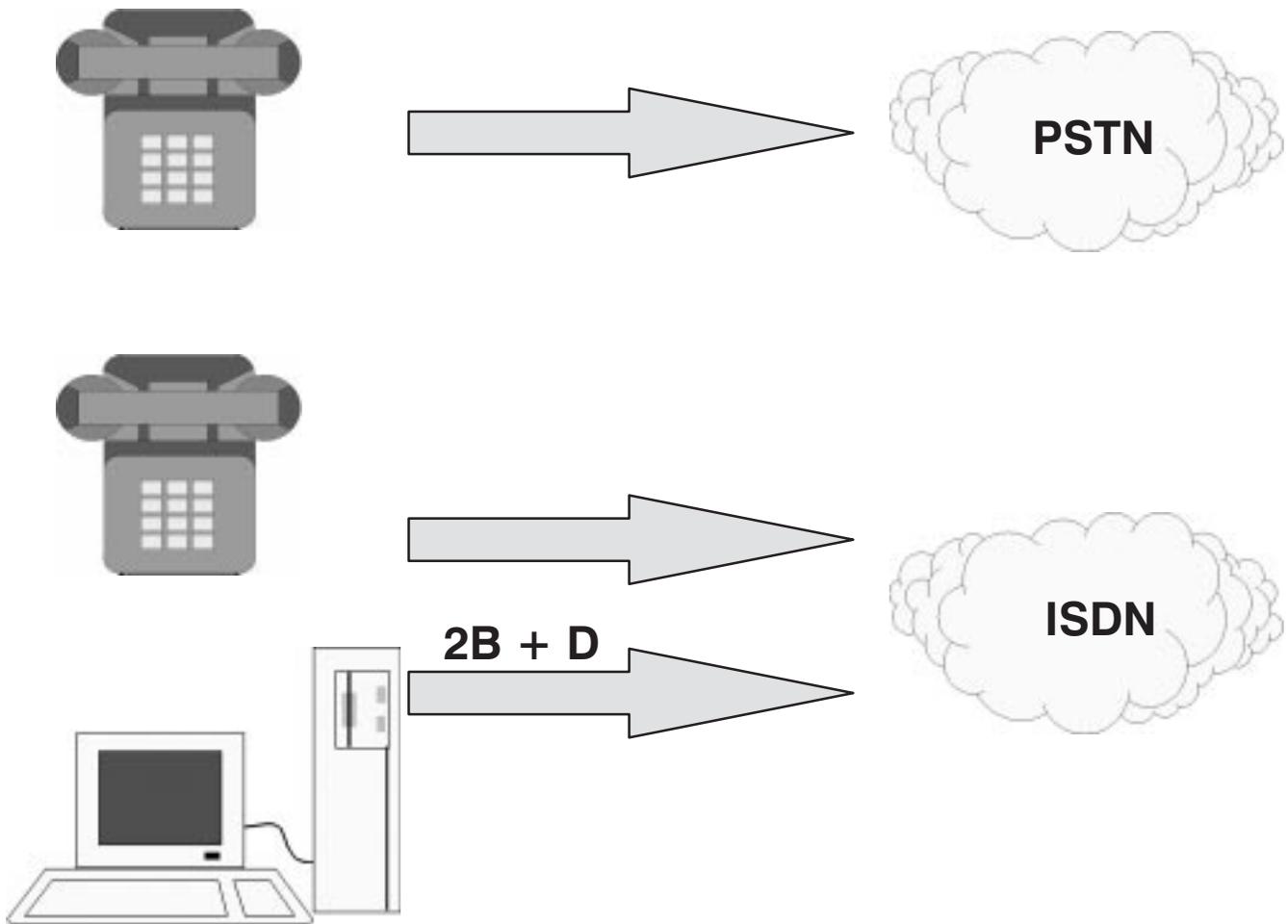
Major telephone companies in Europe, North America, Hong Kong, Australia and Japan are committed to commercial enterprises using ISDN.

The GSM network has been designed to operate with the ISDN system and provides features which are compatible with it. GSM can provide a maximum data rate of 9.6 kbit/s while ISDN provides much higher data rates than this (standard rate 64 kbit/s, primary rate 2.048 Mbit/s).

2B+D

This refers to the signals and information which may be carried on an ISDN line. There are effectively three connections, one for signalling ('D') and the other two for data or speech ('2B').

ISDN Compatibility



Note:

1. $B = 64 \text{ kbit/s}$
2. $D = 16 \text{ kbit/s}$
- $2B + D = 144 \text{ kbit/s}$

ENHANCED RANGE OF SERVICES

GSM has the potential to offer a greatly enhanced range of services compared to existing analogue cellular systems. As well as a full range of data transmission options and fax, there will be a wide range of supplementary services.

The basic call services which are already provided within analogue systems such as Call Forwarding, Voice Message Services etc, are already available in some operational systems. Whether these services and others are provided as part of the basic service or at additional cost to the subscriber will depend on the network provider.

When services were specified on GSM, the current land PSTN and ISDN system had to be taken into consideration; after all it is these systems we are most likely to be communicating with.

The services available to a subscriber will be determined by three factors:

- The level of service provided by the network provider.
- The level of service purchased by the subscriber.
- The capabilities of the subscriber's mobile equipment.

Enhanced Range of Services

- **Offered by Network Provider**
- **Purchased by Subscriber**
- **Capabilities of Mobile Equipment**

ENHANCED RANGE OF SERVICES . . .

SPEECH SERVICES

The following services listed involve the transmission of speech information and would make up the basic service offered by a network provider:

TELEPHONY

Provides for normal MS originated/terminated voice calls.

EMERGENCY CALLS (WITH/WITHOUT SIM CARD INSERTED IN MS)

The number "112" has been agreed as the international emergency call number. This should place you in contact with the emergency services (Police, Fire, Ambulance) whichever country you are in.

SHORT MESSAGE SERVICE POINT TO POINT

Provides the transmission of an acknowledged short message (128 bytes maximum) from a service centre to a MS. It is also intended that the MS should be able to send short messages to land-based equipment. This will obviously depend upon the equipment owned by the land-based user.

SHORT MESSAGE CELL BROADCAST

Provides the transmission of an unacknowledged short message (75 bytes maximum) from a service centre in the fixed network to all MSs within one cell. This may carry information from the network provider, for example traffic information or advertising.

ADVANCED MESSAGE HANDLING SERVICE

Provides message submission and delivery from the storage from a public Message Handling System (MHS) for example, electronic mail.

DUAL PERSONAL AND BUSINESS NUMBERS

Permits the allocation of dual telephone numbers to a single subscriber. This will allow calls to be made and be billed either to "business" or "personal" numbers.

Speech Services

- **Telephony**
- **Emergency Calls**
- **Short Message Services**
- **Dual Personal and Business Numbers**

ENHANCED RANGE OF SERVICES . . .

DATA SERVICES

Data can be sent over the air using some of the present systems, but this requires specially designed “add ons” to protect the data content in the harsh environment of the air interface.

Special provision is made in the GSM technical specifications for data transmission. Therefore, like ISDN, GSM is “specially designed” for data transmission. GSM can be considered as an extension of ISDN into the wireless environment.

Text files, images, messages and fax may all be sent over the GSM network. The data rates available are 2.4 kbit/s, 4.8 kbit/s and 9.6 kbit/s

Below is a list of the various forms of data service that GSM will support.

- **Videotex Access**
Provides access to computer-based information stored in databases, utilizing public transmission networks, where the requested information is generally in the form of text and/or pictures.
- **Teletex**
Provides for data transfer in a circuit or packet-switched network (ITU–TSS X.200) (that is, document transmission).
- **Alternate Speech and Facsimile Group 3**
Allows the connection of ITU–TS group 3 FAX apparatus (send and/or receive) to the MS.

Data Services

- **Raw Data:**
 - 9.6 kbits**
 - 4.8 kbit/s**
 - 2.4 kbit/s**

- **Videotex**

- **Teletex**

- **Fax**

ENHANCED RANGE OF SERVICES . . .

SUPPLEMENTARY SERVICES

A supplementary service is a modification of, or a supplement to, a basic telecommunication service. The network provider will probably charge extra for these services or use them as an incentive to join their network.

Here is a list of some of the optional supplementary subscriber services that could be offered to GSM subscribers:

Number Identification

- Receiving party requests calling number to be shown.
- Calling party requests calling number not to be shown.

Call Barring

- Bar all incoming or all outgoing calls.
- Bar specific incoming or outgoing calls.

Call Forwarding

- Forward all calls.
- Forward calls when subscriber is busy.
- Forward calls if subscriber does not answer.
- Forward calls if subscriber cannot be located.

Call Completion

- Enable incoming call to wait until subscriber completes current call.
- Enable subscriber to place incoming calls on hold.

Charging

- Display current cost of call.

Multi-party

- Three party service.
- Conference calling.

Supplementary Services

- **Number Identification**
- **Call Barring**
- **Call Forwarding**
- **Call Completion**
- **Charging**
- **Multi-party**



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INTRODUCTION TO DIGITAL CELLULAR

Section 3

GSM Network Components

The information
contained in this document
is not intended to replace that contained
in the relevant equipment manuals and is
for the purpose of training only.

THIS MANUAL WILL NOT BE UPDATED

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Name the major components of a GSM Network and know the functionality of these components.

- . Draw a diagram illustrating the interconnections between the components of the GSM network.



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Introduction to Digital Cellular

Section 3

GSM Network Components

GSM NETWORK OVERVIEW

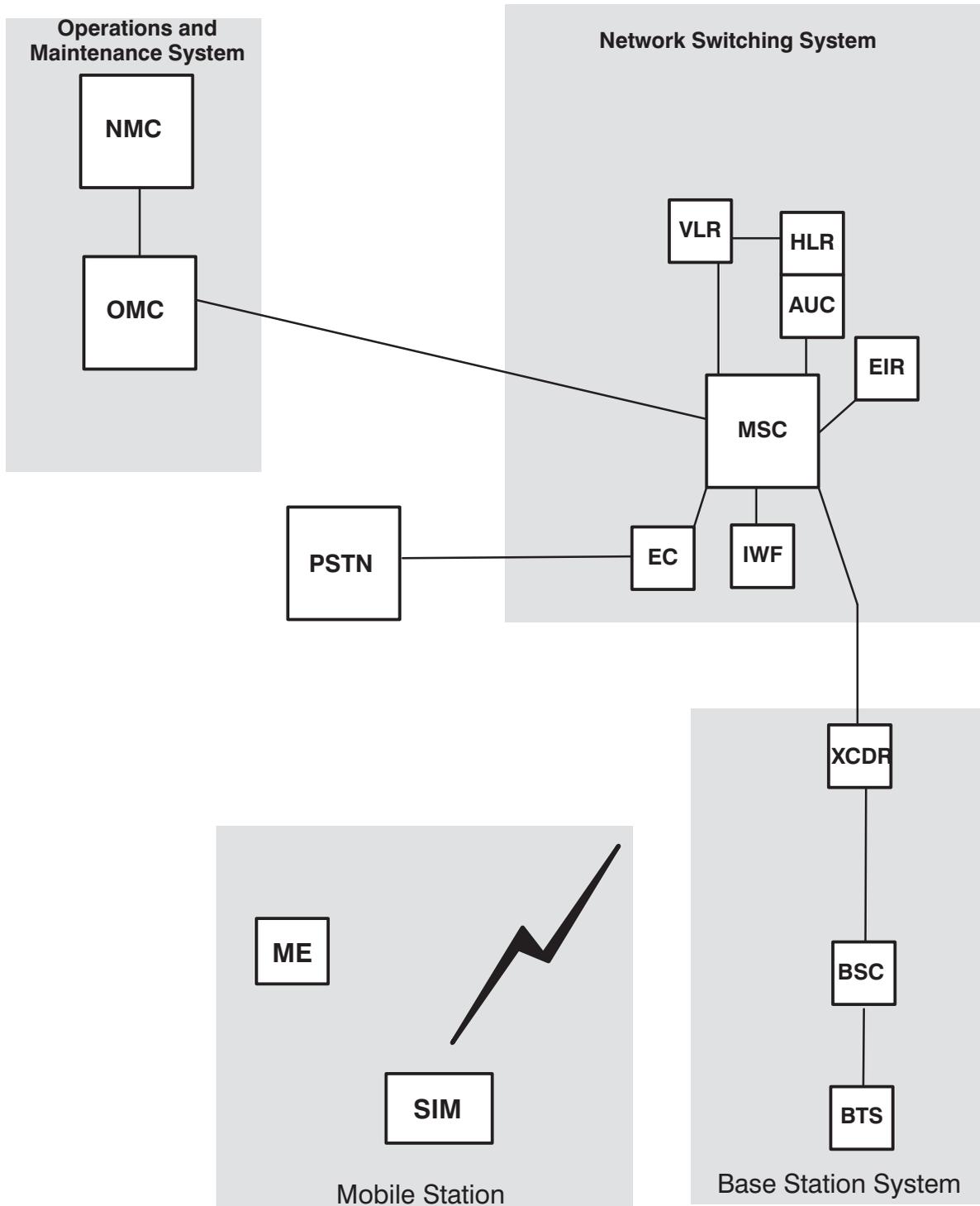
The diagram opposite shows a simplified GSM network. Each network component is illustrated only once, however, many of the components will occur several times throughout a network.

Each network component is designed to communicate over an interface specified by the GSM standards. This provides flexibility and enables a network provider to utilize system components from different manufacturers. For example Motorola Base Station System (BSS) equipment may be coupled with an Ericsson Network Switching System.

The principle component groups of a GSM network are:

- **The Mobile Station (MS)**
This consists of the mobile telephone, fax machine etc. This is the part of the network that the subscriber will see.
- **The Base Station System (BSS)**
This is the part of the network which provides the radio interconnection from the MS to the land-based switching equipment.
- **The Network Switching System**
This consists of the Mobile services Switching Centre (MSC) and its associated system-control databases and processors together with the required interfaces. This is the part which provides for interconnection between the GSM network and the Public Switched Telephone Network (PSTN).
- **The Operations and Maintenance System**
This enables the network provider to configure and maintain the network from a central location.

GSM Network Components



 **Interface/Connection**

MOBILE STATION – MS

The MS consists of two parts, the Mobile Equipment (ME) and an electronic 'smart card' called a Subscriber Identity module (SIM).

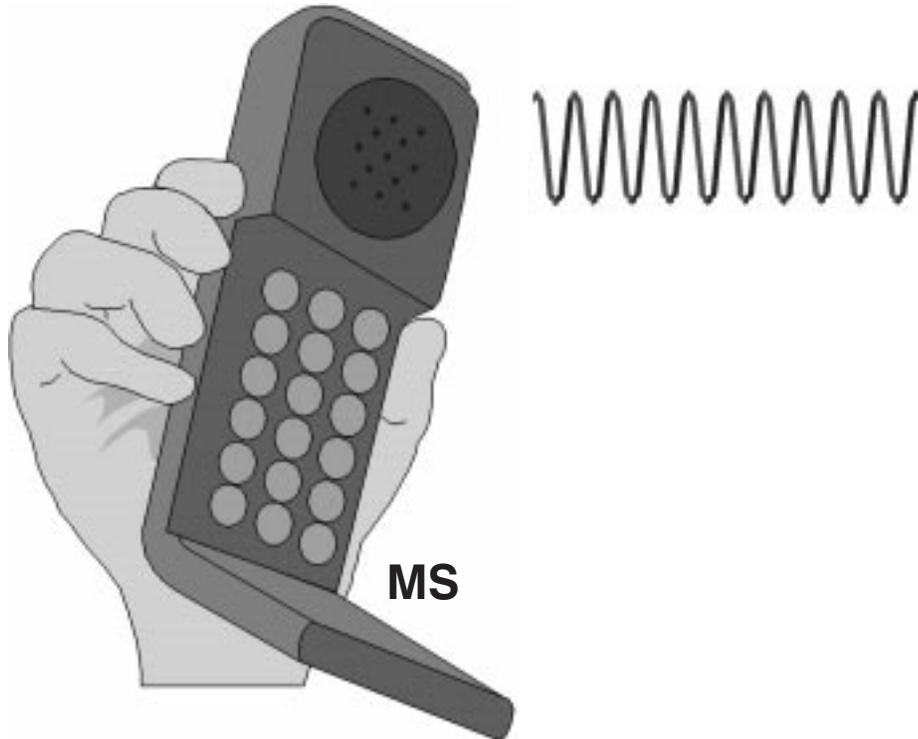
The ME is the hardware used by the subscriber to access the network. The hardware has an identity number associated with it, which is unique for that particular device and permanently stored in it. This enables stolen Mobile Equipment to be detected. This identity number is called the International Mobile Equipment Identity (IMEI).

The SIM is a card which plugs into the Mobile Equipment. This card identifies the mobile subscriber and also provides other information regarding the service that subscriber should receive. The subscriber is identified by an identity number called the International Mobile Subscriber Identity (IMSI).

Mobile Equipment may be purchased from any store but the SIM must be obtained from the GSM network provider. Without the SIM inserted, the ME will only be able to make emergency calls.

By making a distinction between the subscriber identity and the ME identity, GSM can route calls and perform billing based on the identity of the 'subscriber' rather than the equipment or its location.

Mobile Station



Mobile Station (MS)

- Mobile Equipment (ME)
- Subscriber Identity Module (SIM)

MOBILE EQUIPMENT – ME

The ME is the only part of the GSM network which the subscriber will really see. There are three main types of ME, these are listed below:

- **Vehicle Mounted**

These devices are mounted in a vehicle and the antenna is physically mounted on the outside of the vehicle.

- **Portable Mobile Unit**

This equipment can be handheld when in operation, but the antenna is not connected to the handset of the unit.

- **Handportable Unit**

This equipment comprises of a small telephone handset not much bigger than a calculator. The antenna is be connected to the handset.

The ME is capable of operating at a certain maximum power output dependent on its type and use.

These mobile types have distinct features which must be known by the network, for example their maximum transmission power and the services they support. The ME is therefore identified by means of a classmark. The classmark is sent by the ME in its initial message.

The following pieces of information are held in the classmark:

- **Revision Level –**

Identifies the phase of the GSM specifications that the mobile complies with.

- **RF Power Capability –**

The maximum power the MS is able to transmit, used for power control and handover preparation. This information is held in the mobile power class number.

- **Ciphering Algorithm –**

Indicates which ciphering algorithm is implemented in the MS. There is only one algorithm (**A5**) in GSM phase 1, but GSM phase 2 specifies different algorithms (**A5/0–A5/7**).

- **Frequency Capability –**

Indicates the frequency bands the MS can receive and transmit on. Currently all GSM MSs use one frequency band, in the future this band will be extended but not all MSs will be capable of using it.

- **Short Message Capability –**

Indicates whether the MS is able to receive short messages.

Mobile Equipment Capabilities

- **RF Power Capability**

Power Class	Power Output
1	20 Watts (deleted)
1	8 Watts
3	5 Watts
4	2 Watts
5	0.8 Watts

- **Supports of Phase 1 or Phase 2 specification**
- **Encryption Capability**
- **Frequency Capability**
- **Short Message Services Capability**

SUBSCRIBER IDENTITY MODULE – SIM

The SIM as mentioned previously is a “smart card” which plugs into the ME and contains information about the MS subscriber hence the name Subscriber Identity Module.

The SIM contains several pieces of information:

- **International Mobile Subscriber Identity (IMSI)**
This number identifies the MS subscriber. It is only transmitted over the air during initialization.
- **Temporary Mobile Subscriber Identity (TMSI)**
This number identifies the subscriber, it is periodically changed by the system management to protect the subscriber from being identified by someone attempting to monitor the radio interface.
- **Location Area Identity (LAI)**
Identifies the current location of the subscriber.
- **Subscriber Authentication Key (Ki)**
This is used to authenticate the SIM card.
- **Mobile Station International Services Digital Network (MSISDN)**
This is the telephone number of the mobile subscriber. It is comprised of a country code, a national code and a subscriber number.

Most of the data contained within the SIM is protected against reading (Ki) or alterations (IMSI). Some of the parameters (LAI) will be continuously updated to reflect the current location of the subscriber.

The SIM card, and the high degree of inbuilt system security, provide protection of the subscriber’s information and protection of networks against fraudulent access. SIM cards are designed to be difficult to duplicate. The SIM can be protected by use of Personal Identity Number (PIN) password, similar to bank/credit charge cards, to prevent unauthorized use of the card.

The SIM is capable of storing additional information such as accumulated call charges. This information will be accessible to the customer via handset/keyboard key entry.

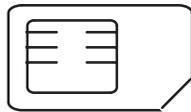
The SIM also executes the Authentication Algorithm.

Subscriber Identity Module (SIM)



↑
SIM CARD
(actual size)

FULL SIZE SIM CARD



MINI SIM CARD

BASE STATION SYSTEM – BSS

The GSM Base Station System is the equipment located at a cell site. It comprises a combination of digital and RF equipment. The BSS provides the link between the Mobile Station (MS) and the Mobile services Switching Centre (MSC).

The BSS communicates with the MS over the digital air interface and with the MSC via 2 Mbit/s links.

The BSS consists of three major hardware components:

- **The Base Transceiver Station – BTS**

The BTS contains the RF components that provide the air interface for a particular cell. This is the part of the GSM network which communicates with the MS. The antenna is included as part of the BTS.

- **The Base Station Controller – BSC**

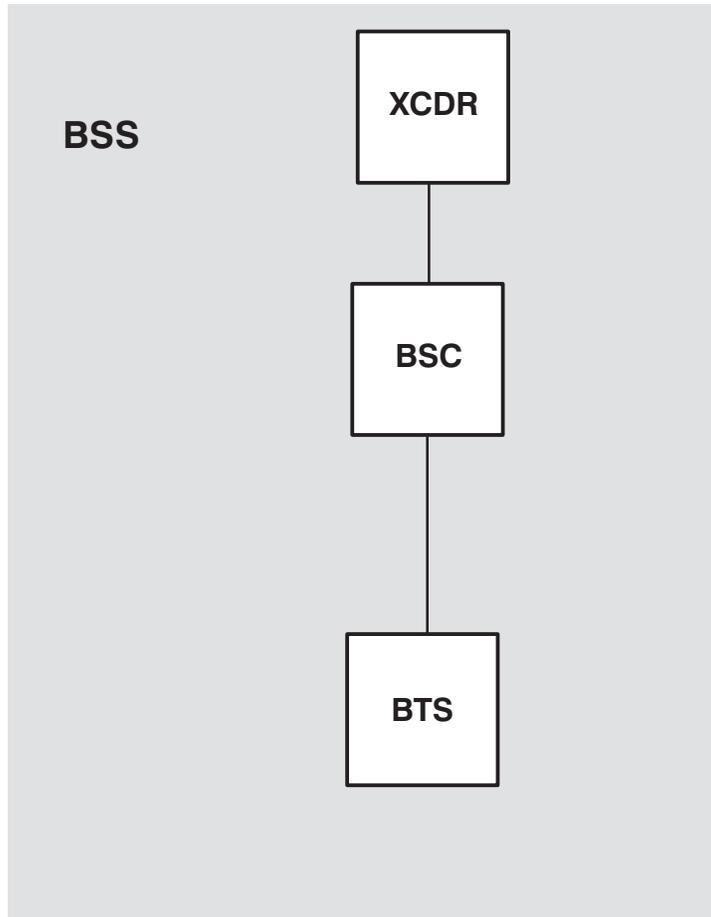
The BSC as its name implies provides the control for the BSS. The BSC communicates directly with the MSC. The BSC may control single or multiple BTSs.

- **The Transcoder – XCDR**

The Transcoder **is used to compact the signals** from the MS so that they are more efficiently sent over the terrestrial interfaces. Although the Transcoder is considered to be a part of the BSS, it is very often located closer to the MSC.

The transcoder is used to reduce the rate at which the traffic (voice/data) is transmitted over the air interface. Although the transcoder is part of the BSS, it is often found physically closer to the NSS to allow more efficient use of the terrestrial links.

Base Station System – BSS



BASE STATION CONTROLLER – BSC

As previously mentioned, the BSC provides the control for the BSS. The functions of the BSC are shown in the table opposite.

Any operational information required by the BTS will be received via the BSC. Likewise any information required about the BTS (by the OMC for example) will be obtained by the BSC.

The BSC incorporates a digital switching matrix, which it uses to connect the radio channels on the air interface with the terrestrial circuits from the MSC.

The BSC switching matrix also allows the BSC to perform “handovers” between radio channels on BTSs, under its control, without involving the MSC.

BASE TRANSCEIVER STATION – BTS

The BTS provides the air interface connection with the MS. It also has a limited amount of control functionality which reduces the amount of traffic passing between the BTS and BSC. The functions of the BTS are shown opposite. Each BTS will support 1 or more cells.

BSS Functionality	Control
Terrestrial Channel Management Channel Allocation	BSC
Radio Channel Management Channel Configuration Management Handover Control	BSC BSC
Frequency Hopping Traffic Channel Management Control Channel Management Encryption Paging Power Control	BSC/BTS BSC/BTS BSC/BTS BSC/BTS BSC/BTS BSC/BTS
Transcoding/Rate Adaption Channel Coding/Decoding Timing Advance Idle Channel Observation Measurement Reporting	BTS BTS BTS BTS BTS

Where the BSC and BTS are both shown to control a function, the control is divided between the two, or may be located wholly at one.

Base Station System

BSC

Controls one or more BTSs.

Conveys information to/from the BTSs.

Connects Terrestrial Circuits and channels on the Air Interface.

Controls handovers performed by BTSs under its control.

BTS

Contains RF Hardware.

Limited control functionality.

Supports 1 or more cells.

BSS CONFIGURATIONS

As we have mentioned, a BSC may control several BTSs, the maximum number of BTSs which may be controlled by one BSC is not specified by GSM.

Individual manufacturer's specifications may vary greatly.

The BTSs and BSC may either be located at the same cell site "Co-located", or located at different sites "Remote". In reality most BTSs will be remote, as there are many more BTSs than BSCs in a network.

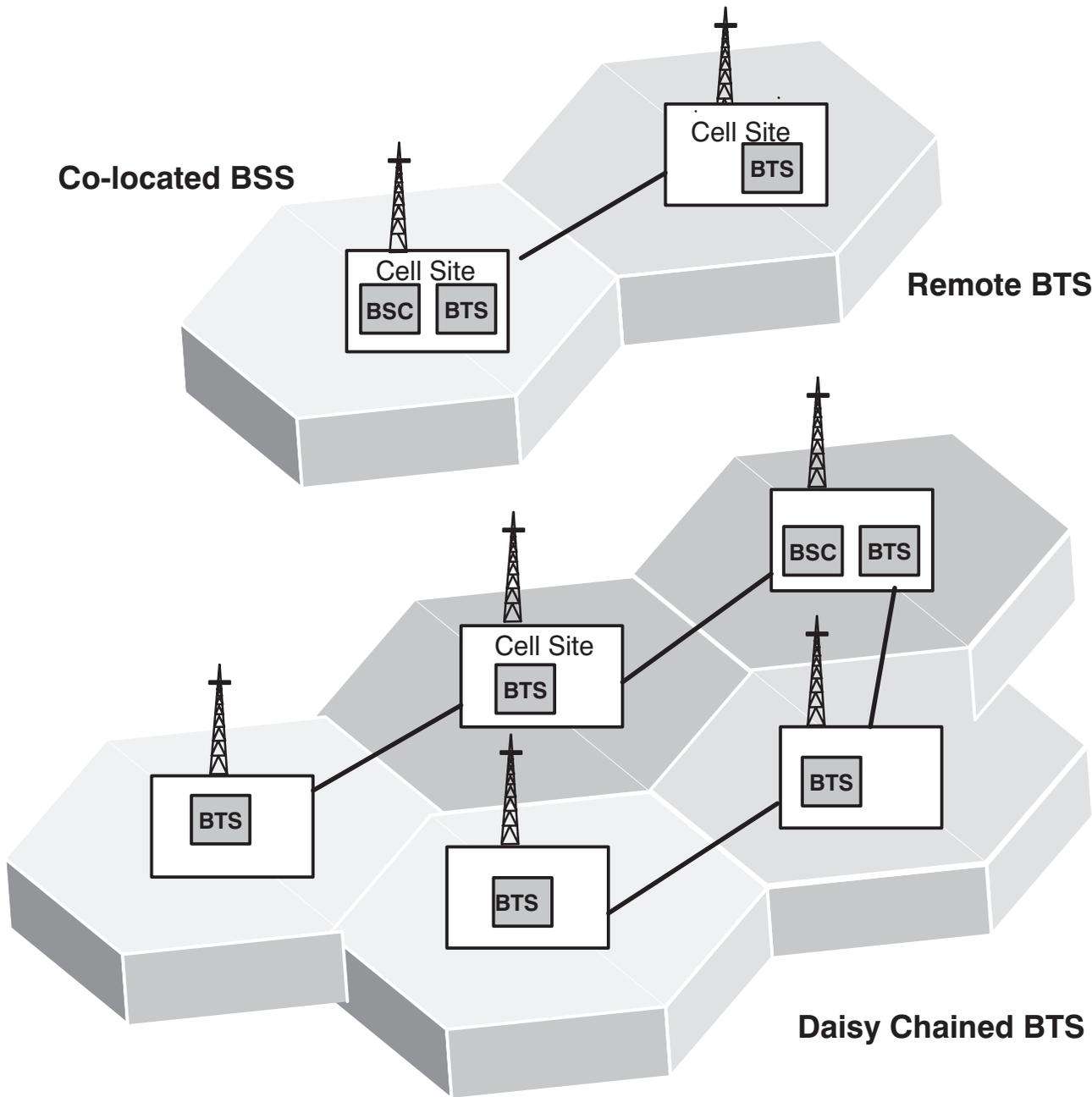
Another BSS configuration is the Daisy Chain. A BTS need not communicate directly with the BSC which controls it, it can be connected to the BSC via a chain of BTSs.

Daisy chaining reduces the amount of cabling required to set up a network as a BTS can be connected to its nearest BTS rather than all the way to the BSC.

Problems may arise when chaining BTSs, due to the transmission delay through the chain. The length of the chain must, therefore, be kept sufficiently short to prevent the round trip speech delay becoming too long.

Other topologies are also permitted, including stars and loops. Loops are used to introduce redundancy into the network, for example if a BTS connection was lost, the BTS may still be able to communicate with the BSC if a second connection is available.

BSS Configurations



TRANSCODER – XCDR

The Transcoder (XCDR) is required to convert the speech or data output from the MSC (64 kbit/s PCM), into the form specified by GSM specifications for transmission over the air interface, that is, between the BSS and MS (64 kbit/s to 16 kbit/s and vice versa)

The 64 kbit/s Pulse Code Modulation (PCM) circuits from the MSC, if transmitted on the air interface without modification, would occupy an excessive amount of radio bandwidth. This would use the available radio spectrum inefficiently. The required bandwidth is therefore reduced by processing the 64 kbit/s circuits so that the amount of information required to transmit digitized voice falls to 13 kbit/s.

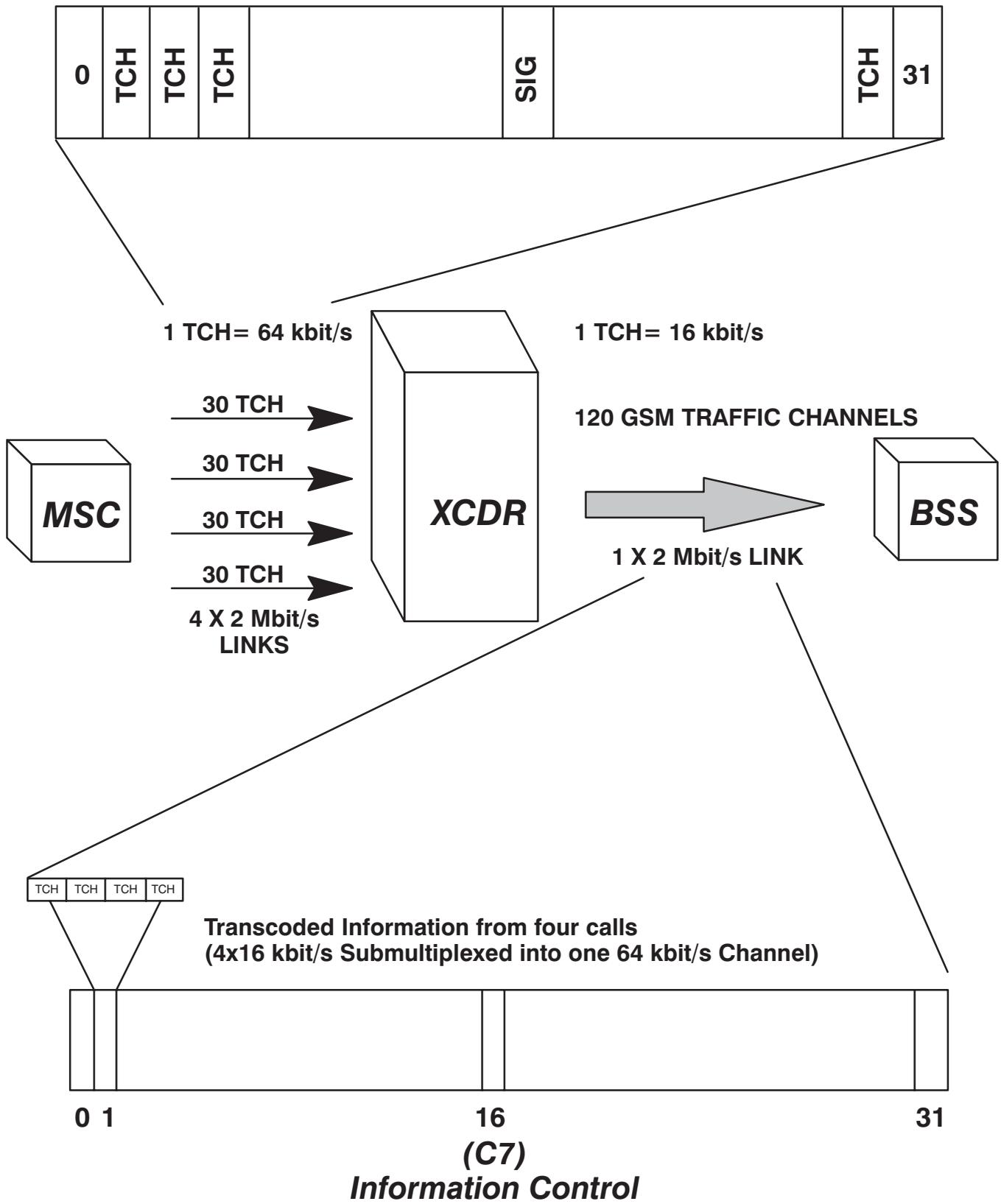
The transcoding function may be located at the MSC, BSC, or BTS.

A Transcoder Rate Adaption Unit (TRAU) of 3 kbit/s is added to the 13 kbit/s channel leaving the transcoding function to form a gross traffic channel of 16 kbit/s which is transmitted over the terrestrial interfaces to the BTS. At the BTS the TRAU is removed and the 13 kbit/s is processed to form a gross rate of 22.8 kbit/s for transmission over the air interface.

For data transmissions the data is not transcoded but data rate adapted from 9.6 kbit/s (4.8 kbit/s or 2.4 kbit/s may also be used) up to a gross rate of 16 kbit/s for transmission over the terrestrial interfaces, again this 16 kbit/s contains a 3 kbit/s TRAU.

As can be seen from the diagram opposite, although the reason for transcoding was to reduce the data rate over the air interface, the number of terrestrial links is also reduced approximately on a 4:1 ratio.

Transcoder



NETWORK SWITCHING SYSTEM

The Network Switching System includes the main switching functions of the GSM network. It also contains the databases required for subscriber data and mobility management. Its main function is to manage communications between the GSM network and other telecommunications networks.

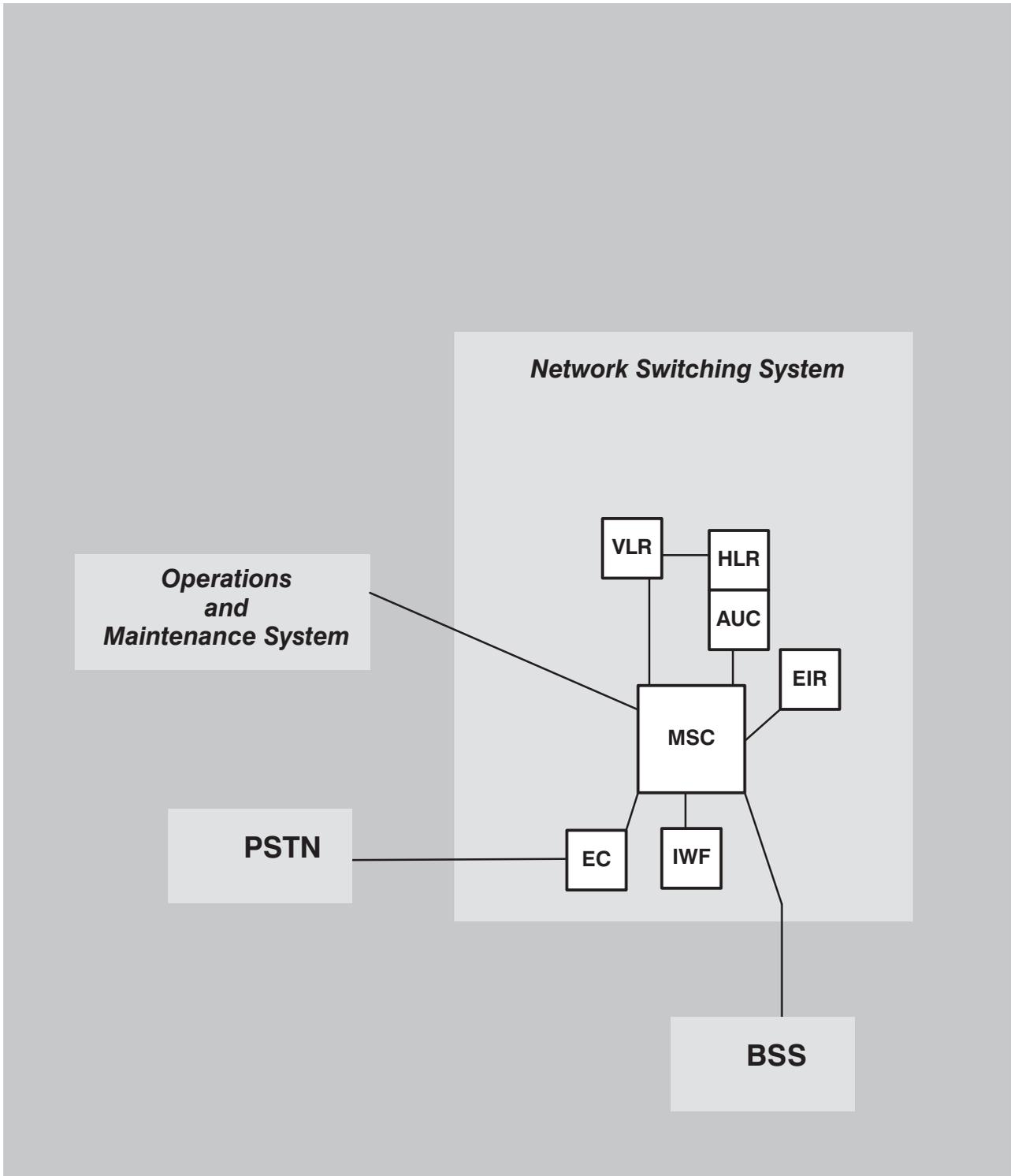
The components of the Network Switching System are listed below:

- Mobile Services Switching Centre – MSC
- Home Location Register – HLR
- Visitor Location Register – VLR
- Equipment Identity Register – EIR
- Authentication Centre – AUC
- InterWorking Function – IWF
- Echo Canceller – EC

In addition to the more traditional elements of a cellular telephone system, GSM has Location Register network entities. These entities are the Home Location Register (HLR), Visitor Location Register (VLR), and the Equipment Identity Register (EIR). The location registers are database-oriented processing nodes which address the problems of managing subscriber data and keeping track of a MSs location as it roams around the network.

Functionally, the Interworking Function and the Echo Cancellers may be considered as parts of the MSC, since their activities are inextricably linked with those of the switch as it connects speech and data calls to and from the MSs.

The Network Switching System



MOBILE SERVICES SWITCHING CENTRE – MSC

The MSC is included in the GSM system for call-switching. Its overall purpose is the same as that of any telephone exchange.

However, because of the additional complications involved in the control and security aspects of the GSM cellular system and the wide range of subscriber facilities that it offers, the MSC has to be capable of fulfilling many additional functions.

The MSC will carry out several different functions depending upon its position in the network. When the MSC provides the interface between the PSTN and the BSSs in the GSM network it will be known as a Gateway MSC. In this position it will provide the switching required for all MS originated or terminated traffic.

Each MSC provides service to MSs located within a defined geographic coverage area, the network typically contains more than one MSC. One MSC is capable of supporting a regional capital with approximately one million inhabitants. An MSC of this size will be contained in about half a dozen racks.

The functions carried out by the MSC are listed below:

- **Call Processing**
Includes control of data/voice call setup, inter-BSS and inter-MSC handovers and control of mobility management (subscriber validation and location).
- **Operations and Maintenance Support**
Includes database management, traffic metering and measurement, and a man-machine interface.
- **Internetwork Interworking**
Manages the interface between the GSM network and the PSTN.
- **Billing**
Collects call billing data.

Mobile Services Switching Centre

- **Call Processing**
- **Operations & Maintenance**
- **Internetwork Interworking**
- **Billing**

HOME LOCATION REGISTER – HLR

The HLR is the reference database for subscriber parameters.

Various identification numbers and addresses are stored, as well as authentication parameters. This information is entered into the database by the network provider when a new subscriber is added to the system.

The parameters stored in the HLR are listed opposite:

The HLR database contains the master database of all the subscribers to a GSM PLMN. The data it contains is remotely accessed by all the MSCs and the VLRs in the network and, although the network may contain more than one HLR, there is only one database record per subscriber – each HLR is therefore handling a portion of the total subscriber database. The subscriber data may be accessed by either the IMSI or the MSISDN number. The data can also be accessed by an MSC or a VLR in a different PLMN, to allow inter-system and inter-country roaming.

Home Location Register (HLR)

- **Subscriber ID (IMSI and MSISDN)**
- **Current subscriber VLR (current location)**
- **Supplementary services subscribed to**
- **Supplementary service information
(e.g. current forwarding number)**
- **Subscriber status (registered/deregistered)**
- **Authentication key and AUC functionality**
- **Mobile Subscriber Roaming Number
(MSRN)**

VISITOR LOCATION REGISTER – VLR

The VLR contains a copy of most of the data stored at the HLR. It is, however, temporary data which exists for only as long as the subscriber is “active” in the particular area covered by the VLR. The VLR database will therefore contain some duplicate data as well as more precise data relevant to the subscriber remaining within the VLR coverage.

The VLR provides a local database for the subscribers wherever they are physically located within a PLMN, this may or may not be the “home” system. This function eliminates the need for excessive and time-consuming references to the “home” HLR database.

The additional data stored in the VLR is listed below:

- Mobile status (busy/free/no answer etc.).
- Location Area Identity (LAI).
- Temporary Mobile Subscriber Identity.
- Mobile Station Roaming Number.

LOCATION AREA IDENTITY

Cells within the Public Land Mobile Network (PLMN) are grouped together into geographical areas. Each area is assigned a Location Area Identity (LAI), a location area may typically contain 30 cells. Each VLR controls several LAIs and as a subscriber moves from one LAI to another, the LAI is updated in the VLR. As the subscriber moves from one VLR to another, the VLR address is updated at the HLR.

TEMPORARY MOBILE SUBSCRIBER IDENTITY

The VLR controls the allocation of new Temporary Mobile Subscriber Identity (TMSI) numbers and notifies them to the HLR. The TMSI will be updated frequently, this makes it very difficult for the call to be traced and therefore provides a high degree of security for the subscriber. The TMSI may be updated in any of the following situations:

- Call setup.
- On entry to a new LAI.
- On entry to a new VLR.

MOBILE SUBSCRIBER ROAMING NUMBER

As a subscriber may wish to operate outside its “home” system at some time, the VLR can also allocate a Mobile Station Roaming Number (MSRN). This number is assigned from a list of numbers held at the VLR (MSC). The MSRN is then used to route the call to the MSC which controls the base station in the MSs current location.

The database in the VLR can be accessed by the IMSI, the TMSI or the MSRN. Typically there will be one VLR per MSC.

Visitor Location Register

- **Mobile Status**
- **Location Area Identity (LAI)**
- **Temporary Mobile Subscriber Identity (TMSI)**
- **Mobile Station Roaming Number (MSRN)**

EQUIPMENT IDENTITY REGISTER – EIR

The EIR contains a centralized database for validating the International Mobile Equipment Identity (IMEI).

This database is concerned solely with MS equipment and not with the subscriber who is using it to make or receive a call.

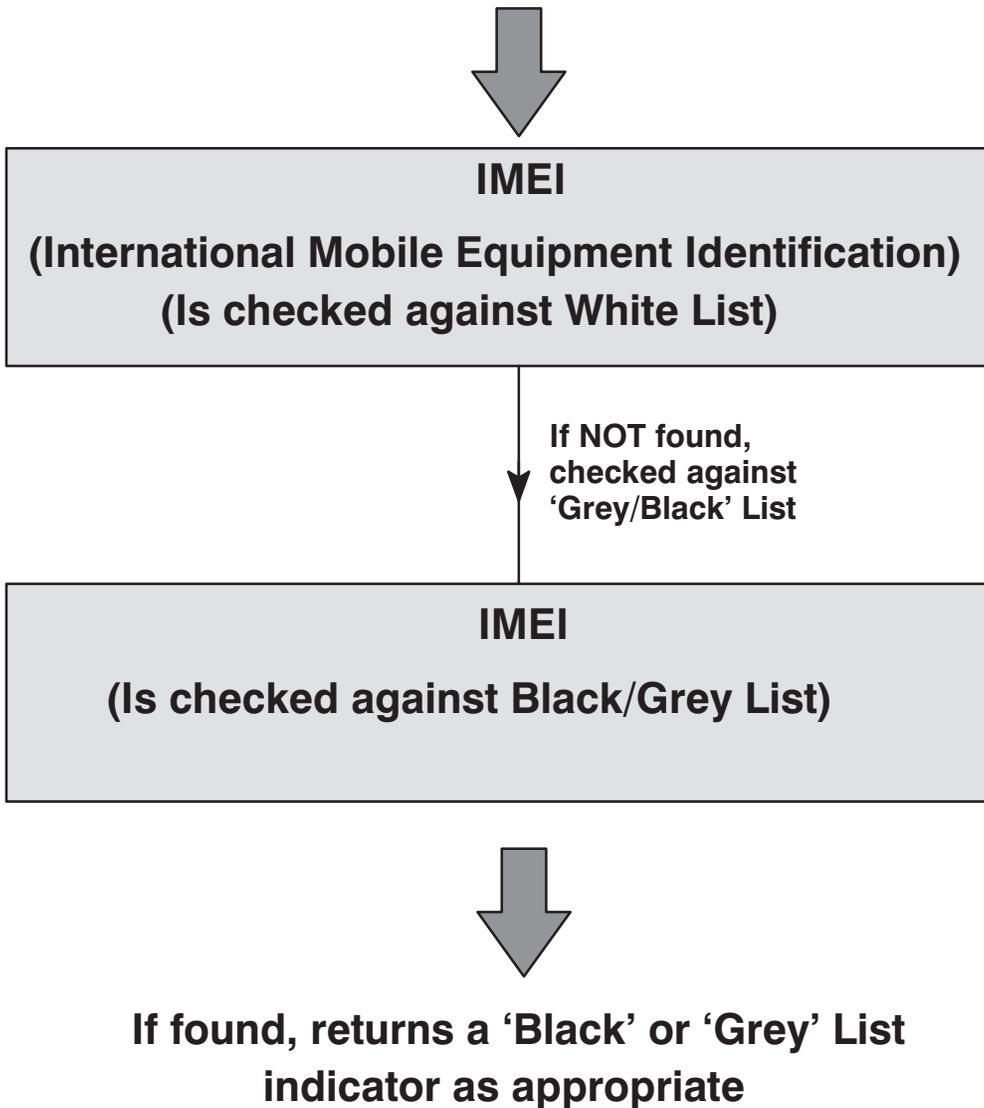
The EIR database consists of lists of IMEIs (or ranges of IMEIs) organized as follows:

- **White List**
Contains those IMEIs which are known to have been assigned to valid MS equipment.
- **Black List**
Contains IMEIs of MS which have been reported stolen or which are to be denied service for some other reason.
- **Grey List**
Contains IMEIs of MS which have problems (for example, faulty software). These are not, however, sufficiently significant to warrant a “black listing”.

The EIR database is remotely accessed by the MSCs in the network and can also be accessed by an MSC in a different PLMN.

As in the case of the HLR, a network may well contain more than one EIR with each EIR controlling certain blocks of IMEI numbers. The MSC contains a translation facility, which when given an IMEI, returns the address of the EIR controlling the appropriate section of the equipment database.

Call Processing Functions – EIR



AUTHENTICATION CENTRE – AUC

The AUC is a processor system, it performs the “authentication” function.

It will normally be co-located with the Home Location Register (HLR) as it will be required to continuously access and update, as necessary, the system subscriber records. The AUC/HLR centre can be co-located with the MSC or located remote from the MSC.

The authentication process will usually take place each time the subscriber “initializes” on the system.

AUTHENTICATION PROCESS

To discuss the authentication process we will assume that the VLR has all the information required to perform that authentication process (Kc, SRES and RAND). If this information is unavailable, then the VLR would request it from the HLR/AUC.

1. Triples (Kc, SRES and RAND) are stored at the VLR, each triple is allocated a Cipher Key Sequence Number (CKSN).
2. The VLR sends RAND and CKSN of a triple, via the MSC and BSS, to the MS (unencrypted).
3. The MS, using the A3 and A8 algorithms and the parameter Ki stored on the MS SIM card, together with the received RAND from the VLR, calculates the values of SRES and Kc.
4. The MS sends SRES and CKSN unencrypted to the VLR
5. Within the VLR the value of SRES is compared with the SRES of the triple for the specified CKSN. If the two values match, then the authentication is successful.
6. Kc from the assigned triple is now passed to the BSS.
7. The mobile calculates Kc from the RAND and A8 and Ki on the SIM.
8. Using Kc, A5 and the GSM hyperframe number, encryption between the MS and the BSS can now occur over the air interface.

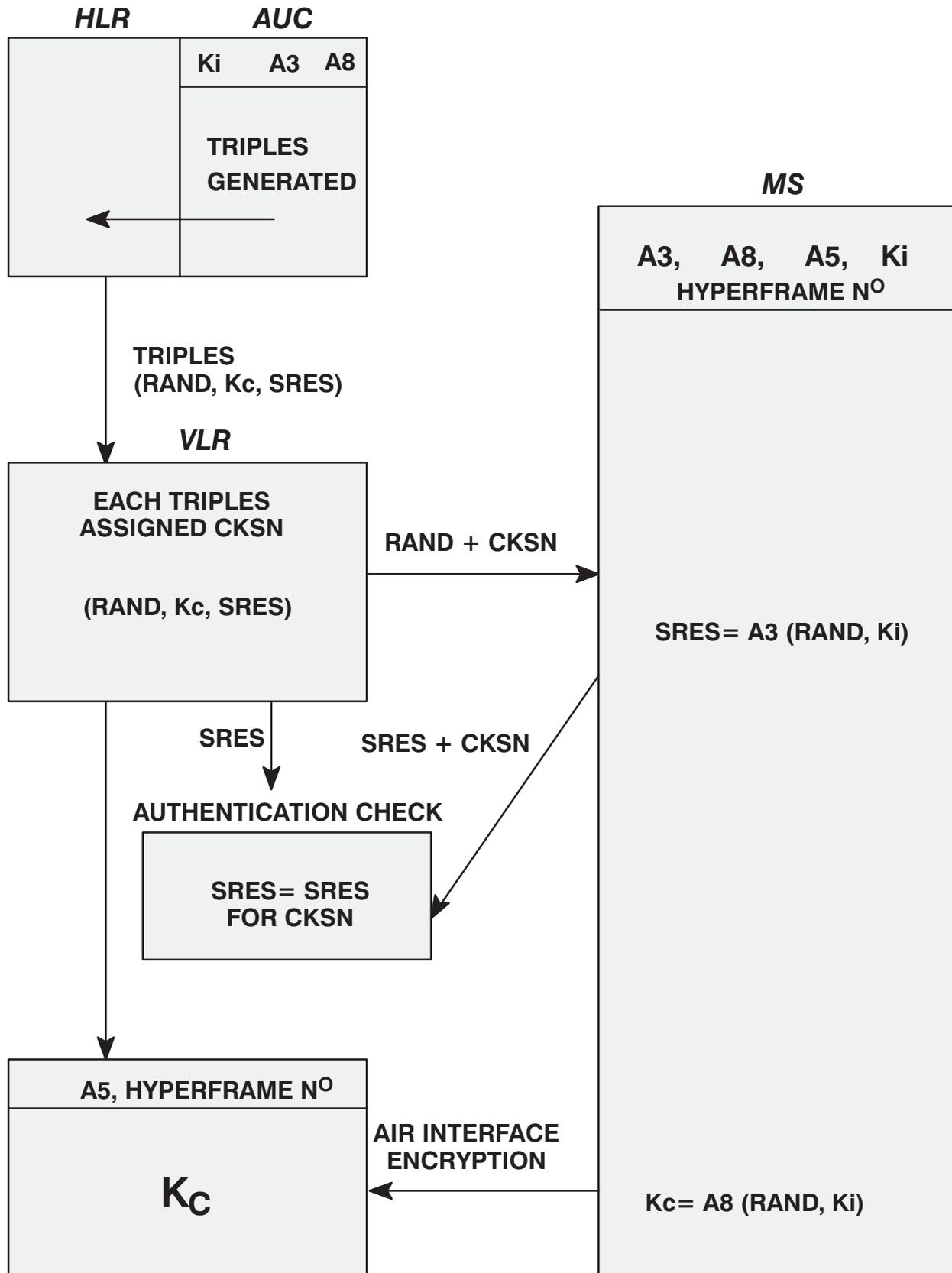
Note: The triples are generated at the AUC by:

- RAND = Randomly generated number.
SRES = Derived from A3 (RAND, Ki).
Kc = Derived from A8 (RAND, Ki).
A3 = From 1 of 16 possible algorithms defined on allocation of IMSI and creation of SIM card.
A8 = From 1 of 16 possible algorithms defined on allocation of IMSI and creation of SIM card.
Ki = Authentication key, assigned at random together with the versions of A3 and A8.

The first time a subscriber attempts to make a call, the full authentication process takes place.

However, for subsequent calls attempted within a given system control time period, or within a single system provider’s network, authentication may not be necessary, as the data generated during the first authentication will still be available.

Authentication Process



INTERWORKING FUNCTION – IWF

The IWF provides the function to enable the GSM system to interface with the various forms of public and private data networks currently available.

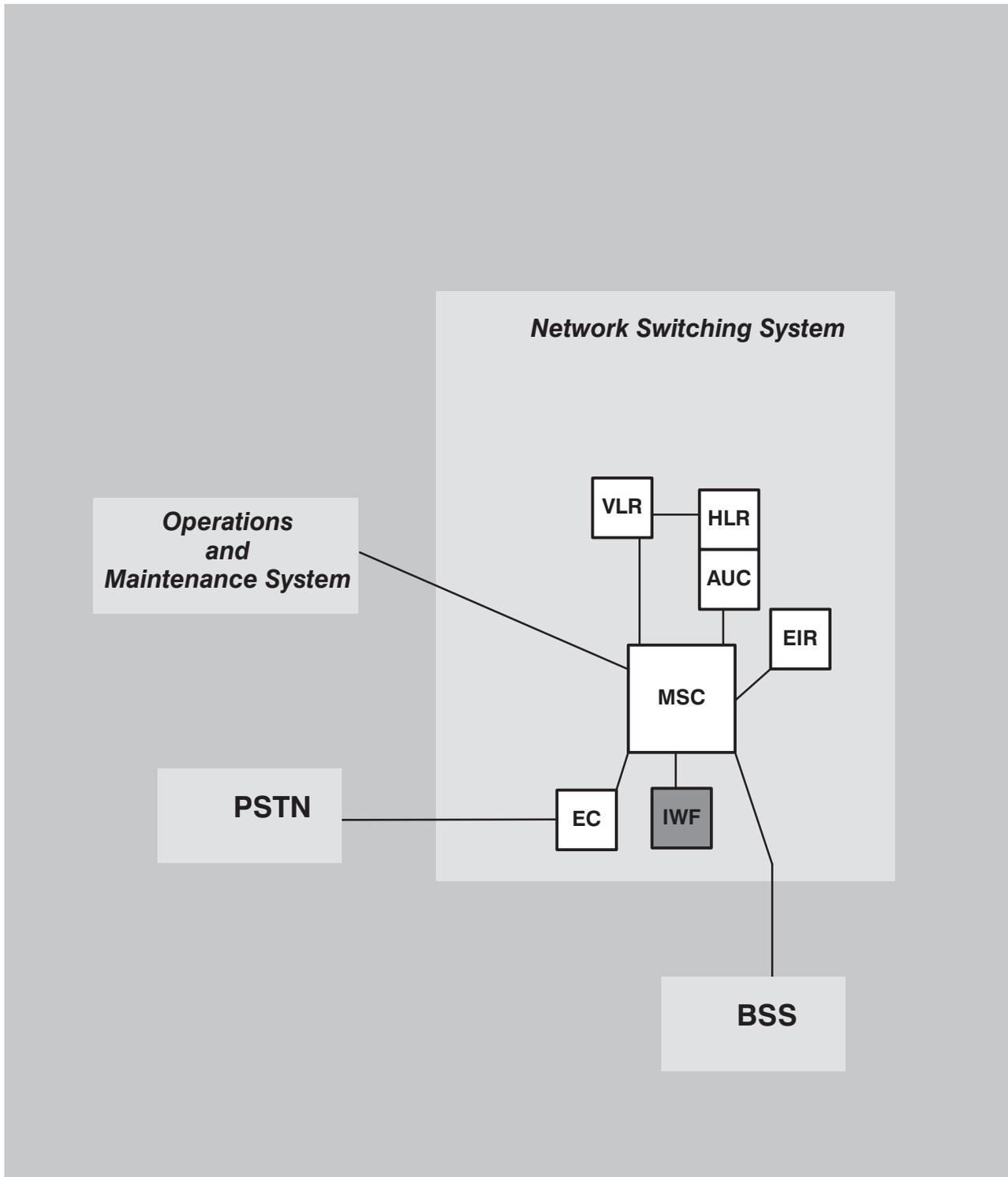
The basic features of the IWF are listed below.

- Data rate adaption.
- Protocol conversion.

Some systems require more IWF capability than others, this depends upon the network to which it is being connected.

The IWF also incorporates a “modem bank”, which may be used when, for example, the GSM **Data Terminal Equipment (DTE)** exchanges data with a land DTE connected via an analogue modem.

Interworking Function



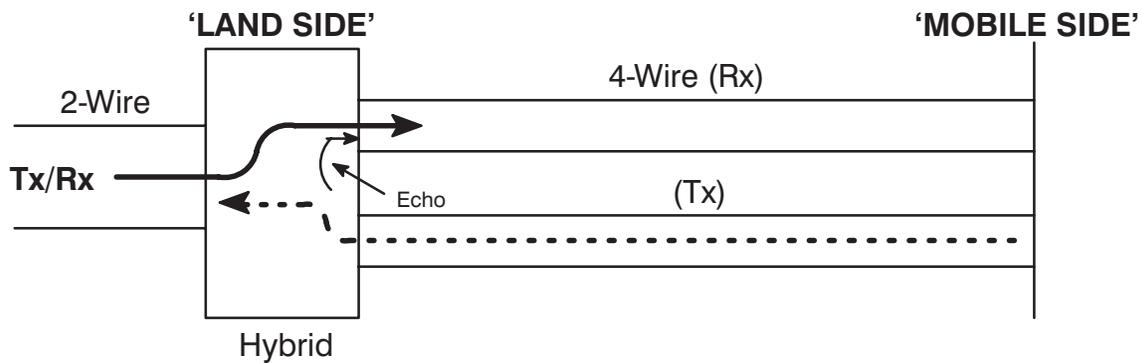
ECHO CANCELLER – EC

An Echo Canceller is used on the PSTN side of the MSC for all voice circuits. Echo control is required at the switch because the inherent GSM system delay can cause an unacceptable echo condition, even on short distance PSTN circuit connections.

The total round trip delay introduced by the GSM system (the cumulative delay caused by call processing, speech encoding and decoding etc) is approximately 180 mS. This would not be apparent to the MS subscriber, but for the inclusion of a 2-wire to 4-wire hybrid transformer in the circuit. This is required at the land party's local switch because the standard telephone connection is 2-wire. The transformer causes the echo. This does not affect the land subscriber.

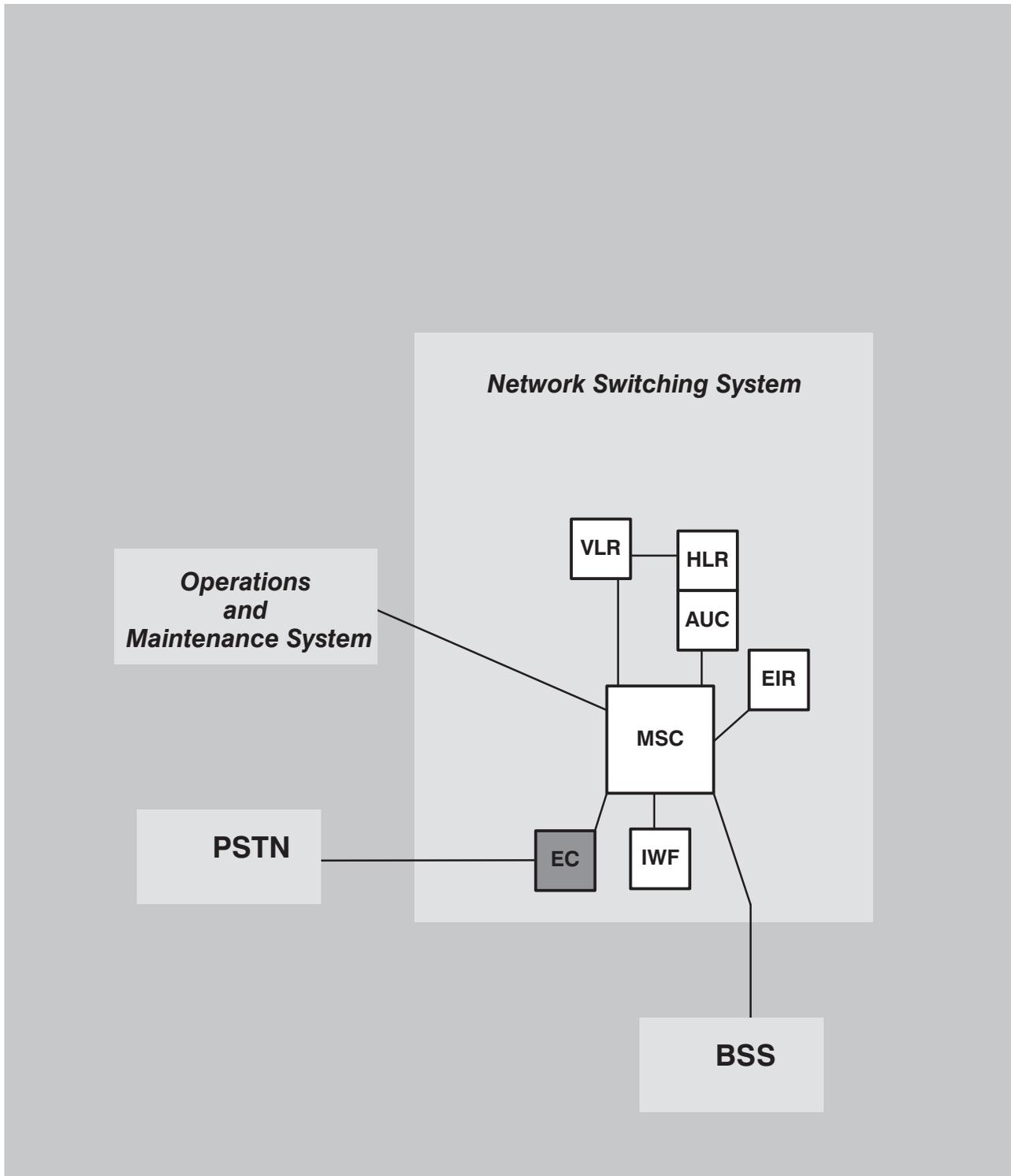
During a normal PSTN land to land call, no echo is apparent because the delay is too short and the user is unable to distinguish between the echo and the normal telephone "side tone". However, without the EC and with the GSM round trip delay added, the effect would be very irritating to the MS subscriber, disrupting speech and concentration.

The standard EC will provide cancellation of up to 68 milliseconds on the "tail circuit" (the tail circuit is the connection between the output of the EC and the land telephone).



Generation of Echoes at 2-Wire to 4-Wire interface

Echo Celler



OPERATIONS AND MAINTENANCE SYSTEM

The operations and maintenance system provides the capability to manage the GSM network remotely.

This area of the GSM network is not currently tightly specified by the GSM specifications, it is left to the network provider to decide what capabilities they wish it to have. The Operations and Maintenance System comprises of two parts:

NETWORK MANAGEMENT CENTRE – NMC

The Network Management Centre (NMC) has a view of the entire PLMN and is responsible for the management of the network as a whole. The NMC resides at the top of the hierarchy and provides global network management.

OPERATIONS AND MAINTENANCE CENTRE – OMC

The Operations and Maintenance Centre (OMC) is a centralized facility that supports the day to day management of a cellular network as well as providing a database for long term network engineering and planning tools. An OMC manages a certain area of the PLMN thus giving regionalized network management.

Operations & Maintenance System

OMC (REGIONAL)	NMC (GLOBAL)
<p><u>Multiple</u> OMCs per network</p> <p><u>Regionalized</u> network management</p> <p>Employed in <u>daily operations</u></p> <p>Used by network <u>operators</u></p>	<p><u>Single</u> NMC per network</p> <p><u>Global</u> network management</p> <p>Employed in <u>long term planning</u></p> <p>Used by network <u>managers</u> and <u>planners</u></p> <p>24 hour <u>supervision</u></p>

NETWORK MANAGEMENT CENTRE – NMC

The NMC offers the ability to provide hierarchical regionalized network management of a complete GSM system.

It is responsible for operations and maintenance at the network level, supported by the OMCs which are responsible for regional network management.

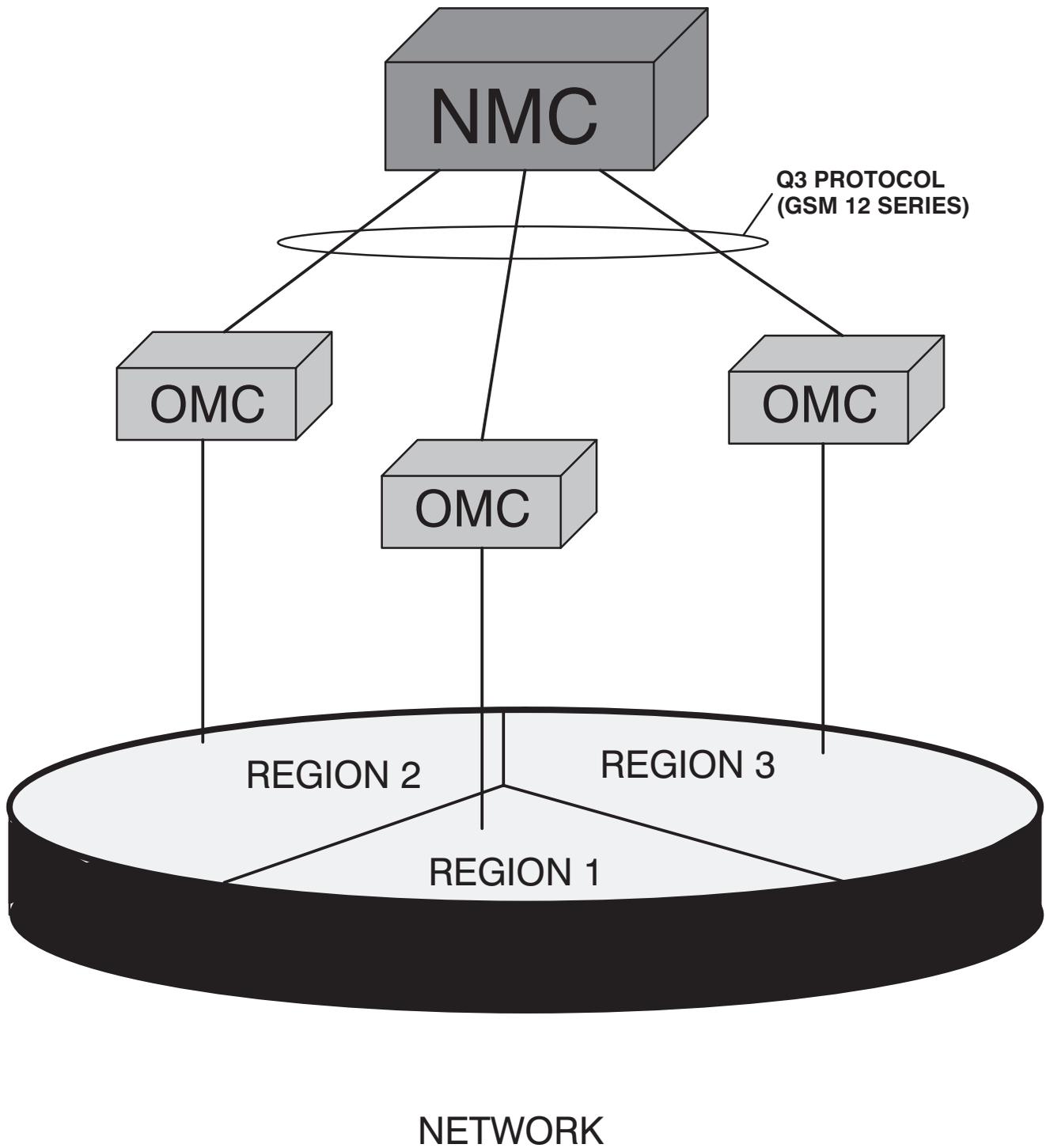
The NMC is therefore a single logical facility at the top of the network management hierarchy.

The NMC has a high level view of the network, as a series of network nodes and interconnecting communications facilities. The OMC, on the other hand, is used to filter information from the network equipment for forwarding to the NMC, thus allowing it to focus on issues requiring national co-ordination. The NMC can also co-ordinate issues regarding interconnection to other networks, for example the PSTN.

The NMC can take regional responsibility when an OMC is not manned, with the OMC acting as a transit point between the NMC and the network equipment. The NMC provides operators with functions equivalent to those available at the OMC

Functionality of the NMC
Monitors nodes on the network
Monitors GSM Network Element Statistics
Monitors OMC regions & provides information to OMC staff
Passes on statistical information from one OMC region to another to improve problem solving strategies
Enables Long Term Planning for the entire network

Network Management Centre



OPERATIONS AND MAINTENANCE CENTRE – OMC

The OMC provides a central point from which to control and monitor the other network entities (ie Base Stations, switches, database, etc) as well as monitor the quality of service being provided by the network.

At present, equipment manufacturers have their own OMCs which are not compatible in every aspect with those of other manufacturers. This is particularly the case between Radio Base Station equipment suppliers, where in some cases the OMC is a separate item and Digital Switching equipment suppliers, where the OMC is an integral, but functionally separate, part of the hardware.

There are two types of OMC these are:

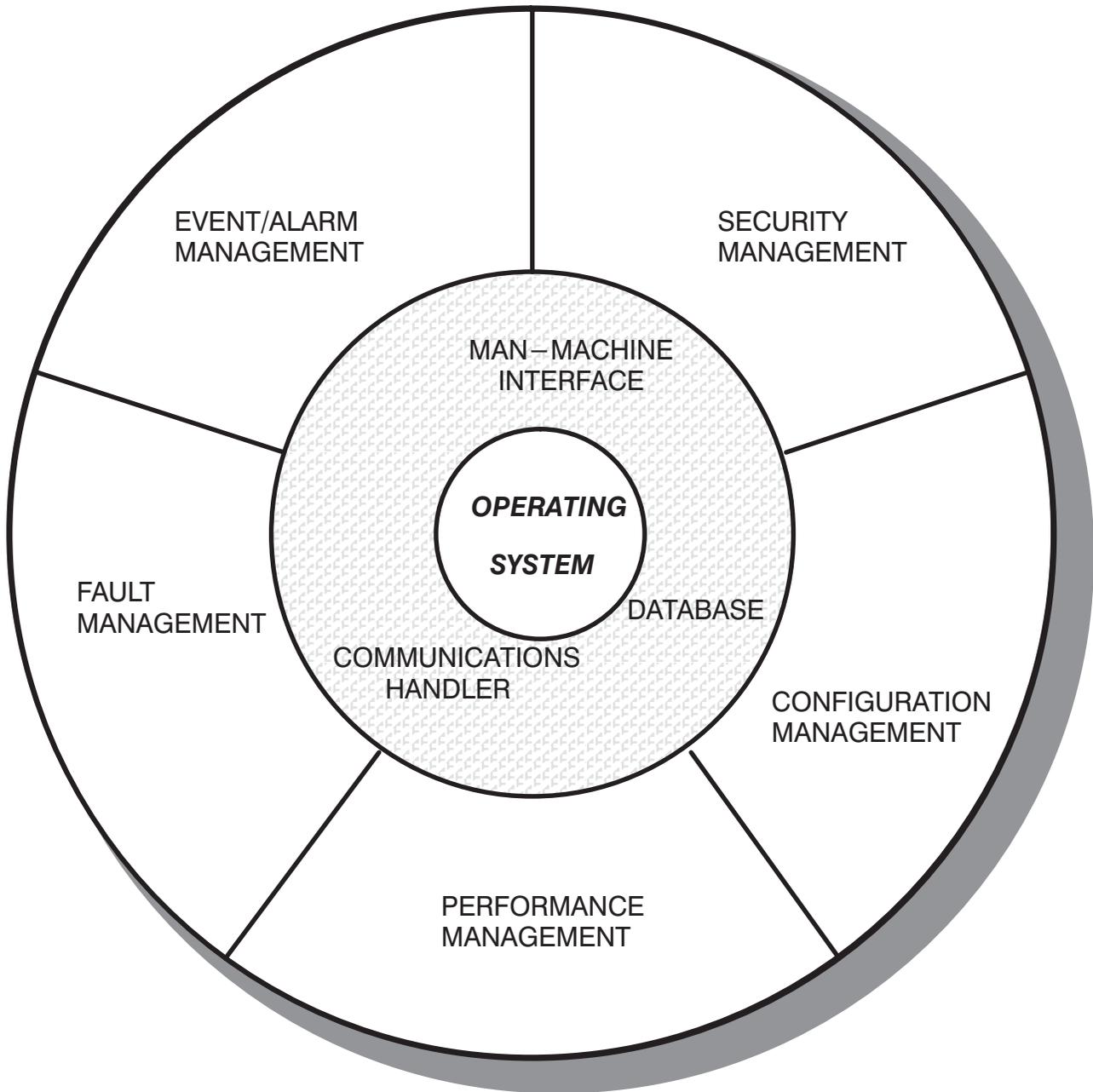
- **OMC (R)**
OMC controls specifically the Base Station System.
- **OMC (S)**
OMC controls specifically the Network Switching System.

The OMC should support the following functions as per ITS–TS recommendations:

- Event/Alarm Management.
- Fault Management.
- Performance Management.
- Configuration Management.
- Security Management.

The OMC Functional Architecture is illustrated in the diagram opposite.

OMC Functional Architecture



THE NETWORK IN REALITY

In reality a GSM network is much more complicated than we have seen. The diagram opposite illustrates how multiple BSS and Network Switching System components will be connected within a network.

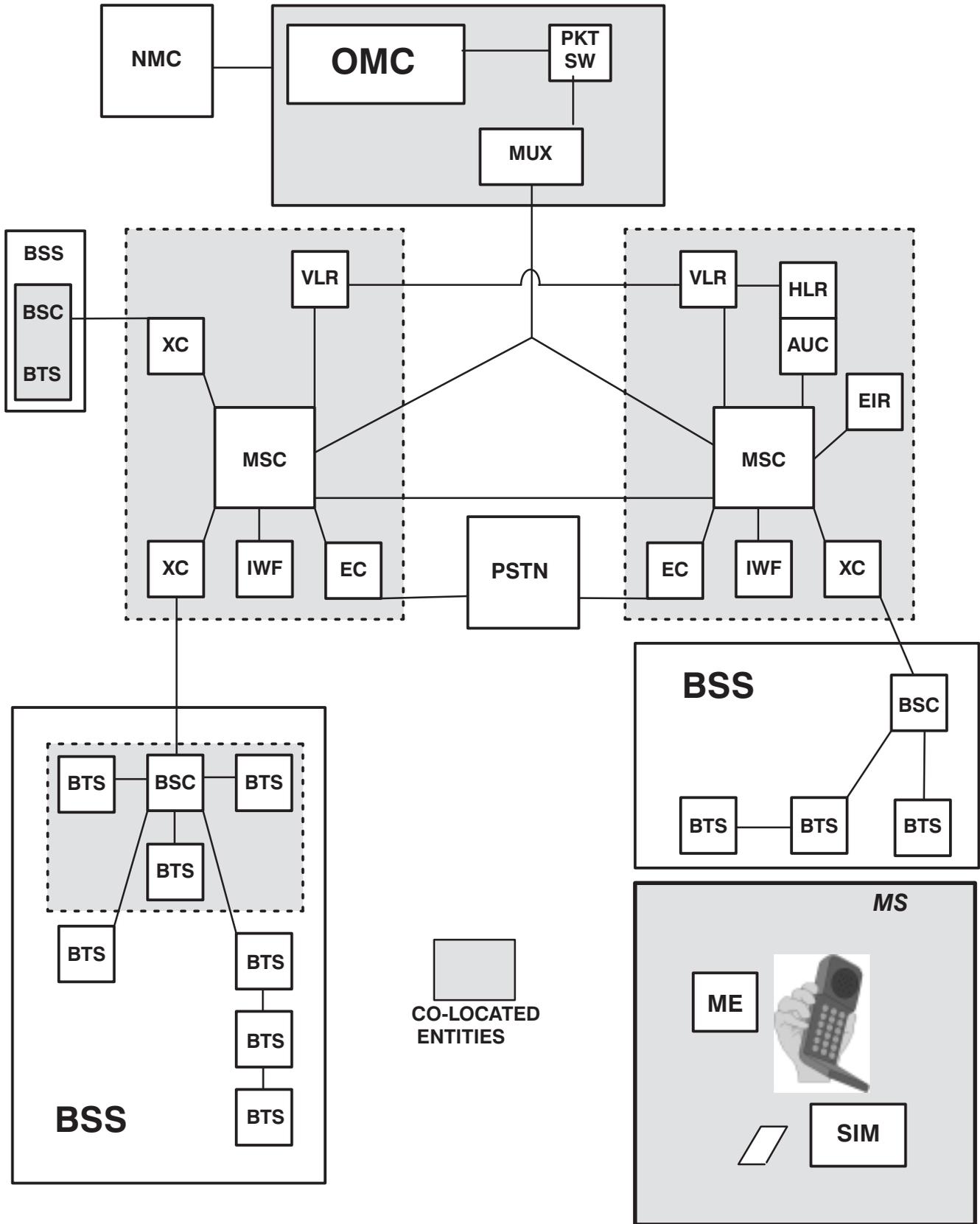
A typical city (for example, London) will have approximately the following number of network components:

Network Component	Quantity
Operations and Maintenance Centre (Base Station Equipment) – OMC(R)	1
Operations and Maintenance Centre (Switching) – OMC(S)	1
Mobile Services Switching Centre – MSC/VLR	1–2
Base Station Controller – BSC	5–15
Base Transceiver Station – BTS	200–400

A typical network (for example, UK) will have approximately the following number of network components.

Network Component	Quantity
Operations and Maintenance Centre (Base Station Equipment) – OMC(R)	6
Operations and Maintenance Centre (Switching) – OMC(S)	6
Mobile Services Switching Centre – MSC/VLR	6
Base Station Controller – BSC	40+
Base Transceiver Station – BTS	1200+

GSM Network Components





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INTRODUCTION TO DIGITAL CELLULAR

Section 4

GSM Terrestrial Interfaces

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contained in this document
is not intended to replace that contained
in the relevant equipment manuals and is
for the purpose of training only.

THIS MANUAL WILL NOT BE UPDATED

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- Identify the protocols used on the terrestrial interfaces between the GSM system entities.



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Introduction to Digital Cellular

Section 4

GSM Terrestrial Interfaces

INTRODUCTION

The *terrestrial interfaces* comprise all the connections between the GSM system entities, apart from the Um, or air interface.

They are represented on the diagram opposite by the lines that connect the various entities together.

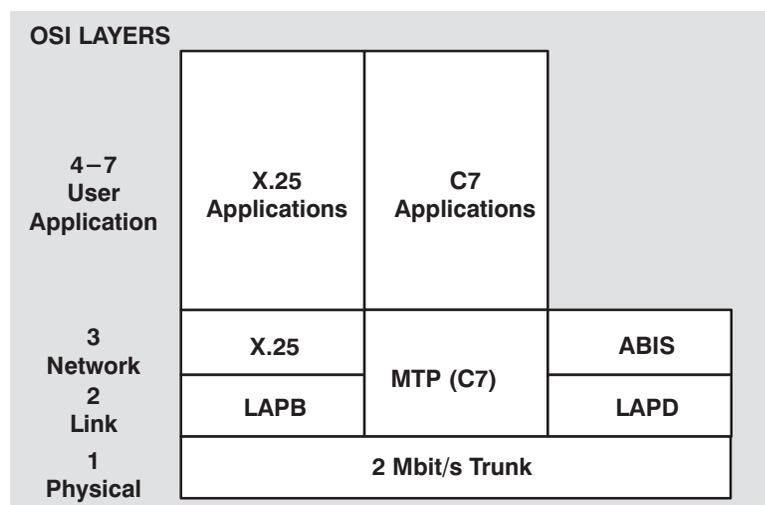
The GSM terrestrial interfaces and message-transport mediums all conform to ITU-TSS specifications widely used throughout the world. As we stated previously, it is from this use of standardized interfaces that the flexibility of GSM largely derives.

The terrestrial interfaces transport the traffic across the system and allow the passage of the thousands of data messages necessary to make the system function. They transport the data for software downloads and uploads, the collection of statistical information and the implementation of operations and maintenance commands.

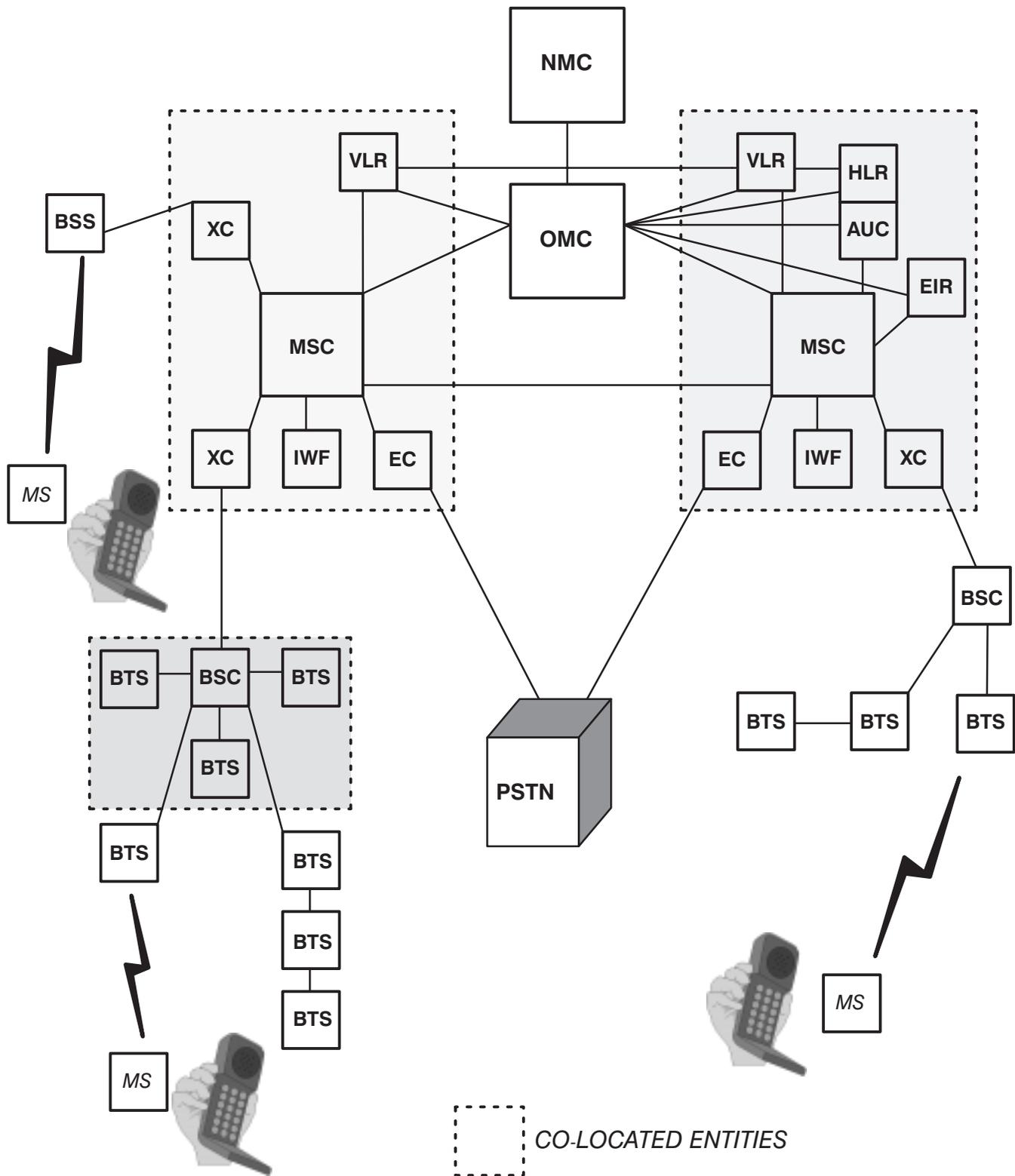
The standard interfaces used are as follows:

- 2 Mbit/s.
- Signalling System ITU-TSS #7 (“C7” or “SS#7”).
- X.25 (packet switched data); (LAPB).
- A bis using the LAPD protocol (Link Access Procedure “D”).

Whatever the interfaces and whatever their function, they will often share a common physical bearer (cable) between two points, for example, the MSC and a BSS.



The GSM System



2 MBIT/S TRUNK 30-CHANNEL PCM

This diagram opposite shows the logical GSM system with the 2 Mbit/s interfaces highlighted. They carry traffic from the PSTN to the MSC, between MSCs, from an MSC to a BSC and from a BSC to remotely sited BTSs. These links are also used between the MSC and IWF.

Each 2.048 Mbit/s link provides thirty 64 kbit/s channels available to carry speech, data, or control information.

The control information may contain C7, LAPD or X.25 formatted information.

These 2 Mbit/s links commonly act as the physical bearer for the interfaces used between the GSM system entities.

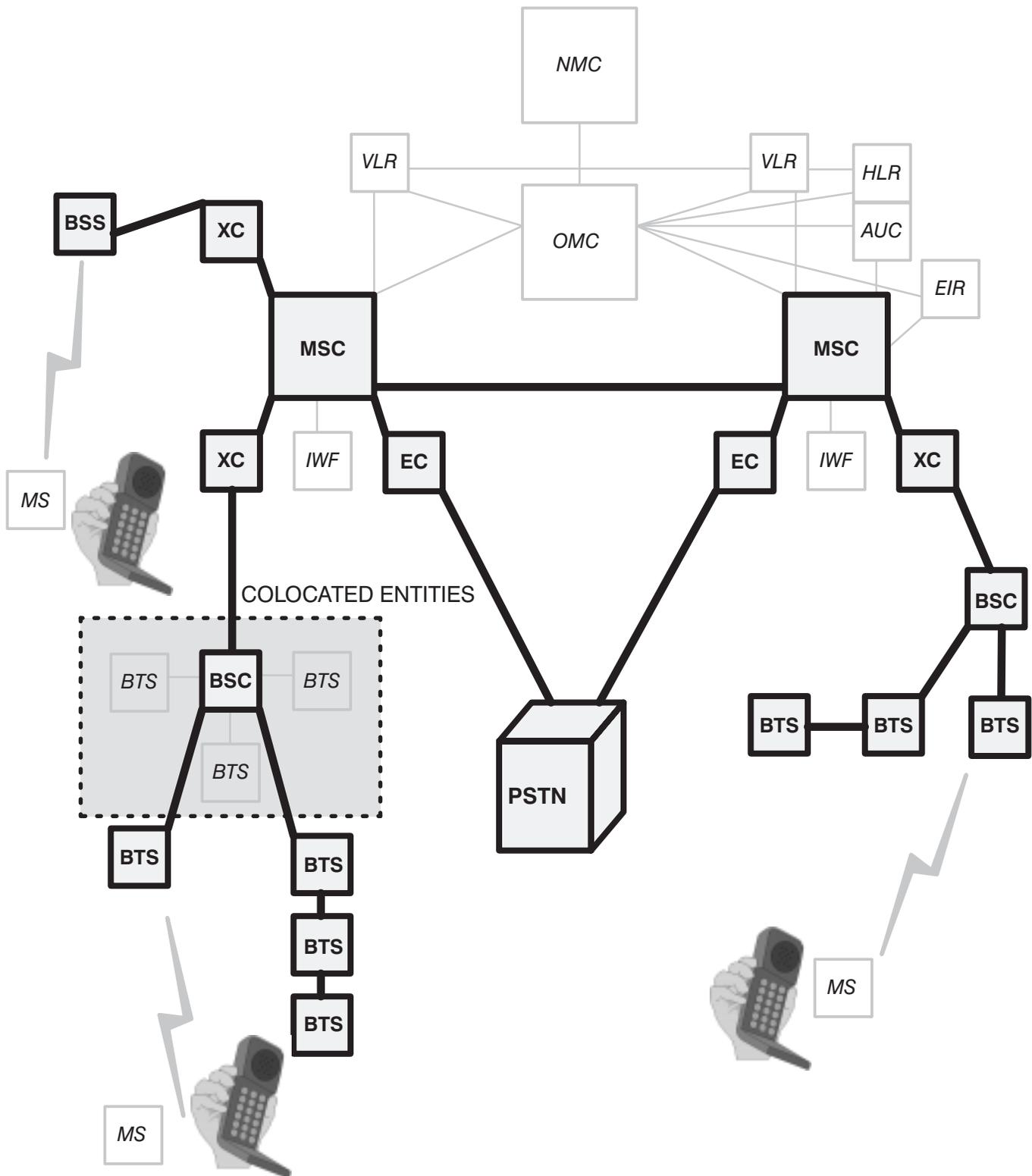
Typical Configuration

TS 0	TS 1-15	TS16	TS 17-31
------	---------	------	----------

TS#	Used for
0	Frame Alignment/ Error Checking/ Signalling/ Alarms
1-15	Traffic
16	Signalling (other TS may also be used)
17-31	Traffic

TS = Timeslot

2 Mbit/s Trunks

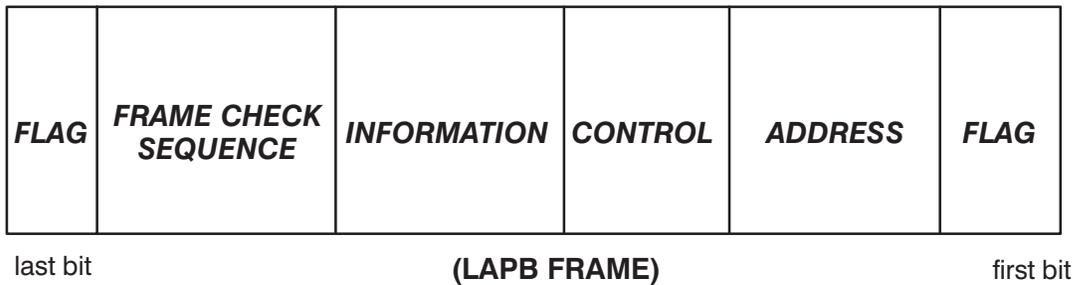


X.25 INTERFACES

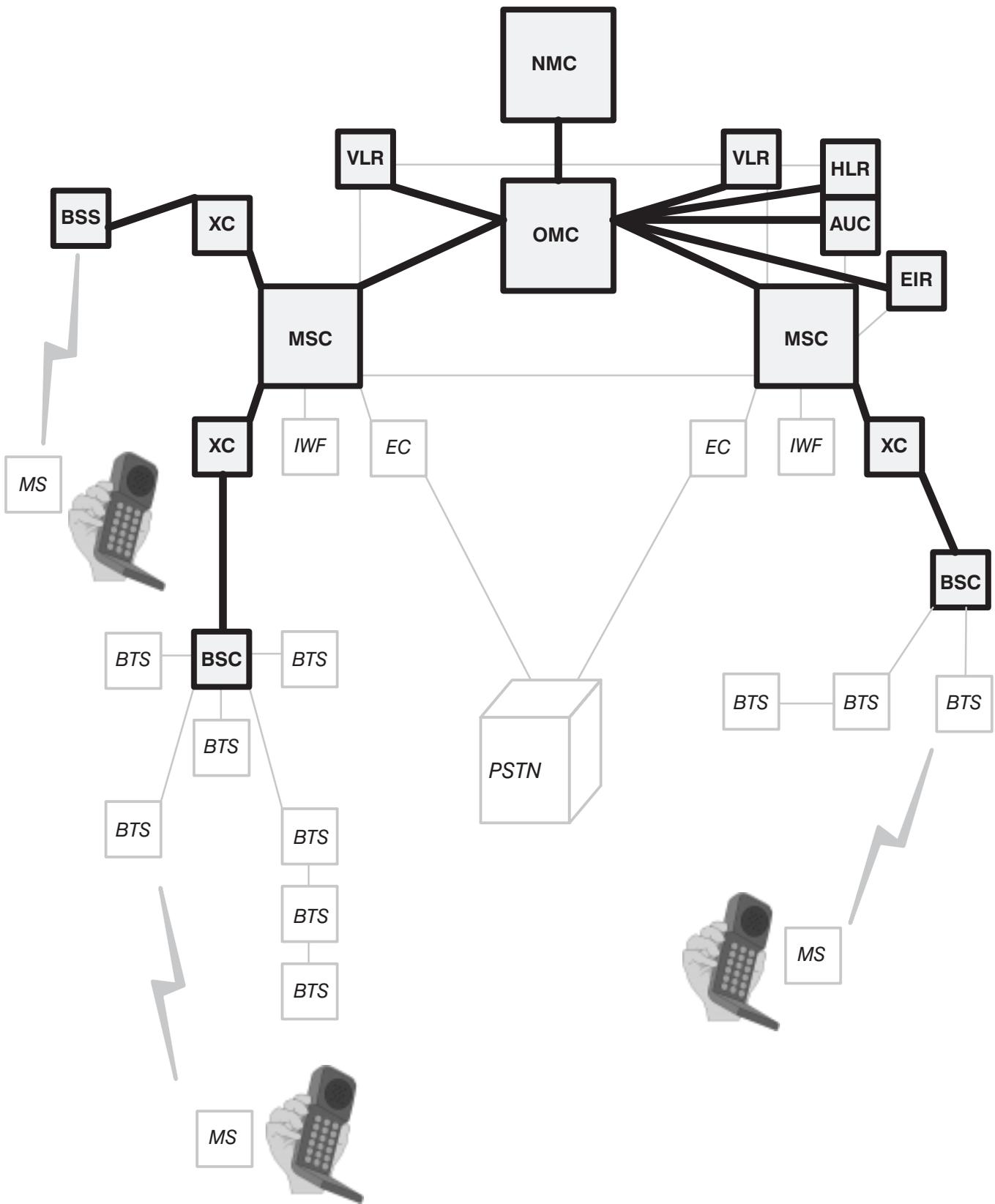
The diagram opposite shows the X.25 packet data connections of the system.

The X.25 packets provide the OMC with communications to all the entities over which it has control and oversight. Remember that these X.25 connections will commonly be contained within 2 Mbit/s links using a dedicated timeslot.

Note that the X.25 connection from the OMC to the BSS may be “nailed through” (or permanently connected by software) at the MSC, or may be supported by a completely independent physical route.



X.25 Interfaces



ITU-TS SIGNALLING SYSTEM #7

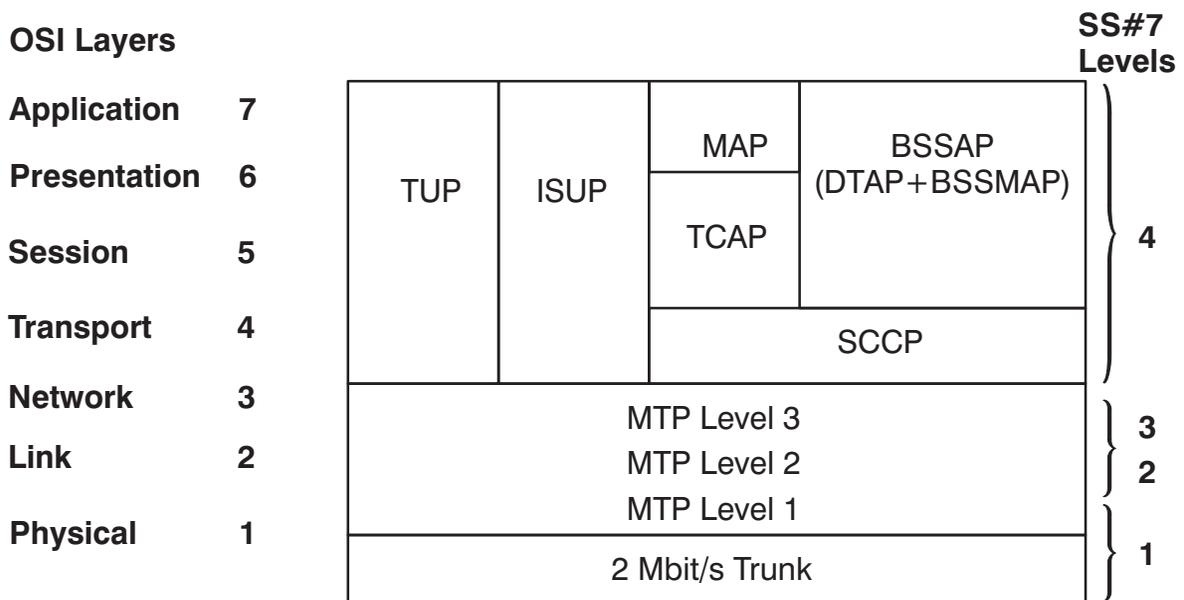
The diagram opposite illustrates the use of C7 in the GSM system; carrying signalling and control information between most major entities, and to and from the PSTN.

The following message protocols, which are part of C7, are used to communicate between the different GSM network entities:

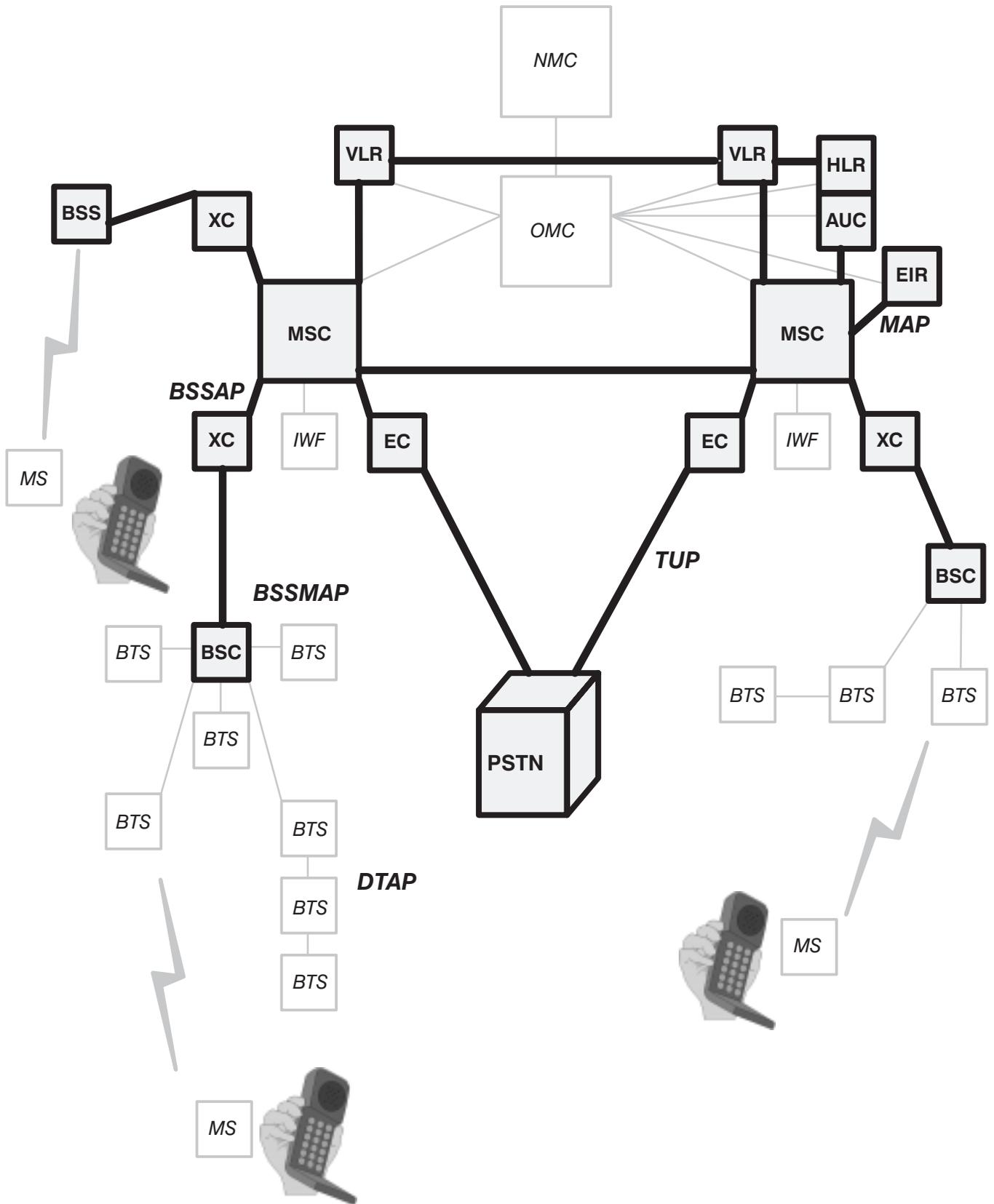
- Interfacing the PSTN, the MSC performs call signalling functions using the Telephone User Part (TUP), or interfacing the ISDN, the ISDN User Part (ISUP).
- Between the MSC and the BSC, the Base Station System Management Application Part (BSSMAP) is used. The Direct Transfer Application Part (DTAP) is used to send messages between the MSC and the mobile (MS). MAP is used between the MSC and the VLR, EIR, and HLR.

Acronyms:

BSSAP	Base Station System Application Part
BSSMAP	Base Station System Management Application Part
DTAP	Direct Transfer Application Part
ISUP	ISDN User Part
MAP	Mobile Application Part
SCCP	Signalling Connection Control Part
TUP	Telephone User Part
TCAP	Transaction Capabilities Application Part



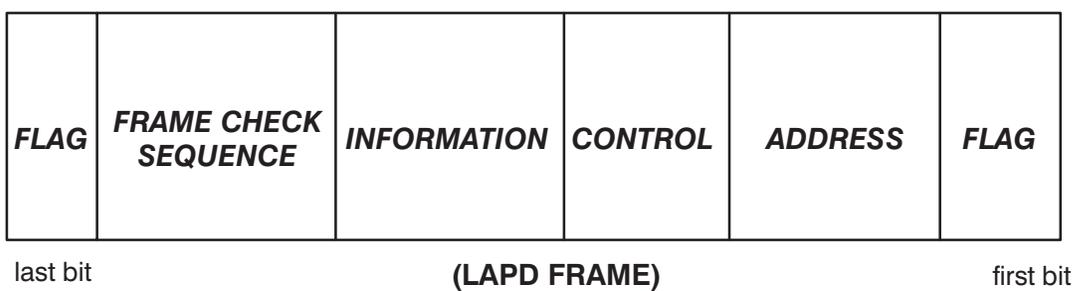
C7 Interfaces



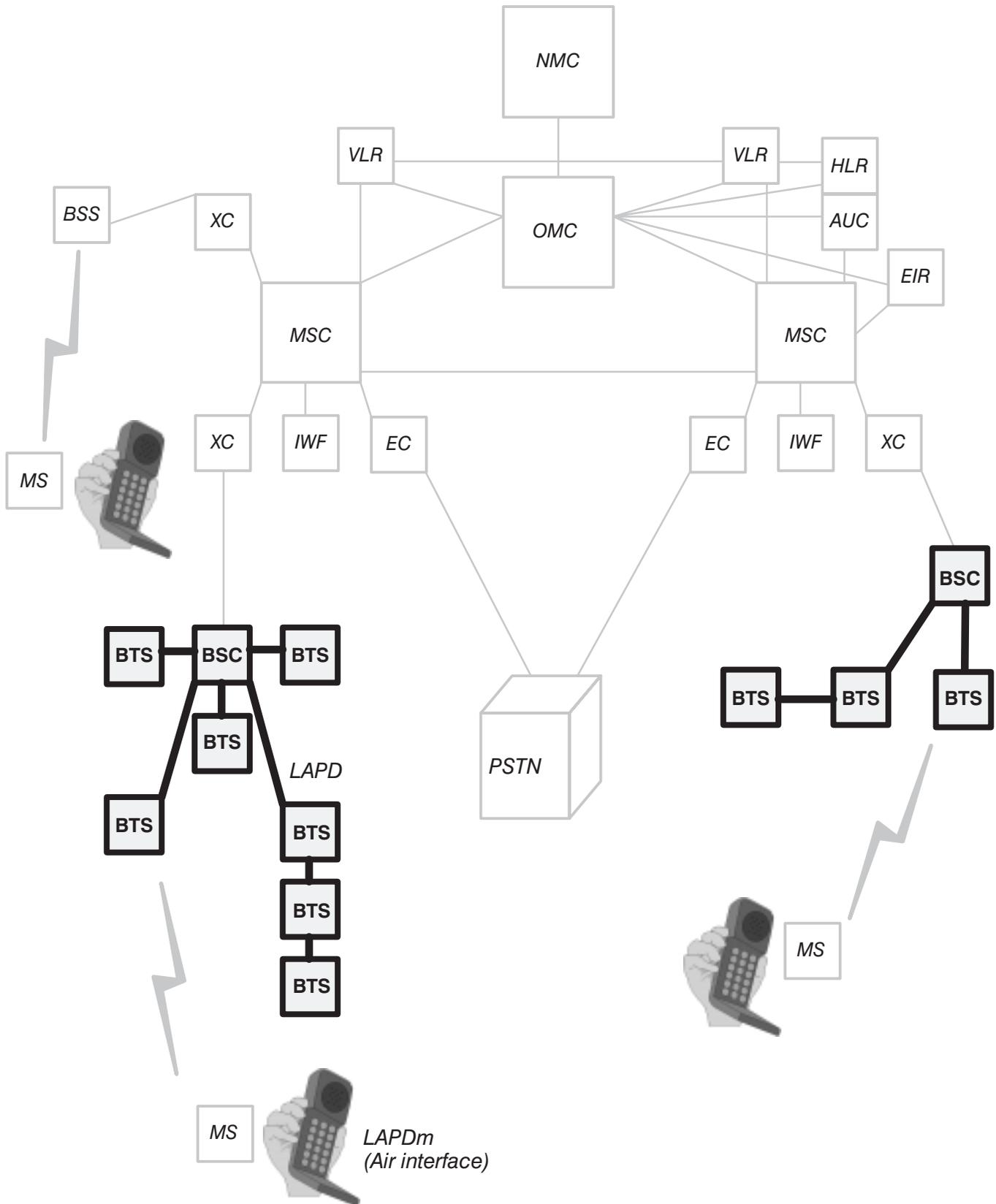
ABIS (LAPD) INTERFACES

Because of the specific nature of the signalling and control information passing over the 2 Mbit/s links between the BSC and remotely sited BTS, a different type of interface is required. GSM has specified the use of LAPD. This protocol uses the standard frame structure shown below.

The GSM specifications for this interface (termed "Abis") are not very specific and therefore interpretations of the interface vary. This means that one manufacturer's BTS will not work with another manufacturer's BSC. As we have already mentioned, the functionality split between the BTS and BSC is also largely in the hands of the manufacturer and therefore it is unlikely that they would operate together, even if this interface were rigidly enforced by the specifications.



Abis (LAPD) Interfaces



INTERCONNECTIONS

The interface between the BSC and the MSC is a standardized ITU-TSS signalling system N^o7 (C7) interface, referred to as the A interface.

The interface supports the following connections:

- BSC–MSC, BSC–BTS and MSC–MS.
- Operation and Maintenance interface.
- All call processing functions.

These interfaces are commonly transported on a physical bearer, the 2 Mbit/s link.

Each of these 2 Mbit/s links provide 32 x 64 kbit/s channels (Timeslots), the first channel (TS0) is used for frame alignment, leaving 31 channels available for carry “traffic channels” or “signalling interfaces”.

The signalling protocols used between GSM networks are:

- X.25 (LAPB), 1 x 64 kbit/s timeslot.
- C7 (SS7), 1 x 64 kbit/s timeslot (BSSAP, MAP, TCAP, SCCP, MTP).
- LAPD, 1 x 64 kbit/s timeslot.

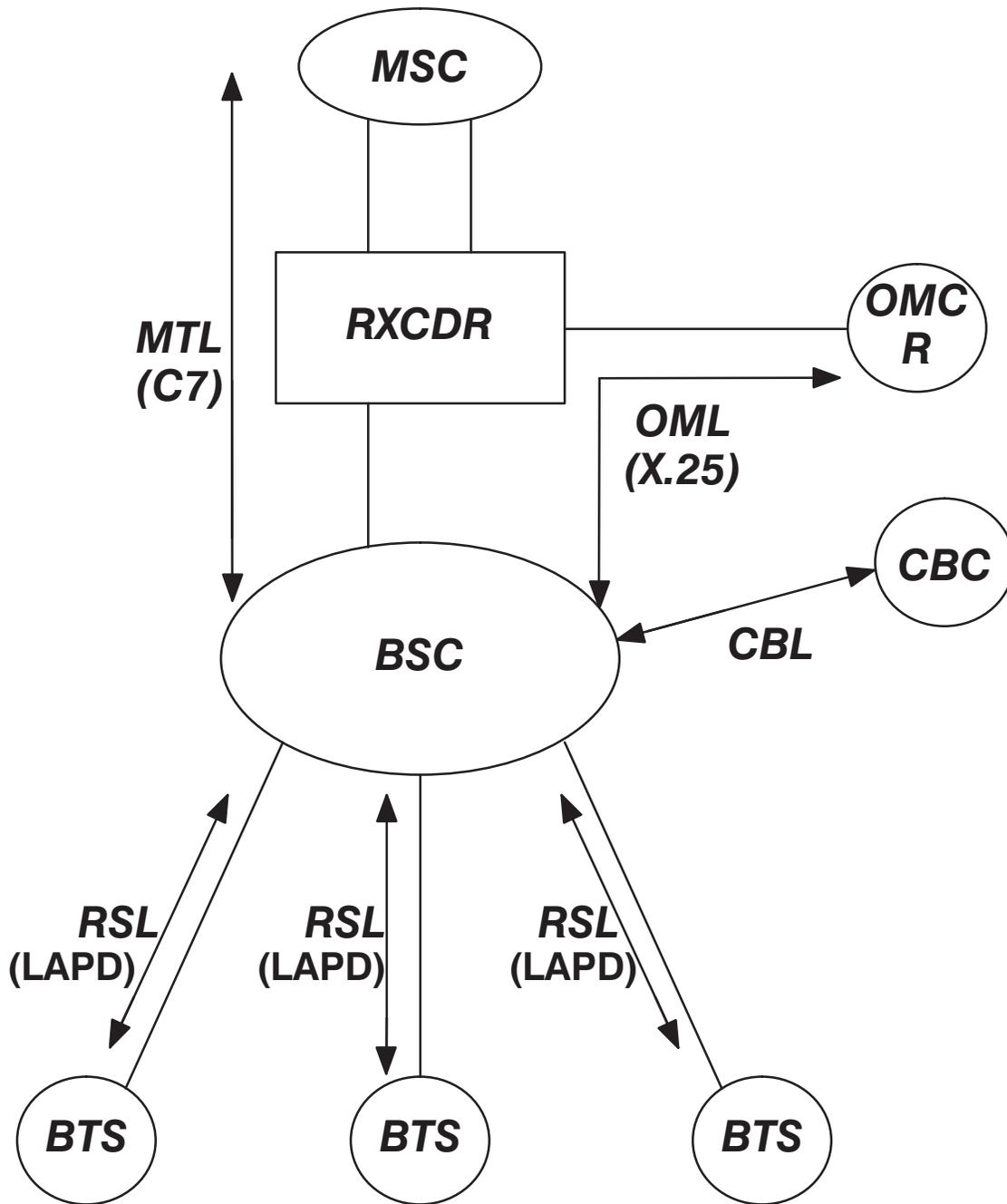
The X.25 protocol is used between the BSC–OMC.

The C7 link is between the BSC–MSC, dependent on what type of signalling is required will depend on which part of the C7 protocol will be used (for example, MSC–MS will use a subset of BSSAP called DTAP to transfer messages).

The LAPD protocol is used between the BSC–BTS, this is normally 64 kbit/s as stated but some manufactures offer 16 kbit/s links as well.

The link between the BSC–CBC does not use a specified protocol. The choice of protocol is decided between the PLMN provider and the CBC provider. (Typically X.25 or C7 may be used.)

BSC Connections

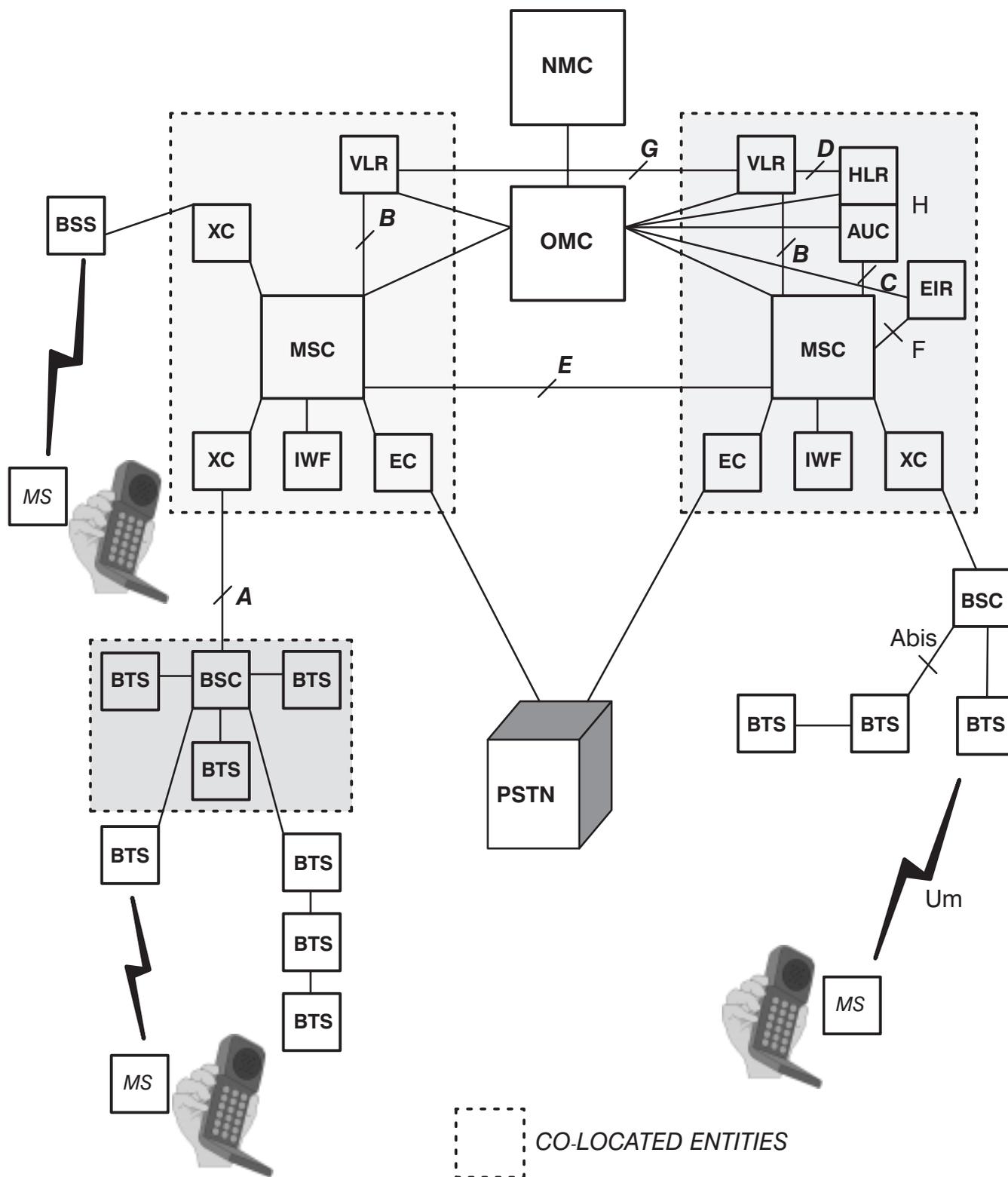


INTERFACE NAMES

Each interface specified within the GSM system has a name associated with it. The diagram opposite illustrates the names of all the interfaces specified by GSM.

Name	Interface
Um	MS ↔ BTS
Abis	BTS ↔ BSC
A	BSC ↔ MSC
B	MSC ↔ VLR
C	MSC ↔ HLR
D	VLR ↔ HLR
E	MSC ↔ MSC
F	MSC ↔ EIR
G	VLR ↔ VLR
H	HLR ↔ AUC

The GSM System Interface Names





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INTRODUCTION TO DIGITAL CELLULAR

Section 5

Channels on the Air Interface

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Understand why GMSK is used to modulate the GSM signal.

- . Name the four most commonly used channel combinations and provide reasons why each would be used.

- . State the reason why multiframes, superframes & hyperframes are utilized.



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Introduction to Digital Cellular

Section 5

Channels on the Air Interface

TRANSMISSION OF ANALOGUE AND DIGITAL SIGNALS

The main reasons why GSM uses a digital air interface:

- It is “noise robust”, enabling the use of tighter frequency re-use patterns and minimizing interference problems;
- It incorporates error correction, thus protecting the traffic that it carries;
- It offers greatly enhanced privacy to subscribers and security to network providers;
- It is ISDN compatible, uses open standardized interfaces and offers an enhanced range of services to its subscribers.

MODULATION TECHNIQUES

There are three methods of modulating a signal so that it may be transmitted over the air:

- **Amplitude Modulation (AM)**

Amplitude Modulation is very simple to implement for analogue signals but it is prone to noise.

- **Frequency Modulation (FM)**

Frequency Modulation is more complicated to implement but provides a better tolerance to noise.

- **Phase Modulation (PM)**

Phase Modulation provides the best tolerance to noise but it is very complex to implement for analogue signals and therefore is rarely used.

Digital signals can use any of the modulation methods, but phase modulation provides the best noise tolerance. Since phase modulation can be implemented easily for digital signals, this is the method which is used for the GSM air interface. Phase Modulation is known as Phase Shift Keying when applied to digital signals.

Modulation Techniques

- 1. Amplitude Modulation (AM)**
- 2. Frequency Modulation (FM)**
- 3. Phase Shift Keying (PSK)**

TRANSMISSION OF DIGITAL SIGNALS

PHASE SHIFT KEYING – PSK

Phase modulation provides a high degree of noise tolerance. However, there is a problem with this form of modulation. When the signal changes phase abruptly, high frequency components are produced, thus a wide bandwidth would be required for transmission.

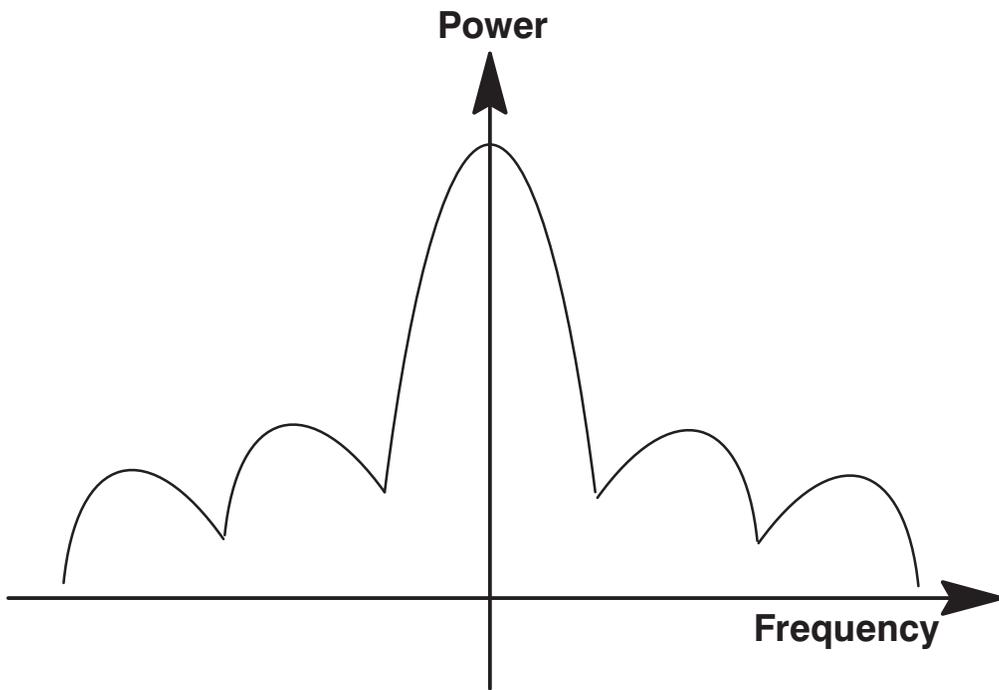
GSM has to be as efficient as possible with the available bandwidth. Therefore, it is not this technique, but a more efficient development of phase modulation that is actually used by the GSM air interface, it is called Gaussian Minimum Shift Keying (GMSK).

GAUSSIAN MINIMUM SHIFT KEYING – GMSK

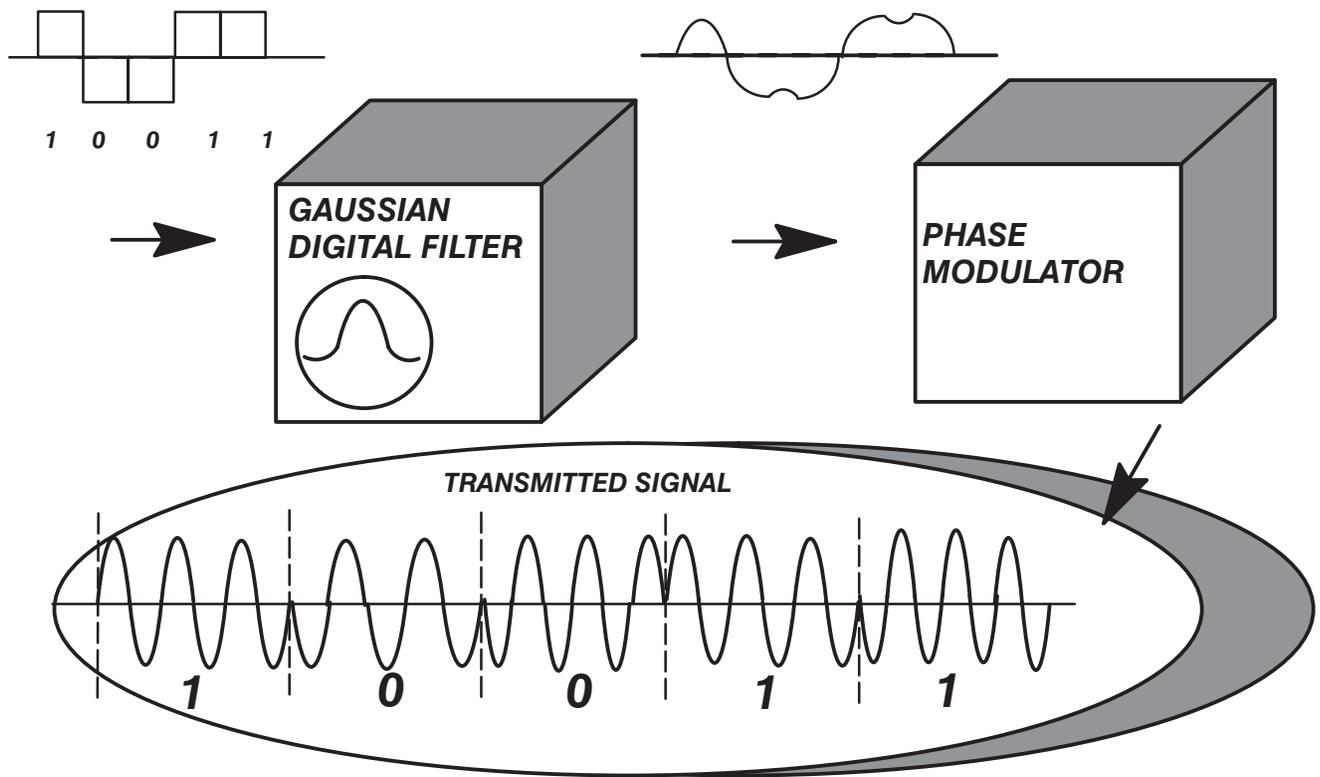
With GMSK, the phase change which represents the change from a digital '1' or a '0' does not occur instantaneously as it does with Binary Phase Shift Keying (BPSK). Instead it occurs over a period of time and therefore the addition of high frequency components to the spectrum is reduced.

With GMSK, first the digital signal is filtered through a Gaussian filter. This filter causes distortion to the signal, the corners are rounded off. This distorted signal is then used to phase shift the carrier signal. The phase change therefore is no longer instantaneous but spread out.

Frequency Spectrum



Gaussian Minimum Shift Keying (GMSK)



PHYSICAL AND LOGICAL CHANNELS

The physical channel is the medium over which the information is carried, in the case of a terrestrial interface this would be a cable. The logical channels consist of the information carried over the physical channel.

GSM PHYSICAL CHANNELS

A single GSM RF carrier can support up to eight MS subscribers simultaneously. The diagram opposite shows how this is accomplished. Each channel occupies the carrier for one eighth of the time. This is a technique called *Time Division Multiple Access*.

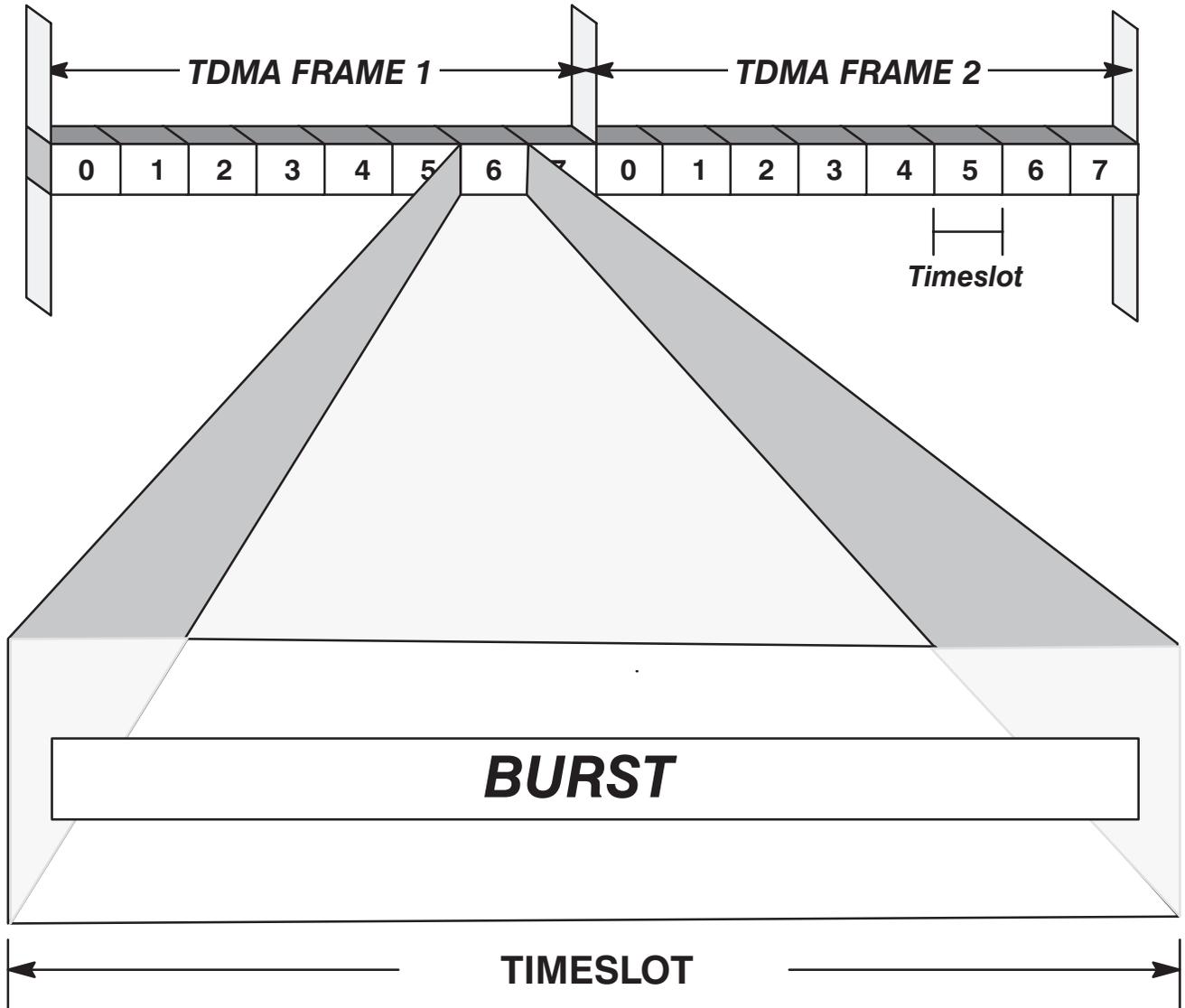
Time is divided into discrete periods called "*timeslots*". The timeslots are arranged in sequence and are conventionally numbered 0 to 7. Each repetition of this sequence is called a "TDMA frame".

Each MS telephone call occupies one timeslot (0-7) within the frame until the call is terminated, or a handover occurs. The TDMA frames are then built into further frame structures according to the type of channel. We shall later examine how the information carried by the air interface builds into frames and multi-frames and discuss the associated timing.

For such a system to work correctly, the timing of the transmissions to and from the mobiles is critical. The MS or Base Station must transmit the information related to one call at exactly the right moment, or the timeslot will be missed. The information carried in one timeslot is called a "*burst*".

Each data burst, occupying its allocated timeslot within successive TDMA frames, provides a single GSM physical channel carrying a varying number of logical channels between the MS and BTS.

Timeslots and TDMA Frames



GSM LOGICAL CHANNELS

There are two main groups of logical channels, traffic channels and control channels.

TRAFFIC CHANNELS – TCH

The traffic channel carries speech or data information. The different types of traffic channel are listed below:

- **Full rate**

TCH/FS: Speech (13 kbit/s net, 22.8 kbit/s gross)
TCH/F9.6: 9.6 kbit/s – data
TCH/F4.8: 4.8 kbit/s – data
TCH/F2.4 2.4 kbit/s – data

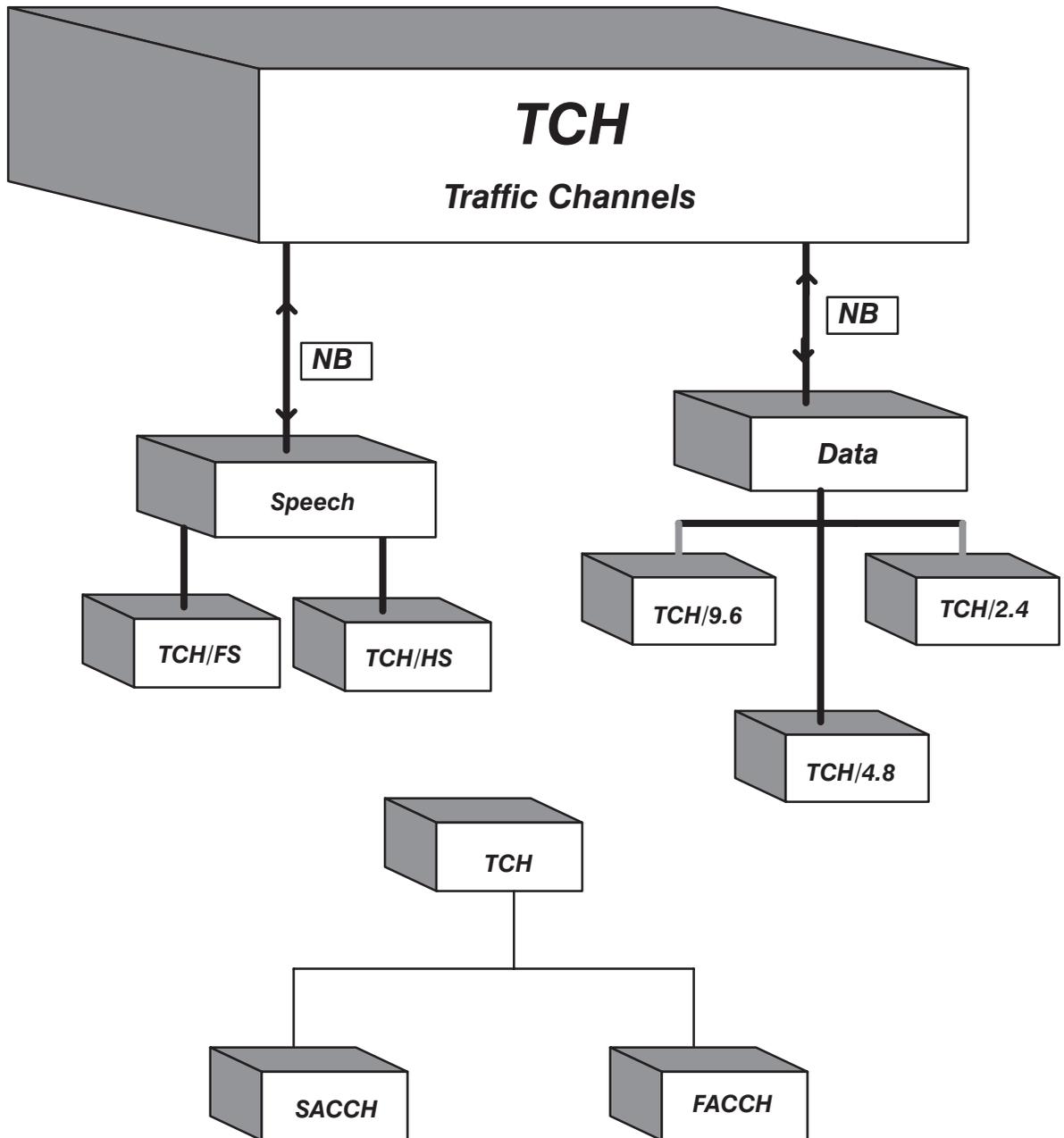
- **Half rate**

TCH/HS: speech (6.5 kbit/s net, 11.4 kbit/s gross)
TCH/H4.8 4.8 kbit/s – data
TCH/H2.4 2.4 kbit/s – data

Acronyms:

TCH	Traffic Channel
TCH/FS	Full rate speech channel
TCH/HS	Half rate speech channel
TCH/9.6	Data channel 9.6 kbit/s
TCH/4.8	Data channel 4.8 kbit/s
TCH/2.4	Data channel 2.4 kbit/s

Channels on the Air Interface



ACRONYMS

- NB** = **Normal Burst**
- SACCH** = **Slow Associated Control Channel**
- FACCH** = **Fast Associated Control Channel**

GSM CONTROL CHANNELS

These are: Broadcast Control Channel (BCCH); Common Control Channel (CCCH); Dedicated Control Channel (DCCH).

BCCH GROUP

The Broadcast Control Channels are downlink only (BSS to MS) and comprise the following:

- BCCH carries info about the network, a MS's present cell and the surrounding cells. It is transmitted continuously as its signal strength is measured by all MSs on surrounding cells.
- The Synchronizing Channel (SCH) carries information for frame synchronization.
- The Frequency Control Channel (FCCH) provides information for carrier synchronization.

CCCH GROUP

The Common Control Channel Group is bi-directional, that is, it works in both uplink and downlink directions.

- Random Access Channel (RACH) is the "up link" used by MSs to gain access to the system.
- Paging Channel (PCH) and Access Granted Channel (AGCH) operate in the "downlink" direction. The AGCH is used to assign resources to the MS, such as a Stand-alone Dedicated Control Channel (SDCCH). The PCH is used by the system to call a MS. The PCH and AGCH are never used at the same time.
- Cell Broadcast Channel (CBCH) is used to transmit messages to be broadcast to all MSs within a cell, for example, traffic information.

DCCH GROUP

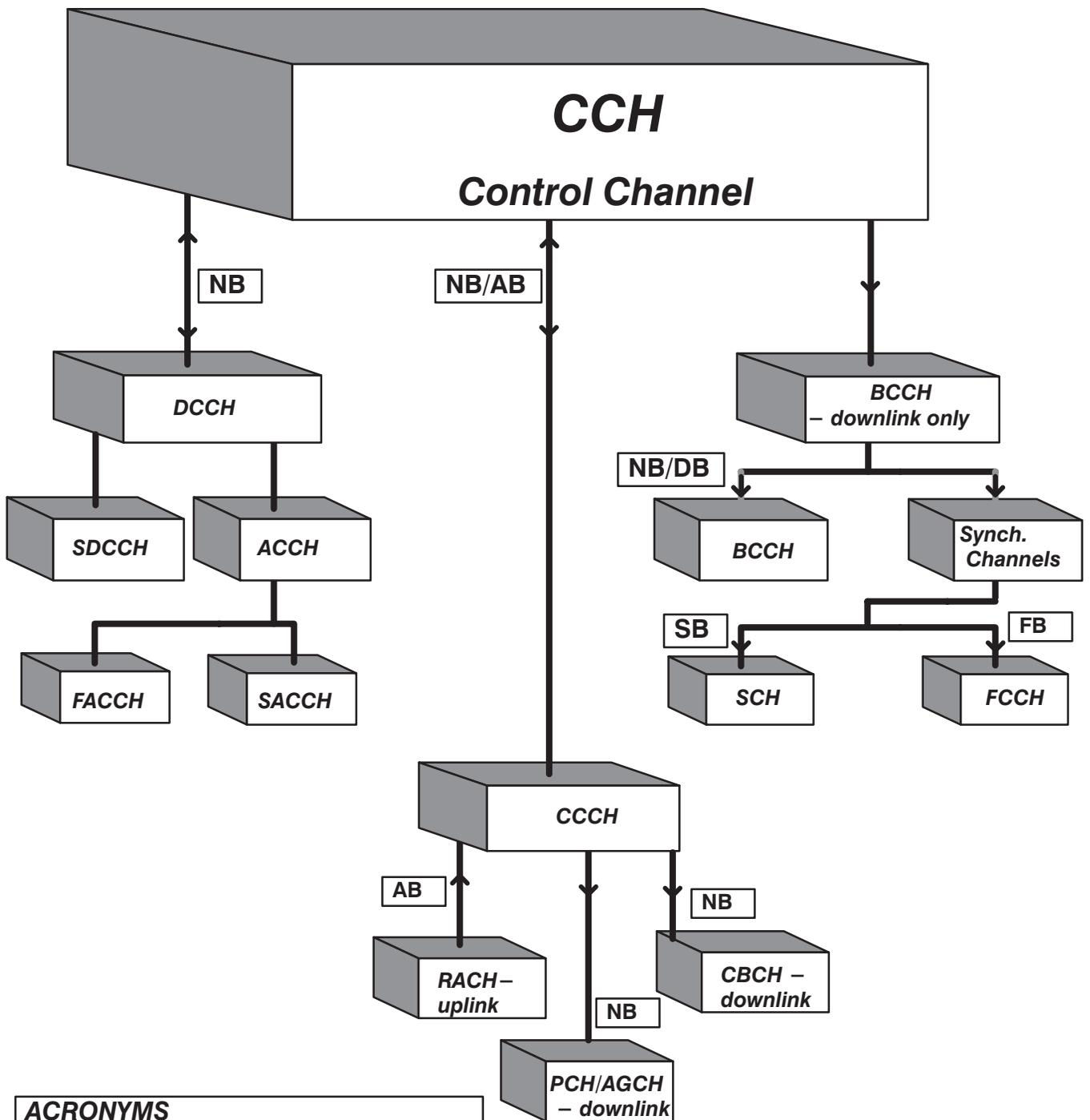
Dedicated Control Channels are assigned to a single MS for call setup and subscriber validation. DCCH comprises:

- Stand-alone Dedicated Control Channel (SDCCH) which supports the transfer of Data to and from the MS during call setup and validation.
- Associated Control Channel. This consists of Slow ACCH which is used for radio link measurement and power control messages. Fast ACCH is used to pass "event" type messages, for example, handover messages. Both FACCH and SACCH operate in uplink and downlink directions.

Acronyms

BCCH	Broadcast Control Channel	CCCH	Common Control Channel
DCCH	Dedicated Control Channel	ACCH	Associated Control Channel
SDCCH	Stand-alone Dedicated Control Channel	RACH	Random Access Channel
AGCH	Access Grant Channel	PCH	Paging Channel
		CBCH	Cell Broadcast Channel

Control Channels



ACRONYMS

NB = NORMAL BURST
FB = FREQUENCY BURST
SB = SYNCHRONISATION BURST
AB = ACCESS BURST
DB = DUMMY BURST

GSM LOGICAL CHANNELS

CONTROL CHANNELS

Broadcast Control Channel – BCCH

The Broadcast Control Channel is transmitted by the BTS at all times. The RF carrier used to transmit the BCCH is referred to as the BCCH carrier. The information carried on the BCCH is monitored by the MS periodically (at least every 30 secs), when it is switched on and not in a call.

Broadcast Control Channel (BCCH) – Carries the following information (this is only a partial list):

- Location Area Identity (LAI).
- List of neighbouring cells which should be monitored by the MS.
- List of frequencies used in the cell.
- Cell Identity.
- Power Control Indicator.
- DTX permitted.
- Access Control (for example, emergency calls, call barring).
- CBCH description.

The BCCH is transmitted at constant power at all times, and its signal strength is measured by all MS which may seek to use it. “Dummy” bursts are transmitted to ensure continuity when there is no BCCH carrier traffic.

- **Frequency Correction Channel (FCCH)**

This is transmitted frequently on the BCCH timeslot and allows the mobile to synchronize its own frequency to that of the transmitting base site.

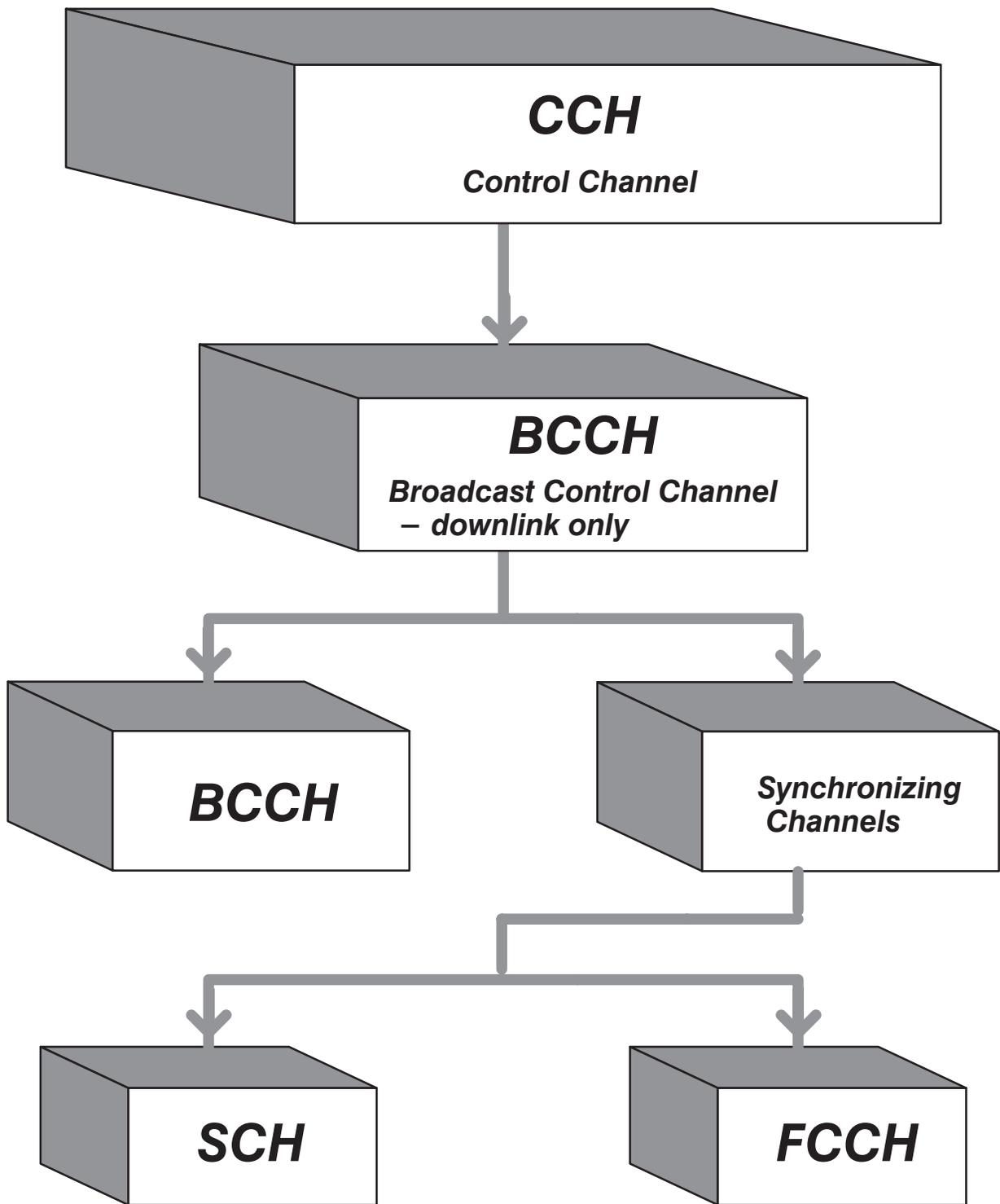
- **Synchronization Channel (SCH)**

The SCH carries the information to enable the MS to synchronize to the TDMA frame structure and know the timing of the individual timeslots. The following parameters are also carried:

- Frame Number.
- Base Site Identity Code (BSIC).

The MS will monitor BCCH information from surrounding cells and store the information from the best six cells. The SCH information on these cells is also stored so that the MS may quickly resynchronize when it enters a new cell.

Broadcast Control Channel (BCCH)



GSM LOGICAL CHANNELS . . .

CONTROL CHANNELS . . .

Common Control Channels – CCCH

The Common Control Channel (CCCH) is responsible for transferring control information between all mobiles and the BTS. This is necessary for the implementation of “call origination” and “call paging” functions.

It consists of the following:

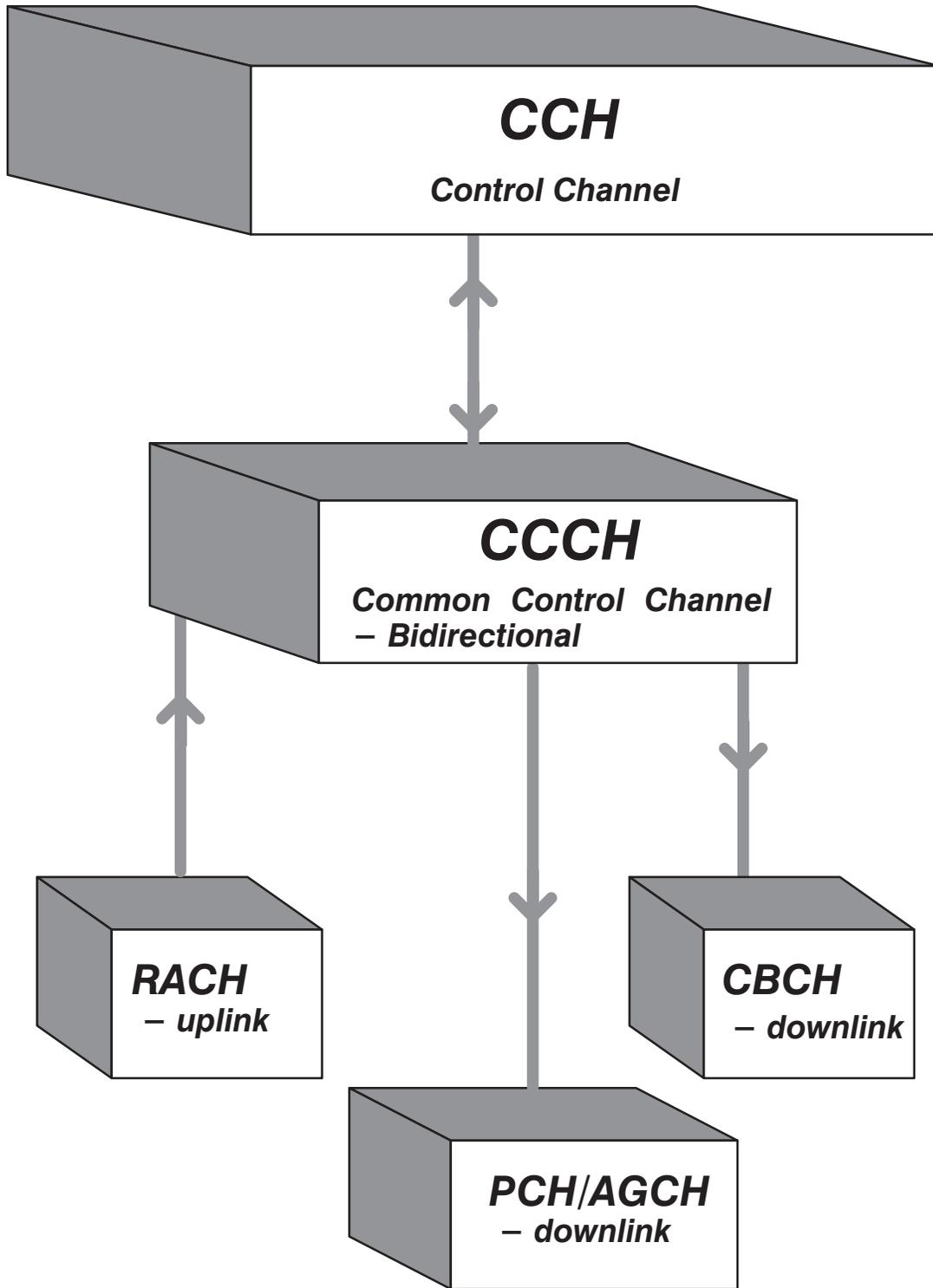
- **Random Access Channel (RACH)**
Used by the mobile when it requires to gain access to the system. This occurs when the mobile initiates a call or responds to a page.
- **Paging Channel (PCH)**
Used by the BTS to page MS, (paging can be performed by an IMSI, TMSI or IMGI).
- **Access Grant Control Channel (AGCH)**
Used by the BTS to assign dedicated resources to an MS such as a Stand-alone Dedicated Control Channel (SDCCH).
- **Cell Broadcast Channel (CBCH)**
This channel is used to transmit messages to be broadcast to all MSs within a cell. The CBCH uses block two of the DCCH blocks.

Active MSs must frequently monitor both BCCH and CCCH. The CCCH will be transmitted on the RF carrier with the BCCH.

Acronyms:

CCCH	Common Control Channel
RACH	Random Access Channel
PCH	Paging Channel
AGCH	Access Grant Channel
CBCH	Cell Broadcast Channel

Common Control Channel (CCCH)



GSM LOGICAL CHANNELS . . .

CONTROL CHANNELS . . .

Dedicated Control Channels – DCCH

The DCCH is a single timeslot on an RF Carrier which is used to convey eight SDCCH (Stand-alone Dedicated Control Channels). An SDCCH is used by a single MS for call setup, authentication, location updating and SMS point to point.

As we will see later, SDCCH can also be found on a BCCH/CCCH timeslot, this configuration only allows four SDCCHs.

Associated Control Channels – ACCH

These channels can be associated with either an SDCCH or a TCH. They are used for carrying information associated with the process being carried out on either the SDCCH or the TCH.

- **Slow Associated Control Channel (SACCH)**

Conveys power control and timing information in the downlink direction (towards the MS) and RSSI (Receive Signal Strength Indicator), and link quality reports in the uplink direction.

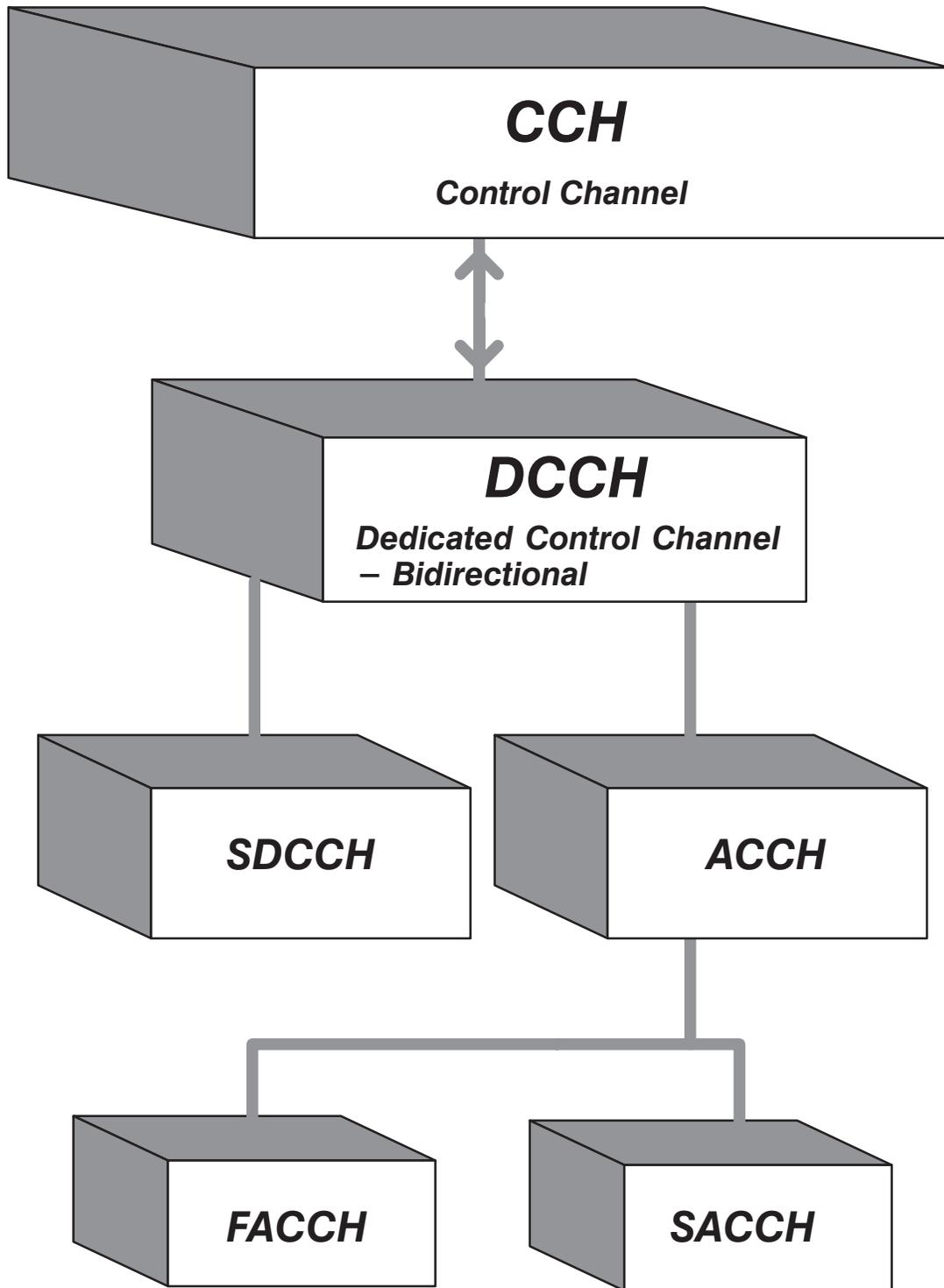
- **Fast Associated Control Channel (FACCH)**

The FACCH is transmitted instead of a TCH. The FACCH “steals” the TCH burst and inserts its own information. The FACCH is used to carry out user authentication, handovers and immediate assignment.

Acronyms:

SDCCH	Stand-alone Dedicated Control Channel
SACCH	Slow Associated Control Channel
FACCH	Fast Associated Control Channel

Dedicated Control Channel (DCCH)



GSM LOGICAL CHANNELS . . .

CHANNEL COMBINATIONS

The different logical channel types mentioned are grouped into what are called channel combinations. The four most common channel combinations are listed below:

- Full Rate Traffic Channel Combination – TCH8/FACCH + SACCH
- Broadcast Channel Combination – BCCH + CCCH
- Dedicated Channel Combination – SDCCH8 + SACCH8
- Combined Channel Combination – BCCH+CCCH+SDCCH4+SACCH4

The half rate channel combination (when introduced) will be very similar to the full rate traffic combination.

- Half Rate Traffic Channel Combination – TCH16/FACCH + SACCH

CHANNEL COMBINATIONS AND TIMESLOTS

The channel combinations we have identified are sent over the air interface in a selected timeslot.

Some channel combinations may be sent on any timeslot, but others must be sent on specific timeslots. Below is a table mapping the channels combinations to their respective timeslots:

Channel Combination	Timeslots
Traffic	Any timeslot
Broadcast	0,2,4,6 (0 must be used first)
Dedicated	Any timeslot
Combined	0 only

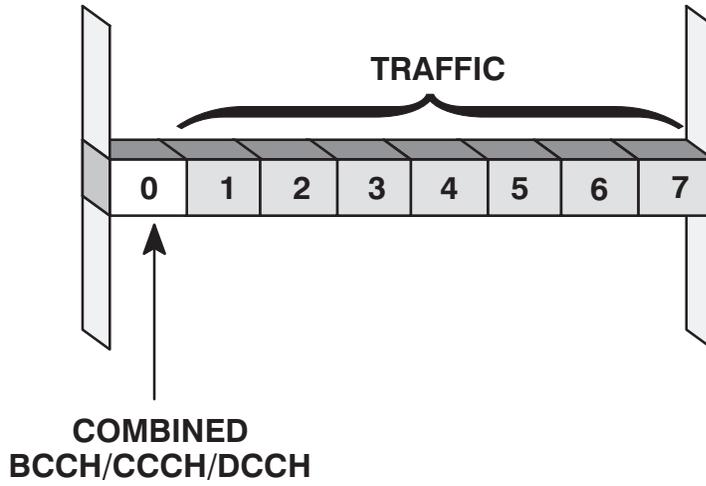
The diagram opposite illustrates how these different channel combinations may be mapped onto the TDMA frame structure.

Note:

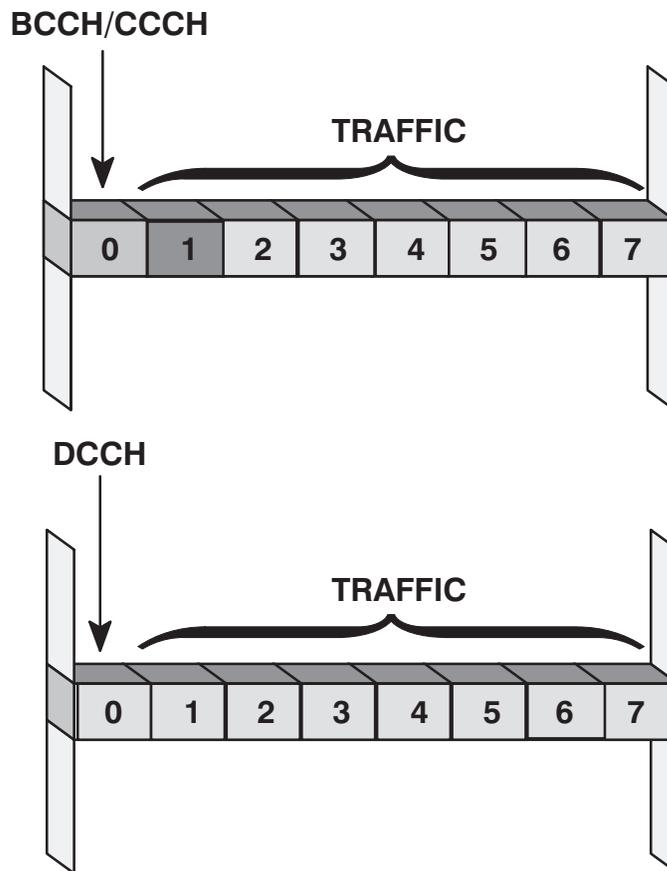
Only one BCCH/CCCH timeslot is required per cell (not RF carrier).

Timeslots and TDMA Frames

LOW CAPACITY CELL



HIGHER CAPACITY CELL



MULTIFRAMES AND TIMING

There are eight time-slots within each TDMA frame, enabling eight physical channels to share a single physical resource – the RF carrier. In turn, each physical channel may be shared by a number of logical channels.

In order to understand how a single physical channel is shared by various logical channels, it is necessary to introduce the GSM *multiframe* structures that make it possible.

THE 26-FRAME TRAFFIC CHANNEL MULTIFRAME

The illustration opposite shows the time relationship between time-slot, TDMA frame, and the 26-frame multiframe. Some of the times shown are approximate numbers as the GSM recommendations actually state the exact values as fractions rather than in decimal form (for example, the exact duration of a time-slot is $15/26$ ms).

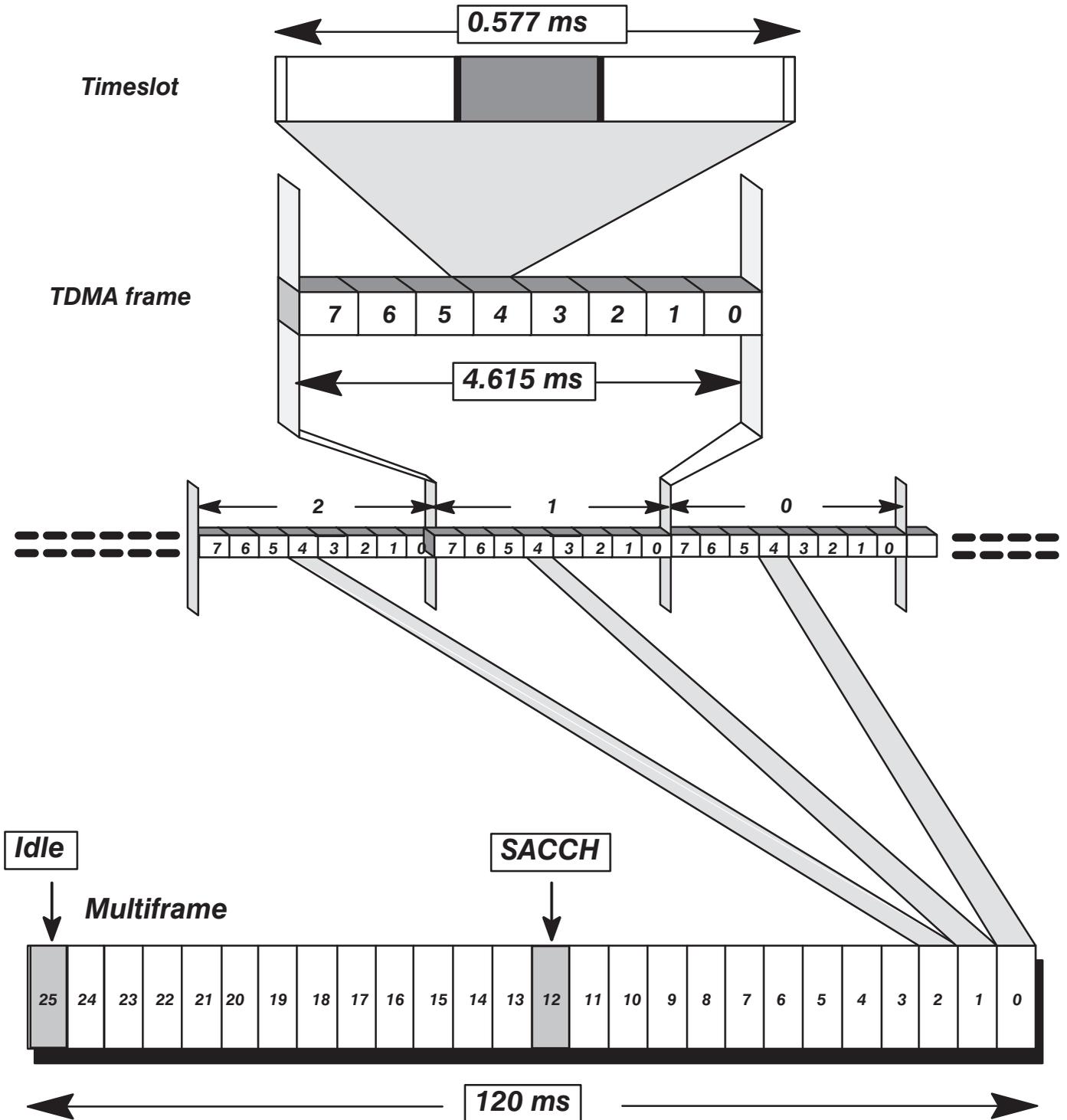
Note:

The 12th frame (no. 13) in the 26-frame traffic channel multiframe is used by SACCH, the Slow Associated Control Channel which carries link control information to and from the MS–BTS. Each timeslot in a cell allocated to traffic channel usage will follow this format, that is, 12 bursts of traffic, 1 burst of SACCH, 12 bursts of traffic and 1 idle.

The duration of a 26-frame traffic channel multiframe is 120 ms (25 TDMA frames).

When half rate is used, each frame of the 26-frame traffic channel multiframe allocated for traffic will now carry two MS subscriber calls (the data rate for each MS is halved over the air interface). Although the data rate for traffic is halved, each MS still requires the same amount of SACCH information to be transmitted, therefore frame 12 WILL BE USED as SACCH for one half of the MSs and the others will use it as their IDLE frame, and the same applies for frame 25, this will be used by the MSs for SACCH (those who used frame 12 as IDLE) and the other half will use it as their IDLE frame.

26-Frame Traffic Channel Multiframe

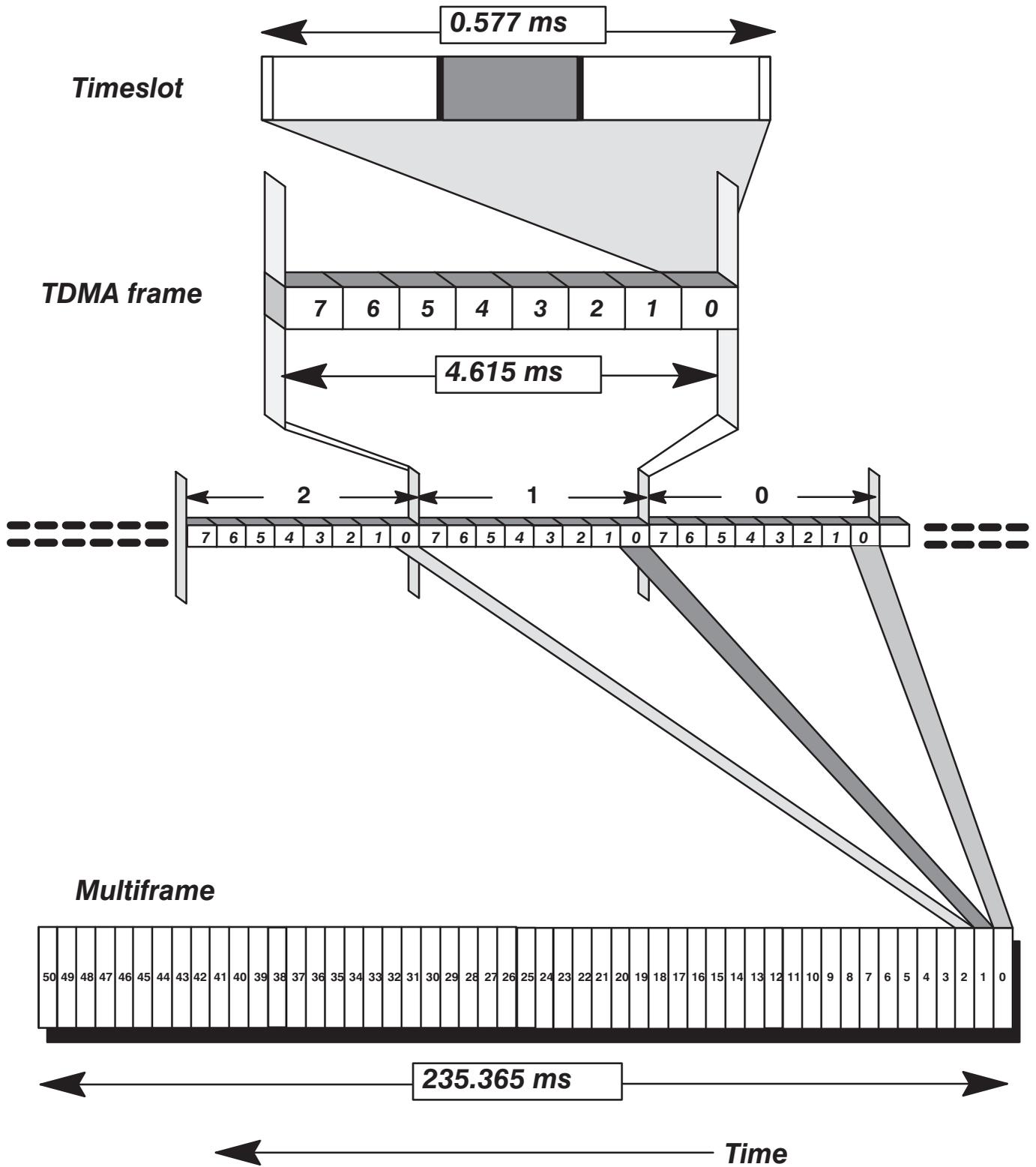


MULTIFRAMES AND TIMING . . .

THE 51-FRAME CONTROL CHANNEL MULTIFRAME

The 51-frame structure used for control channels is considerably more complex than the 26-frame structure used for the traffic channels. The 51-frame structure occurs in several forms, depending on the type of control channel and the network provider's requirements.

51-Frame Control Channel Multiframes



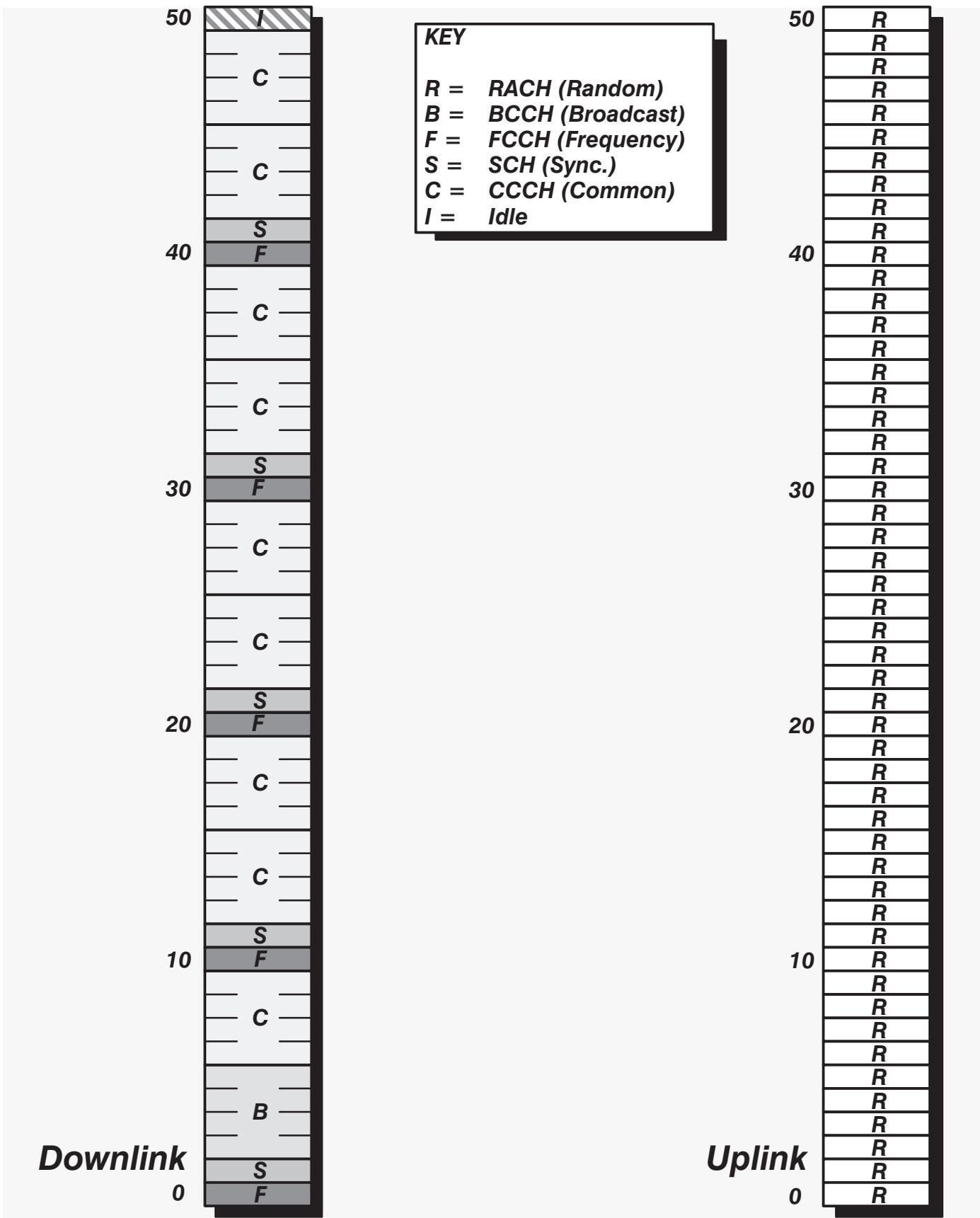
MULTIFRAMES AND TIMING . . .

THE 51-FRAME CONTROL CHANNEL MULTIFRAME – BCCH/CCCH

The BCCH/CCCH 51-frame structure illustrated on the opposite page will apply to timeslot 0 of each TDMA frame on the 'BCCH carrier' (the RF carrier frequency to which BCCH is assigned on a per cell basis). In the diagram, each vertical step represents one repetition of the timeslot (= one TDMA frame), with the first repetition (numbered 0) at the bottom.

Looking at the uplink (MS–BSS) direction, all timeslot 0s are allocated to RACH. This is fairly obvious because RACH is the only control channel in the BCCH/CCCH group which works in the uplink direction. In the downlink direction (BSS–MS), the arrangement is more interesting. Starting at frame 0 of the 51-frame structure, the first timeslot 0 is occupied by a frequency burst ('F' in the diagram), the second by a synchronizing burst ('S') and then the following four repetitions of timeslot 0 by BCCH data (B) in frames 2–5. The following four repetitions of timeslot 0 in frames 6–9 are allocated to CCCH traffic (C), that is, to either PCH (mobile paging channel) or AGCH (access grant channel). Then follows, in timeslot 0 of frames 10 and 11, a repeat of the frequency and synchronising bursts (F and S), four further CCCH bursts (C) and so on. Note that the last timeslot 0 in the sequence (the fifty-first frame – frame 50) is idle.

BCCH/CCCH Multiframe



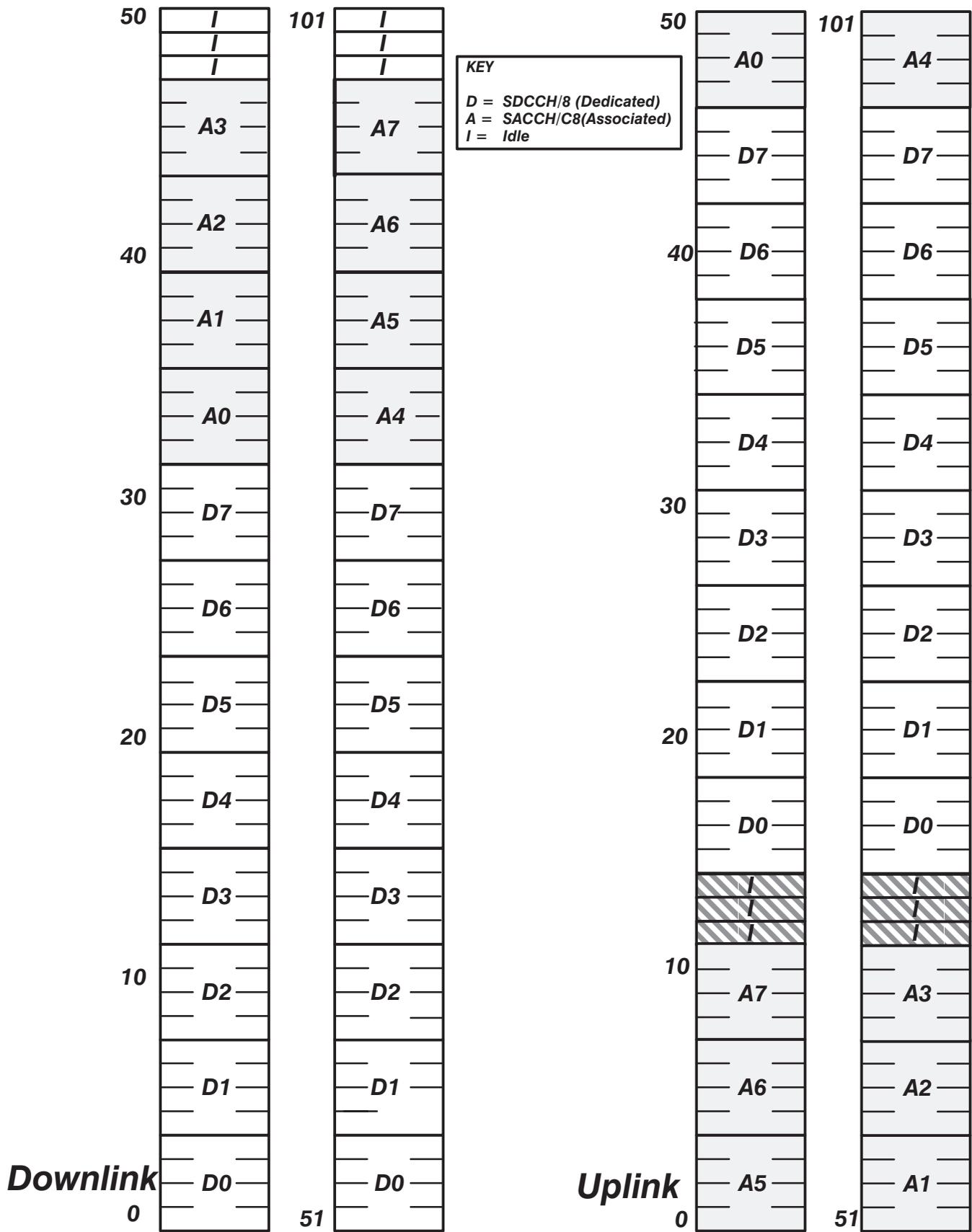
MULTIFRAMES AND TIMING . . .

THE 51-FRAME CONTROL CHANNEL MULTIFRAME – DCCH/8 (SDCCH AND SACCH)

The diagram opposite shows the 51-frame structure used to accommodate eight SDCCHs, although, as it takes two repetitions of the multiframe to complete the entire sequence, it may be more logical to think of it as a 102-frame structure. This structure may be transmitted on any timeslot.

Note that the SACCHs (shaded) are associated with the SDCCHs. It is important to remember that each SDCCH has an SACCH just like a traffic channel.

DCCH/8 Multiframe



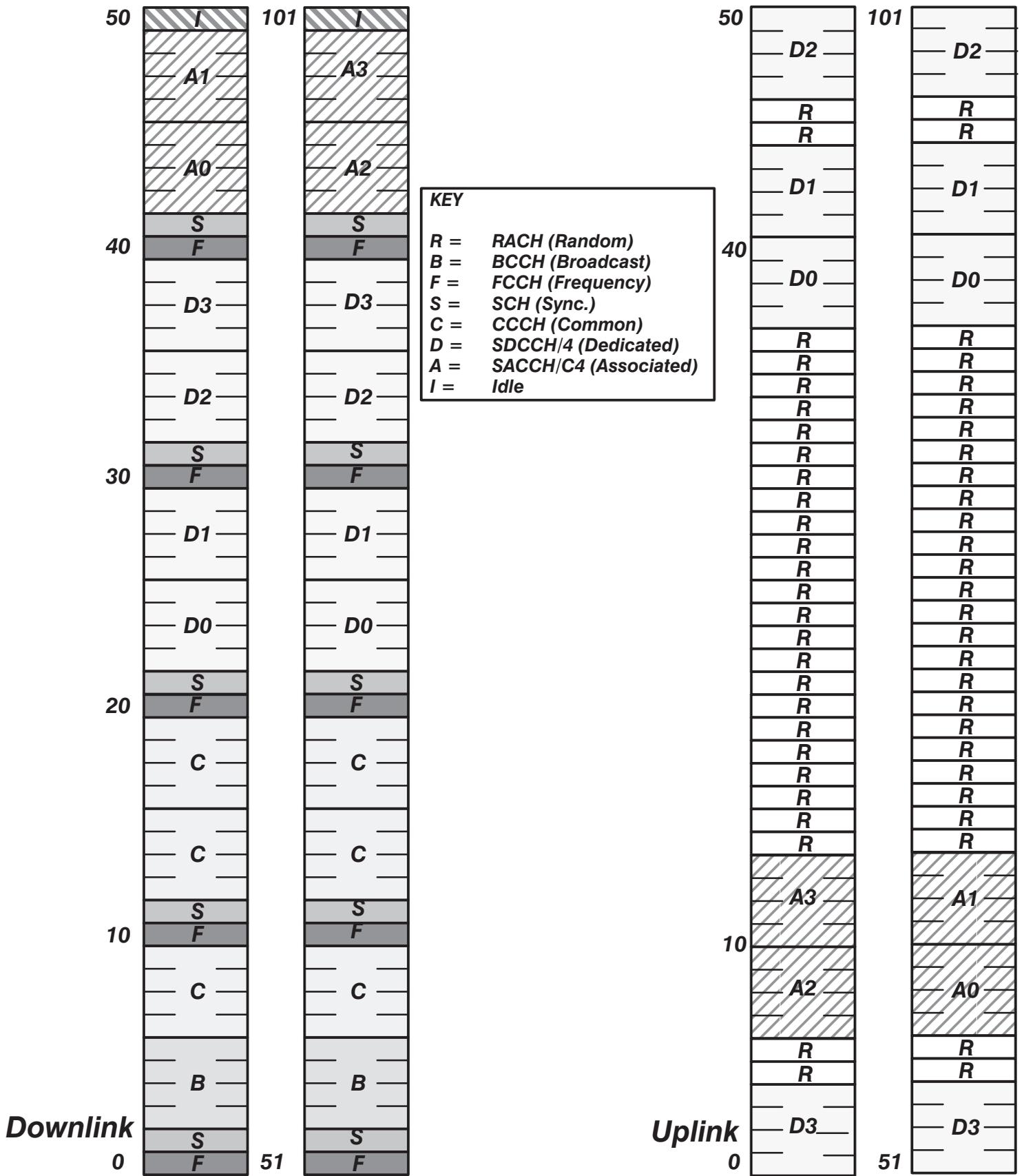
MULTIFRAMES AND TIMING . . .

THE 51-FRAME CONTROL CHANNEL MULTIFRAME – COMBINED STRUCTURE

A we can see in the diagram opposite, each of the control channel types are present on a single timeslot. The number of MSs which can effectively use this cell is therefore reduced, as we now only have 3 CCCH groups and 4 SDCCHs, which translates into fewer pages and simultaneous cell setups.

A typical use of this type of control channel timeslot is in rural areas, where the subscriber density is low.

Combined Multiframe



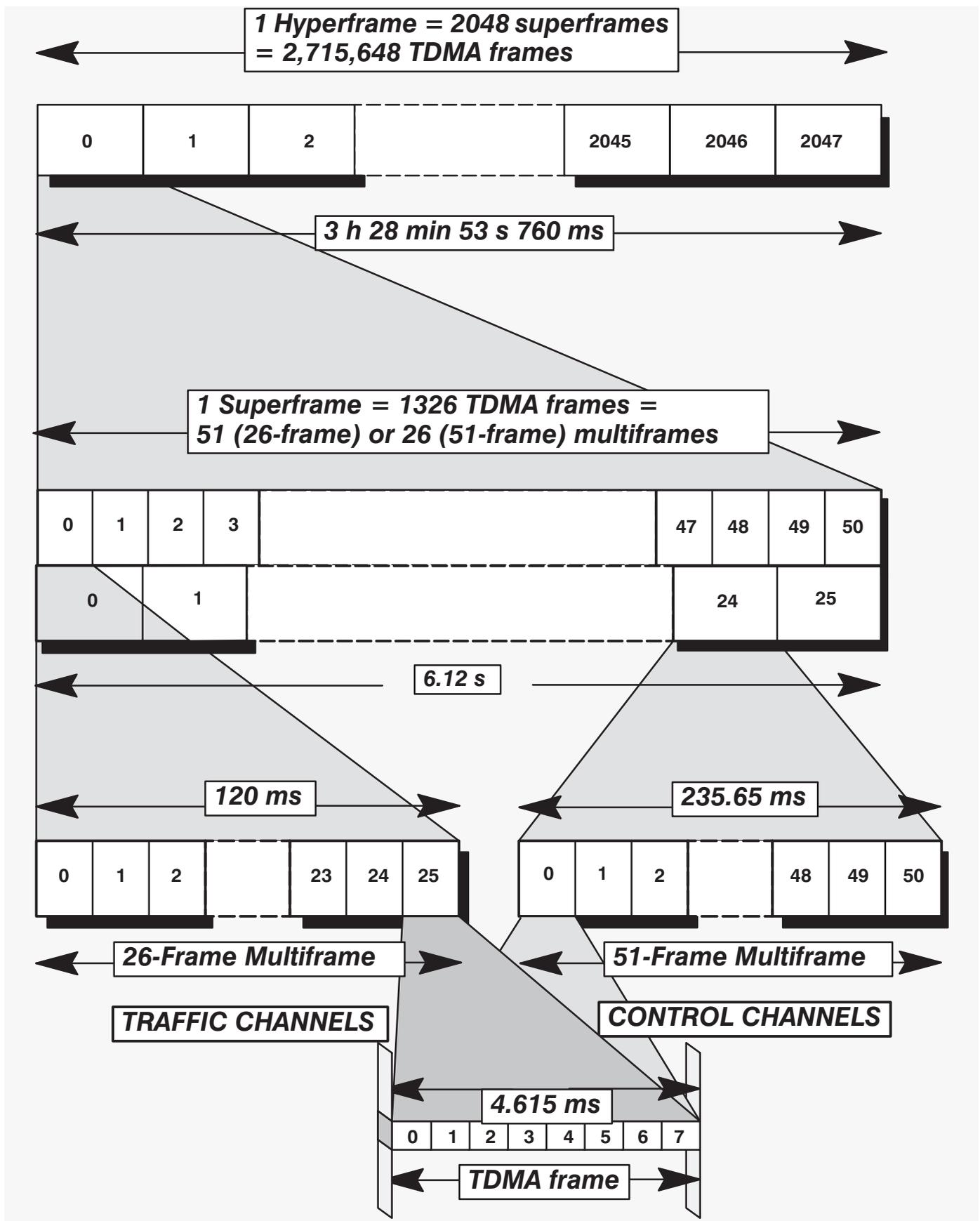
SUPERFRAMES AND HYPERFRAMES

It is not by accident that the control channel multiframe is not a direct multiple of the traffic channel multiframe. From the diagram, it can be seen that any given frame number will only occur simultaneously in both multiframes every 1326 TDMA frames (26 x 51). This number of TDMA frames is termed a “superframe” and it takes 6.12 s to transmit. This arrangement means that the timing of the traffic channel multiframe is always moving in relation to that of the control channel multiframe and this enables a MS to receive and decode BCCH information from surrounding cells.

If the two multiframes were exact multiples of each other, then control channel timeslots would be permanently ‘masked’ by traffic channel timeslot activity. This changing relationship between the two multiframes is particularly important, for example, to a MS which needs to be able to monitor and report the RSSIs of neighbour cells (it needs to be able to ‘see’ all the BCCHs of those cells in order to do this).

The “hyperframe” consists of 2048 superframes, this is used in connection with ciphering and frequency hopping. The hyperframe lasts for over three hours, after this time the ciphering and frequency hopping algorithms are restarted.

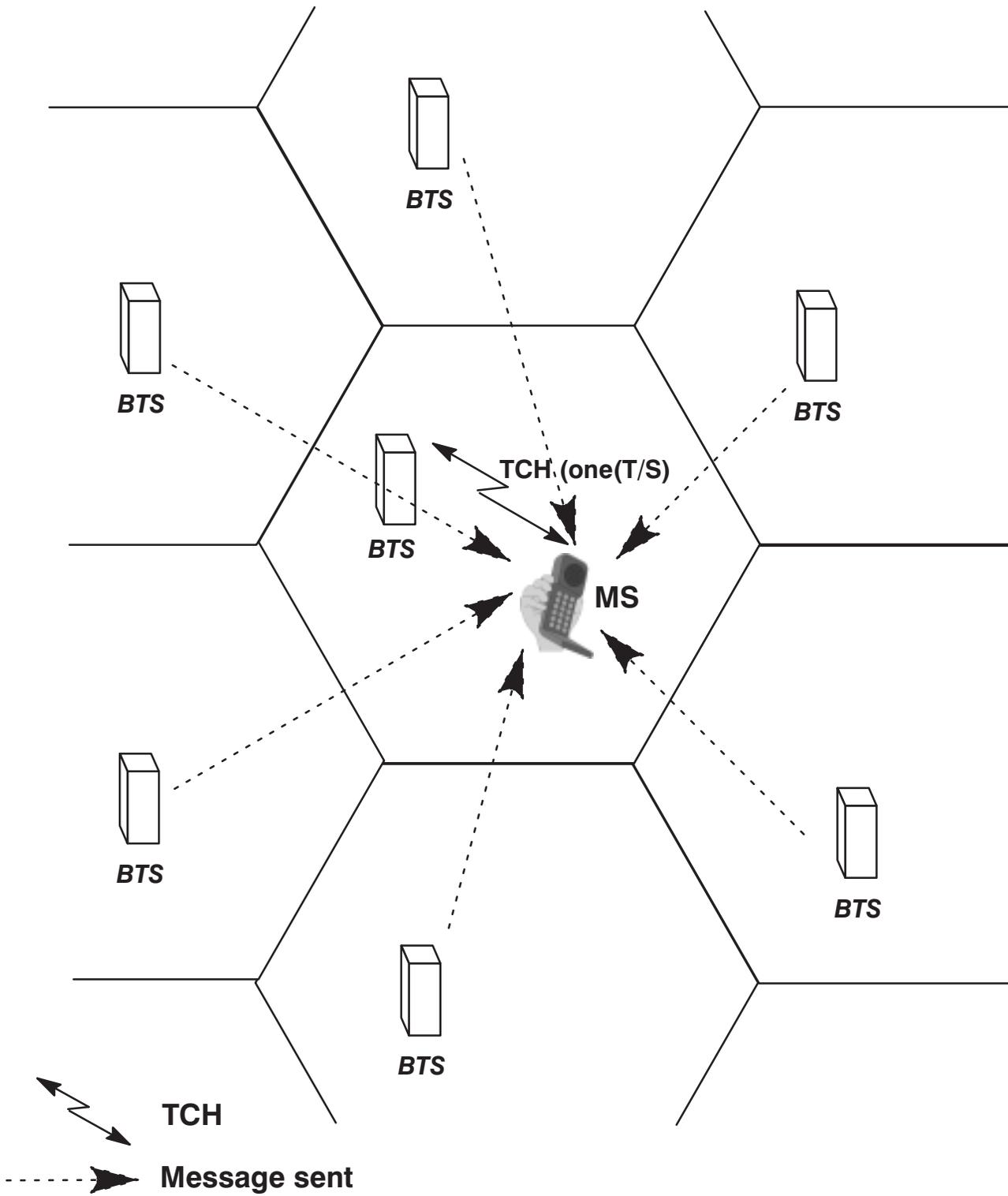
Superframe and Hyperframe



MOBILE ACTIVITY – TRANSMIT AND RECEIVE TIMESLOTS

As the MS only transmits or receives its own physical channel (normally containing TCH and SACCH) for one-eighth of the time, it uses the remaining time to monitor the BCCHs of adjacent 'target' cells. It completes the process every 480 ms, or four 26-TCH multiframes. The message that it sends to the BSS (on SACCH, uplink) contains the Receive Signal Strength Indication (RSSI) of the adjacent cells, plus that of the link to the BSS itself, plus an indication of the *quality* of the current connection. This quality measurement is somewhat similar to a bit error rate test. Just as the mobile completes one series of measurements, it completes sending the previous series to the BSS and starts to send the latest series; thus the processes of compilation and transmission form a continuous cycle.

Mobile Activity





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INTRODUCTION TO DIGITAL CELLULAR

Section 6

Channel Coding on the Air Interface

The information
contained in this document
is not intended to replace that contained
in the relevant equipment manuals and is
for the purpose of training only.

THIS MANUAL WILL NOT BE UPDATED

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Draw the structure of a GSM burst and identify the purpose of each component.
- . Have an understanding of the different mechanisms used to protect the air interface from errors on speech, data and control channels.



GSM BURSTS	2
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Introduction to Digital Cellular

Section 6

Channel Coding on the Air Interface

GSM BURSTS

The diagram opposite illustrates a GSM burst. It consists of several different elements. These elements are described below:

- **Info**

This is the area in which the speech, data or control information is held.

- **Guard Period**

The BTS and MS can only receive the burst and decode it, if it is received within the timeslot designated for it. The timing, therefore, must be extremely accurate, but the structure does allow for a small margin of error by incorporating a 'guard period' as shown in the diagram. To be precise, the timeslot is 0.577 ms long, whereas the burst is only 0.546 ms long, therefore there is a time difference of 0.031 ms to enable the burst to hit the timeslot.

- **Stealing Flags**

These two bits are set when a traffic channel burst has been "stolen" by a FACCH (the Fast Associated Control Channel). One bit set indicates that half of the block has been stolen.

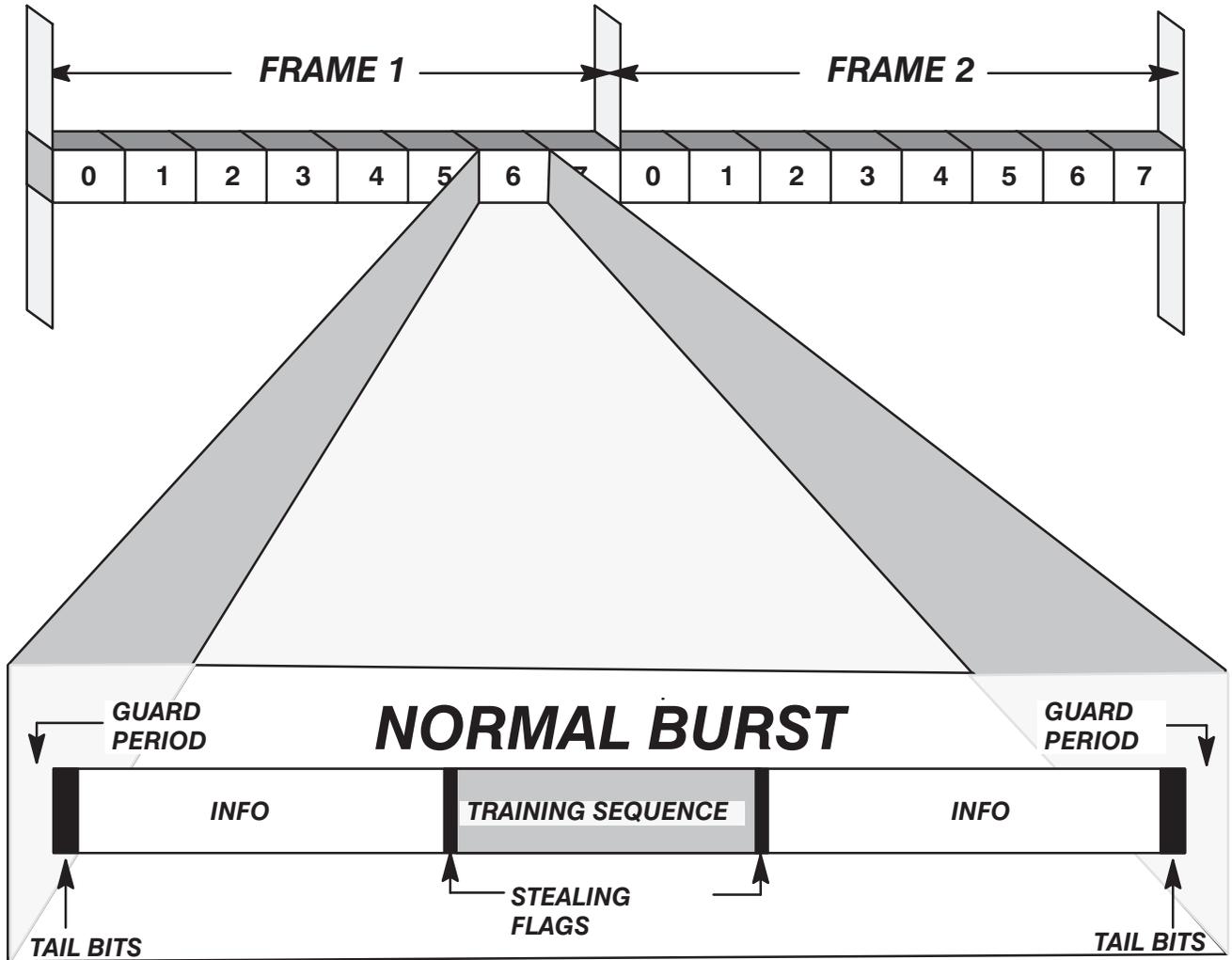
- **Training Sequence**

This is used by the receiver's equalizer as it estimates the transfer characteristic of the physical path between the BTS and the MS. The training sequence is 26 bits long.

- **Tail Bits**

These are used to indicate the beginning and end of the burst.

GSM Burst and TDMA Frame



GSM BURSTS . . .

BURST TYPES

The diagram opposite shows the five types of burst employed in the GSM air interface. All bursts, of whatever type, have to be timed so that they are received within the appropriate timeslot of the TDMA frame.

The burst is the sequence of bits transmitted by the BTS or MS, the timeslot is the discrete period of real time within which it must arrive in order to be correctly decoded by the receiver:

- **Normal Burst**

The normal burst carries traffic channels and all types of control channels apart from those mentioned specifically below. (Bi-directional).

- **Frequency Correction Burst**

This burst carries FCCH downlink to correct the frequency of the MS's local oscillator, effectively locking it to that of the BTS.

- **Synchronization Burst**

So called because its function is to carry SCH downlink, synchronizing the timing of the MS to that of the BTS.

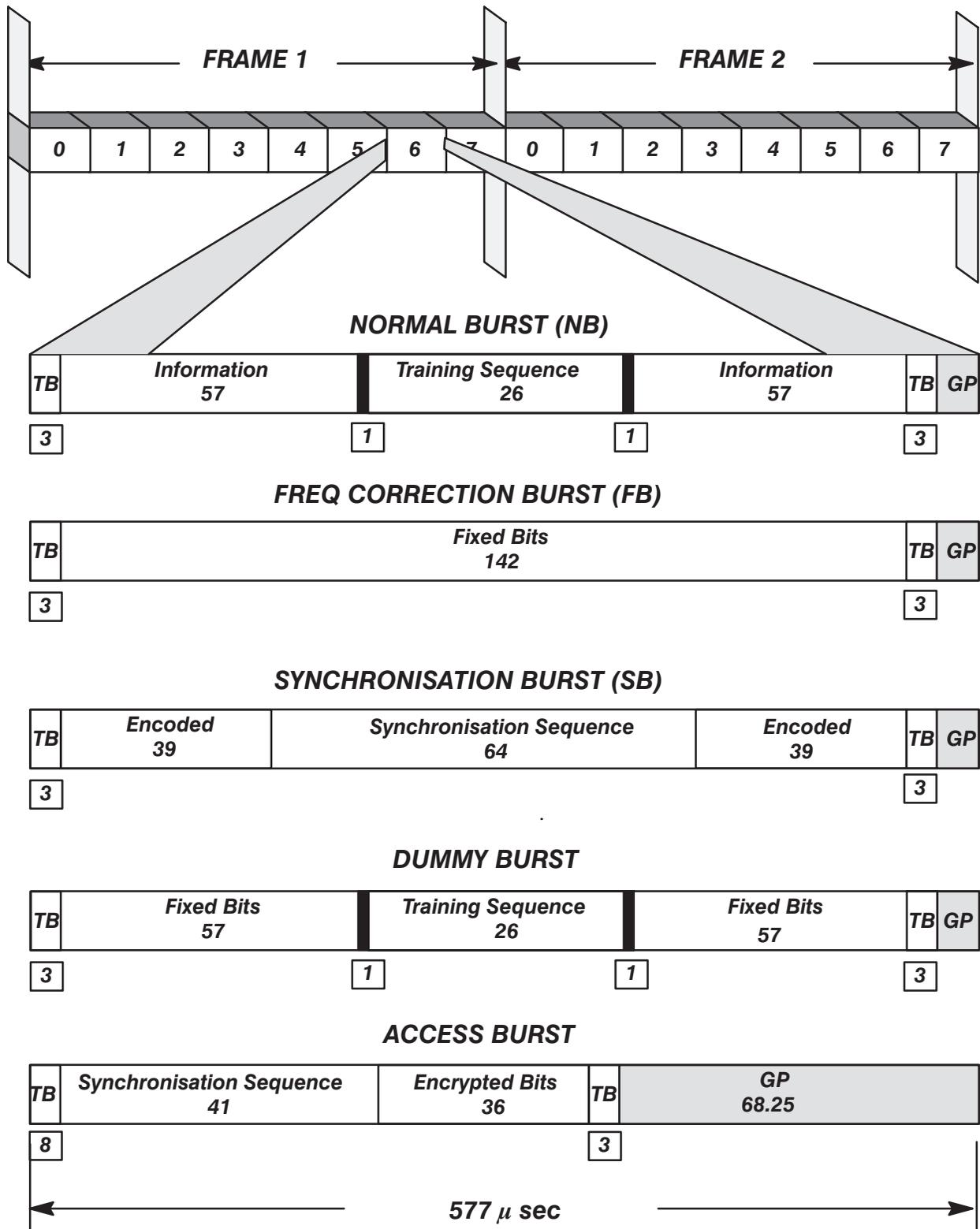
- **Dummy Burst**

Used when there is no information to be carried on the unused timeslots of the BCCH Carrier (Downlink only).

- **Access Burst**

This burst is of much shorter duration than the other types. The increased guard period is necessary because the timing of its transmission is unknown. When this burst is transmitted, the BTS does not know the location of the MS and therefore the timing of the message from the MS can not be accurately accounted for. (The Access Burst is uplink only.)

GSM Burst Types



ERROR PROTECTION AND DETECTION

To protect the logical channels from transmission errors introduced by the radio path, many different coding schemes are used. The diagram overleaf illustrates the coding process for speech, control and data channels; the sequence is very complex.

The coding and interleaving schemes depend on the type of logical channel to be encoded. All logical channels require some form of convolutional encoding, but since protection needs are different, the code rates may also differ.

Three coding protection schemes:

- **Speech Channel Encoding**

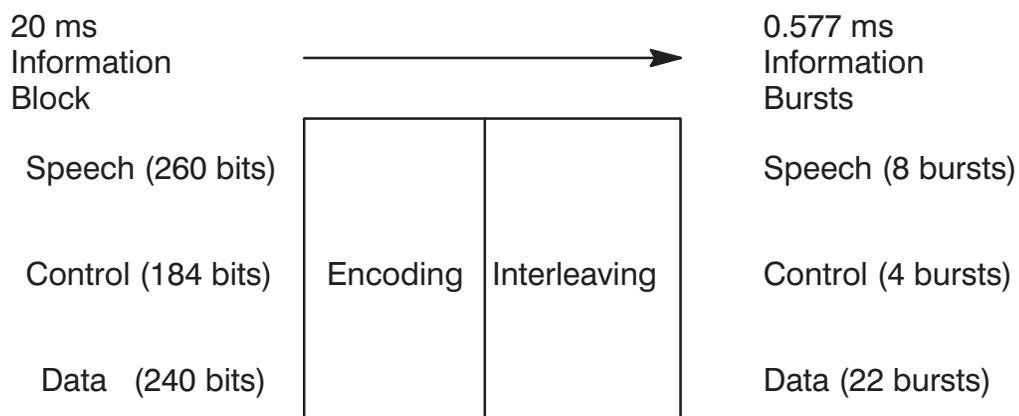
The speech information for one 20 ms speech block is divided over eight GSM bursts. This ensures that if bursts are lost due to interference over the air interface the speech can still be accurately reproduced.

- **Common Control Channel Encoding**

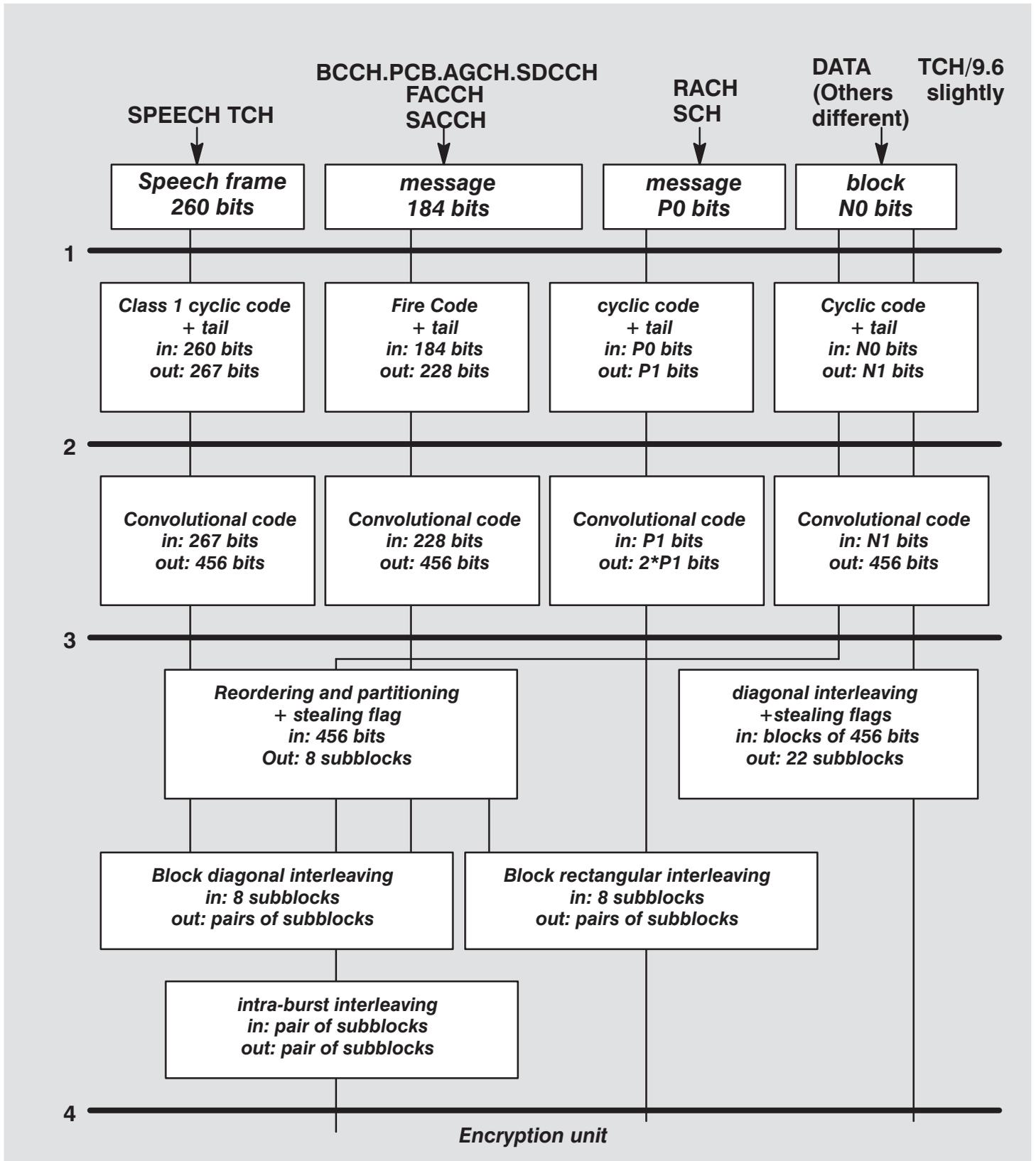
20 ms of information over the air will carry four bursts of control information, for example BCCH. This enables the bursts to be inserted into one TDMA multiframe.

- **Data Channel Encoding**

The data information is spread over 22 bursts. This is because every bit of data information is very important. Therefore, when the data is reconstructed at the receiver, if a burst is lost, only a very small proportion of the 20 ms block of data will be lost. The error encoding mechanisms should then enable the missing data to be reconstructed.



Error Protection and Detection



ERROR PROTECTION AND DETECTION . . .

SPEECH CHANNEL ENCODING

The BTS receives transcoded speech over the Abis interface from the BSC. At this point the speech is organized into its individual logical channels by the BTS. These logical channels of information are then channel coded before being transmitted over the air interface.

The transcoded speech information is received in frames, each containing 260 bits. The speech bits are grouped into three classes of sensitivity to errors, depending on their importance to the intelligibility of speech.

- **Class 1a**

Three parity bits are derived from the 50 class 1a bits. Transmission errors within these bits are catastrophic to speech intelligibility, therefore, the speech decoder is able to detect uncorrectable errors within the class 1a bits. If there are class 1a bit errors, the whole block is usually ignored.

- **Class 1b**

The 132 class 1b bits are not parity checked, but are fed together with the class 1a and parity bits to a convolutional encoder. Four tail bits are added which set the registers in the receiver to a known state for decoding purposes.

- **Class 2**

The 78 least sensitive bits are not protected at all.

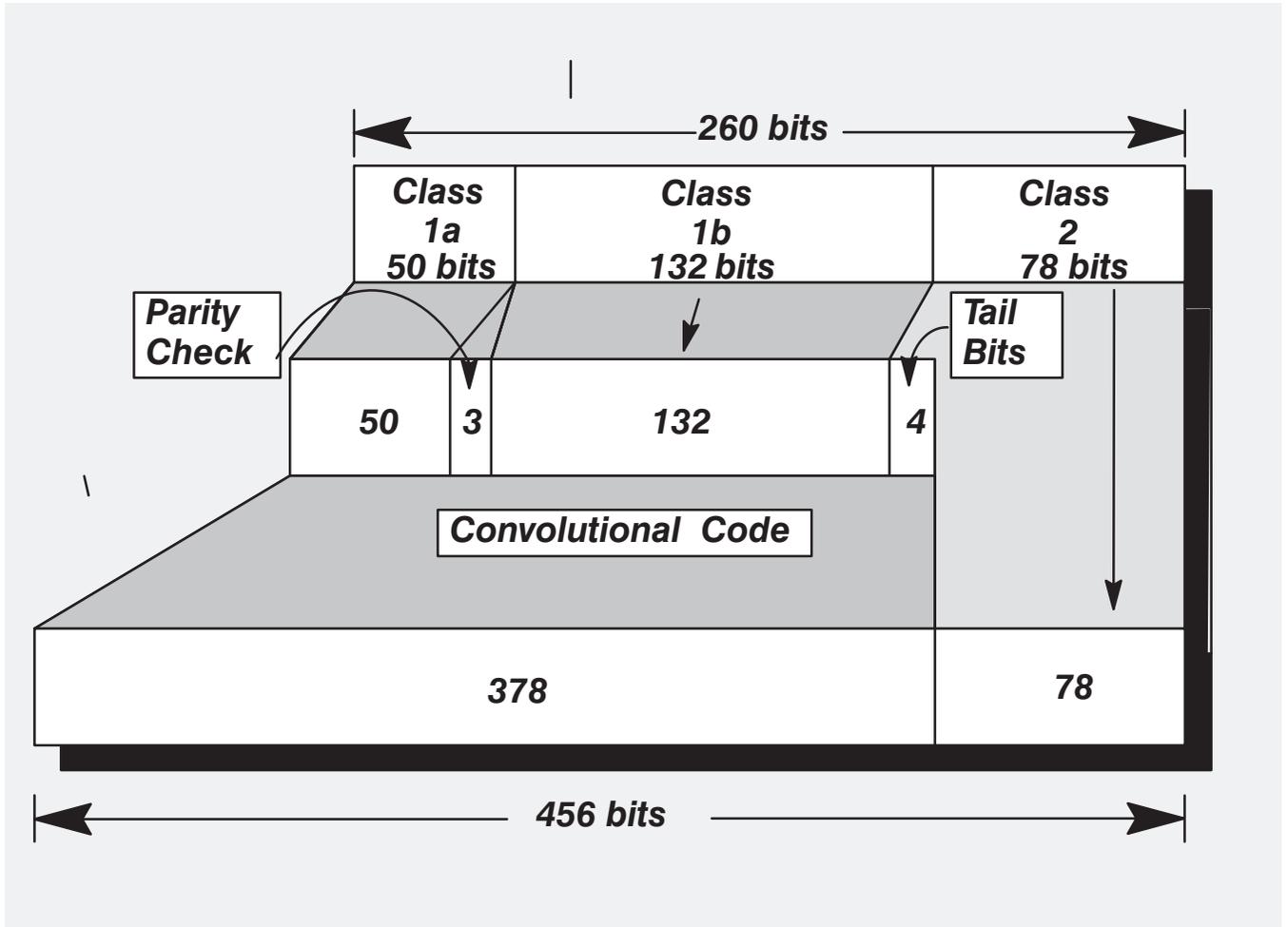
The resulting 456 bit block is then interleaved before being sent over the air interface.

Note:

Over the Abis link 260 bits were transmitted in 20 ms equalling a transmission rate of 13 kbit/s.

The encoded speech now occupies 456 bits but is still transmitted in 20 ms thus raising the transmission rate to 22.8 kbit/s.

Speech Channel Coding



ERROR PROTECTION AND DETECTION . . .

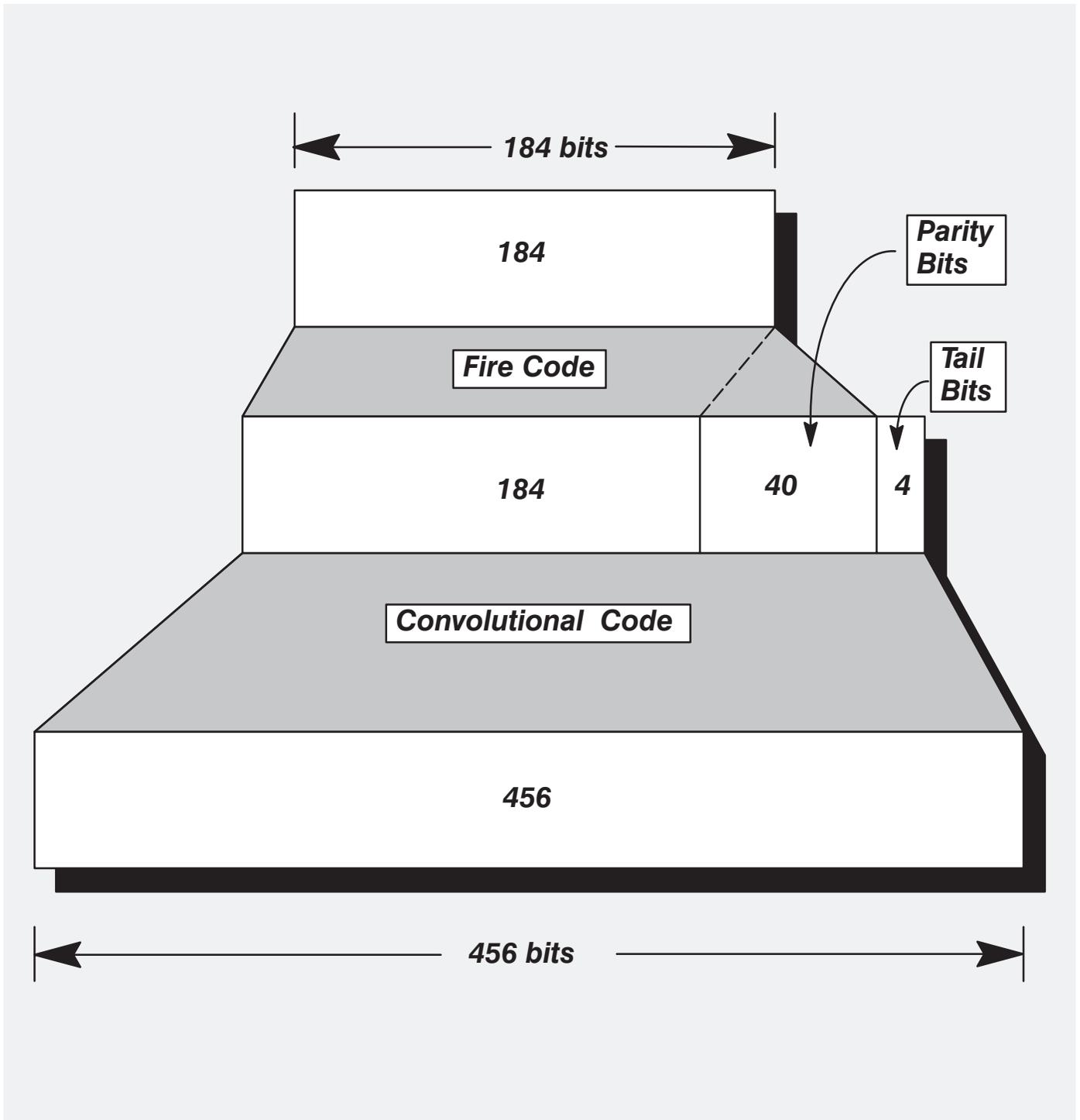
CONTROL CHANNEL ENCODING

The diagram opposite shows the principle of the error protection for the control channels. This scheme is used for all the logical signalling channels, the synchronization channel (SCH) and the random access burst (RACH). The diagram applies to SCH and RACH, but with different numbers.

When control information is received by the BTS it is received as a block of 184 bits. These bits are first protected with a cyclic block code of a class known as a Fire Code,. This is particularly suitable for the detection and correction of burst errors, as it uses 40 parity bits. Before the convolutional encoding, four tail bits are added which set the registers in the receiver to a known state for decoding purposes.

The output from the encoding process for each block of 184 bits of signalling data is 456 bits, exactly the same as for speech. The resulting 456 bit block is then interleaved before being sent over the air interface.

Control Channel Encoding



ERROR PROTECTION AND DETECTION . . .

DATA CHANNEL ENCODING

The diagram opposite shows the principle of the error protection for the 9.6 kbit/s data channel. The other data channels at rates of 4.8 kbit/s and 2.4 kbit/s are encoded slightly differently, but the principle is the same.

Data channels are encoded using a convolutional code only. With the 9.6 kbit/s data some coded bits need to be removed (*punctuated*) before interleaving, so that like the speech and control channels they contain 456 bits every 20 ms.

The data traffic channels require a higher net rate ('net rate' means the bit rate before coding bits have been added) than their actual transmission rate. For example, the 9.6 kbit/s service will require 12 kbit/s, because status signals (such as the RS-232 DTR (Data Terminal Ready) have to be transmitted as well.

The output from the encoding process for each block of 240 bits of data traffic is 456 bits, exactly the same as for speech and control. The resulting 456 bit block is then interleaved before being sent over the air interface.

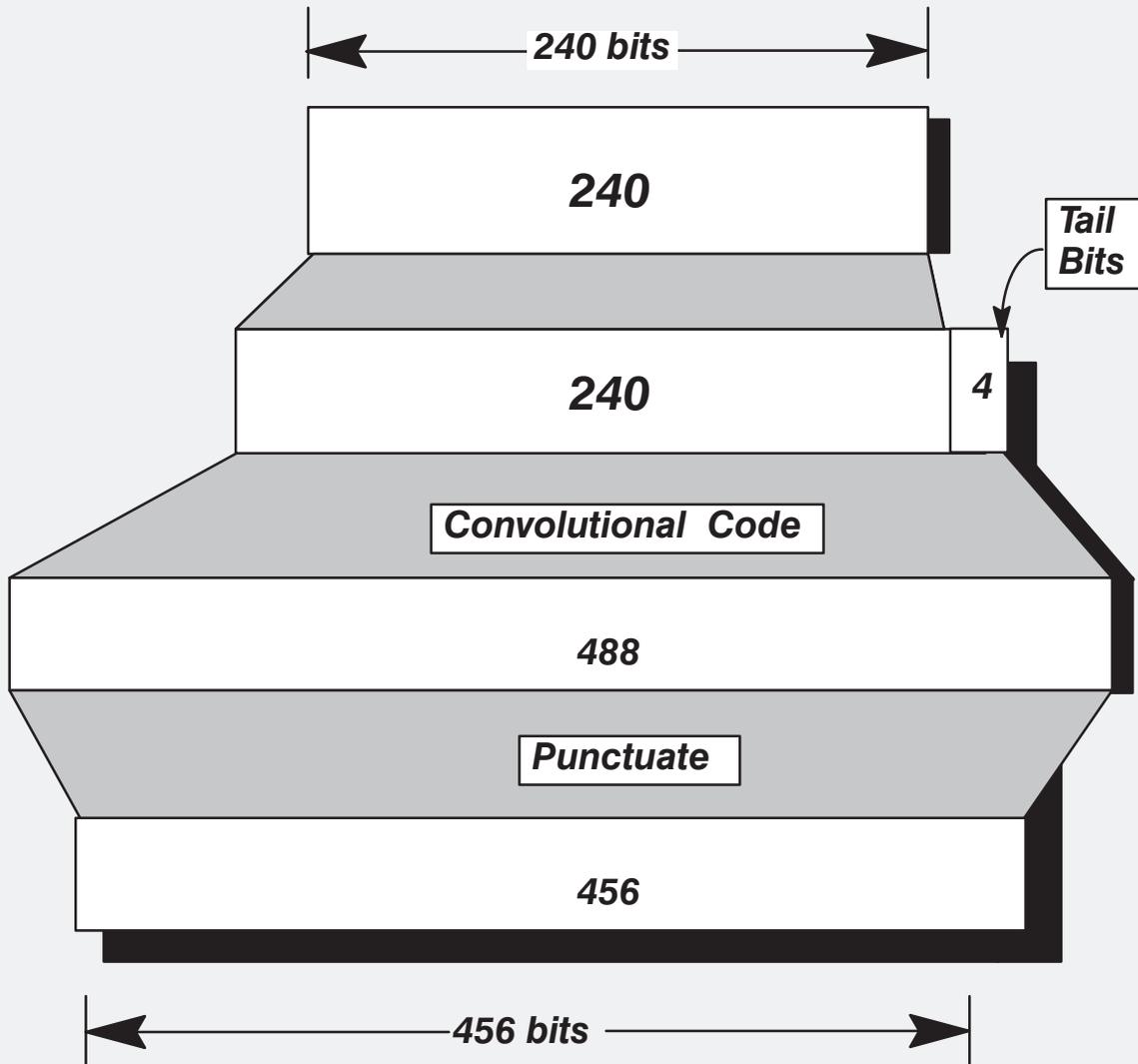
Note:

Over the PCM link 240 bits were transmitted in 20 ms equalling a transmission rate of 12 kbit/s. 9.6 kbit/s raw data and 2.4 kbit/s signalling information.

The encoded control information now occupies 456 bits but is still transmitted in 20 ms thus raising the transmission rate to 22.8 kbit/s.

Data Channel Encoding

Data Channel 9.6 kbit/s



MAPPING LOGICAL CHANNELS ONTO THE TDMA FRAME STRUCTURE

INTERLEAVING

Having encoded, or error protected the logical channel, the next step is to build its bitstream into bursts that can then be transmitted within the TDMA frame structure. It is at this stage that the process of interleaving is carried out. Interleaving spreads the content of one traffic block across several TDMA timeslots. The following interleaving depths are used:

- Speech – 8 blocks
- Control – 4 blocks
- Data – 22 blocks

This process is an important one, for it safeguards the data in the harsh air interface radio environment.

Because of interference, noise, or physical interruption of the radio path, bursts may be destroyed or corrupted as they travel between MS and BTS, a figure of 10–20% is quite normal. The purpose of interleaving is to ensure that only some of the data from each traffic block is contained within each burst. By this means, when a burst is not correctly received, the loss does not affect overall transmission quality because the error correction techniques are able to interpolate for the missing data. If the system worked by simply having one traffic block per burst, then it would be unable to do this and transmission quality would suffer.

It is *interleaving* that is largely responsible for the robustness of the GSM air interface, enabling it to withstand significant noise and interference and maintain the quality of service presented to the subscriber.

Interleaving

TRAU Frame Type	Number of GSM Bursts Spread Over
Speech	8
Control	4
Data	22

Note:

TRAU = Transcoder Rate Adaption Unit

MAPPING LOGICAL CHANNELS ONTO THE TDMA FRAME STRUCTURE . . .

DIAGONAL INTERLEAVING – SPEECH

The diagram opposite illustrates, in a simplified form, the principle of the interleaving process applied to a full-rate speech channel.

The diagram shows a sequence of ‘speech blocks’ after the encoding process previously described, all from the same subscriber conversation. Each block contains 456 bits, these blocks are then divided into eight blocks each containing 57 bits. Each block will only contain bits from even bit positions or bits from odd bit positions.

The GSM burst will now be produced using these blocks of speech bits.

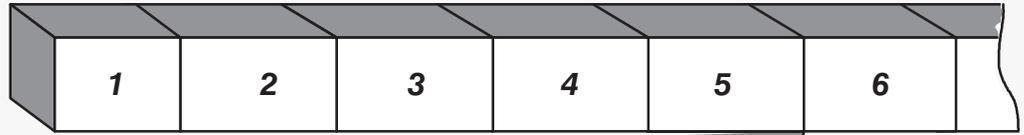
The first four blocks will be placed in the even bit positions of the first four bursts. The last four blocks will be placed in the odd bit positions of the next four bursts.

As each burst contains 114 traffic carrying bits, it is in fact shared by two speech blocks. Each block will share four bursts with the block preceding it, and four with the block that succeeds it, as shown. In the diagram block 5 shares the first four bursts with block 4 and the second four bursts with block 6.

Diagonal interleaving – Speech

Full-rate speech blocks from one conversation arrive after encoding. They each contain 456 bits.

Speech Blocks



456 bits

5

57 bits even, 57 bits odd, 57 bits even, 57 bits odd, 57 bits even, 57 bits odd, 57 bits even, 57 bits odd



Shared by blocks 4 & 5
block 5 even bits
block 4 odd bits

Shared by blocks 5 & 6
block 6 even bits
block 5 odd bits

MAPPING LOGICAL CHANNELS ONTO THE TDMA FRAME STRUCTURE . . .

TRANSMISSION – SPEECH

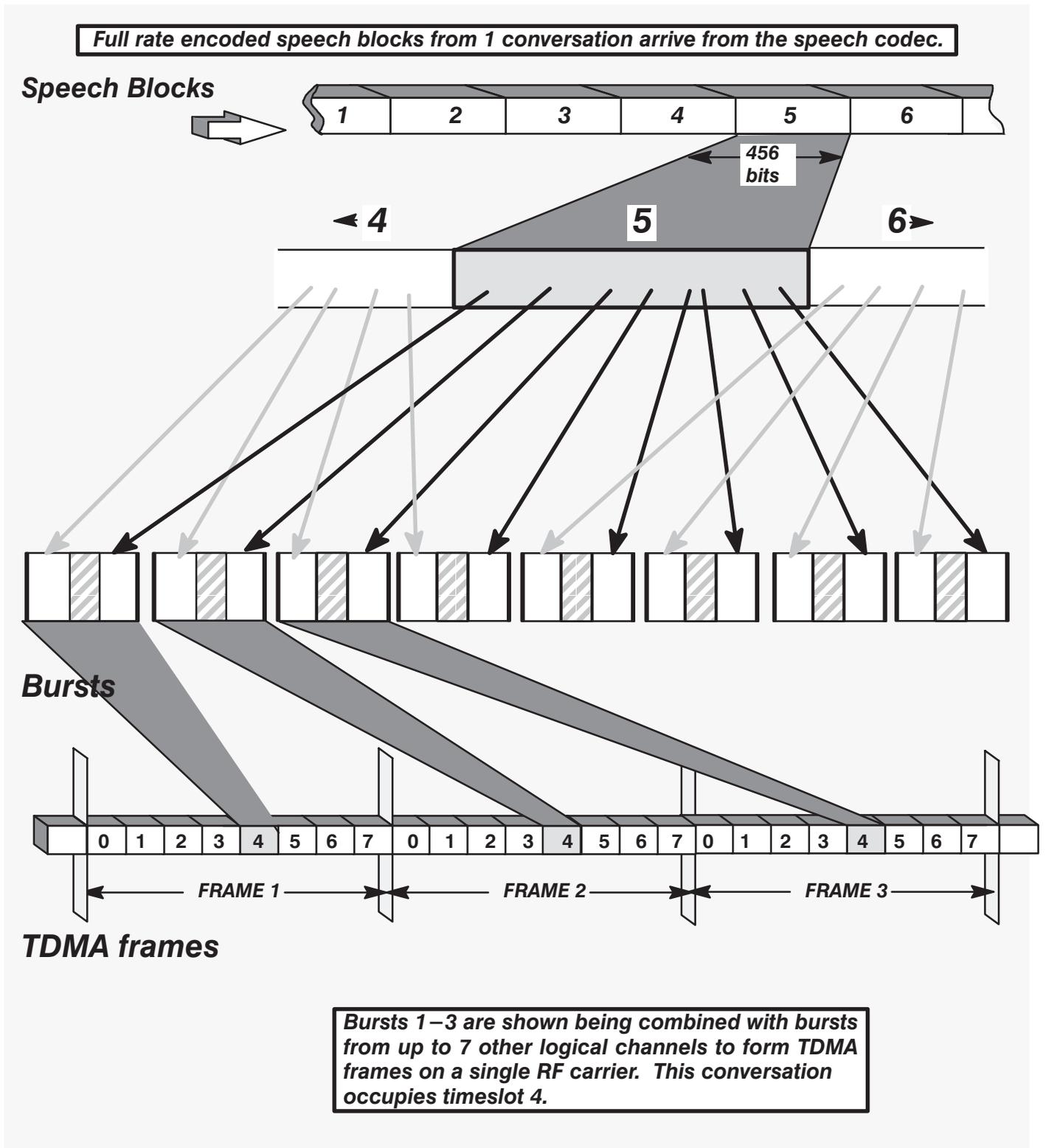
Each burst will be transmitted in the designated timeslot of eight consecutive TDMA frames, providing the interleaving depth of eight.

The diagram opposite shows how successive bursts from this particular subscriber conversation are transmitted. The subscriber is allocated timeslot 4 of the TDMA frame; it will share this frame with up to seven other subscribers.

It is important to remember that each timeslot on this carrier may be occupied by a different channel combination: traffic, broadcast, dedicated or combined.

Note that FACCH, because it ‘steals’ speech bursts from a subscriber channel, experiences the same kind of interleaving as the speech data that it replaces (interleaving depth = 8). The FACCH will steal a 456 bit block and be interleaved with the speech. Each burst containing a FACCH block of information will have the appropriate stealing flag set.

Diagonal Interleaving – Speech



MAPPING LOGICAL CHANNELS ONTO THE TDMA FRAME STRUCTURE . . .

RECTANGULAR INTERLEAVING – CONTROL

The diagram opposite illustrates, in a simplified form, the principle of rectangular interleaving. This is applied to most control channels.

The diagram shows a sequence of 'control blocks' after the encoding process previously described. Each block contains 456 bits, these blocks are then divided into four blocks each containing 114 bits. Each block will only contain bits for even or odd bit positions.

The GSM burst will be produced using these blocks of control.

TRANSMISSION – CONTROL

Each burst will be transmitted in the designated timeslot of four consecutive TDMA frames, providing the interleaving depth of four.

The control information is not diagonally interleaved as are speech and data. This is because only a limited amount of control information is sent every multiframe. If the control information was diagonally interleaved, the receiver would not be capable of decoding a control message until at least two multiframes were received. This would be too long a delay.



MAPPING LOGICAL CHANNELS ONTO THE TDMA FRAME STRUCTURE . . .

DIAGONAL INTERLEAVING – DATA

The diagram opposite illustrates, in a simplified form, diagonal interleaving applied to a 9.6 kbit/s data channel.

The diagram shows a sequence of 'data blocks' after the encoding process previously described, all from the same subscriber. Each block contains 456 bits, these blocks are divided into four blocks each containing 114 bits. These blocks are then interleaved together.

The first 6 bits from the first block are placed in the first burst. The first 6 bits from the second block will be placed in the second burst and so on. Each 114 bit block is spread across 19 bursts and the total 456 block will be spread across 22 bursts.

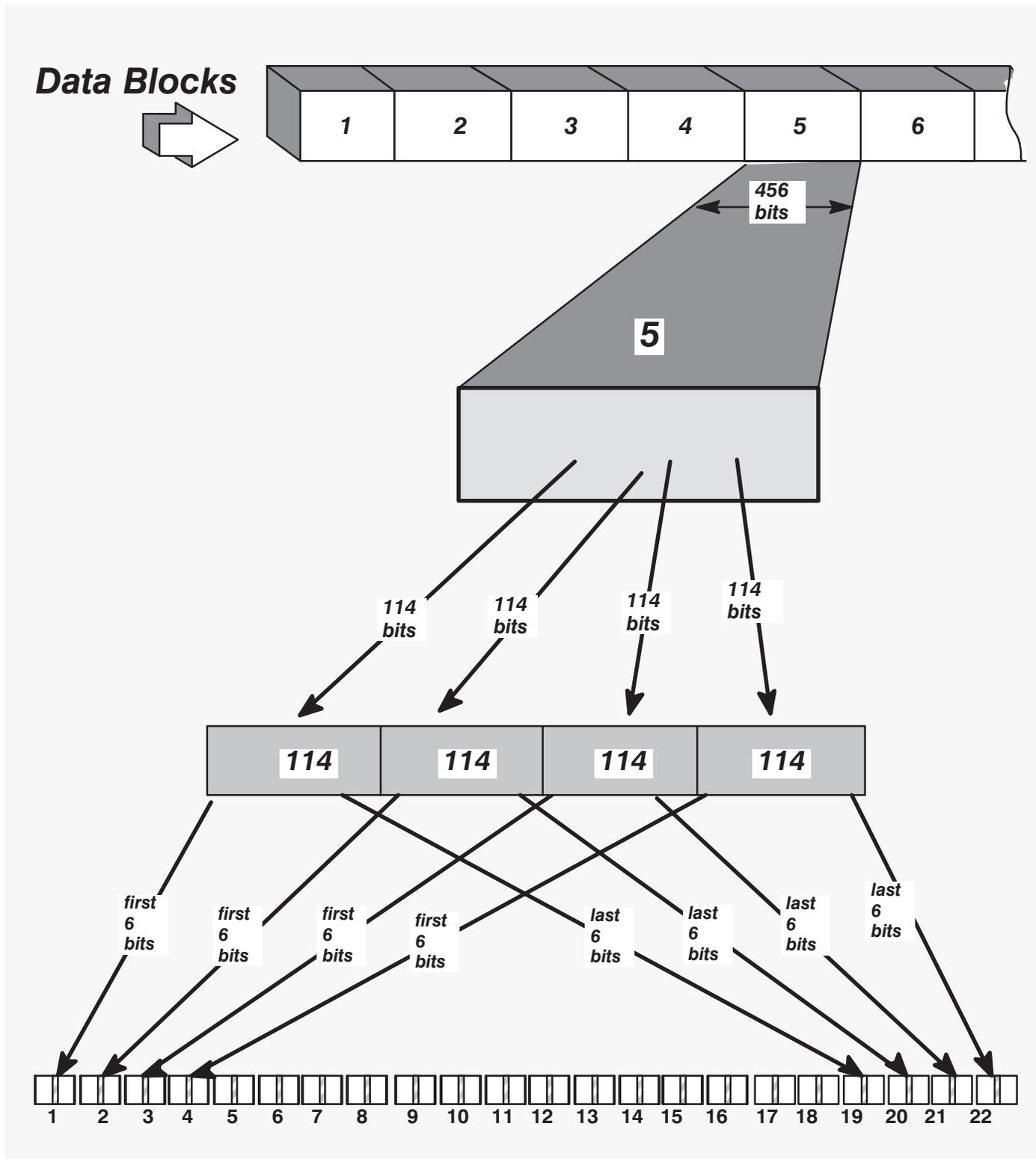
Data channels are said to have an interleaving depth of 22, although this is sometimes also referred to as an interleaving depth of 19.

TRANSMISSION – DATA

The data bits are spread over a large number of bursts to ensure that the data is protected. Therefore, if a burst is lost, only a very small amount of data from one data block will actually be lost. Due to the error protection mechanisms used, the lost data can be reproduced at the receiver.

This wide interleaving depth, although providing a high resilience to error, does introduce a time delay in the transmission of the data. If data transmission is slightly delayed, it will not effect the reception quality, whereas with speech, if a delay were introduced this could be detected by the subscriber. This is why speech uses a shorter interleaving depth.

Diagonal Interleaving – Data





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INTRODUCTION TO DIGITAL CELLULAR

Section 7

Radio Interface Optimisation

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contained in this document
is not intended to replace that contained
in the relevant equipment manuals and is
for the purpose of training only.

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Know the methods used to combat the following problems using GSM.
 - . Transmission Timing
 - . Multipath Fading
 - . Battery Life



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Introduction to Digital Cellular

Section 7

Radio Interface Optimization

TRANSMISSION TIMING

To simplify the design of the MS, the GSM specifications specify an offset of three timeslots between the BSS and MS timing, thus avoiding the necessity for the MS to transmit and receive simultaneously. The diagram opposite illustrates this.

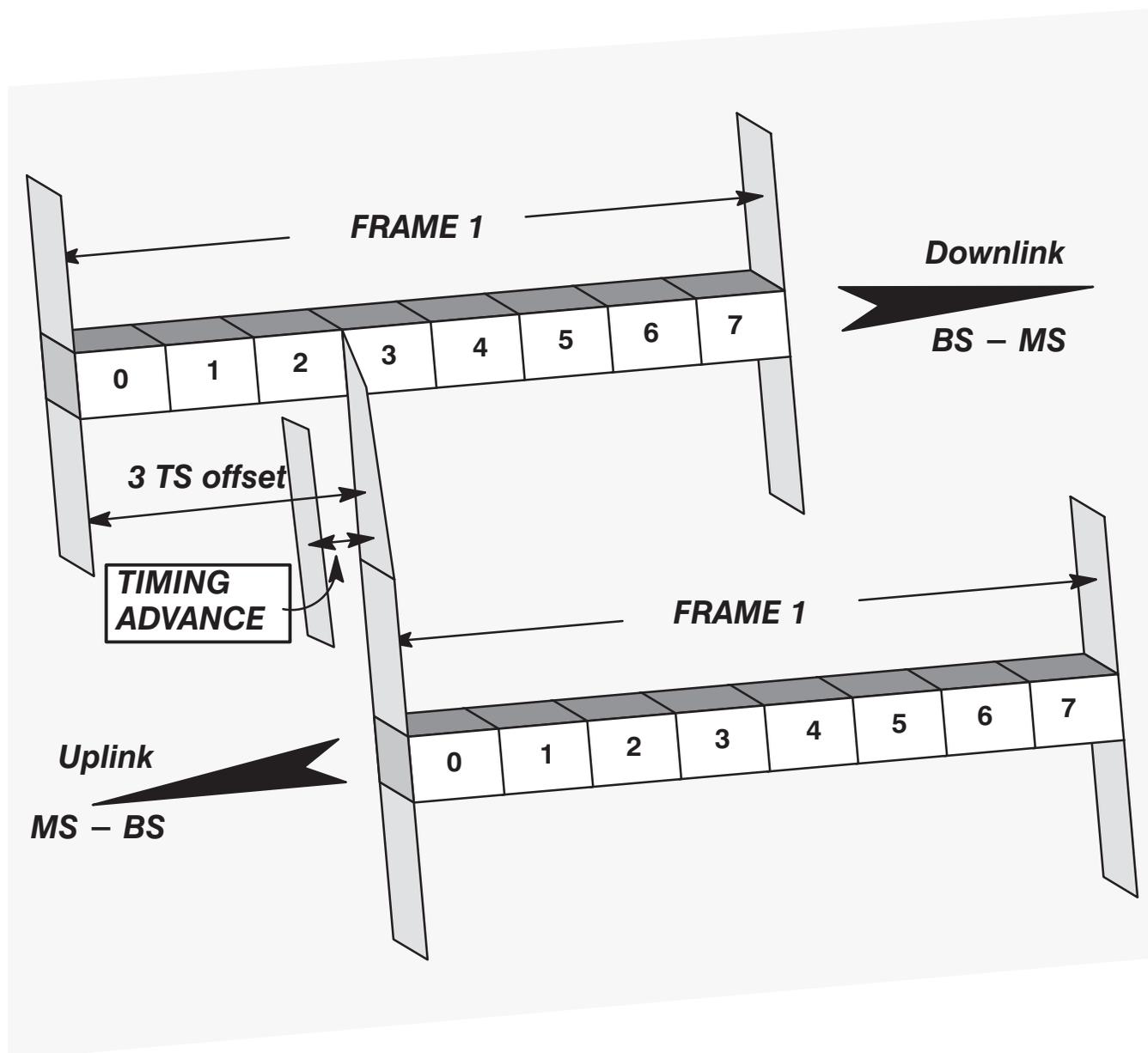
The synchronization of a TDMA system is critical because bursts have to be transmitted and received within the "real time" timeslots allotted to them. The further the MS is from the base station then, obviously, the longer it will take for the bursts to travel the distance between them. The GSM BTS caters for this problem by instructing the MS to advance its timing ((that is, transmit earlier) to compensate for the increased propagation delay.

This advance is then superimposed upon the three timeslot nominal offset.

The timing advance information is sent to the MS twice every second using the SACCH.

The maximum timing advance is approximately 233 μ s. This caters for a maximum cell radius of approximately 35 km.

Timing Advance



BATTERY LIFE

One of the main factors which restrict reducing the size of a MS is the battery.

A battery must be large enough to maintain a telephone call for an acceptable amount of time without needing to be recharged. Since there is demand for MSs to become smaller and lighter the battery must also become smaller and lighter.

Four features which enable the life of a GSM MS battery to be extended.

- Power Control
- Voice Activity Detection – VAD
- Discontinuous Transmission – DTX
- Discontinuous Reception – DRX

POWER CONTROL

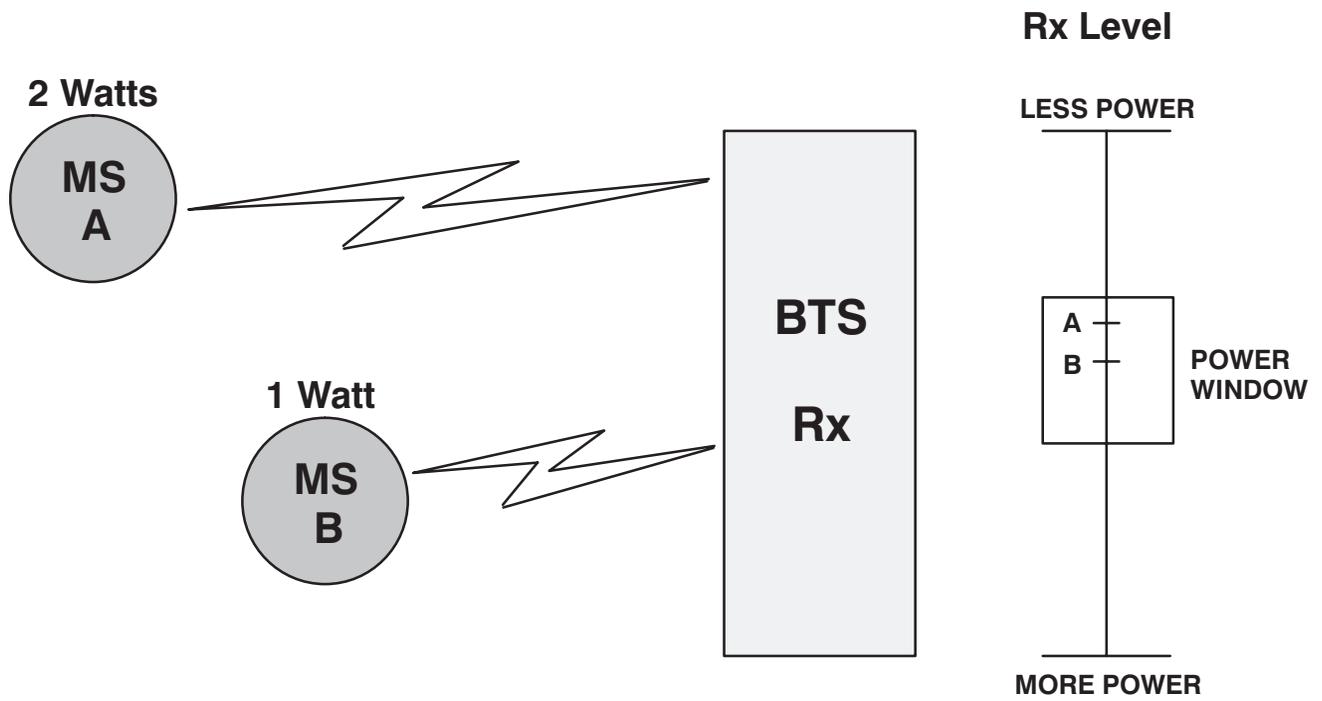
This is a feature of the GSM air interface which allows the network provider to not only compensate for the distance from MS to BTS as regards timing, but can also cause the BTS and MS to adjust their power output to take account of that distance also. The closer the MS is to the BTS, the less the power it and the BTS will be required to transmit. This feature saves radio battery power at the MS, and helps to reduce co-channel and adjacent channel interference.

Both Uplink and Downlink power settings can be controlled independently and individually at the discretion of the network provider.

Initial power setting for the MS is set by the information provided on the Broadcast Control Channel (BCCH) for a particular Cell.

The BSS controls the transmit power of both the MS and the BTS. The received MS power is monitored by the BSS and the receive BTS power is monitored by the MS and then reported to the BSS. Using these measurements the power of both MS and BTS can be adjusted accordingly

Power Control



Note:

The BTS will adjust the Tx power of each MS to ensure that the Rx signal at the BTS is maintained within the defined power window.

VOICE ACTIVITY DETECTION – VAD

VAD is a mechanism whereby the source transmitter equipment identifies the presence or absence of speech.

VAD implementation is effected in speech mode by encoding the speech pattern silences at a rate of 500 bit/s rather than the full 13 kbit/s. This results in a data transmission rate for background noise, known as “comfort” noise, which is regenerated in the receiver.

Without “comfort” noise the total silence between the speech would be considered to be disturbing by the listener.

DISCONTINUOUS TRANSMISSION – DTX

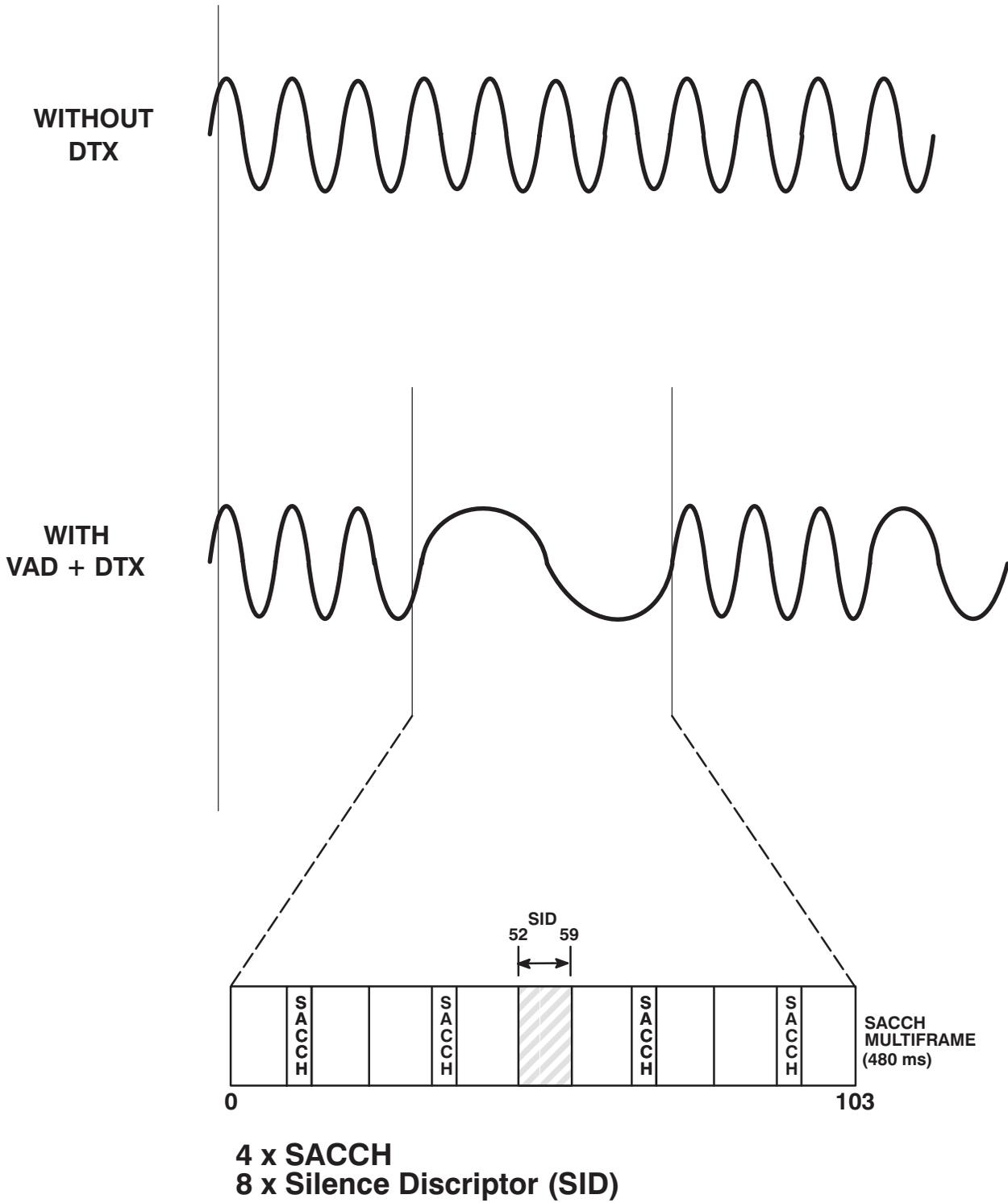
DTX increases the efficiency of the system through a decrease in the possible radio transmission interference level. It does this by ensuring that the MS does not transmit unnecessary message data. DTX can be implemented, as necessary, on a call by call basis. The effects will be most noticeable in communications between two MS.

DTX in its most extreme form, when implemented at the MS can also result in considerable power saving. If the MS does not transmit during ‘silences’ there is a reduction in the overall power output requirement.

The implementation of DTX is very much at the discretion of the network provider and there are different specifications applied for different types of channel usage.

DTX is implemented over a SACCH multiframe (480 ms). During this time, of the possible 104 frames, only the 4 SACCH frames and 8 Silence Descriptor (SID) frames are transmitted.

VAD & DTX



DISCONTINUOUS RECEPTION – DRX

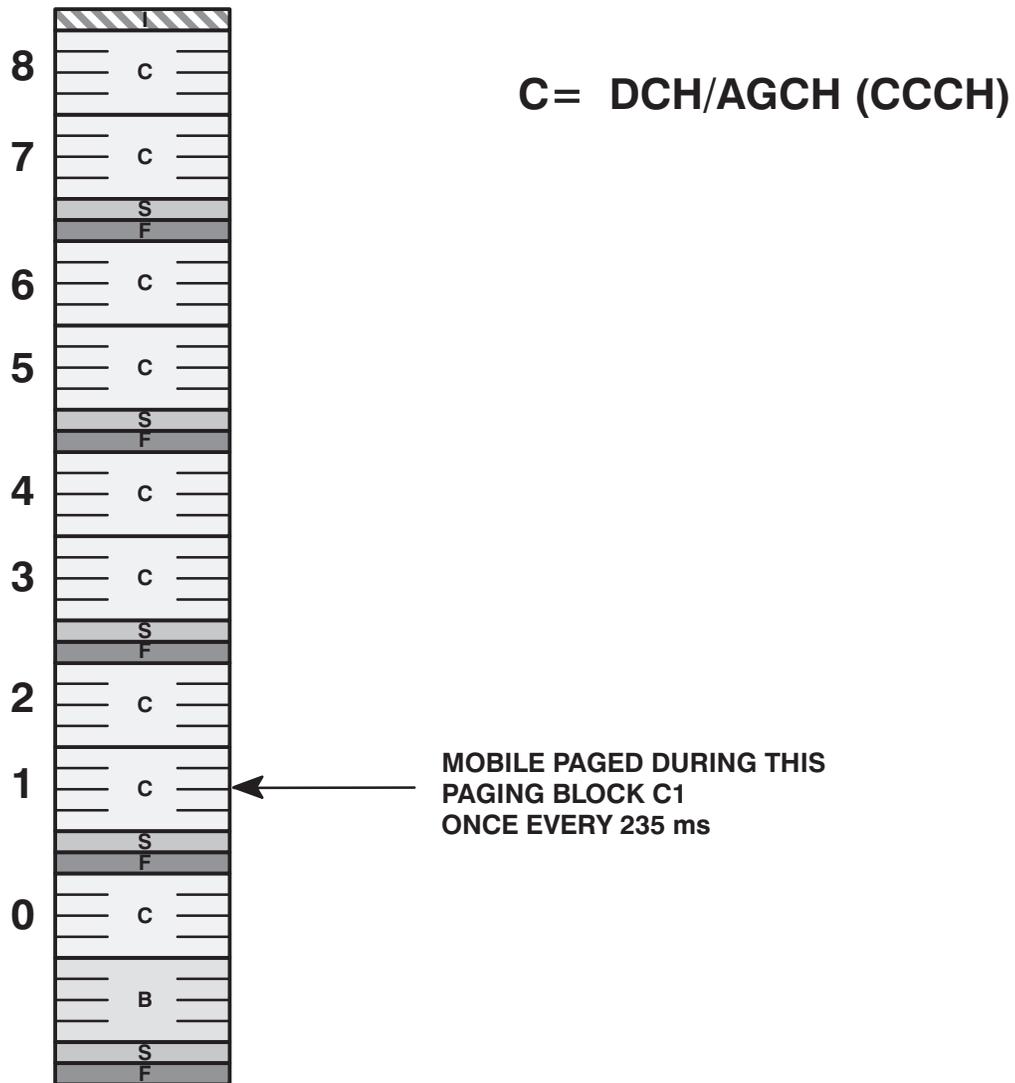
DRX allows the MS to effectively “switch off” during times when reception is deemed unnecessary.

By monitoring the Broadcast Control Channel (BCCH), the Frequency Correction Control Channel (FCCH) and the Synchronisation Control Channel (SCCH) the MS is aware of the Frame Number and repetition format for Frame Synchronization. It can therefore, after initially locking on to a BCCH, determine when the next relevant information is to be transmitted. This allows the MS to ‘go to sleep’ and listen-in only when necessary, with the effective saving in power usage.

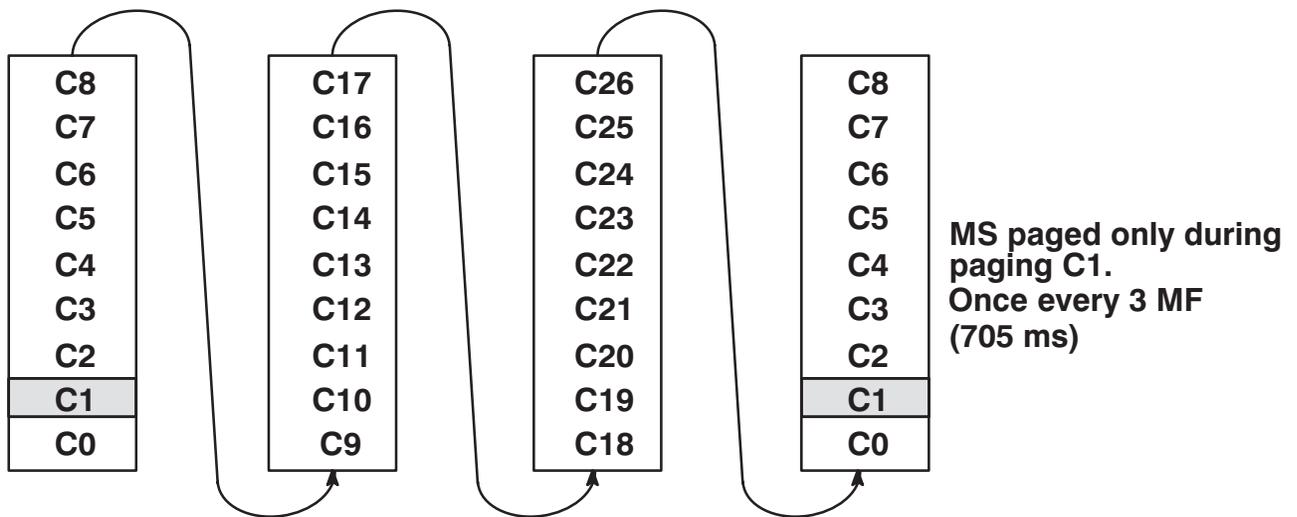
DRX may only be used when a MS is not in a call.

When DRX is employed, the MS using information broadcast on the BCCH determines its “paging group”. The paging group may appear once during a control channel multiframe, or may only be scheduled to appear once over several multiframe – the rate of repetition is determined by the network provider and it is this information which is broadcast over the BCCH, which allows the MS to determine its paging group.

DRX



OPTIONALLY: The MS may be paged once over a number of multiframes



MULTIPATH FADING

Multipath Fading results from a signal travelling from a transmitter to a receiver by a number of routes. This is caused by the signal being reflected from objects, or being influenced by atmospheric effects as it passes, for example, through layers of air of varying temperatures and humidity.

Received signals will therefore arrive at different times and not be in phase with each other, they will have experienced time dispersion. On arrival at the receiver, the signals combine either constructively or destructively, the overall effect being to add together or to cancel each other out. If the latter applies, there may be hardly any usable signal at all. The frequency band used for GSM transmission means that a “good” location may be only 15 cm from a “bad” location!

When the receive antenna is moving, the exact phase of each path changes and consequently the combined signal-strength is also continually changing. When the antenna is moving rapidly, this loss is recovered by interleaving and channel coding. When it is slow moving or stationary however, the receiver may be in a “null” (point of minimum signal) for several consecutive frames.

The diagram opposite shows a few routes by which a pulse of radio energy might be propagated from a base station to a mobile.

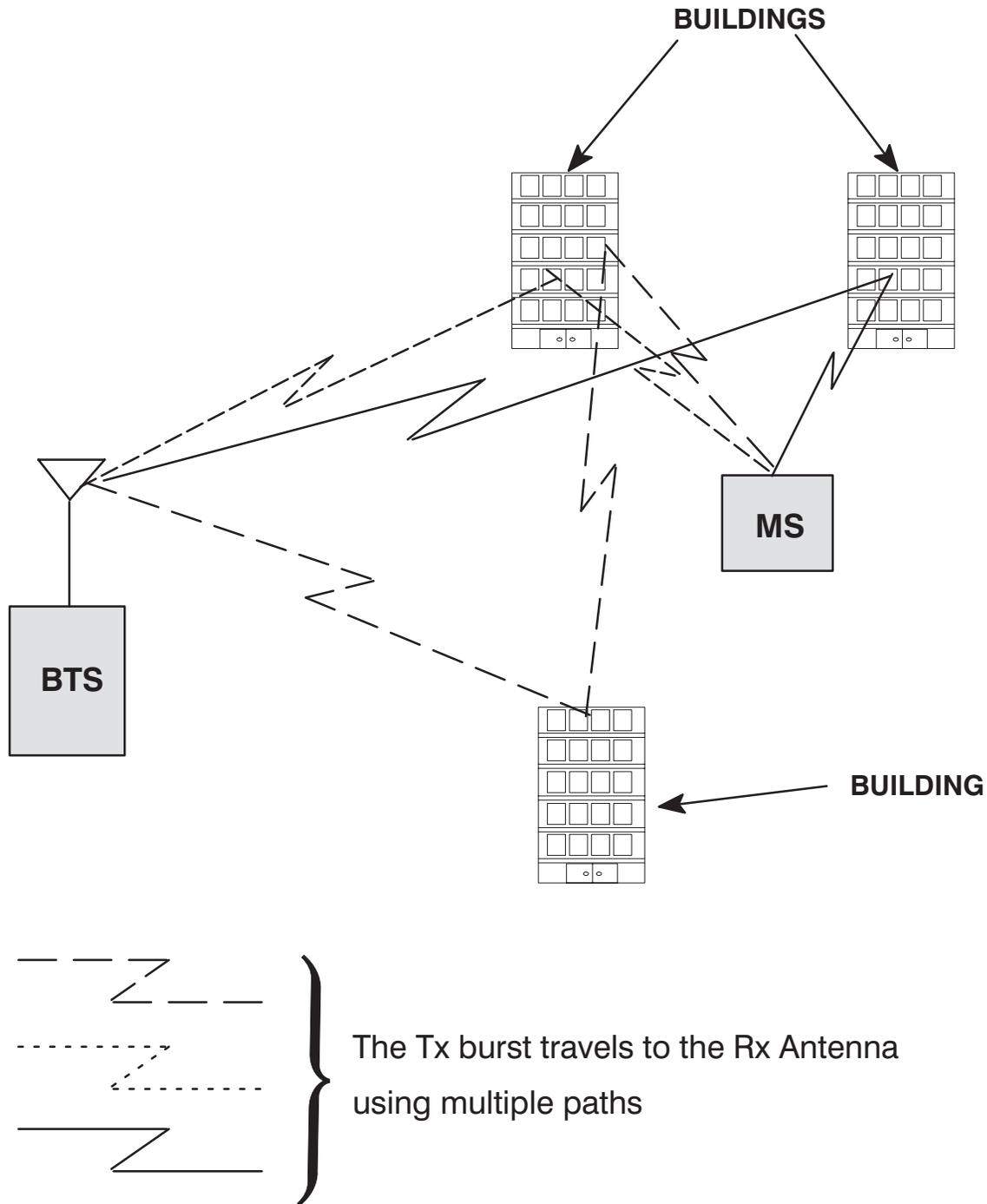
Each has suffered varying losses in transmission (path attenuation), hence the variety of amplitudes. A typical urban profile would cause dispersion of up to 5 microseconds, whereas, a hilly terrain would cause dispersion of up to 20 microseconds.

GSM offers five techniques which combat multipath fading effects:

- Equalization.
- Diversity.
- Frequency Hopping.
- Interleaving.
- Channel coding.

The equalizer must be able to cope with a dispersion of up to 17 microseconds.

Multipath Fading



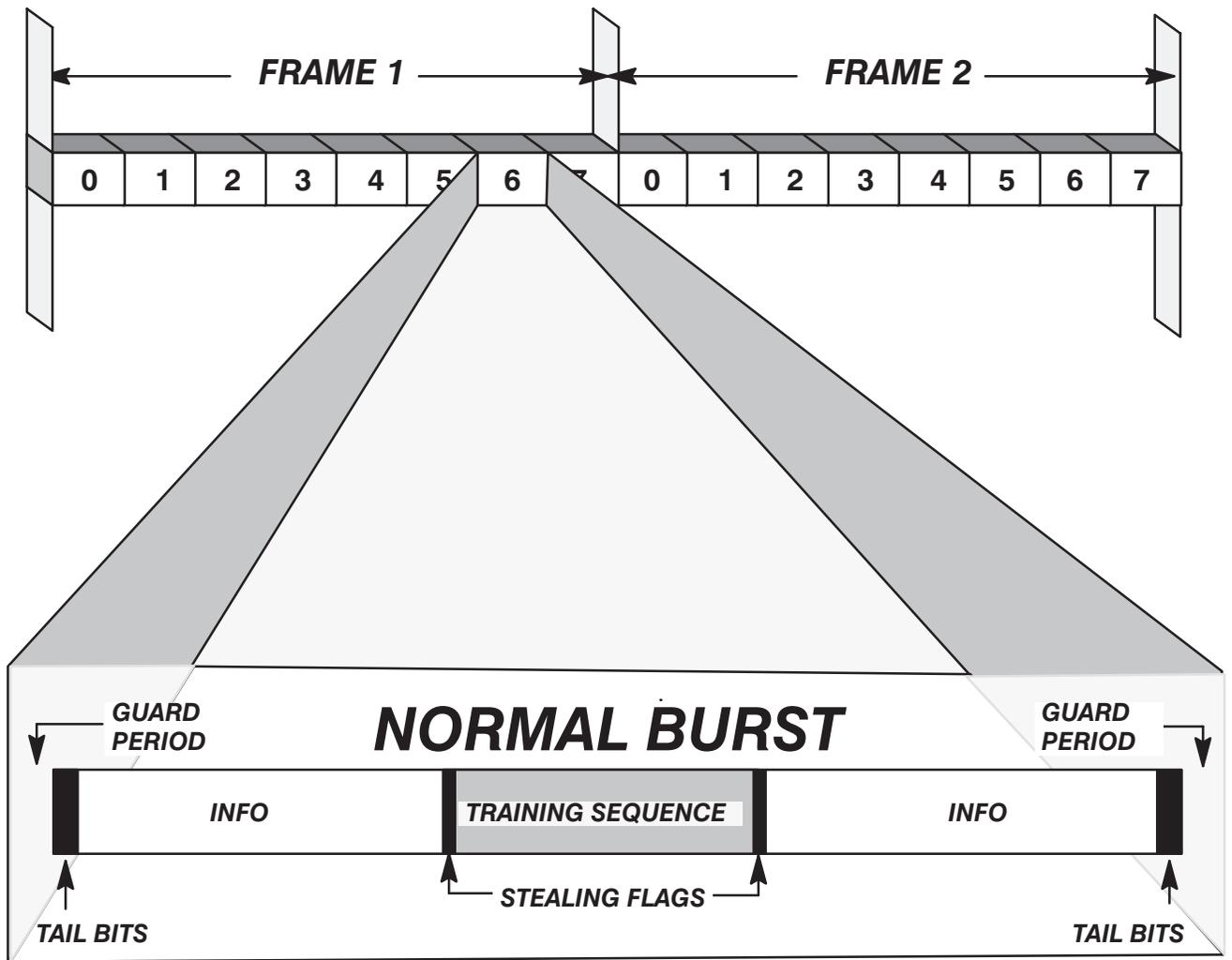
EQUALIZATION

Due to the signal dispersion caused by multipath signals the receiver cannot be sure exactly when a burst will arrive and how distorted it will be. To help the receiver identify and synchronize to the burst, a Training Sequence is sent at the centre of the burst. This is a set sequence of bits which is known by both the transmitter and receiver.

When a burst of information is received, the equalizer searches for the training sequence code. When it has been found, the equaliser measures and then mimics the distortion which the signal has been subjected to. The equalizer then compares the received data with the distorted possible transmitted sequences and chooses the most likely one.

There are eight different Training Sequence codes numbered 0-7. Nearby cells operating with the same RF carrier frequency will use different Training Sequence Codes to enable the receiver to discern the correct signal.

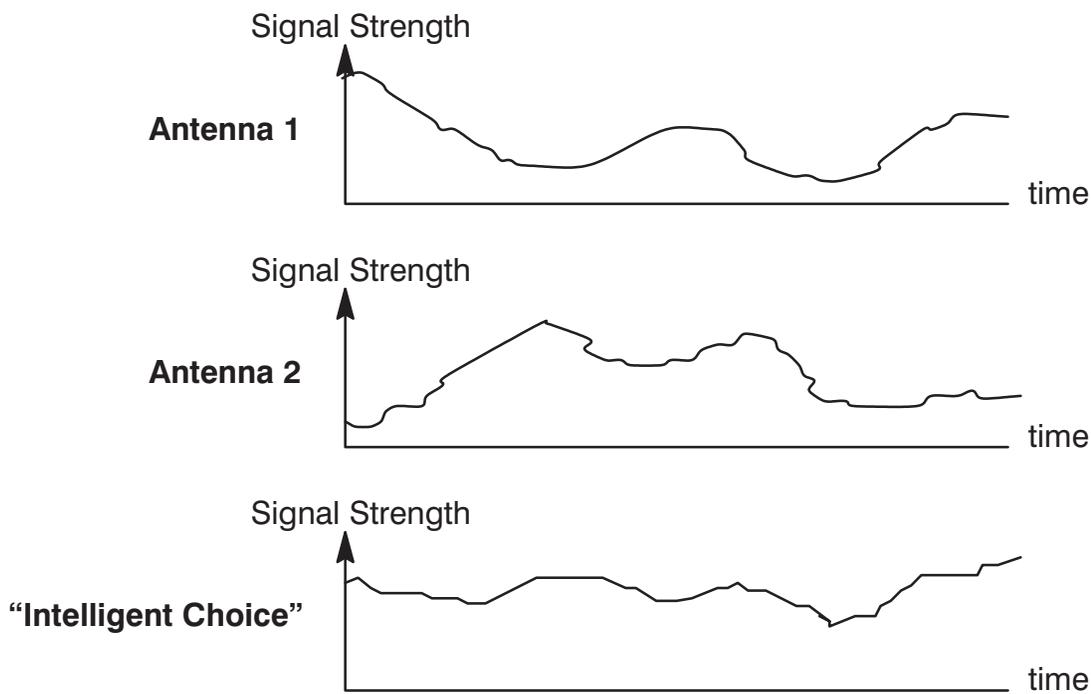
Training Sequence Code



DIVERSITY

Signals arrive at the receive antenna from multiple paths. The signals are therefore received by the antenna at different phases, some at a peak and some at a trough. This means that some signals will add together to form a strong signal, while others will subtract causing a weak signal.

When diversity is implemented, two antennas are situated at the receiver. These antennas are placed several wavelengths apart to ensure minimum correlation between the two receive paths. The two signals are then combined and the signal strength improved.



FREQUENCY HOPPING

INTRODUCTION

Frequency hopping allows the RF channel used for carrying signalling channel timeslots or traffic channel (TCH) timeslots to change frequency every frame (or 4.615 msec). This capability provides a high degree of immunity to interference, due to the effect of interference averaging, as well as providing protection against signal fading.

The effective "radio channel interference averaging" assumes that radio channel interference does not exist on every allocated channel and the RF channel carrying TCH timeslots changes to a new allocated RF channel every frame. Therefore, the overall received data communication experiences interference only part of the time.

All mobile subscribers are capable of frequency hopping under the control of the BSS. To implement this feature, the BSS software must include the frequency hopping option. Cyclic or pseudo random frequency hopping patterns are possible, by network provider selection.



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INTRODUCTION TO DIGITAL CELLULAR

Section 8

Call and Handover Sequences

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . Outline the basic GSM call set-up and handover processes and have an appreciation of the necessary message exchanges between GSM system entities.



GSM BASIC CALL SEQUENCE	2
MOBILE TO LAND SEQUENCE	4
LAND TO MOBILE SEQUENCE	6
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Introduction to Digital Cellular

Section 8

Call and Handover Sequences

GSM BASIC CALL SEQUENCE

The diagram opposite reminds us of the basic components and processes involved in setting up a call between a GSM MS and an ordinary “land” telephone.

- **In the MS – Land direction**

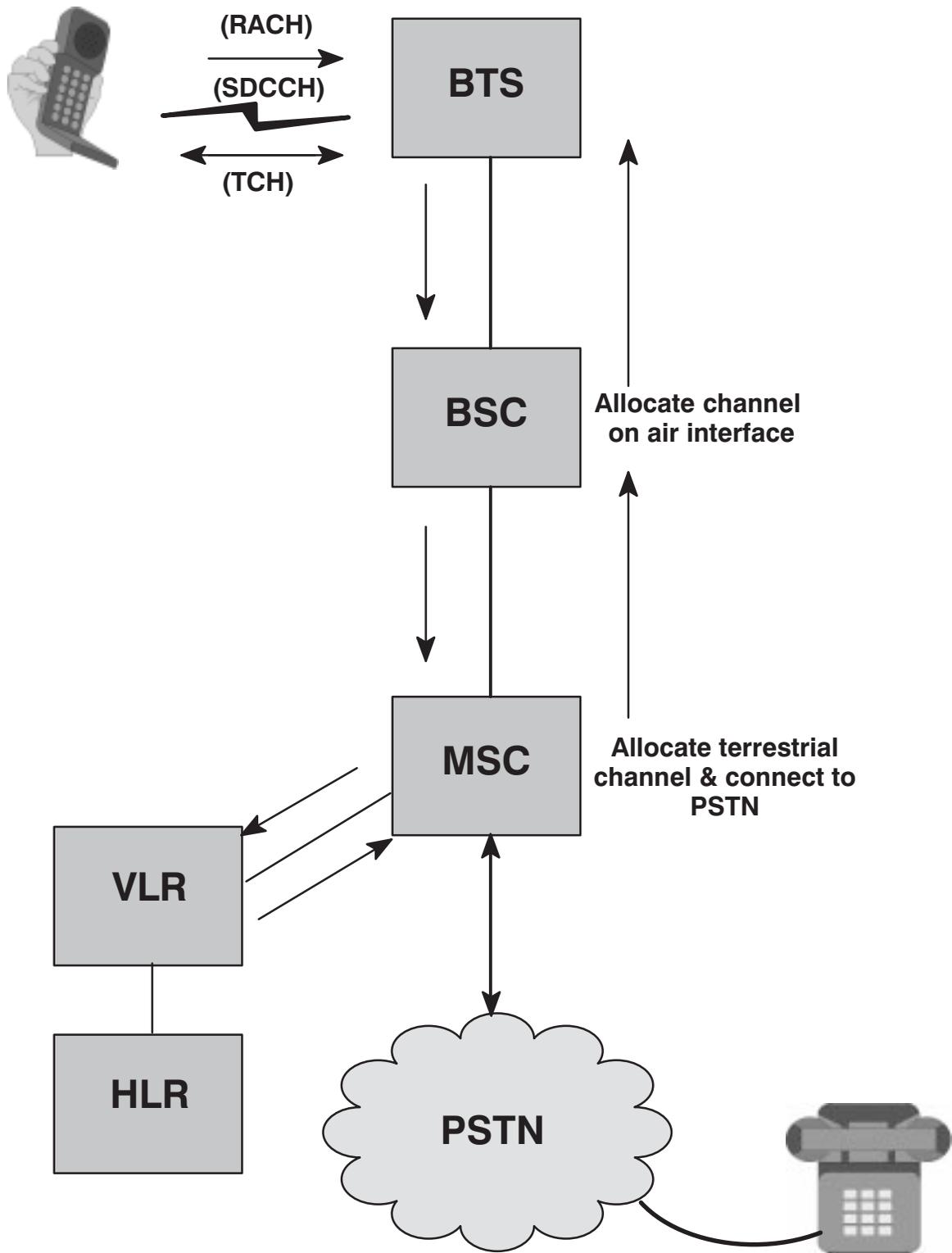
The BTS receives a data message from the MS which it passes it to the BSC. The BSC relays the message to the MSC via C7 signalling links, and the MSC then sets up the call to the land subscriber via the PSTN. The MSC connects the PSTN to the GSM network, and allocates a terrestrial circuit to the BSS serving the MS’s location. The BSC of that BSS sets up the air interface channel to the MS and then connects that channel to the allocated terrestrial circuit, completing the connection between the two subscribers.

- **In the Land to MS direction**

The MSC receives its initial data message from the PSTN (via C7) and then establishes the location of the MS by referencing the HLR. It then knows which other MSC to contact to establish the call and that MSC then sets up the call via the BSS serving the MS’s location.

The actual processes are, of course, considerably more complex than described above. Also, there are many different GSM call sequence and handover scenarios – enough to form the subject of their own training programme! In this course we consider in detail just the MS to Land and Land to MS call sequences and the intra-MSC (inter-BSS) handover sequence. This will give you a good appreciation of the messaging that occurs in the GSM system, and how the PLMN interacts with the PSTN.

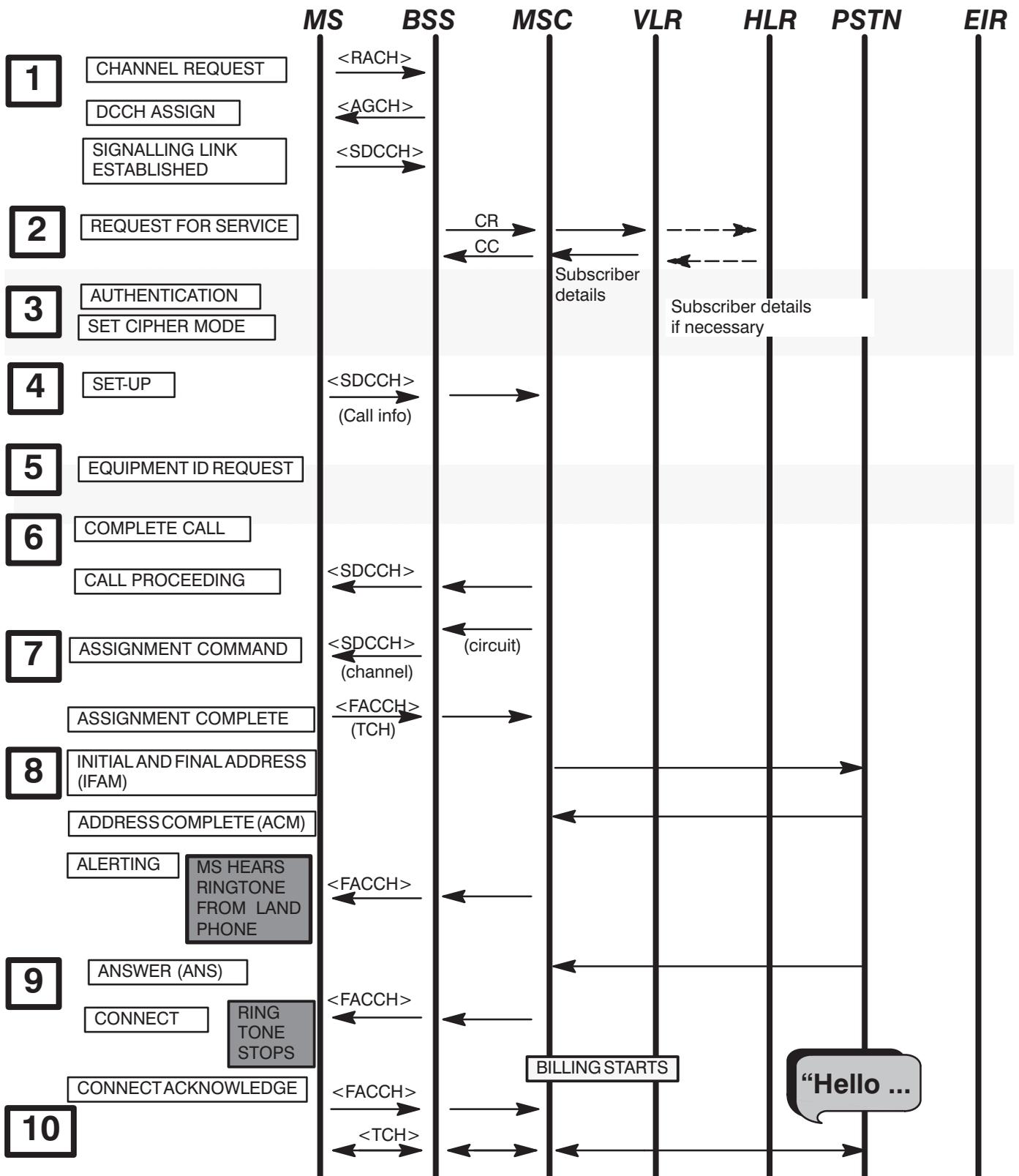
GSM Basic Call Sequence



MOBILE TO LAND SEQUENCE

- 1** → The subscriber pressing the “send” key initiates a “Channel Request” message from the MS to the BSS. This is followed by the assignment of a dedicated control channel by the BSS and the establishment of the signalling link between the MS and BSS (“SABM” – Set Asynchronous Balanced Mode).
- 2** → The message “Request for Service” is passed to the MSC which relays it to the VLR. The VLR will carry out the authentication process if the MS has been previously registered on this VLR – if not, the VLR will have to obtain authentication parameters from HLR. The diagram assumes the MS was previously registered on this VLR.
- 3** → Subscriber authentication (optional) takes place using authentication messages and encryption algorithms and, if successful the Call setup can continue. If ciphering is to be used this is initiated at this time as the setup message contains sensitive information.
- 4** → The message “Set-Up” is sent by the MS to the MSC accompanied by the call information (type of call, and number being called etc.). The message is forwarded from the MSC to the VLR.
- 5** → The MSC may initiate the MS IMEI check (*is the MS stolen?, etc.*). Note that this check may occur later in the message sequence.
- 6** → In response to the message “Set-Up” (sent at step 4), the VLR sends the message “Complete Call” to the MSC, which notifies the MS with “Call Proceeding”.
- 7** → The MSC then assigns a traffic channel to the BSS (“Assignment Command”), which in turn assigns an air interface traffic channel. The MS responds to the BSS (which responds in turn to the MSC) with “Assignment Complete”.
- 8** → An “Initial and Final Address Message (IFAM)” is sent to the PSTN. Ring tone is applied at the MS in response to “Alerting”, which the MSC sends to the MS when the PSTN responds with an “Address Complete Message (ACM)”.
- 9** → When answered (“Answer (ANS)” from the PSTN), the message “Connect” is forwarded to the MS by the MSC, stopping the MS ring tone. The MSC then connects the GSM traffic channel to the PSTN circuit, thus completing the end to end traffic connection.
- 10** → Conversation takes place for the duration of the call.

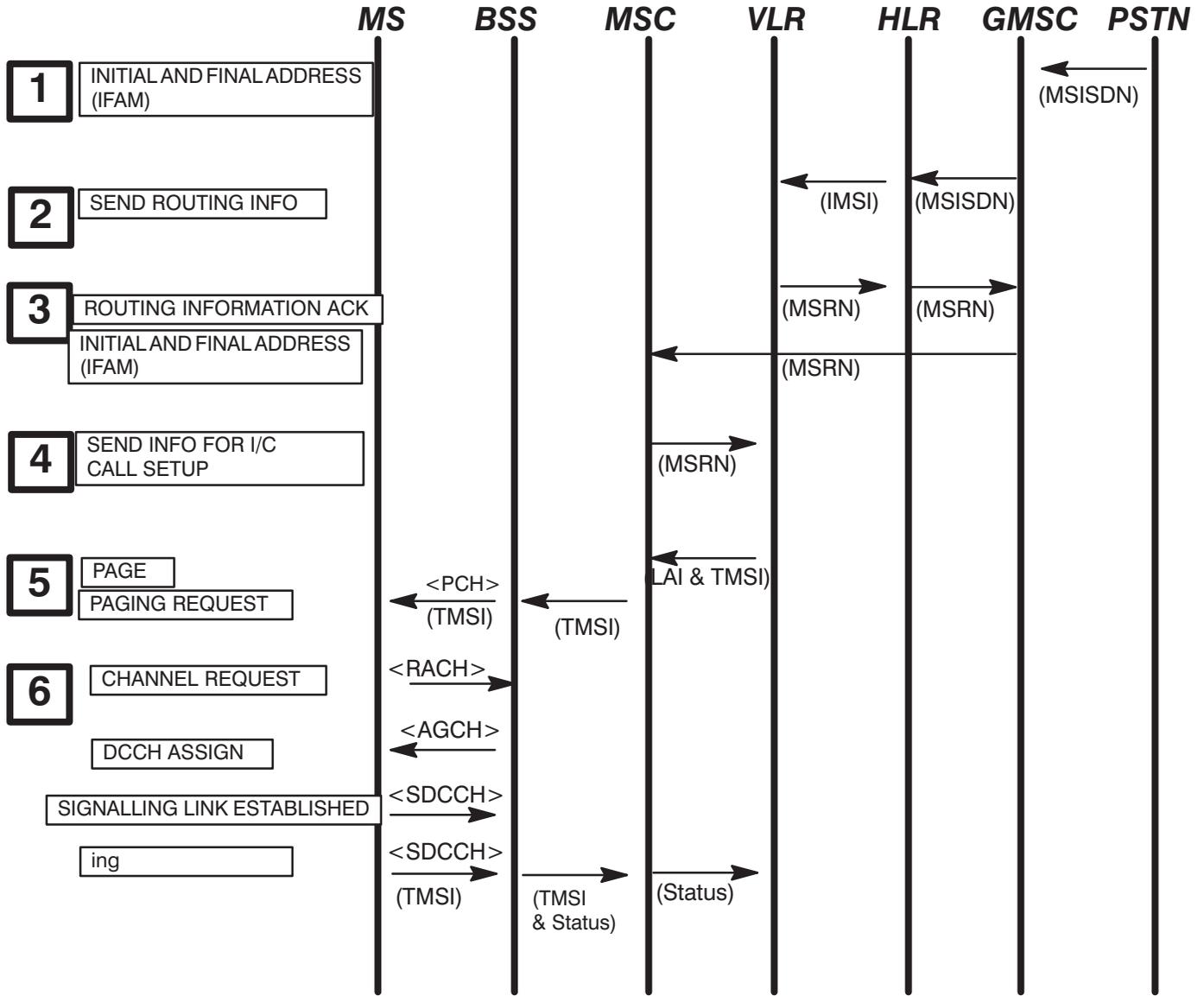
Mobile to Land Sequence



LAND TO MOBILE SEQUENCE

- 1 → A C7 “Initial and Final Address Message (IFAM)” arrives at a “gateway” MSC (GMSC). The MS to be called is identified by its MSISDN.
- 2 → Using the message “Send Routing Info”, still tagged by the MS’s MSISDN, the GMSC requests routing information from the HLR. This forwards the message, now retagged with the MS’s IMSI, to the VLR serving the LAI in which the MS is currently located. The requested information will enable the GMSC to identify the MSC to which the IFAM must be directed.
- 3 → The VLR responds with the message “Routing Information Ack.”, now tagged with an MSRN which is either newly drawn from its pool of MSRNs or already associated with the MS being called. The GMSC now sends an **IFAM** to the MSC serving the MSs location, tagged with the MSRN.
- 4 → The ‘visitor’ MSC then requests call set-up information from the VLR (“Send Info for I/C Call Setup”).
- 5 → The VLR response is the “Page” message back to the MSC, containing the required information. The MSC then sends “Paging Request” to the MS via the appropriate BSS.
- 6 → The MS responds and requests a dedicated control channel from the BSS (“Channel Request”) and the air interface signalling link is established. Once established, this dedicated control channel carries “Paging Response” to the BSS which relays it to the VLR, via the MSC.

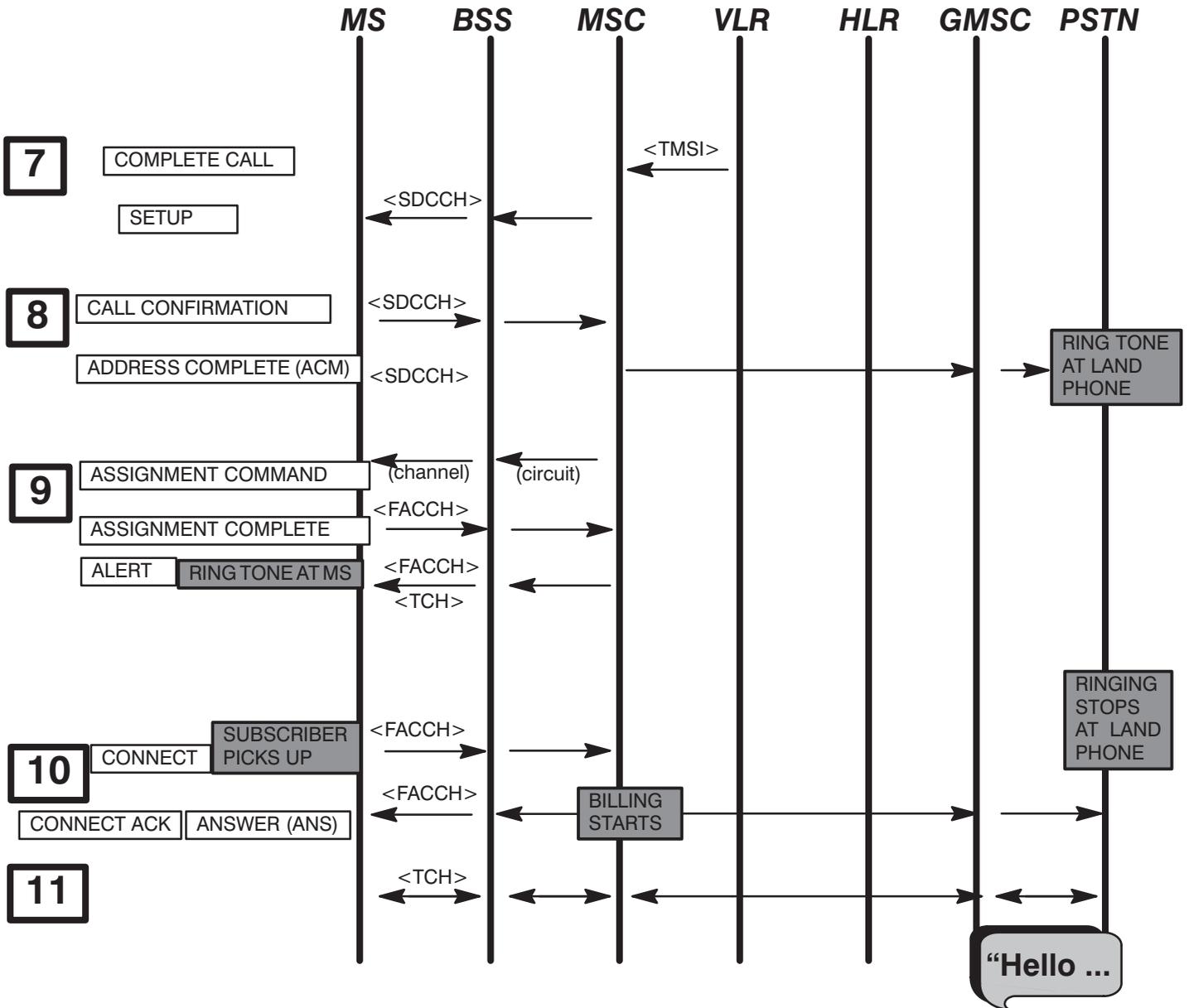
Land to Mobile Sequence



LAND TO MOBILE SEQUENCE . . .

- 7** → The MS subscriber is authenticated and cipher mode is set (opt). The “Complete Call” message is then sent to the MSC from the VLR. This is relayed to the MS via the BSS as the message “Setup”.
- 8** → The MS sends the message “Call Confirmation” to the MSC. This indicates that the MS is capable of receiving a call and the MSC sends an “Address Complete Message (ACM)” to the GMSC which relays it to the PSTN. The land subscriber will now hear ring tone.
- 9** → The MSC then assigns a traffic channel to the BSS (“Assignment Command”), which in turn assigns an air–interface traffic channel. The MS responds to the BSS (which responds in turn to the MSC) with “Assignment Complete”. The MS now rings, sending the message “Alert” to the MSC as confirmation.
- 10** → When the GSM subscriber answers, the MS sends the message “Connect” to the MSC. The MSC acknowledges this (“Connect Ack”) and sends “Answer (ANS)” to the GMSC and PSTN. The land subscriber’s ring tone stops and the GMSC and MSC connect the GSM traffic channel and the PSTN circuit together.
- 11** → Conversation takes place for the duration of the call.

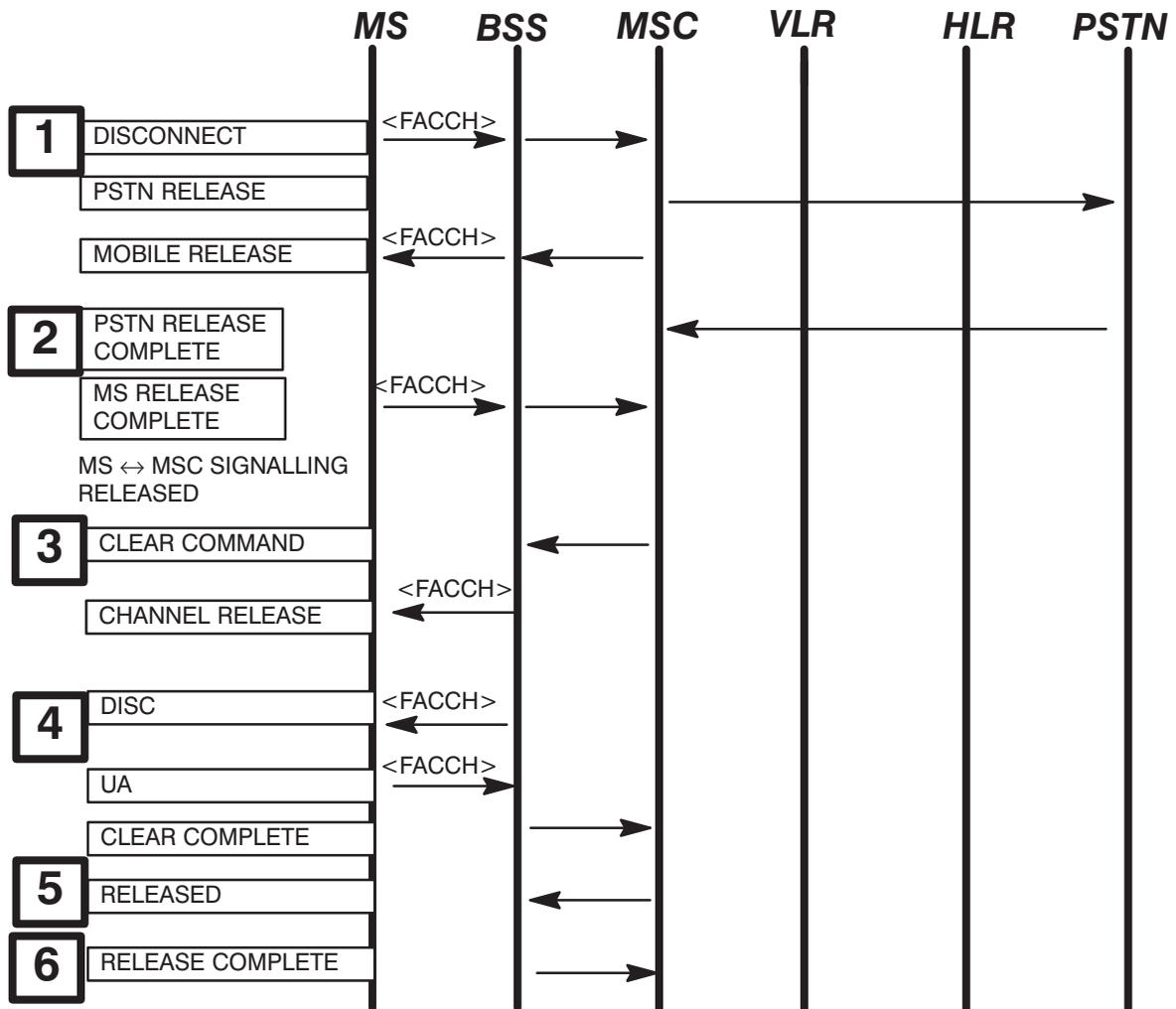
Land to Mobile Sequence ...



MS INITIATED CALL CLEARING SEQUENCE

- 1** → The MS initiates the clearing of the call by sending the “Disconnect” message to the MSC. The MSC will then send a “Release” message to the PSTN which will then start to release the fixed network circuits associated with the call . The MSC will also send a “Release” message to the MS to indicate that it may clear down the call.
- 2** → When the MS receives the message, it will release the call and respond with the “Release Complete” message. The PSTN will also respond with a “Release Complete” message.
- 3** → The MSC now initiates the freeing up of the air interface radio resources and the A interface terrestrial resources related to the call. The MSC will send the “Clear Command” to the BSS. The BSS in turn will send a “Channel Release” on to the MS this will start the release of the radio resources used for that call. The BSS will then respond to the MSC with the “Clear Complete” message indicating that is has released the radio and terrestrial resources.
- 4** → The BSS will complete the release of the radio resources by sending the “DISC” message to the MS. The MS will respond with an “Unnumbered Acknowledgement (UA)” message.
- 5** → The MSC will now initiate the release of the signalling connection related to the call. The MSC will send the “Released” message to the BSS, which will respond with the “Release Complete” message.
- 6** → The call is now cleared and all resources are available for another subscriber.

Mobile Initiated Call Clearing Sequence



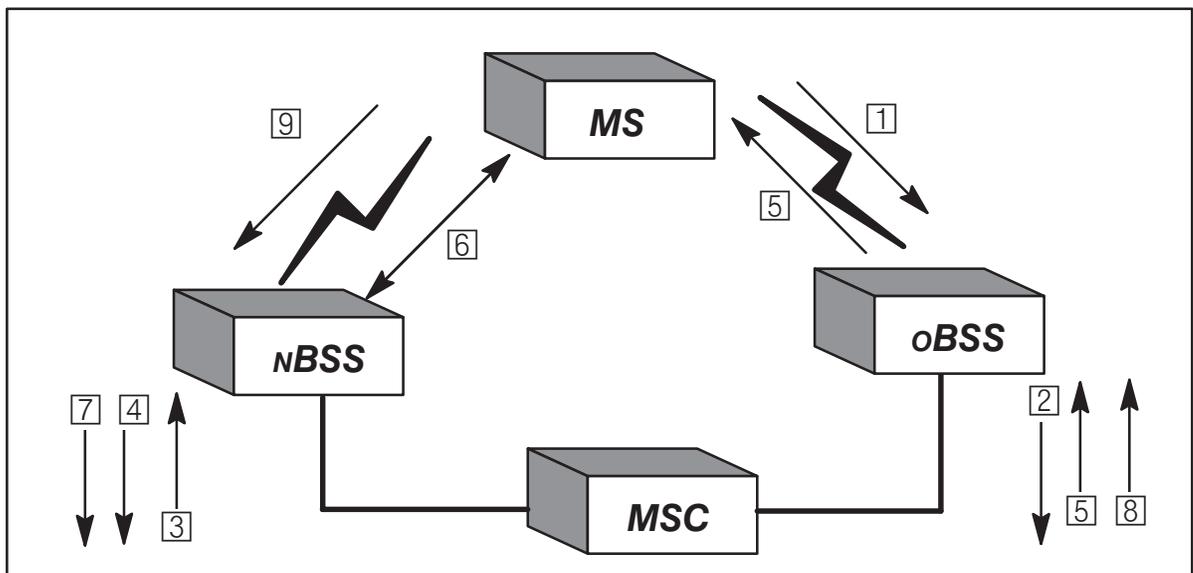
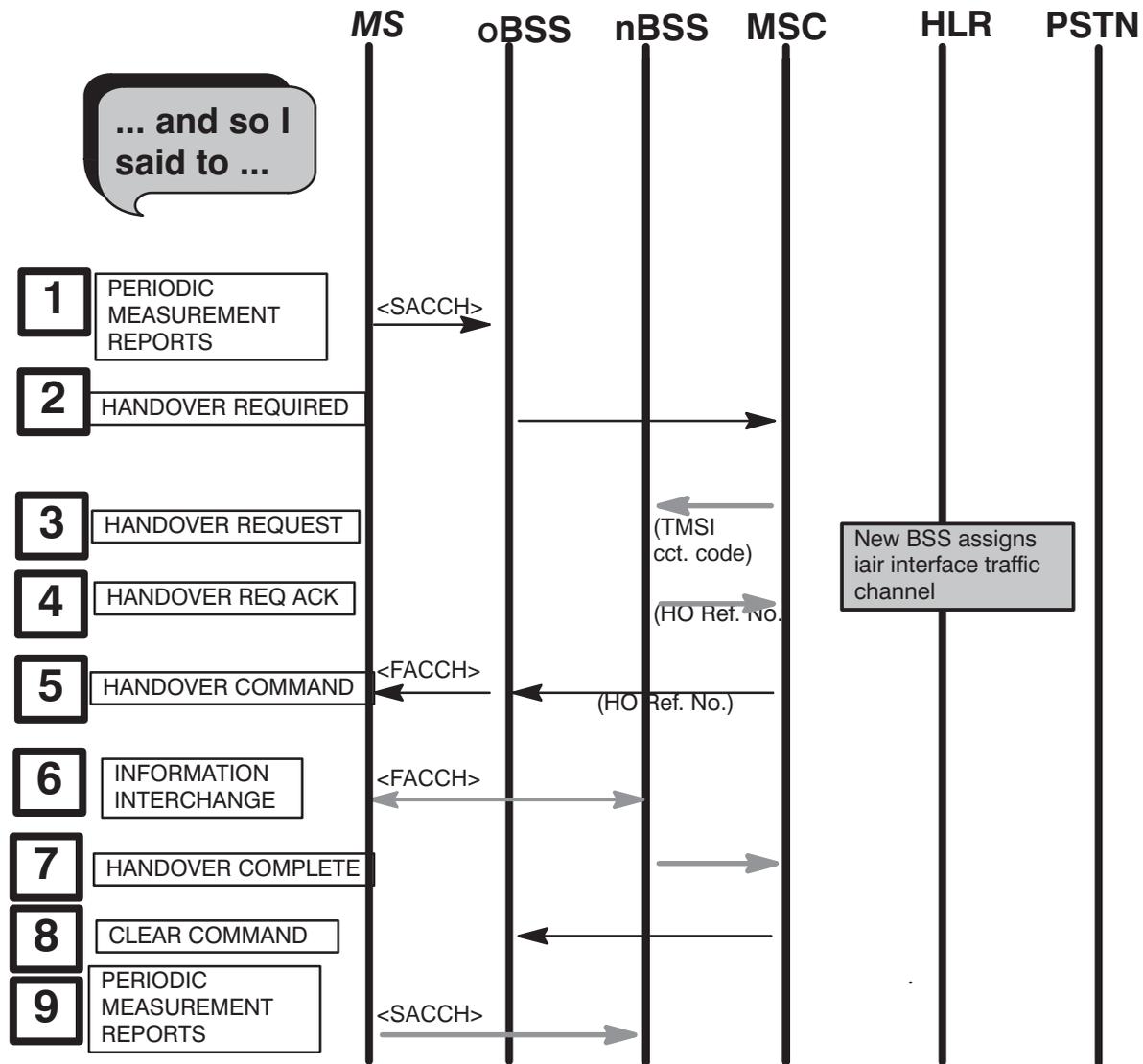
INTER-BSS HANDOVER SEQUENCE

- 1 → The MS is in the conversation state and is continuously compiling measurements both of the current transmission and the broadcast control channels of up to thirty two surrounding cells. The measurements from the six best cells are reported back to the BSS, every 480 ms.
- 2 → When a handover is required, due to low Receive Signal Strength Indication (RSSI) or poor signal quality the existing "originating" BSS (oBSS) notifies the MSC ("Handover Required").
- 3 → The target or new BSS (nBSS) is alerted with the message "Handover Request" tagged with the TMSI.
- 4 → The new BSS allocates a Handover Reference Number which it uses to determine whether the correct MS gains access to the air interface channel which it allocates, and acknowledges the MSC's request with "Handover Request Ack". This is tagged with the HO Reference number. The nBSS assigns a traffic channel.
- 5 → The MSC, via the oBSS orders the MS to change to the new channel with the message "Handover Command" on FACCH.
- 6 → There is an information interchange between nBSS and MS. This uses the FACCH channel but an access burst is used. The messages and information carried depend upon the type of handover being performed.
- 7 → Once all necessary information has been transferred the message "Handover Complete" is sent to the MSC.
- 8 → The MSC now sends a "Clear Command" to the oBSS, this frees the radio resources for another MS. The channel is not cleared until this point in case the new BSS can not accommodate the MS being handed over.
- 9 → The MS, still in the conversation mode, then continues to prepare periodic measurement reports and sends them to the new BSS.

Acronyms:

TMSI	Temporary Mobile Subscriber Identity
MSRN	Mobile Station Roaming Number
IMSI	International Mobile Subscriber Identity
MSISDN	Mobile Station ISDN Number
LAI	Location Area Identity
SACCH	Slow Associated Control Channel
FACCH	Fast Associated Control Channel

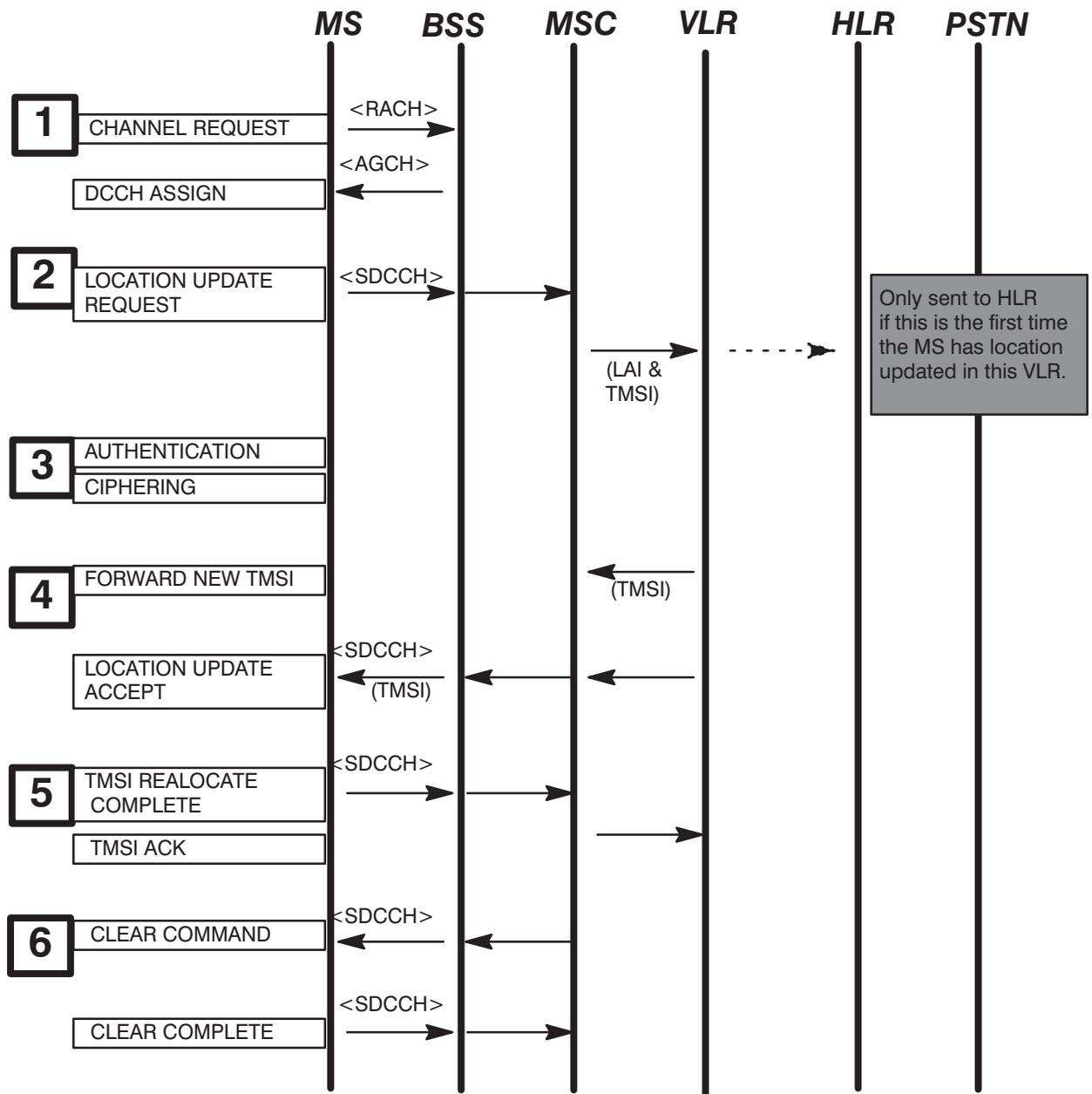
Inter-BSS Handover Sequence



LOCATION UPDATE SEQUENCE

- 1** → A location update is initiated by the MS when it detects that it has entered a new location area. The location area is transmitted on the BCCH as the LAI. The MS will be assigned an SDCCH by the BSS, the location updating procedure will be carried out using this channel.
- 2** → Once the SDCCH has been assigned, the MS transmits a "Location Update Request" message. This message is received by the MSC which then sends the new LAI and the current MS TMSI number to the VLR. The information will also be sent to the HLR if the MS has not previously been updated on the network.
- 3** → Authentication and ciphering may now take place if required.
- 4** → The VLR will now assign a new TMSI for the MS, this number will be sent to the MSC using the "Forward New TMSI" message. The VLR will now initiate the "Location Update Accept" message which will transmit the new TMSI and LAI to the MS.
- 5** → Once the MS has stored both the TMSI and the LAI on its SIM card it will send the "TMSI Relocate Complete" message to the MSC. The MSC will then send the "TMSI ACK" message to the VLR to confirm that the location update has been completed.
- 6** → The SDCCH will then be released by the MS.

Location Update Sequence



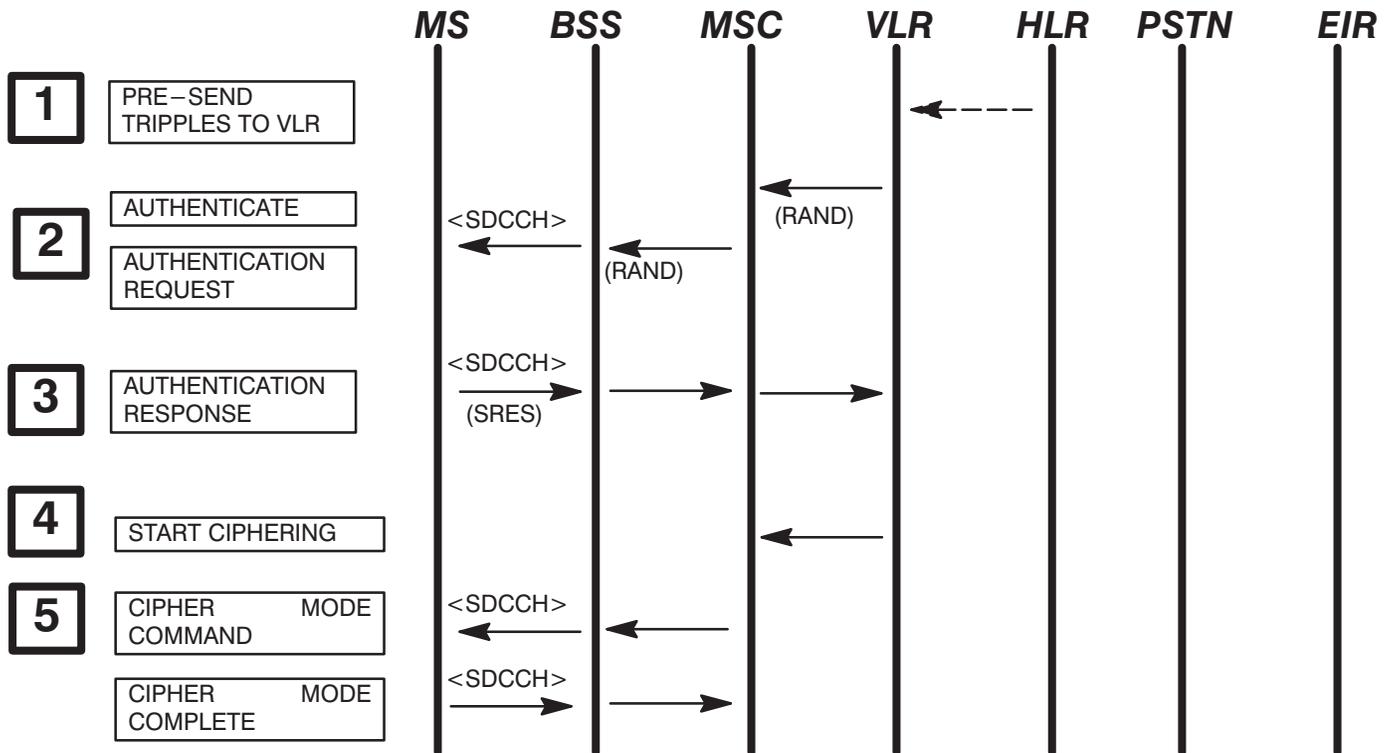
AUTHENTICATION AND CIPHERING

- 1** → Authentication may be executed during call setup, location updating and supplementary services. The HLR/AUC produce the authentication parameters (RAND/SRES/Kc) these are called "triples". Triples are sent to the VLR where the MS is registered. These triples are sent in groups of six and stored in the VLR. This ensures that the VLR can carry out the authentication and that it will not have to contact the HLR.
- 2** → The VLR initiates the authentication by sending a message "Authenticate" to the MSC. The MSC will repackage this message and send it on to the MS. The message is an "Authentication Request" and contains the random number RAND.
- 3** → The MS responds with the "Authentication Response" message, this contains the signed response (SRES).
- 4** → If authentication is successful, the VLR will request that the MSC start ciphering procedures, using the "Start Ciphering" message. This message contains information indicating whether ciphering is required.
- 5** → The MSC will start ciphering procedures by sending the "Cipher Mode Command" message to the BSS. This message contains the encryption information required by the BSS. The BSS will respond with the "Cipher Mode Complete" message.

Note:

If the authentication fails, the HLR will be notified and an "Authentication Reject" message will be send to the MS.

Authentication and Ciphering

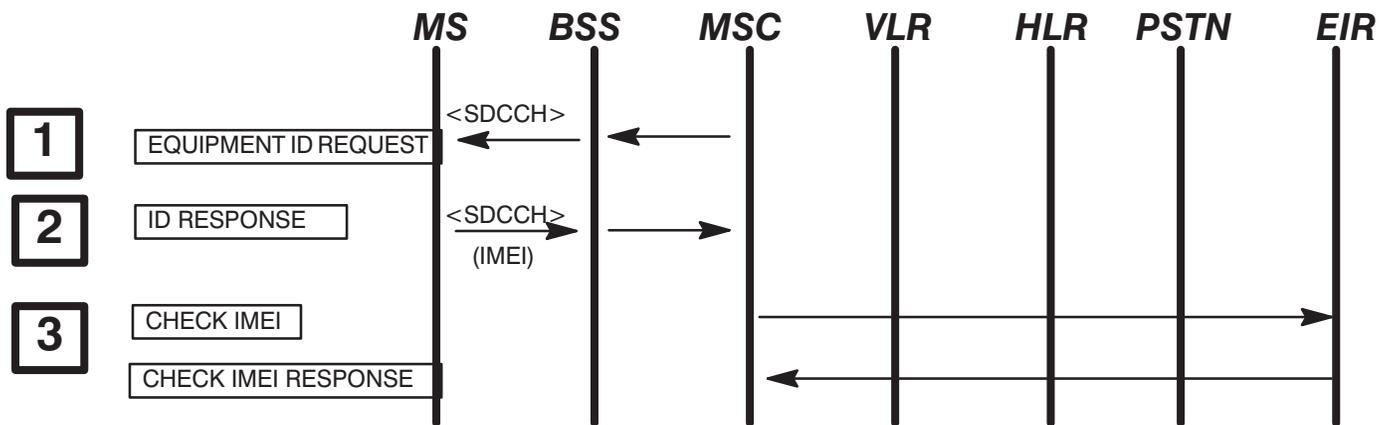


AUTHENTICATION AND CIPHERING

EQUIPMENT IDENTIFICATION

- 1** → Equipment Identification will be initiated by the MSC sending the “Equipment ID Request” message to the MS. This will be carried out less frequently than authentication. The frequency of the checks will be at the discretion of the network provider. Equipment Identification will be carried out during a Location Update or a Call Setup.
- 2** → The MS will respond to the message by sending the “ID Response” message. This message contains the equipment’s IMEI number.
- 3** → The MSC will send the IMEI number on to the EIR using the “Check IMEI” message. The EIR will respond with the “Check IMEI Response”. Checking of the IMEI at the EIR may occur after the TCH has been allocated to the MS.

Equipment Identification



Note:

IMEI check may be deferred until after traffic channel has been established!



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INTRODUCTION TO DIGITAL CELLULAR

Section 9

Introduction to Microcellular

The information
contained in this document
is not intended to replace that contained
in the relevant equipment manuals and is
for the purpose of training only.

THIS MANUAL WILL NOT BE UPDATED

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SECTION OBJECTIVES

On completion of this section the student will be able to:

- . understand what a microcell is and how they may be employed

- . understand the advantages of microcellular over other capacity enhancement techniques



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Microcellular Overview

Section 9

Introduction to Microcellular

INTRODUCTION

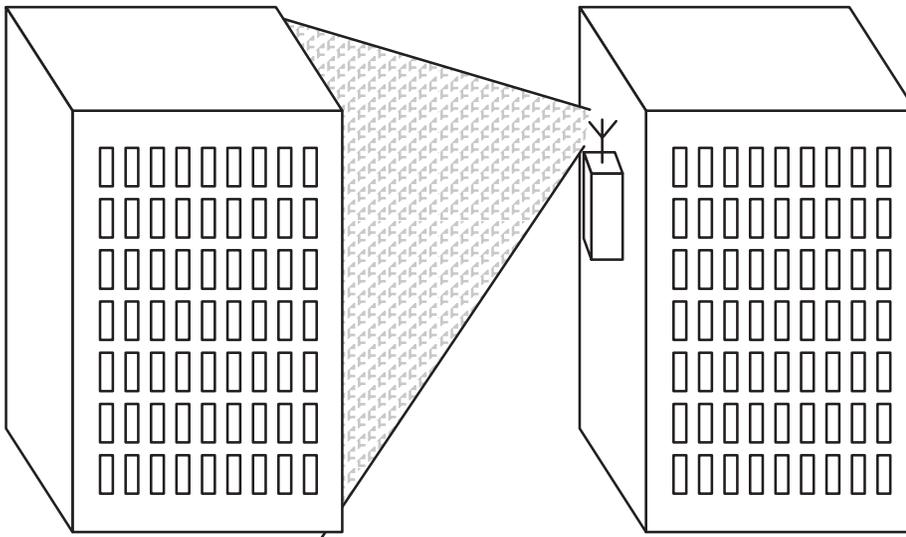
WHAT IS MICROCELL?

The term microcell suggests a small cell. This is true, but microcells are defined as cells for which the antennas are mounted below local rooftop level. This helps contain the microcells RF radiation to within the street canyons.

Why Deploy Microcells?

At present 80 to 90% of the current worldwide GSM subscribers fall into one category, that of slow moving and stationary handportable units (class 4 mobiles).

Microcellular Concept



The Microcellular principle has applications in:

- GSM, DCS, PCS
- Urban areas
- In building systems

Microcellular offers independence of:

- **Frequency** (using existing networks ARFCN's)
- **Technology base** (i.e. Any existing or future hardware)
- **Products** (for example, Motorola microcells under another vendors macrocells)

HOW ARE MICROCELLS DEPLOYED?

By placing the antenna below the rooftop, the RF propagation can be contained. This allows the frequency reuse within the microcells coverage area to be tighter than in the existing network. This means greater spectrum efficiency. The microcells are also deployed underneath the existing network. This introduces the term, layered architecture. This would suggest that the current system cells become “umbrella or macrocells”. Therefore, in the area of macro- and microcell coverage we have enhanced capacity. We can now say that the microcells have introduced better capacity and spectrum efficiency.

We could also assume that any areas of poor or no coverage in the existing network could also be overcome by the use of microcells. This would mean that microcells can provide greater:

- Capacity
- Coverage
- Spectrum efficiency

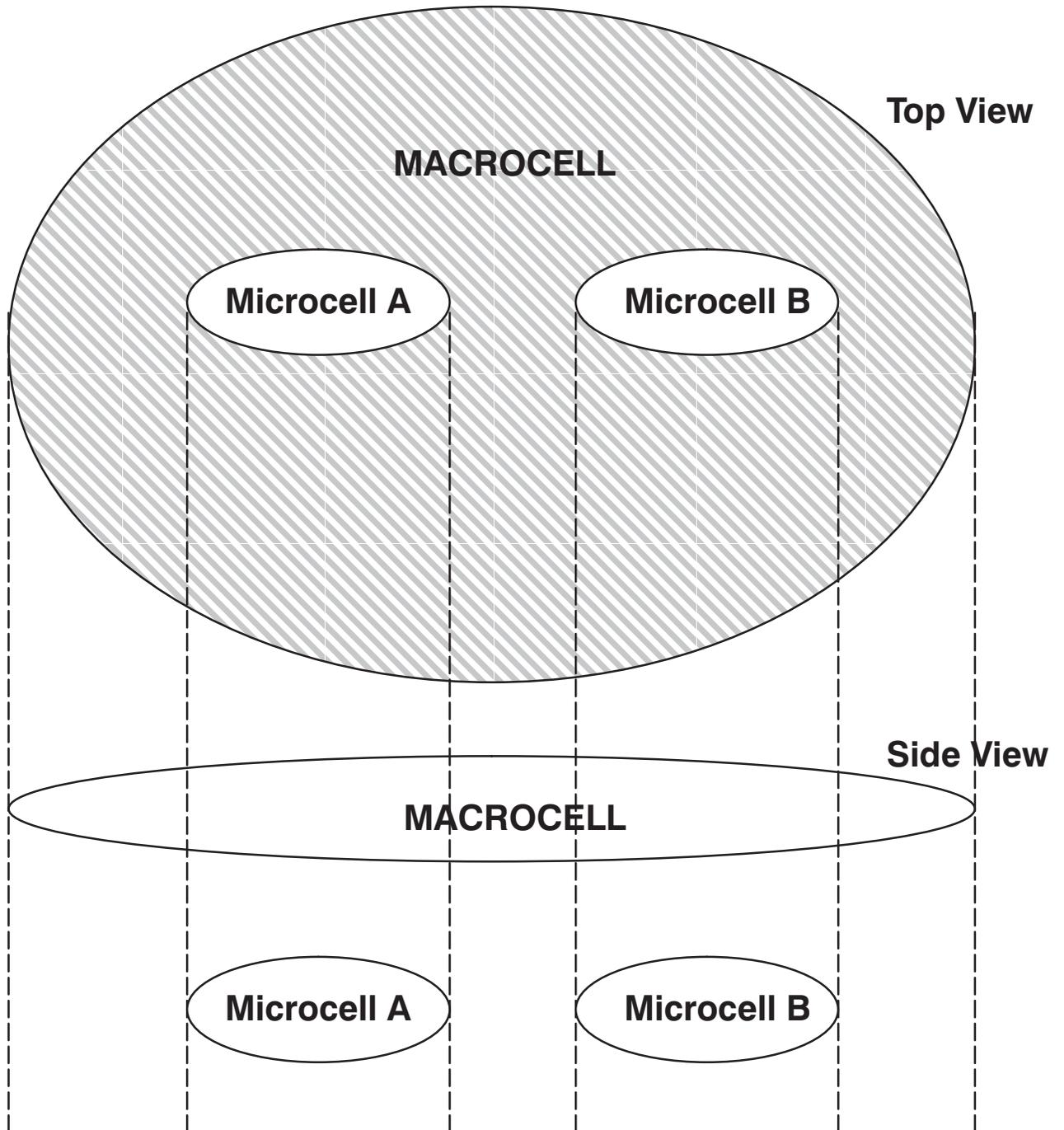
or

- Erlangs
- Km²
- MHz

Note:

One Erlang is a measure of one traffic channel permanently utilized.

Layered Architecture



BUILDING PENETRATION FROM EXTERNALLY MOUNTED CELLS

For a cell with an outdoor mounted antenna, path loss defines the limit of possible coverage, including building penetration losses and “on-street” path loss. This suggests that, as the distance from the antenna increases, the depth of penetration into buildings will reduce.

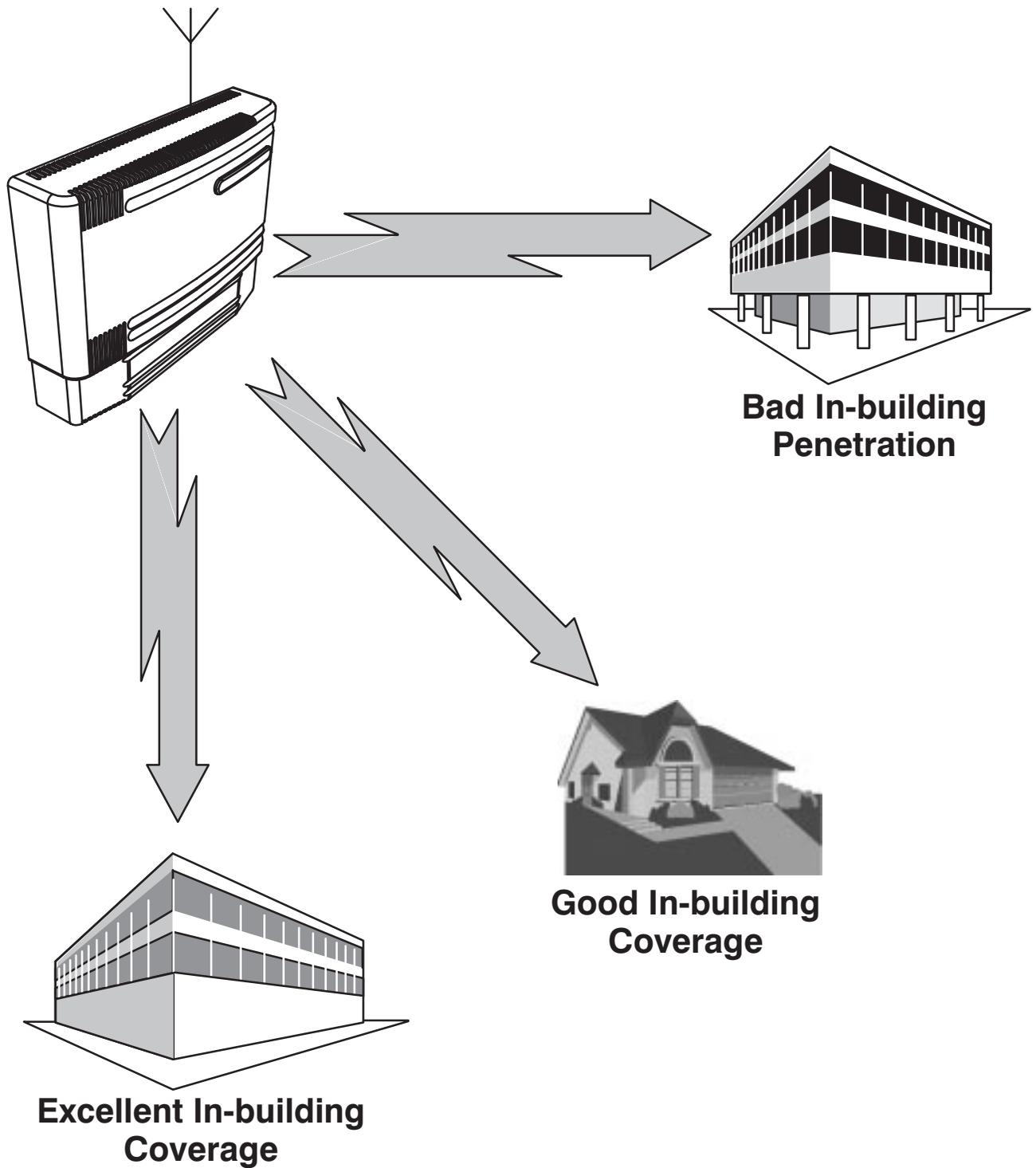
There may be situations where a building further away has better indoor coverage, for example, due to the fact that the angle of incidence to the building is more favourable for better penetration. The level of penetration into a building depends on a number of factors some of which are:

- Building material.
- Number of windows.
- Angle of incidence.
- Internal structure.

A microcell could give enhanced coverage within a building, even if it is deployed primarily as an external or on-street microcell. This aids providing the user with greater coverage.

Microcells may even be deployed within buildings, especially in larger indoor areas (for example, conference centres etc.)

Building Penetration from Externally Mounted Cells



ANTENNA TYPES

Both directional and omni-directional antennas have their uses in a microcellular system. The different attributes of these antennas can be used by the cell planners to avoid shadows, reduce handover requests, and maximize call success.

DIRECTIONAL ANTENNAS

Directional antennas are useful for covering long streets and have the following advantages:

- Extra gain in the forward direction.
- Suppressed signal in the reverse direction, this is a useful characteristic if the cell is a potential interferer with another cell located behind it.

It is also worth noting that a directional antenna could be used to improve in-building coverage, in specific buildings, within the microcell area.

OMNI ANTENNAS

Omni antennas are useful for covering open areas (for example squares, plazas). In these areas, it is desirable to have a clearly designated 'best server' cell to avoid excessive handovers and their attendant problems.

Another application is to create a "corner crossroads" cell. This avoids having transient cells at street crossroads. However, by intersecting with more streets, the potential for interference with other cells may be increased.