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GSM SYSTEM OVERVIEW

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Table of Contents

Course Objectives and Structure

Course Objectives

- Describe the architecture of a GSM network
- Appreciate the main activities and operations in a GSM network
- Describe the allocation of radio spectrum for mobile systems
- Understand the TDMA structure of GSM
- Describe the use and implementation of GSM logical channels
- Appreciate the OSI protocol model and the GSM air interface protocols
- Describe the methods of speech and error coding on the air interface
- Understand the principals of radio propagation in a multipath environment
- Describe the principals of cell planning including: coverage, capacity, frequency planning
- Understand some options for cell planning including: frequency hopping, diversity reception.
- Describe the evolution of GSM towards 3G systems

Course Outline

Day 1	Day 2
1. Introduction to GSM	**1. Speech and Channel Coding**
2. Services and Operations	**2. Radio Propagation**
3. Radio Waves and Antennas	**3. Cell Planning Principles**
4. The Air Interface	**4. Cell Planning Options**
5. Protocols	**5. GSM Evolution**

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1. Introduction to GSM

1.1 Introduction

The course starts with a review of first and second generation cellular systems and is followed by an overview of the functional blocks of GSM architecture, and its functional entities. Topics covered include:

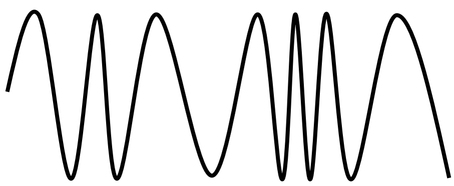
- 1st and 2nd Generation Cellular Systems
- GSM Architecture Overview
- The mobile station (MS) – the handset and SIM card
- The Base Station Subsystem
- The Network Switching System

1.2 1st and 2nd Generation Cellular Systems

Section 1 – Introduction to GSM

The First Generation

- The first mobile networks in the early 1980s were analog modulation systems such as:
  - AMPS (Advanced Mobile Phone System) in the USA
  - TACS (Total Access Communications System) in the UK
  - C-Netz in Germany
  - Radiocom 2000 in France
  - NMT in Scandinavia



- These networks were planned to achieve maximum coverage with as few antennas as possible

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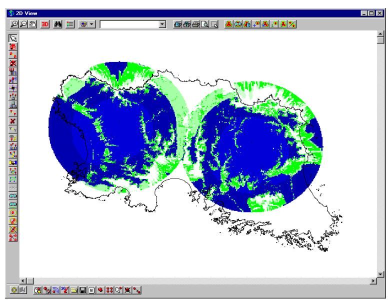
In early networks, the emphasis was to provide radio coverage with little consideration for the number of calls to be carried. As the subscriber base grew, the need to provide greater traffic capacity had to be addressed.

Section 1 – Introduction to GSM

Coverage and Capacity

- Coverage simply asks the question: where can you receive a usable radio signal ?
- Most of Jersey could be covered with a few powerful transmitters. But would this provide the required subscriber service?
- The system capacity must also be considerd: Can it handle the calls (traffic) that the subscribers are trying to make?



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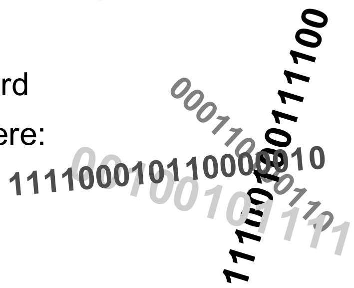
The First Generation - Problems

- Problems with the analog systems included:
  - Limited capacity – could not cope with increase in subscribers
  - Bulky equipment
  - Poor reliability
  - Lack of security – analog signals could be intercepted
  - Incompatibility between systems in different countries - no roaming
- To improve on the analog systems, the European Conference of Posts and Telecommunications Administrations (CEPT) established Groupe Speciale Mobile (GSM) to set a new standard

Originally GSM referred to the European working party set up to establish a new standard. A digital system offered considerable advantages in terms of capacity and security and introduced new possibilities for data traffic.

Section 1 – Introduction to GSM

Second Generation - Digital



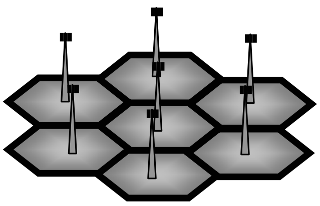
- 1987: GSM agreed on a digital standard
- The advantages of a digital system were:
  - Efficient use of radio spectrum
  - Security for voice transmission
  - Possibilities of data transmission
  - Very Large Scale Integrated (VLSI) components allowing smaller, cheaper handsets
  - Compatibility with ISDN land based networks
- The system developed became the Global System for Mobile Telecommunications (also GSM)

While first generation systems used a cellular structure and frequency re-use patterns, digital systems developed this concept to include multi-layer cellular patterns (microcells and macrocells). The greater immunity to interference inherent in digital transmission allowed tighter frequency re-use patterns to be implemented.

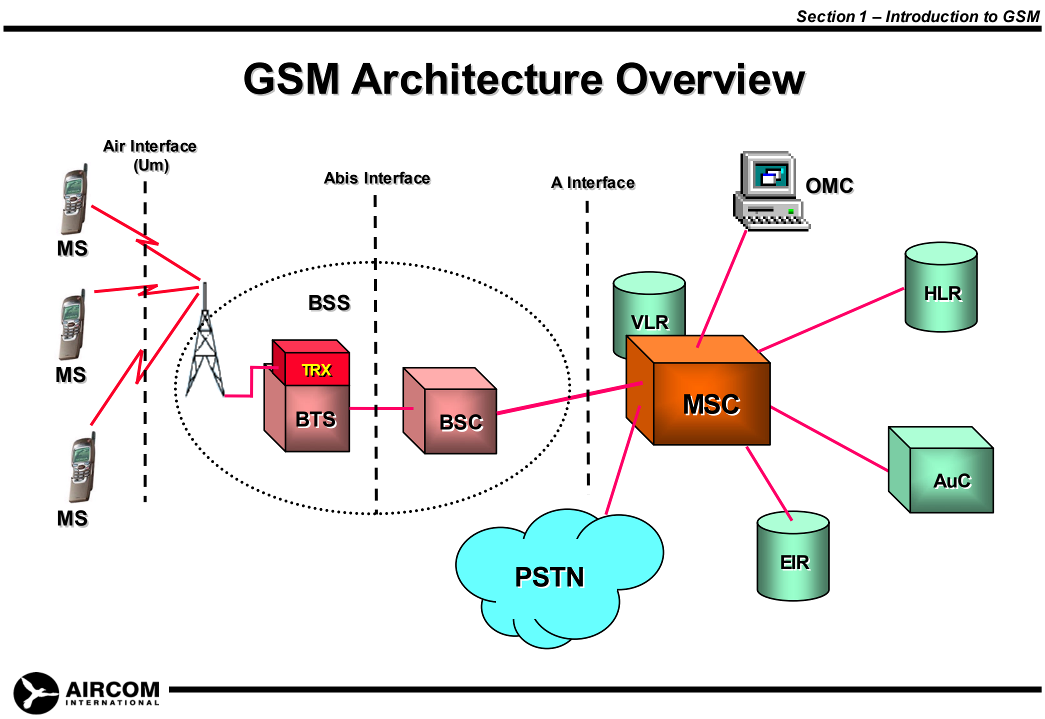
GSM Cellular Structure

- The aim of a GSM system is to make best use of the available frequencies (spectrum) to provide:
  - Coverage – getting a usable radio signal to all areas in the network
  - Capacity – handling the call traffic generated by the subscribers
  - Quality – low interference, few calls dropped etc.

- The cellular structure allows the re-use of frequencies across the network
- Planning the pattern of this re-use is a key part of the system design



1.3 GSM Architecture Overview



A GSM network is made up of three subsystems:

- The Mobile Station (MS)
- The Base Station Sub-system (BSS) – comprising a BSC and several BTSs
- The Network and Switching Sub-system (NSS) – comprising an MSC and associated registers

Several interfaces are defined between different parts of the system:

- 'A' interface between MSC and BSC
- 'Abis' interface between BSC and BTS
- 'Um' air interface between the BTS (antenna) and the MS

Abbreviations:

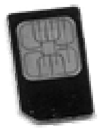
MSC – Mobile Switching Centre
BSC – Base Station Controller
BTS – Base Transceiver Station
TRX – Transceiver
MS – Mobile Station
OMC – Operations and Maintenance Centre
PSTN – Public Switched Telephone Network
BSS – Base Station Sub-system
HLR – Home Location Register
VLR – Visitor Location Register
AuC – Authentication Centre
EIR – Equipment Identity Register

1.4 The GSM Mobile Station (MS)

Section 1 – Introduction to GSM

The Mobile Station (MS)

- The mobile station consists of:
  - mobile equipment (ME)
  - subscriber identity module (SIM)



- The SIM stores permanent and temporary data about the mobile, the subscriber and the network, including:
  - The International Mobile Subscribers Identity (IMSI)
  - MS ISDN number of subscriber
  - Authentication key (K_i) and algorithms for authentication check

- The mobile equipment has a unique International Mobile Equipment Identity (IMEI), which is used by the EIR

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The two parts of the mobile station allow a distinction between the actual equipment and the subscriber who is using it.

The IMSI identifies the subscriber within the GSM network while the MS ISDN is the actual telephone number a caller (possibly in another network) uses to reach that person.

Security is provided by the use of an authentication key (explained later in this section) and by the transmission of a temporary subscriber identity (TMSI) across the radio interface where possible to avoid using the permanent IMSI identity.

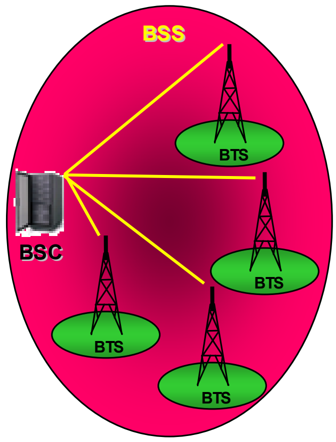
The IMEI may be used to block certain types of equipment from accessing the network if they are unsuitable and also to check for stolen equipment.

1.5 The Base Station Subsystem (BSS)

Section 1 – Introduction to GSM

The Base Station Sub-System (BSS)

- The BSS comprises:
  - Base Transceiver Station (BTS)
  - One or more Base Station Controllers (BSC)
- The purpose of the BTS is to:
  - provide radio access to the mobile stations
  - manage the radio access aspects of the system
- BTS contains:
  - Radio Transmitter/Receiver (TRX)
  - Signal processing and control equipment
  - Antennas and feeder cables
- The BSC:
  - allocates a channel for the duration of a call
  - maintains the call:
    - monitoring quality
    - controlling the power transmitted by the BTS or MS
    - generating a handover to another cell when required
- Siting of the BTS is crucial to the provision of acceptable radio coverage



The effect of gains and losses in the BTS equipment on the signal power sent to the antenna is an important consideration for link budget calculations. Planning BTS positions requires a software tool such as Asset. Acquiring sites and implementing the plan involves a combination of surveying, engineering and legal work.

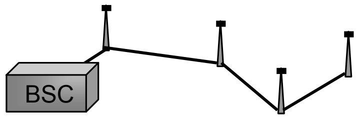
Handover in GSM is always 'hard' that is the mobile only ever has a communication link (traffic channel) open with one base station at one time. This is true of any system with multiple frequencies, since the mobile must re-tune at the handover. Single frequency systems (such as CDMA) may use soft handover.

The quality and power level of the radio link compared with that available from neighbouring cells are important inputs to the handover decision made by the BSC.

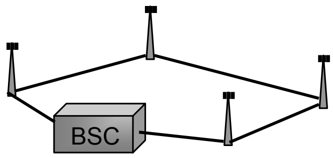
Base stations are linked to the parent BSC in one of several standard network topologies. The actual physical link may be microwave, optical fibre or cable. Planning of these links may be done using a tool such as Connect.

BSS Network Topologies

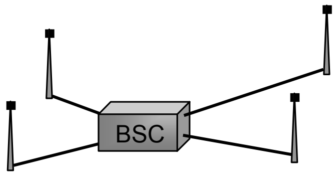
- **Chain:** cheap, easy to implement
  - One link failure isolates several BTSs



- **Ring:** Redundancy gives some protection if a link fails
  - More difficult to roll-out and extend - ring must be closed



- **Star:** most popular configuration for first GSM systems
  - Expensive as each BTS has its own link
  - One link failure always results in loss of BTS



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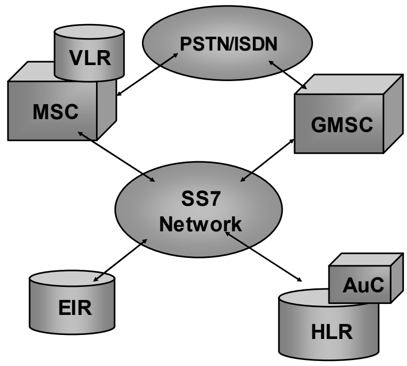
The NSS combines the call routing switches (MSCs and GMSC) with database registers required to keep track of subscribers' movements and use of the system. Call routing between MSCs is taken via existing PSTN or ISDN networks. Signalling between the registers uses Signalling System No. 7 protocol.

1.6 The Network Switching System (NSS)

Network Switching System (NSS)

- Key elements of the NSS:
  - Mobile Switching Centre (MSC) with:
    - Visitor Location Register (VLR)
  - Home Location Register (HLR) with:
    - Authentication Centre (AuC)
  - Equipment Identity Register (EIR)
  - Gateway MSC (GMSC)



- These elements are interconnected by means of an SS7 network

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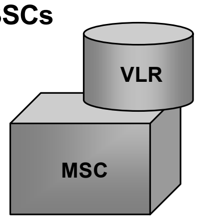
Mobile Switching Centre (MSC)

- **Functions of the MSC:**
  - **Switching calls, controlling calls and logging calls**
  - **Interface with PSTN, ISDN, PSPDN**
  - **Mobility management over the radio network and other networks**
  - **Radio Resource management - handovers between BSCs**
  - **Billing Information**



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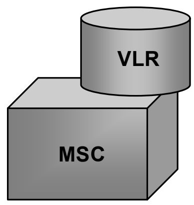
Visitor Location Register (VLR)

- Each MSC has a VLR
- VLR stores data temporarily for mobiles served by the MSC
- Information stored includes:
  - IMSI
  - Mobile Station ISDN Number
  - Mobile Station Roaming Number
  - Temporary Mobile Station Identity
  - Local Mobile Station Identity
  - The location area where the mobile station has been registered
  - Supplementary service parameters



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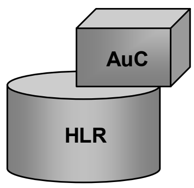
Notice that the VLR stores the current Location Area of the subscriber, while the HLR stores the MSC/VLR they are currently under. This information is used to page the subscriber when they have an incoming call.

Home Location Register (HLR)

- Stores details of all subscribers in the network , such as:
  - Subscription information
  - Location information: mobile station roaming number, VLR, MSC
  - International Mobile Subscriber Identity (IMSI)
  - MS ISDN number
  - Tele-service and bearer service subscription information
  - Service restrictions
  - Supplementary services
- Together with the AuC, the HLR checks the validity and service profile of subscribers



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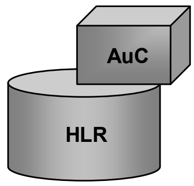
There is logically only one HLR in the network, although it may consist of several separate computers.

HLR Implementation

- One HLR in a network
- May be split regionally
- Stores details of several thousand subscribers
- Stand alone computer - no switching capabilities
- May be located anywhere on the SS7 network
- Combined with AuC



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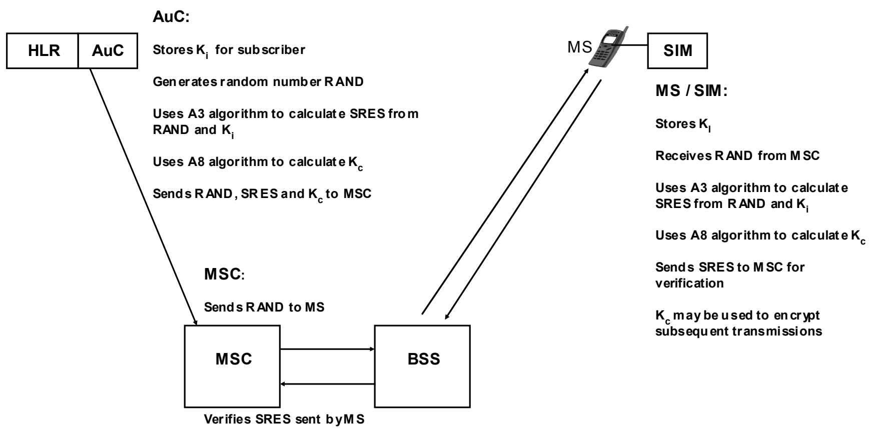
Authentication Process



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The authentication process is designed to prevent fraudulent use of a subscriber's account by imitating their SIM card. The process involves a challenge set by the network to which the mobile must give the correct response.

There is a secret authentication key K_i for each subscriber, which is stored in their SIM and in the AuC, but nowhere else.

The AuC generates a random number (RAND) which is passed together with the key through an algorithm known as A3. This produces a signed result value (SRES).

The values of RAND and SRES (but not the key) are passed to the MSC.

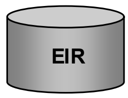
The MSC sends RAND to the mobile, which uses its key and the A3 algorithm to generate SRES.

The MS returns its SRES value to the MSC, which compares the two values. If they are the same, the mobile is allowed on the network.

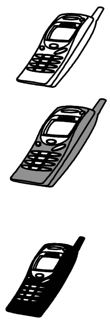
This system provides fairly good (but not perfect) protection against fraud and SIM cloning. It can however be broken.

The A8 algorithm is used to generate a second key (K_c) which is used to apply encryption to the voice or data being transmitted. Again this provides limited protection against interception of the message.

Equipment Identity Register (EIR)



- EIR is a database that stores a unique International Mobile Equipment Identity (IMEI) number for each item of mobile equipment
- The EIR controls access to the network by returning the status of a mobile in response to an IMEI query
- Possible status levels are:
  - White-listed The terminal is allowed to connect to the network.
  - Grey-listed The terminal is under observation by the network for possible problems.
  - Black-listed The terminal has either been reported stolen, or is not a type approved for a GSM network. The terminal is not allowed to connect to the network.



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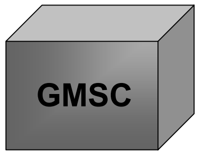
The EIR may optionally be used by the operator to control access to the network by certain types of equipment or to monitor lost or stolen handsets.

Gateway Mobile Switching Centre (GMSC)

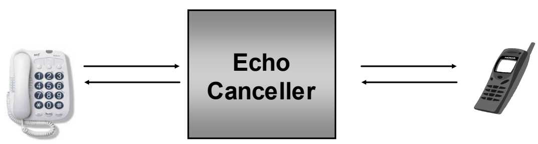
- A Gateway Mobile Switching Centre (GMSC) is a device which routes traffic entering a mobile network to the correct destination
- The GMSC accesses the network's HLR to find the location of the required mobile subscriber
- A particular MSC can be assigned to act as a GMSC
- The operator may decide to assign more than one GMSC



The GMSC routes calls out of the network and is the point of access for calls entering the network from outside.

Echo Canceller

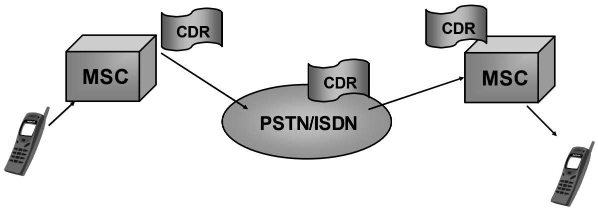
- Operation:
  - An echo canceller models the voice signal passing through it
  - As the voice passes back through the canceller it applies a signal to remove it dynamically
- Cause of Echo:
  - Delays due to signal processing in the handset and at interfaces in the network
  - Signal processing which leads to echo includes:
    - channel coding
    - equalization



Echo cancelling is carried out in the NSS as it occurs at the interfaces between networks.

Billing

- The MSC/GMSC that originates a call generates a record (Call Detail Record) which contains:
  - subscriber identity
  - number called
  - call length
  - routing of the call



- This record acts as a 'toll ticket' which tracks the call on its route through various networks
- The record passes along the backbone to the home network
- Billing computer generates bills to be sent to the user
- Under international agreements, the home network collects the charges
- Payment due to other networks is settled by transfer of monies

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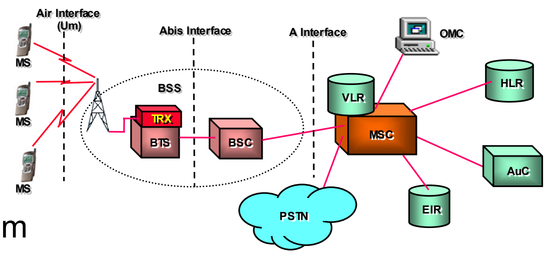
The MSC which originates the call keeps control of it throughout subsequent handovers in order to maintain the Call Detail Record.

Summary

- 1st and 2nd Generation Cellular Systems
  - Analog and digital systems; advantages of digital; coverage / capacity
- GSM Architecture
  - MS - BSS - NSS
- The Mobile Station
  - ME / SIM; IMSI
- The Base Station Sub-system
  - BTS / BSC; TRX
- The Network Switching System
  - MSC / HLR / AuC/ VLR / EIR / GMSC; Authentication, EC, Billing



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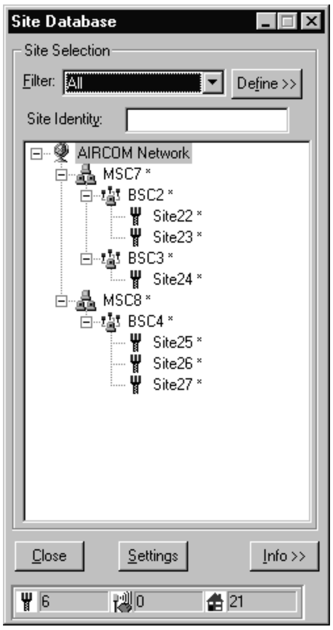
Section 1 Self-Assessment Exercises

Exercise 1.1 – GSM Architecture

The following exercises tests your understanding of GSM architecture as applied to a small network.

Here is a screen shot from Asset showing the site database of a small network:



Sites 22 and 23 are connected in a star configuration to the BSC.
Sites 25, 26 and 27 are connected in a chain.

Draw a full architecture diagram for this network, showing all BSS and NSS elements and their connections.

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2. Services and Operations

2.1 Introduction

This section covers some of the main services and operations within the GSM network. Areas covered include:

- Subscriber services offered by GSM
- Network areas
- Roaming
- Activities and operations in the network

2.2 GSM Subscriber Services

Section 2 – Services & Operations

GSM Subscriber Services

- Two types of basic service can be offered to the end user:
  - Teleservices - service completely defined including terminal equipment functions - telephony and various data services
  - Bearer services - basic data transmission capabilities - protocols and functions not defined
- There are also supplementary services which support and complement both the telephony and data services

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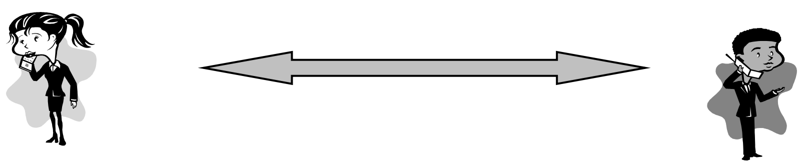
Section 2 – Services & Operations

Telephony Services

- Two types of telephony:
  - Basic speech telephony
  - Emergency calls
- Speech Telephony:
  - Transmission of speech information and fixed network signalling tones
  - Transmission can be mobile originated as well as mobile terminated



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Emergency Calls

- Provides standard access to the emergency services irrespective of the country in which the call is made
- Mandatory in GSM networks
- May be initiated from a mobile without a SIM
- Emergency calls can override any locked state the phone may be in
- Uses a standard access to the emergency call (112) as well as the national emergency call code
- If the national emergency code is used the SIM must be present

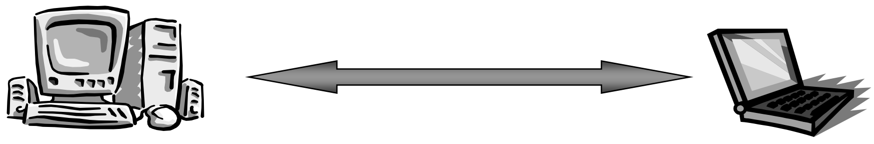
Other Teleservices

Some services supported by GSM:

- DTMF - Dual Tone Multi-Frequency - used for control purposes - remote control of answering machine, selection of options
- FAX - GSM connected fax can communicate with analog machines
- SMS - short message service - Text
- Cell Broadcast - short text messages sent by the operator to all users in an area, e.g. to warn of road traffic problems, accidents
- Voice Mail - answering machine in the network, controlled by subscriber
- Fax Mail - fax messages stored - subscriber can direct message to any fax machine by using a security code

GSM Bearer Services

- Some data transfer bearer services offered by GSM are:
  - Asynchronous data
  - Synchronous data
  - Packet switched assembler/disassembler access
  - Alternate speech and data



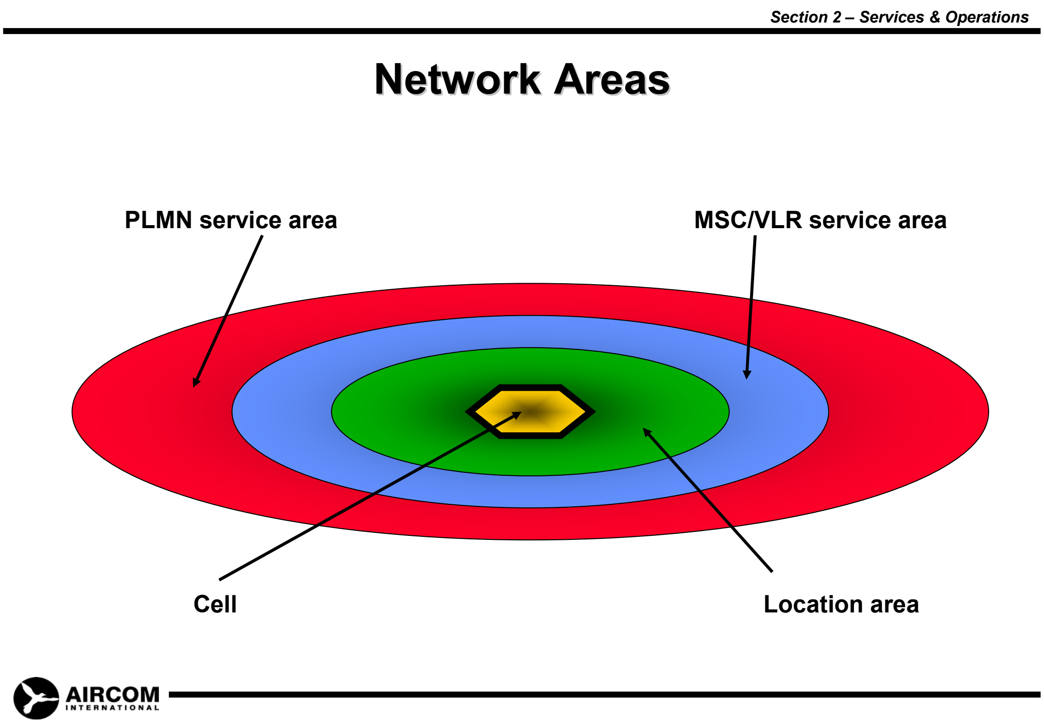
Section 2 – Services & Operations

Supplementary Services

Additional support services include:

- Call forwarding - forward incoming calls to another number
- Bar outgoing calls
- Bar incoming calls - all calls, calls when roaming outside home PLMN
- Advice of charge - estimates of billing data
- Call hold - interrupting a call - normal telephony only
- Call waiting - notification of new incoming call during another call
- Multi-party service - simultaneous conversation between 3 - 6 subscribers
- Calling line identification - presentation of callers ISDN number - caller can override this
- Closed user groups - group of users who can only call each other and certain specified numbers

2.3 Network Areas



Notice that a location area may involve more than one BSC.

A subscriber outside of their PLMN may access their normal service with a roaming agreement.

2.4 Roaming

Roaming

- Allows subscriber to travel to different network areas, different operator’s networks, different countries - keeping the services and features they use at home
- Billing is done through home network operator, who pays any other serving operator involved
- Requires agreements between operators on charge rates, methods of payments etc.

- Clearing house companies carry out data validation on roamer data records, billing of home network operators and allocation of payments

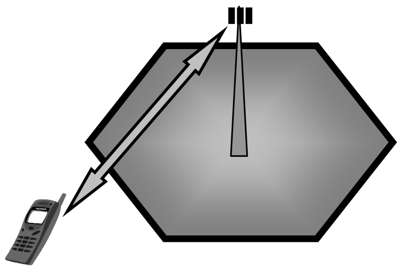
2.5 Activities and Operations

Section 2 – Services & Operations

Activities and Operations

- Main activities which the network must carry out are:
  - Switching mobile on (IMSI attach)
  - Switching mobile off (IMSI detach)
  - Location updating
  - Making a call (mobile originated)
  - Receiving a call (mobile terminated)
  - Cell measurements and handover

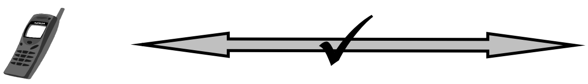
Mobility Management



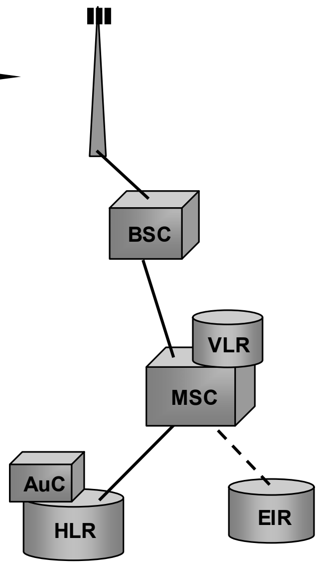
Mobility Management refers to the way in which the network keeps track of a mobile in idle mode, so that it can be located when there is an incoming call (mobile terminated).

Section 2 – Services & Operations

IMSI Attach (Switch on)



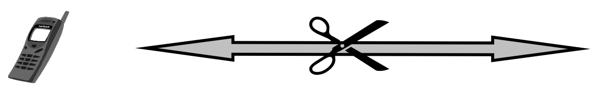
- Mobile camps on to best serving BTS
- Mobile sends IMSI to MSC
- MSC/VLR is updated in HLR
- Subscriber data including current location area is added to local VLR
- MSC and HLR carry out authentication check - challenge and response using K_i
- Optionally EIR checks for status of mobile (white/grey/black)



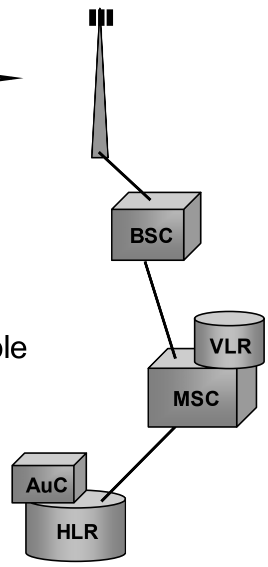
The process of camping on to the best BTS is cell selection which involves calculating a parameter C1 for each cell. Subsequent re-selections are based on a second parameter, C2. This is covered in detail in course G103.

Section 2 – Services & Operations

IMSI Detach (Switch off)



- Mobile informs MSC it is switching off
- HLR stores last location area for mobile
- VLR records that mobile is no longer available on network
- Mobile powers down



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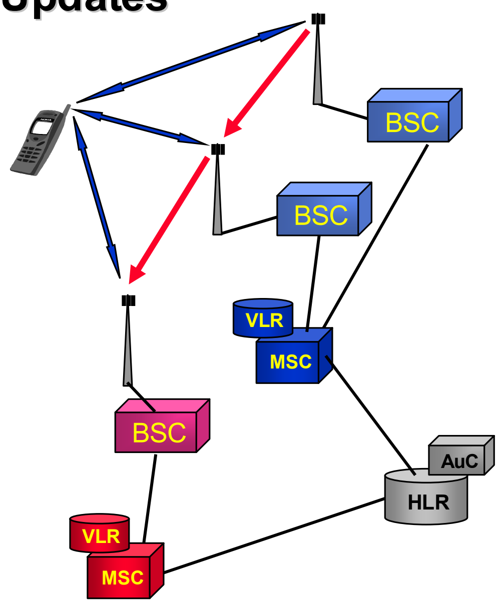
If the mobile is not powered down correctly, the network will lose track of it. Periodic Location Updates may be carried out to check the mobile is still in the network.

Section 2 – Services & Operations

Location Updates

- Automatic Location Update - when mobile moves to new location area
- Periodic Location Update - checks that mobile is still attached to network
- Updates location area in VLR
- If move is to a new MSC/ VLR then HLR is informed



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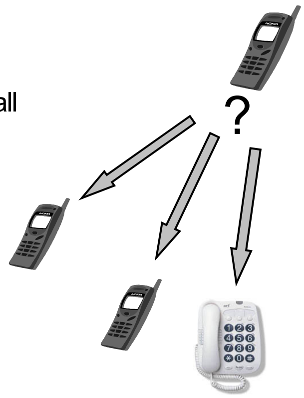
Mobile Originated Call

- When the mobile requests access to the network to make a call:
- BSS determines the nature of the call - e.g. regular voice call, emergency call, supplementary service
  - Allocates radio resources to the mobile for the call
- NSS determines the destination of the call:
  - •Mobile to mobile on same PLMN
  - •Mobile to mobile on another PLMN
  - •Mobile to fixed network (PSTN, ISDN)
  - MSC / GMSC routes the call appropriately and handles signalling



If the call is for another network, the originating MSC will route it to the gateway (GMSC) where it will be passed to the other network's gateway.

For calls within the home network, the VLR and possibly the HLR must be interrogated to find the current location of the recipient. See the activity at the end of this section for more details.

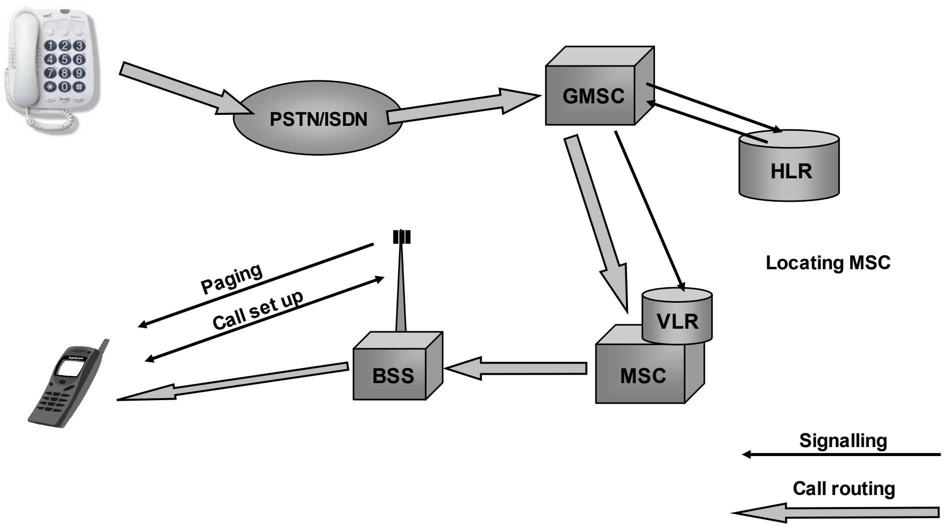
Mobile Terminated Call

- A telephone user (within the mobile network or outside) tries to call a mobile subscriber - dials MS ISDN for subscriber
- For external caller:
  - ISDN routes call to GMSC
  - Current VLR is found from HLR
  - Mobile Subscriber Roaming Number sent to GMSC
  - GMSC routes call to correct MSC/VLR
- For internal caller: HLR supplies current MSC/VLR
- VLR supplies current location area
- BSS pages mobile within location area
- Mobile responds and radio resources are allocated by BSS

The HLR stores location information only to the level of the MSC/VLR of the subscriber.

Their VLR stores the Location Area within that MSC/VLR.

Routing of External Call



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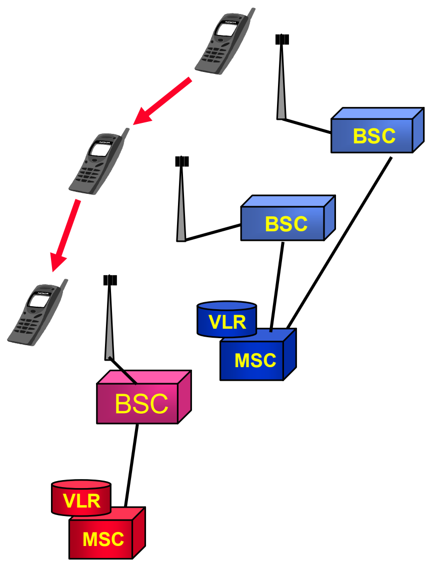
Cell Measurements and Handover

- As mobile moves around it monitors signal strength and quality from up to 6 neighbour cells
- BSS determines when handover should occur, based on cell measurements and traffic loading on neighbour cells
- Handover may be to:
  - another channel in the same cell
  - new cell, same BSC
  - new cell, new BSC
  - new cell, new MSC/VLR
- GSM handover is 'hard' - mobile only communicates with one cell at a time



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The mobile remains under the control of the originating MSC throughout subsequent handovers.

Example of an Inter – MSC handover:

The call starts with MSC A and is handed over to MSC B. As the call continues it is necessary to handover to MSC C.

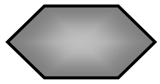
To do this, the call is first handed back to MSC A, which then hands it over to MSC C.

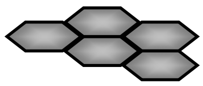
Intra-cell handovers (within the same cell) may occur if there is interference on a particular physical channel.

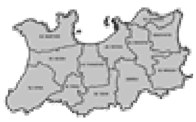
Section 2 – Services & Operations

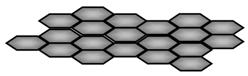
Summary

- Subscriber services offered by GSM:
  tele-services (voice), bearer services (data), supplementary services
- Network areas: PLMN, MSN, LA, Cell
- Roaming: billing arrangements, clearing houses
- Activities and operations on the network:
  IMSI attach / detach, location updating,
  Calls: mobile originated / mobile terminated
  Cell measurements, handover









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Section 2 Self-Assessment Exercises

Exercise 2.1 – Mobile-Originated Calls

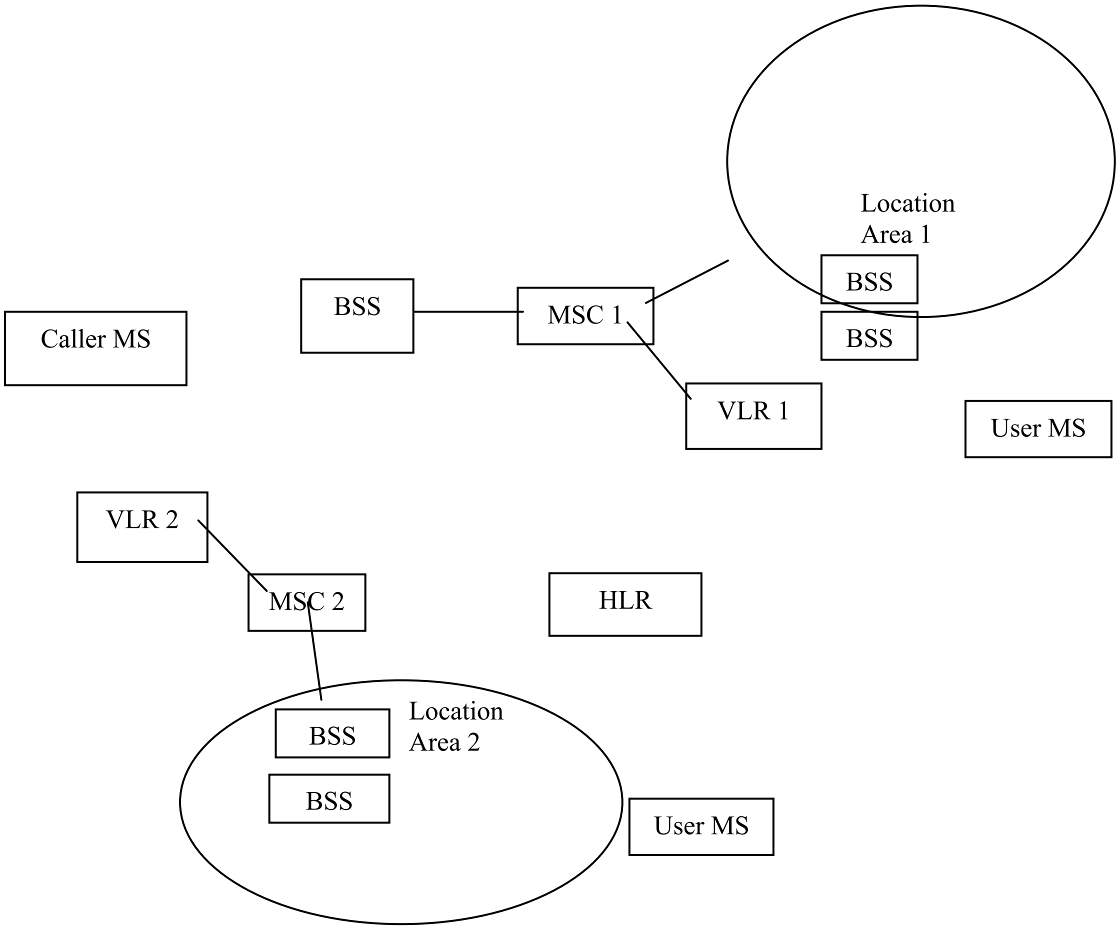
The following exercise re-visits the situation of a mobile originated call. You will need to consider how the network determines the location of the recipient in order to route the call correctly.

Mobile Originated Calls

A subscriber is trying to call another user of the same network.

The other user may be in the same MSC as the caller (Location Area 1) or a different MSC (Location Area 2).

Add notes and arrows to the diagram below to show the call routing and signalling required to locate the user and set up the call



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3. Radio Waves and Antennas

3.1 Introduction

This section looks briefly at the basic physics of electromagnetic waves to prepare for considering the effects of the environment on the propagation of radio waves later in the course.

3.2 Radio Wave Propagation

Section 3 – Radio Waves & Antennas

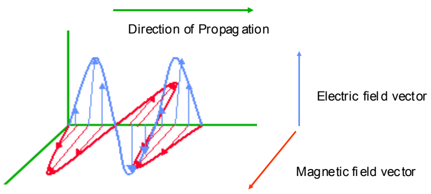
Electromagnetic Waves

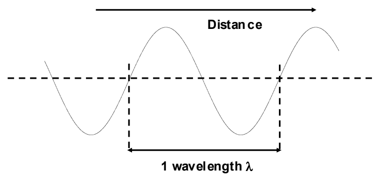
- Self-sustaining disturbance in the form of electric and magnetic fields
  - Propagate carrying energy
  - Transverse wave
- Equation: $v = f\lambda$

  v = velocity of propagation
  (speed of light, $c = 3 \times 10^8$ m/s)

  f = frequency (Hertz)

  λ = wavelength (metres)

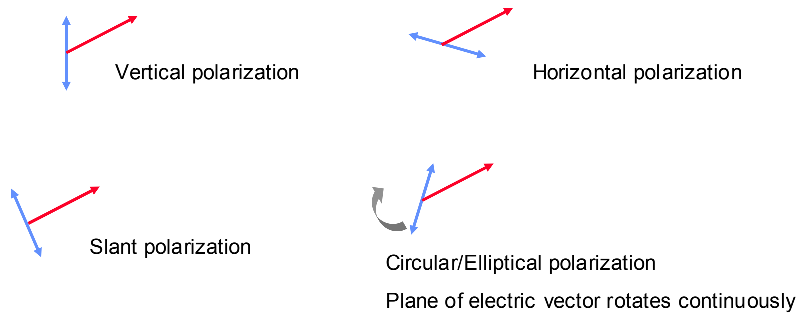




Using the equation, find the wavelength of a GSM 900 MHz wave. Waves suffer diffraction effects more strongly when their wavelength is similar to the size of objects in the environment. What are the implications of this for the 900 MHz wave?

Polarization

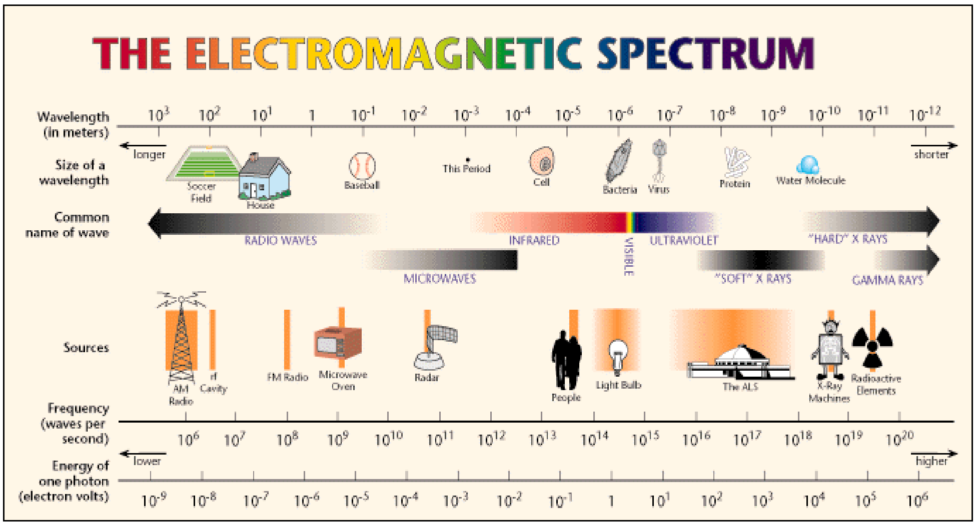
- Transverse wave - the electric and magnetic fields oscillate at right angles to the direction of propagation
- The plane of polarization is defined as the plane in which the electric field oscillates



Radio waves in GSM are generally vertically polarized, but the plane may be rotated due to reflections. This can be used to provide diversity reception (see Section 9).
Vertical and horizontal polarization may be used to isolate microwave signals in transmission links.

3.3 Radio Spectrum

Spectrum Diagram



Advanced Light Source, Berkeley Lab.

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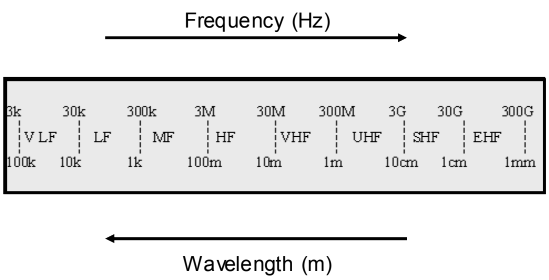
Radio Spectrum

- Radio Spectrum is a limited resource
- Controlled internationally by ITU and in Europe by ETSI



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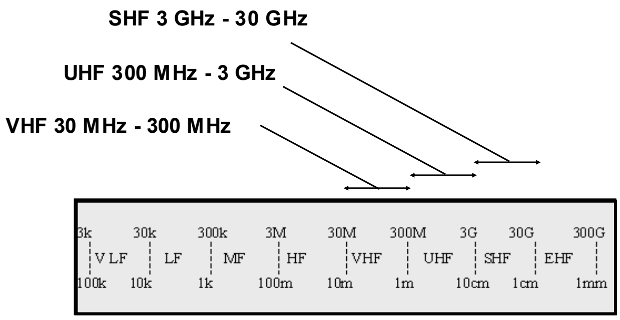
The whole radio spectrum is divided for convenience into bands such as VHF, UHF and so on. The range of the spectrum used by GSM is in the UHF band.

Spectrum for Mobile Communication

For mobile communication we are using following ranges:



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Section 3 – Radio Waves & Antennas

Frequency Allocation

- Authority to use a frequency is given under certain conditions such as:
  - Location
  - Power levels
  - Modulation types
  - Bandwidth
- Regulatory bodies deal with this allocation in different parts of the world:
  - International Telecommunications Union (ITU)
  - European Telecommunications Standards Institute (ETSI)
  - Radiocommunications Agency (RA) in the UK

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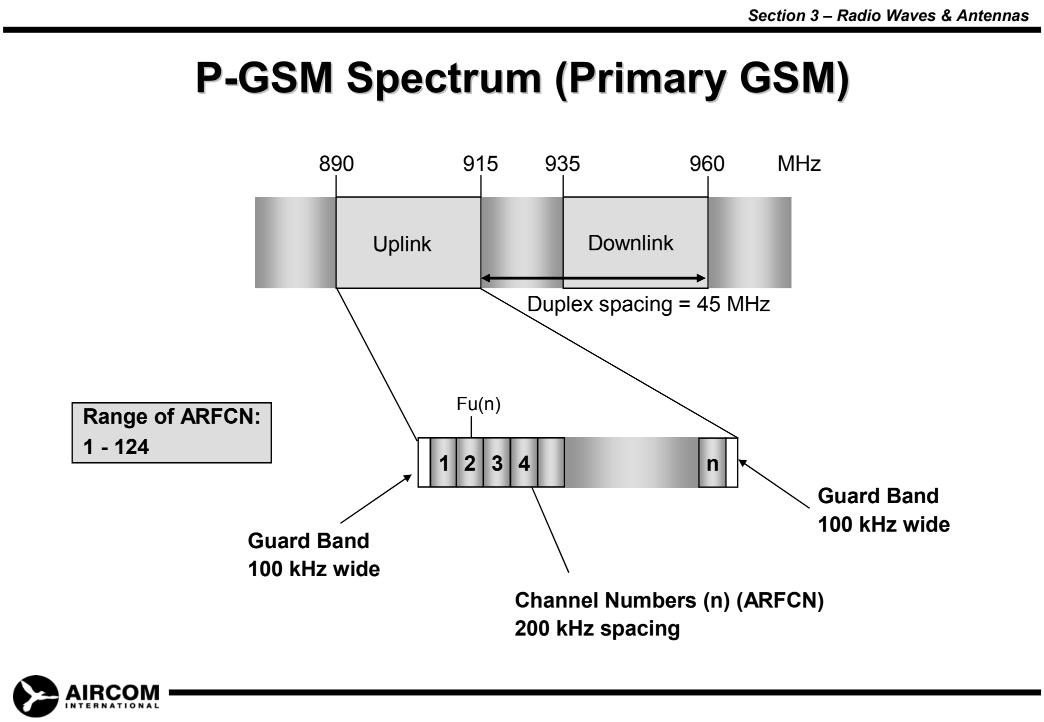
A major initial financial outlay for network operators is to acquire a licence to use a particular bandwidth of radio spectrum. The method of allocation differs from country to country, but may be by auction or direct choice of operators by the government organisation responsible.

3.4 GSM Spectrum Allocation



The initial allocation of spectrum for GSM provided 124 carriers with Frequency Division Duplex for uplink and downlink:

Duplex sub bands of width 25 MHz - duplex spacing 45 MHz

Uplink sub band: 890 MHz to 915 MHz
Downlink sub band: 935 MHz to 960 MHz

Frequency spacing between carriers is 200 kHz (0.2 MHz)
One carrier is used for guard bands, giving:

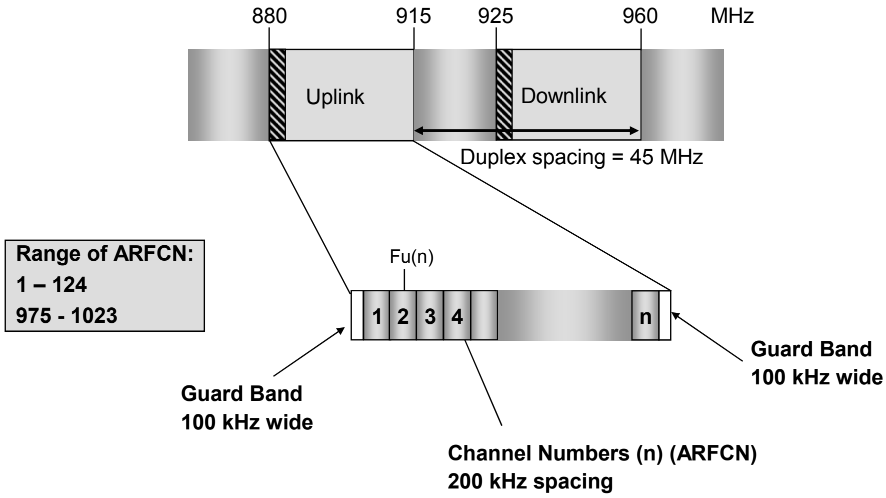
Total number of carriers (ARFCNs) = (25 – 0.2) / 0.2 = 124

Uplink frequencies: Fu(n) = 890 + 0.2 n   (1 <= n <= 124)

Downlink frequencies: Fd(n) = Fu(n) + 45

Where n = ARFCN (ARFCN – Absolute Radio Frequency Carrier Number)

E-GSM Spectrum (Extended GSM)



E-GSM allocated extra carriers at the low end of the spectrum. The ARFCN numbers of P-GSM were retained (with 0 now included) and new ARFCNs introduced for the lower end, numbered 975 – 1023.

Duplex sub bands of width 35 MHz - duplex spacing 45 MHz (same as P-GSM)
Uplink sub band: 880 MHz to 915 MHz
Downlink sub band: 925 MHz to 960 MHz

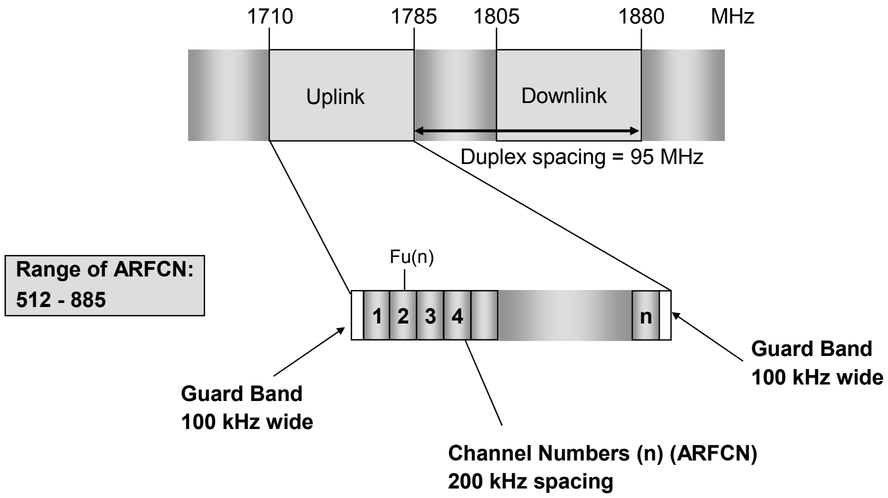
Frequency spacing of 200 kHz
One carrier used to provide guard bands, giving:

Total number of carriers (ARFCNs) = (35 – 0.2) / 0.2 = 174

Uplink frequencies: $Fu(n) = 890 + 0.2\,n$ $(0 <= n <= 124)$
$Fu(n) = 890 + 0.2\,(n - 1024)$ $(975 <= n <= 1023)$

Downlink frequencies: $Fd(n) = Fu(n) + 45$

DCS-1800 Spectrum



Digital Communication System – 1800 MHz introduced a further spectrum range for GSM, typically used for smaller microcells overlaid over existing macrocells.

Duplex sub bands of width 75 MHz - duplex spacing 95 MHz

Uplink sub band: 1710 MHz to 1785 MHz
Downlink sub band: 1805 MHz to 1880 MHz

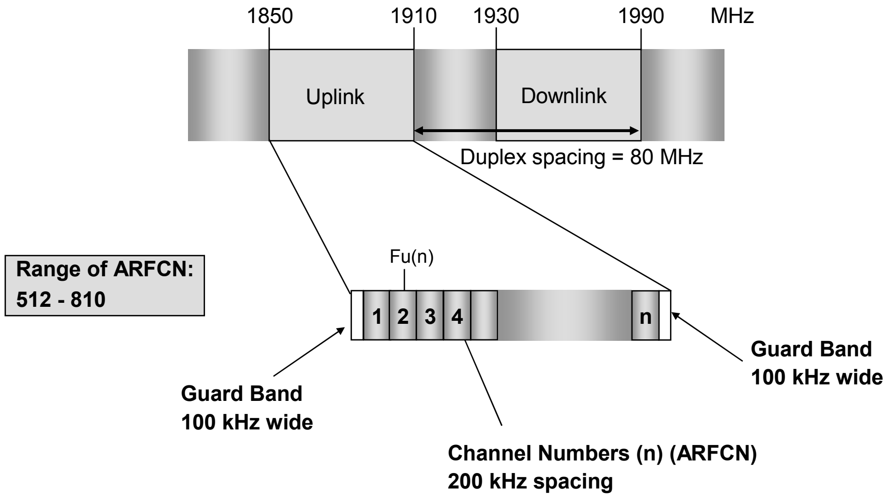
Frequency spacing of 200 kHz
One carrier used to provide guard bands, giving:

Total number of carriers (ARFCNs) = (75 – 0.2) / 0.2 = 374

Uplink frequencies: Fu(n) = 1710.2 + 0.2 (n – 512)   (512 <= n <= 885)

Downlink frequencies: Fd(n) = Fu(n) + 95

PCS-1900 Spectrum



Personal Communication System – 1900 MHz is used in USA and Central America to provide a service similar to GSM.

Duplex sub bands of width 60 MHz - duplex spacing 80 MHz

Uplink sub band: 1850 MHz to 1910 MHz
Downlink sub band: 1930 MHz to 1990 MHz

Frequency spacing of 200 kHz
One carrier used to provide guard bands, giving:

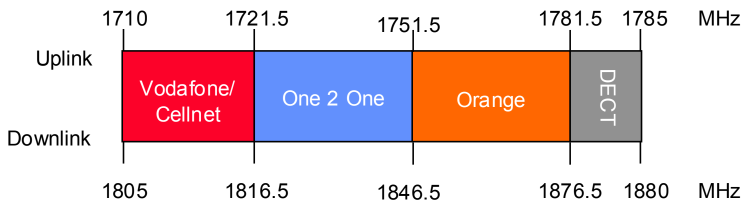
Total number of carriers (ARFCNs) = (60 – 0.2) / 0.2 = 299

Uplink frequencies: Fu(n) = 1850.2 + 0.2 (n – 512)   (512 <= n <= 810)

Downlink frequencies: Fd(n) = Fu(n) + 80

1800 MHz Utilization in UK

The present distribution of frequencies among UK operator is:



DECT: Digital Enhanced Cordless Telecommunications

This spectrum diagram shows the way in which the 1800 MHz band is currently distributed among operators in the UK. Note the uplink and downlink sub bands are shown on the one diagram.

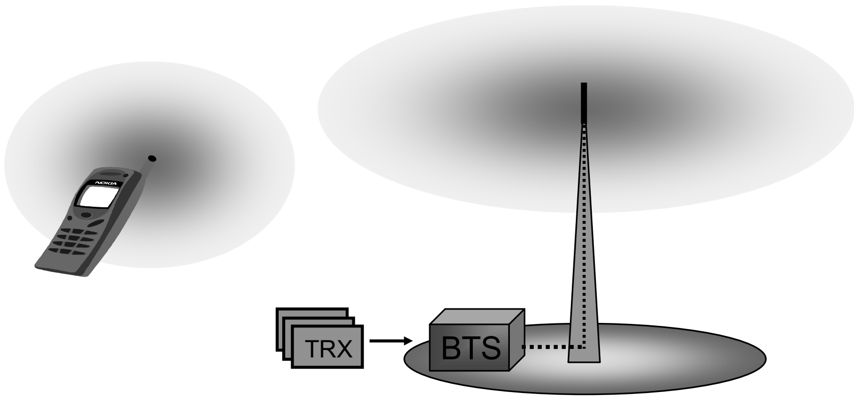
In the following activity, you will use the ARFCN formulae to calculate carrier frequencies on the E-GSM and DCS 1800 bands.

3.5 GSM Antenna Types

Section 3 – Radio Waves & Antennas

Antennas

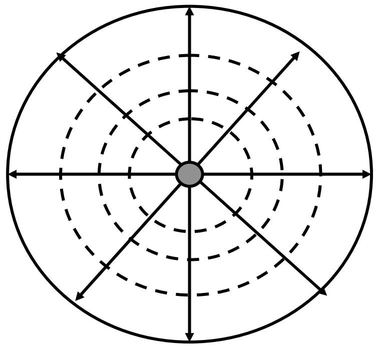
- Radiate and receive radio waves
- In BTS, antenna is connected to transceiver (TRX) via feeder cables



The design of the antenna is crucial to the radio coverage that the BTS will achieve. Essential parameters in the antenna design are its gain, beamwidth and polarization. The coverage region of the antenna is indicated by its radiation pattern.

Isotropic Radiator

- Theoretical form of antenna
- Radiates power equally in all directions
- Radiation pattern is a sphere
- Gain of any real antenna is measured against an isotropic radiator



Section 3 – Radio Waves & Antennas

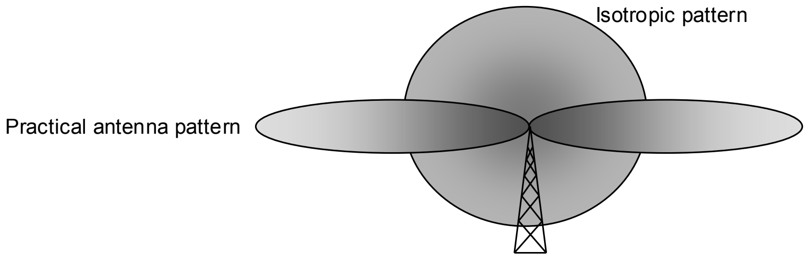
Power Measurement

- Electromagnetic wave carries energy
- Rate of transmission of energy - power in watts (W)
- Generally quoted using decibel scale
- Decibels used to compare power (e.g. gain of amplifier)
  - Gain in dB = **10 log (Output Power / Input Power)**
    - e.g. 0 dB means output = input - no gain or loss
    - -3dB means output power is half of input
- Decibels can measure actual power by relating it to a reference level
  - dBm uses a reference level of 1 mW (milliwatt)
    - e.g.: 0dBm = 1 mW, -3dBm = 0.5 mW, 3 dBm = 2 mW

It is essential to understand the decibel scale and to appreciate the difference between absolute power measurements (in dBm) and changes in power, i.e. gains or losses (in dB or dBi).

Antenna Gain

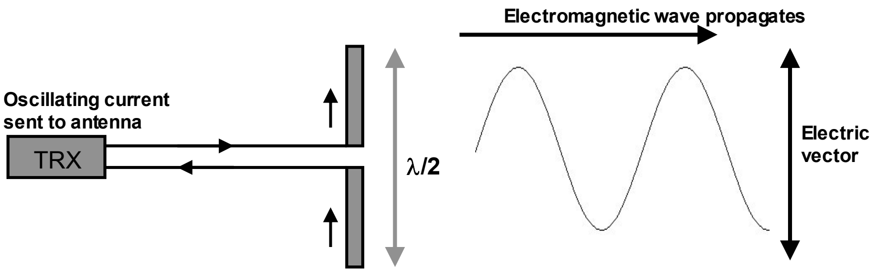
- Practical antennas concentrate their radiated power in certain directions
- Power over a particular area is greater than that from an isotropic radiator
- Antenna is said to have a gain relative to the isotropic radiator
- Measured in dBi



Antenna gain is due to the concentration of power compared to the isotropic pattern. There is no actual power gain as there would be from an amplifier for instance.

Dipole Antenna

- Basic form of practical antenna

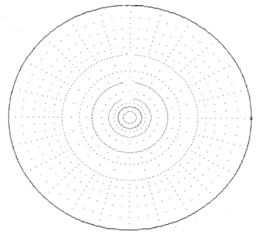


- Dipole radiates most strongly when its length is half the wavelength (**λ/2)**
  of the wave being transmitted
- Vertical polarisation - parallel to dipole

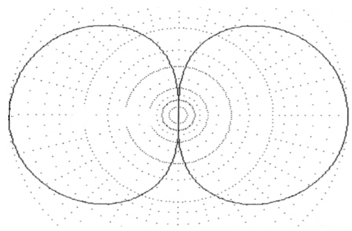
The dipole is simplest form of practical antenna. As such it is often use as a reference point by manufacturers when measuring the gain of more complex antennas. For this reason, antenna specifications often quote gains in dBd.

Dipole Radiation Pattern

- Horizontally (azimuth) radiation is symmetrical - omni-directional
- Vertically (elevation) it is confined to a figure of 8 pattern of lobes



Horizontal pattern



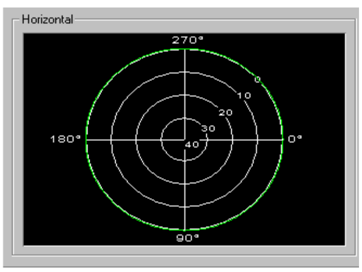
Vertical pattern

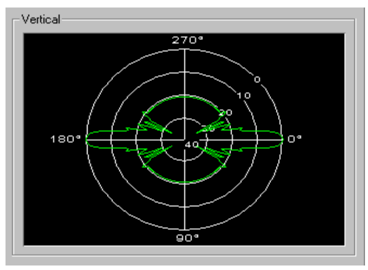
- Dipole antenna has a gain relative to the isotropic radiator of 2.14 dBi
- Gain may be measured relative to dipole in dBd:

Gain in dBi = Gain in dBd + 2.14

Omni-directional Antenna

- Radiation pattern is further concentrated in the vertical plane
- Horizontally the pattern is still symmetrical, but vertically there are different lobes
- Gives a higher gain - typically 8 to 12 dBi

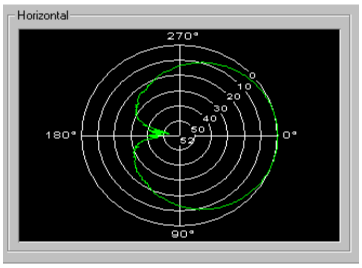


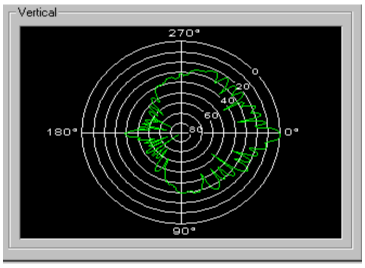


An omni-directional antenna uses a collinear array of dipoles to concentrate the radiation pattern in the vertical plane. Sector antennas use corner reflectors to further concentrate the radiation in the horizontal plane.

Sectored Antenna

- Reflectors used to confine coverage in horizontal plane
- May have main lobe and side lobes
- Gain typically 12 to 18 dBi
- Beam width measured to -3dB level from main direction





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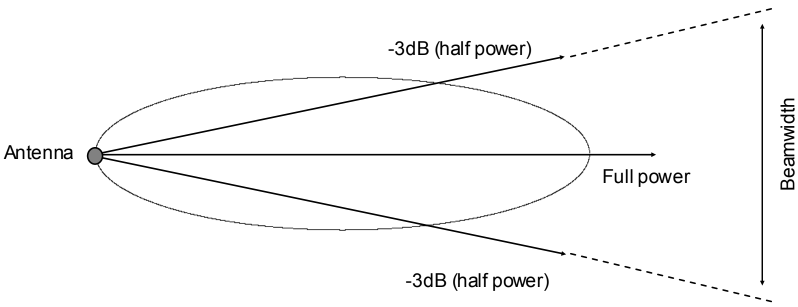
Antenna Beam Width

- Half Power Beam Width (HPBW)



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A typical beam width for a GSM antenna is 80 – 90 degrees. Notice this still gives adequate coverage over a 120 degree sector. The microwave example below has a very small beam width as it would be used with a line of sight link.

Beam Width Example

- Example of microwave antenna beamwidth: 1.5 degrees

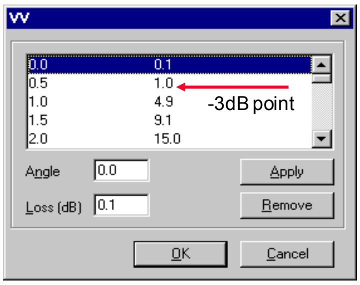
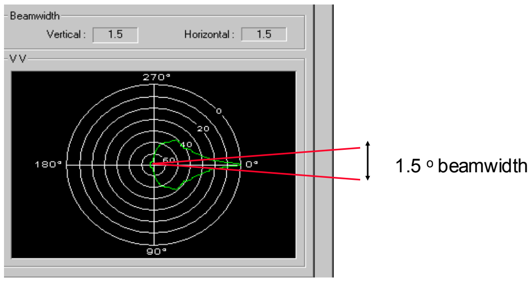


Table shows loss at angles either side of direct line



Vertical radiation pattern with -3dB lines overlaid

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Antenna Tilting

- One option for adjusting the coverage in a cell is to tilt the antenna
  - e.g. down tilting may direct coverage deeper into a building
- Antenna tilt may be:
  - mechanical
  - electrical
- Mechanical tilt is set by operator - affects coverage in a particular direction
- Electrical tilt is set by manufacturer - affects coverage in all directions
- Omni antenna may have electrical tilt but not mechanical

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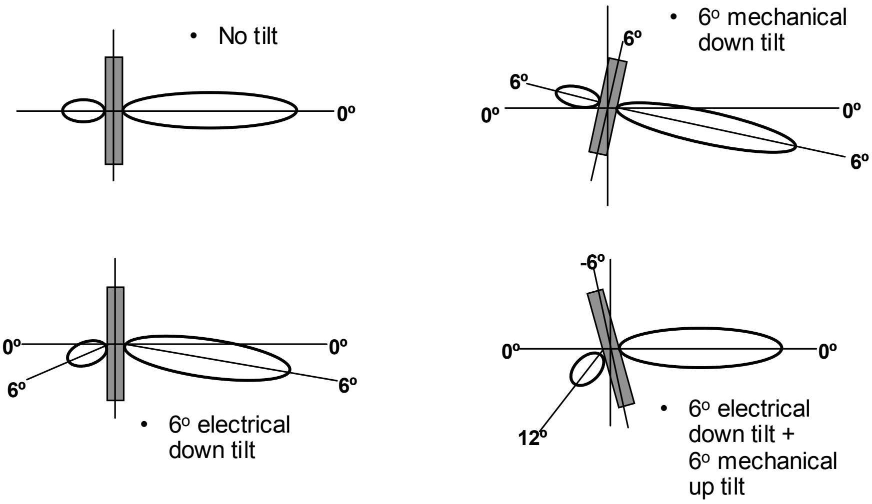
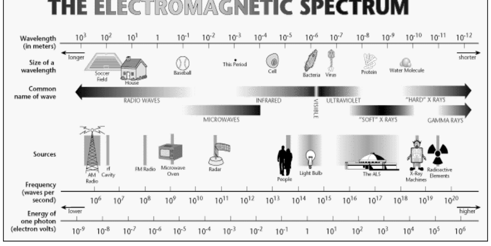
Mechanical tilt is achieved by physical positioning of the antenna. Electrical tilt is built in by setting the phase relationship between the dipoles of the collinear array.

Antenna Tilt Examples



Summary

- Electromagnetic waves:
  wave propagation, $v = f\,\lambda$, polarization
- Radio spectrum allocation: E/M spectrum, radio spectrum, GSM frequency bands, ARFCN
- Antennas: isotropic, units dB, dBi, dipole, dBd, omni, sector, tilting



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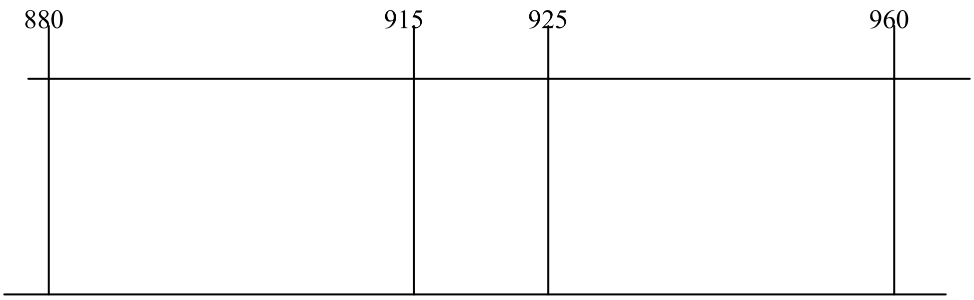
Section 3 Self-Assessment Exercises

Exercise 3.1 – Radio Spectrum Allocation

1. The diagram shows the spectrum for E-GSM



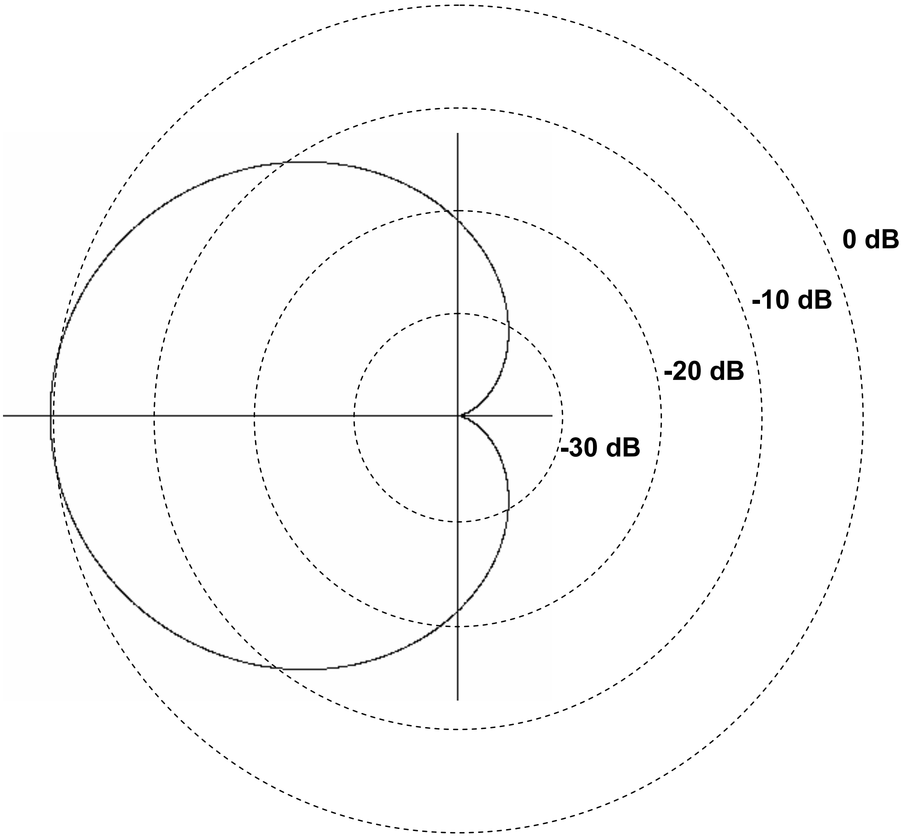
Calculate the up and down link frequencies for ARFCNs 0, 124, 975 and 1023.

Mark these carriers on the diagram.

2. An operator using DCS-1800 is allocated ARFCNs 601 to 625 inclusive.

Calculate the highest and lowest frequencies used for the uplink.

Exercise 3.2 - Antenna Beam Width



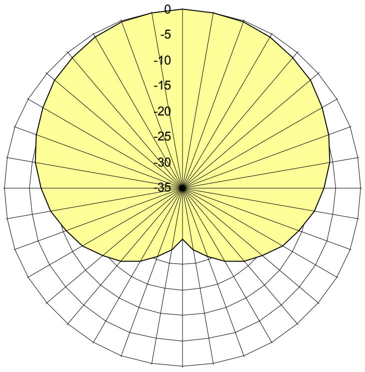
The diagram shows the azimuthal (horizontal) radiation pattern for an antenna.

Draw lines to indicate the half power beam width of the antenna and estimate its angle.

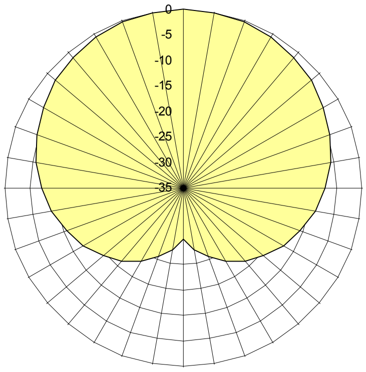
Exercise 3.3 - Antenna Tilting

This activity is based on a spreadsheet simulation of antenna tilting developed by Aircom and show the azimyuth pattern of an anrtenna:

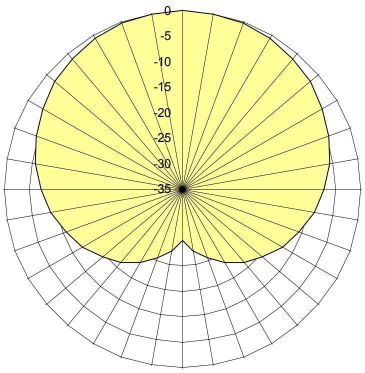
On the three copies of this pattern, sketch what it would be like for the tilt situations shown. Take the angle of tilt to be about 6° in each case.



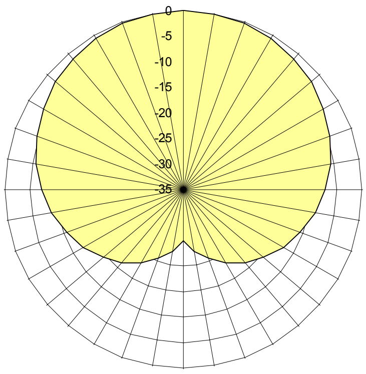
No tilt



Mechanical down tilt only



Electrical down tilt only



Electrical down tilt + mechanical up tilt

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4. The Air Interface

4.1 Introduction

The air interface or radio interface refers to the manner in which communication is achieved between the mobile handset and the base station.

Modulation techniques allow us to put information onto the radio wave, while multiple access techniques allow us to share the limited resources of the radio spectrum among a number of users.

In GSM there are many signalling and communication activities that must be carried out. These are specified as logical channels, which must be mapped onto the physical channels provided by the radio interface.

This mapping is achieved by using multiframes.

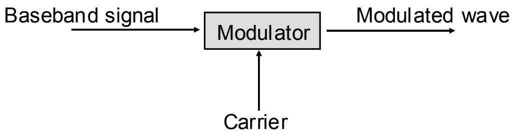
4.2 Modulation Techniques

Analogue modulation is useful for illustrating how information can be carried by a radio wave as it is simple to visualise.

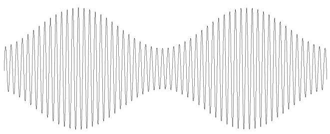
Frequency modulation was used on first generation mobile systems but is very insecure as it can be intercepted and decoded easily.

Modulation

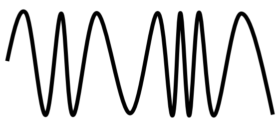
- Process of putting a baseband signal (voice or data) onto a carrier wave



- Analog modulation techniques (1st generation):



Amplitude Modulation (AM)



Frequency Modulation (FM)

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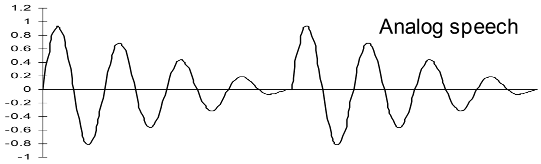
Before looking at the digital modulation techniques used in GSM, we must first consider how the voice, which is naturally an analog signal, can be converted into a train of digital pulses prior to being modulated onto the radio wave.

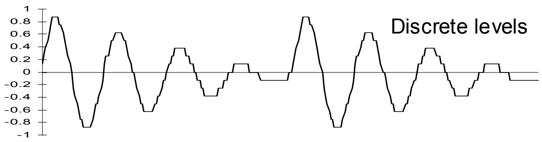
In GSM this is actually done using a vocoder which is dealt with in Section 6. Here we will look at a simpler technique (pulse code modulation) which is used for fixed telephone networks, but requires too high a bandwidth for the GSM air interface.

Digital: Pulse Code Modulation

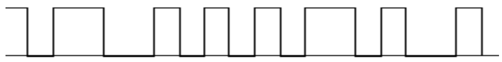
- PCM used on all fixed telephone networks to encode speech
- Analog speech signal is sampled and converted to discrete levels (quantization)



- Sampled levels represented as a sequence of binary data



- Binary data transmitted as a train of digital pulses



Digital pulse train

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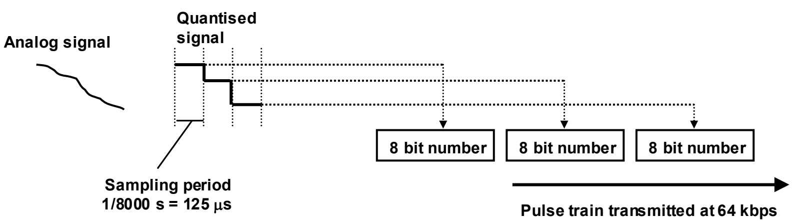
PCM allows us to reproduce speech sound waves accurately up to 4 kHz, which is high enough for the human voice. The rate of sampling must be able to distinguish each peak and trough of the highest frequency waveform. The sampling must thus occur at 8 kHz (twice each period of the waveform), which results in the 64 kbps data rate shown below.

PCM Data Rate

- Standard PCM used on fixed telephone networks transmits at 64 kbps
- Highest frequency needed to reproduce speech = 4 kHz
- Analog signal is sampled 8000 times per second
- Each sample is recorded as a value between 0 and 255 - an 8 bit number
- Bit rate = 8 x 8000 = 64 000 bits per second



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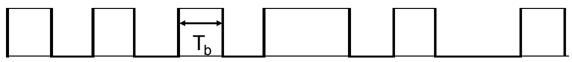
Having turned the speech signal into digital pulses, we now need to modulate these on to the radio wave. We will first look at a range of techniques known as shift key modulation.

Shift Key Modulation

- Shift key modulation techniques are used to put a digital pulse train on to the radio carrier wave
- A property of the carrier wave is changed at the start of each bit period, T_b (symbol period) of the digital signal

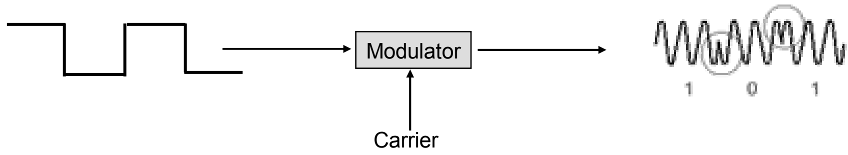


- Two basic forms of shift key modulation are:
  - Phase Shift Keying
  - Frequency Shift Keying

In shift key modulation techniques some property of the wave is changed each bit period to represent the data. Various techniques differ in terms of what property is changed (such as the phase or frequency of the wave) and how many different states of this property can be distinguished (which determines how many actual bits of data are represented by each state change).

Phase Shift Keying

- Phase of carrier wave is altered to represent 1 or 0 in the data signal



- Binary Phase Shift Keying (BPSK) - Two phase states used
- Increased bit rates can be achieved by using more phase states:
  - 4 states: Quadrature Phase Shift Keying (QPSK)
  - 8 states: 8PSK proposed for EDGE systems

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Here the phase of the transmitted wave (compared to a reference state) is the property which is changed each bit period.

In BPSK techniques, such as that used by GSM, only two phase states are used. Each bit period thus represents only one actual bit of data.

QPSK and 8PSK extend the technique to 4 and 8 phase states. Each bit period then represents 2 (QPSK) or 3 (8PSK) actual data bits by mapping the different possible combinations onto the phase states:

Phase	Data Bits		
1	0	0	0
2	0	0	1
3	0	1	1
4	0	1	0
5	1	1	0
6	1	1	1
7	1	0	1
8	1	0	0

Phase	Data Bits	
1	0	0
2	0	1
3	1	1
4	1	0

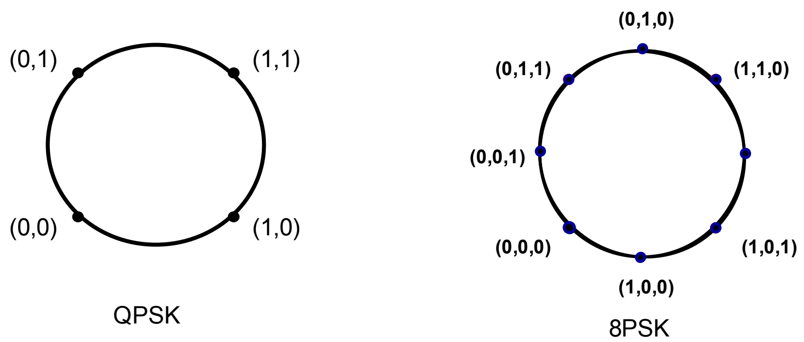
Note the order in which the bit patterns are mapped onto the phase states. This is Gray code in which only one bit changes between adjacent states. Using this technique helps to reduce errors.

The phase states and their mapping onto bit patterns are often shown by constellation diagrams, where the angle around the circle represents the phase angle of the modulation.

Section 4 – The Air Interface

QPSK and 8PSK

- In QPSK each phase state is a *symbol* representing 2 bits of data
- In 8PSK each symbol represents 3 bits of data
- Phase states are represented on a ‘constellation diagram’



This slide brings in the term ‘symbol’ which is used to distinguish the changes of state (symbols) from the number of data bits they represent. Using 8PSK, for example, the data rate (in bits per second) will be 3 times the symbol rate (in symbols per second).

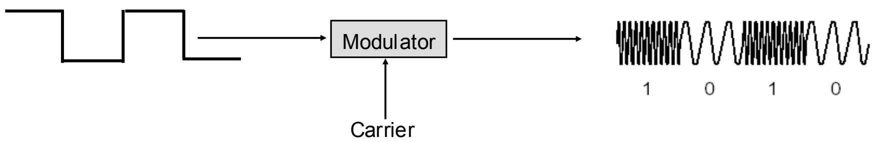
The extension of this technique further is limited by the ability of the receiving equipment to resolve many different phase states in the short time span of the bit period.

A similar modulation scheme is 16QAM (Quadrature Amplitude Modulation) which combines 4 phase states and 4 amplitude states to give 16 combinations allowing 4 bits to be represented by each symbol.

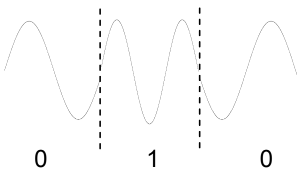
Another limitation on PSK schemes is the sharp phase change at each bit period boundary. Sudden changes in the waveform require high bandwidth to transmit and should be avoided. FSK and MSK described next provide ways of doing this.

Frequency Shift Keying

- Two frequencies are used to represent the two binary levels



- Fast Frequency Shift Keying (FFSK):
  - Frequencies are arranged so there is no phase discontinuity at the change of bit period



> MSK
> FFSK is equivalent to a form of phase shift keying in which the data pulses are shaped in order to smooth the phase transitions. This is called Minimum Shift Keying

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Simple FSK has a sharp transition at the bit period boundaries. By applying a Gaussian filter to the data stream the shift between the frequencies occurs smoothly.

Gaussian Minimum Shift Keying

- Data pulses are shaped using a Gaussian filter:
  - Smoothes phase transitions
  - Gives a constant envelope

> GMSK is used in GSM
>
> QPSK is used in IS-95 (CDMA)

- Comparison of GMSK and QPSK:
  - GMSK requires greater bandwidth
  - QPSK reduces interference with adjacent carrier frequencies
  - GMSK is more power efficient - less battery drain from MS on uplink
  - GMSK has greater immunity to signal fluctuations

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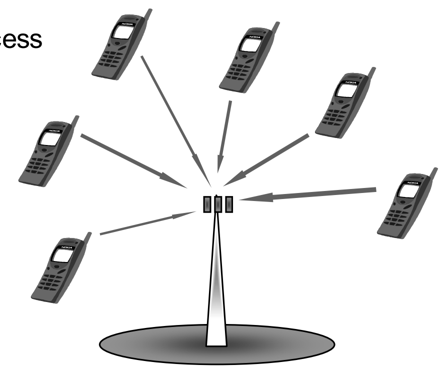
Multiple Access Techniques

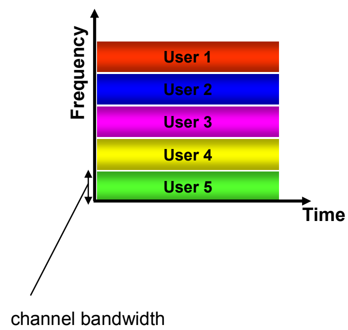
- Purpose: to allow several users to share the resources of the air interface in one cell
- Methods:
  - FDMA - Frequency Division Multiple Access
  - TDMA - Time Division Multiple Access
  - CDMA - Code Division Multiple Access



Multiple access techniques are essential to allow more efficient use of the radio spectrum. 1st generation systems used only FDMA so that a complete radio carrier was allocated to a user throughout their call. This made poor use of the spectrum, but was all that was possible with an analog system.

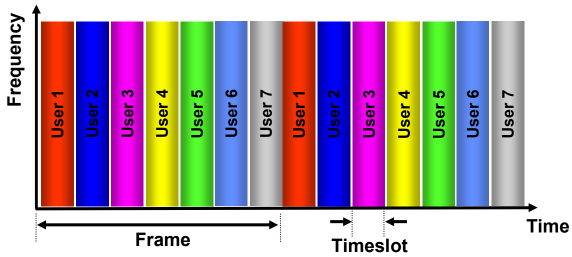
Frequency Division Multiple Access (FDMA)

- Divide available frequency spectrum into channels each of the same bandwidth
- Channel separation achieved by filters:
  - Good selectivity
  - Guard bands between channels
- Signalling channel required to allocate a traffic channel to a user
- Only one user per frequency channel at any time
- Used in analog systems, such as AMPS, TACS
- Limitations on:
  - frequency re-use
  - number of subscribers per area



Time Division Multiple Access (TDMA)

- Access to available spectrum is limited to timeslots
- User is allocated the spectrum for the duration of one timeslot
- Timeslots are repeated in frames

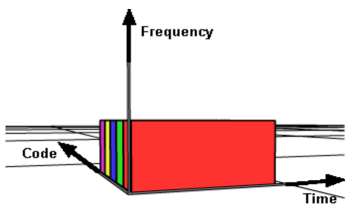


TDMA became possible with digital systems such as GSM in which the data stream could be divided into bursts and allocated to a timeslot. By sharing access to the spectrum, the traffic capacity of the system is enhanced. GSM uses both FDMA to provide carriers and TDMA to share access to the carriers.

Section 4 – The Air Interface

Code Division Multiple Access (CDMA)

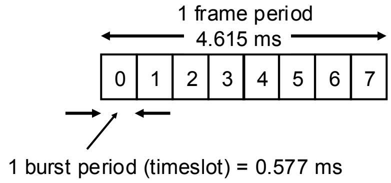
- Each user is assigned a unique digital code (pseudo - random code sequence)
- Code is used at Mobile Station and Base Station to distinguish different user's signals
- Many users' communications can be transmitted simultaneously over the same frequency band
- Advantages:
  - very efficient use of spectrum
  - does not require frequency planning
- Used in IS - 95 (cdmaOne)
- Not used in GSM
- Wideband CDMA techniques to be used in UMTS



4.3 GSM Channels

GSM Channels

- In GSM we refer to two types of channel:
  - Physical Channels - the physical resource available for use
  - Logical Channels - the various ways we use the resource
    - one physical channel may support many logical channels
- Physical Channels
- Using FDMA and TDMA techniques, each carrier is divided into 8 timeslots:



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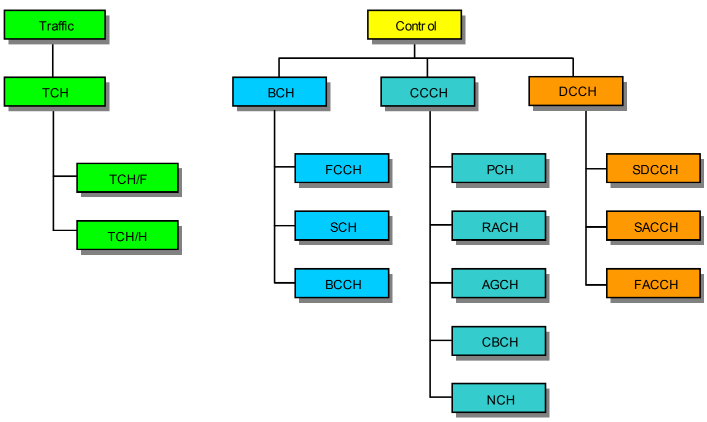
One burst of data (0.577 ms or 156.25 bit periods) is a physical channel. This is used via multiframe structures to provide all the logical channels required.

GSM Logical Channels

- The logical channels are divided into traffic channels and control channels
- They can then be further divided as shown:



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The naming of the GSM logical channels is as follows:

TCH	**Traffic Channels**
TCH/F	Traffic Channel (full rate) (U/D)
TCH/H	Traffic Channel (half rate) (U/D)
BCH	**Broadcast Channels**
FCCH	Frequency Correction Channel (D)
SCH	Synchronisation Channel (D)
BCCH	Broadcast Control Channel (D)
CCCH	**Common Control Channels**
PCH	Paging Channel (D)
RACH	Random Access Channel (U)
AGCH	Access Grant Channel (D)
CBCH	Cell Broadcast Channel (D)
NCH	Notification Channel (D)
DCCH	**Dedicated Control Channels**
SDCCH	Stand alone Dedicated Control Channel (U/D)
SACCH	Slow Associated Control Channel (U/D)
FACCH	Fast Associated Control Channel (U/D)

U = Uplink D = Downlink

The purpose of these channels is outlined in the next four slides.

Traffic Channel (TCH)

- A full rate traffic channel is allocated to one timeslot - normally 1 - 7 if TS0 is used for control signalling
- **TCH/F:** 13 kb/s voice or 9.6 kb/s data
- **TCH/H:** 6.5 kb/s voice or 4.8 kb/s data
- One physical channel (1 timeslot) can support: 1 TCH/F or 2 TCH/H

Uplink / Downlink Synchronisation

A mobile station cannot transmit and receive simultaneously.

The MS transmit burst is delayed by 3 timeslots after the BTS burst.

This delay allows the MS to compare signal quality from neighbouring cells

BTS transmits:

0	**1**	2	3	4	5	6	7

MS transmits:

5	6	7	0	**1**	2	3	4

Half rate TCH is not generally implemented.

The delay between uplink and downlink is generally less than 3 timeslots due to Timing Advance. This is covered in course G103 (Advanced GSM Cell Planning).

Broadcast Channels (BCH)

BCH channels are all **downlink** and are allocated to **timeslot zero**. BCH channels include:

- **FCCH: F**requency **C**ontrol **CH**annel sends the mobile a burst of all ‘0’ bits which allows it to fine tune to the downlink frequency
- **SCH: S**ynchronisation **CH**annel sends the absolute value of the frame number (FN), which is the internal clock of the BTS, together with the Base Station Identity Code (BSIC)
- **BCCH: B**roadcast **C**ontrol **CH**annel sends radio resource management and control messages, Location Area Code and so on. Some messages go to all mobiles, others just to those that are in the idle state

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Common Control Channels (CCCH)

CCCH contains all **point to multi-point downlink** channels (BTS to several MSs) and the **uplink** Random Access Channel:

- **CBCH: C**ell **B**roadcast **CH**annel is an optional channel for general information such as road traffic reports sent in the form of SMS
- **PCH: P**aging **CH**annel sends paging signal to inform mobile of a call
- **RACH: R**andom **A**ccess **CH**annel is sent by the MS to request a channel from the BTS or accept a handover to another BTS. A channel request is sent in response to a PCH message.
- **AGCH: A**ccess **G**rant **CH**annel allocates a dedicated channel (SDCCH) to the mobile
- **NCH: N**otification **CH**annel informs MS about incoming group or broadcast calls

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Dedicated Control Channels (DCCH)

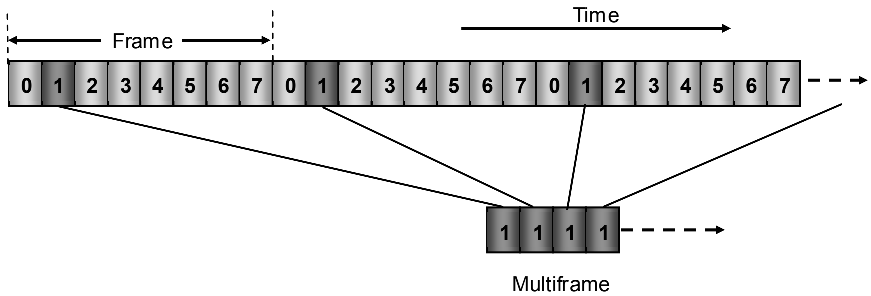
DCCH comprise the following **bi-directional (uplink / downlink) point to point** control channels:

- **SDCCH: S**tandalone **D**edicated **CH**annel is used for call set up, location updating and also SMS
- **SACCH: S**low **A**ssociated **C**ontrol **CH**annel is used for link measurements and signalling during a call
- **FACCH: F**ast **A**ssociated **C**ontrol **CH**annel is used (when needed) for signalling during a call, mainly for delivering handover messages and for acknowledgement when a TCH is assigned

Section 4 – The Air Interface

Multiframes

- Multiframes provide a way of mapping the logical channels on to the physical channels (timeslots)
- A multiframe is a series of consecutive instances of a particular timeslot



- GSM uses multiframes of 26 and 51 timeslots

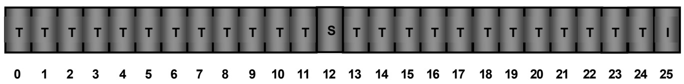
Multiframes allow one timeslot allocation (physical channel) to be used for a variety of purposes (logical channels) by multiplexing the logical channels onto the timeslot.
Notice that a multiframe always refers to a set of instances of the same timeslot. When calculating the timing of a multiframe remember that the time between these instances is that for a complete frame (4.6 ms).

Traffic Channel Multiframe

- The TCH multiframe consists of 26 timeslots.
- This multiframe maps the following logical channels:

•TCH
•SACCH
•FACCH

- TCH Multiframe structure:



T = TCH S = SACCH I = Idle

FACCH is not allocated slots in the multiframe. It steals TCH slots when required.

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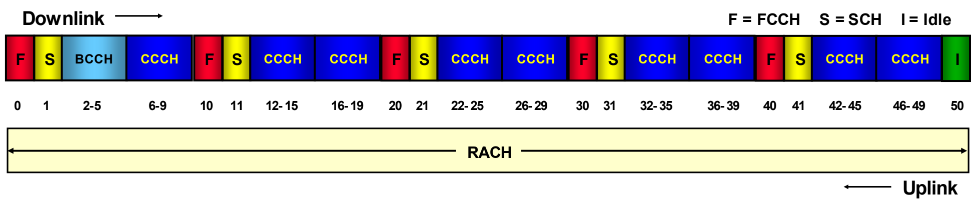
Control Channel Multiframe

- The control channel multiframe is formed of 51 timeslots
- CCH multiframe maps the following logical channels:

Downlink:
- FCCH
- SCH
- BCCH
- CCCH (combination of PCH and AGCH)

Uplink:
•RACH



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During a call the mobile is continually monitoring power levels from neighbouring base stations. It does this in the times between its allocated timeslot. Once each traffic channel multiframe there is a SACCH burst which is used to send a report on these measurements to the current serving base station.

The downlink uses this SACCH burst to send power control and other signals to the mobile.

The idle slot (25) occurs to allow for half rate TCH/H operation in which two mobiles would share the multiframe and sets of reports would need to be sent to the base station. Slot 25 would then be a second SACCH burst.

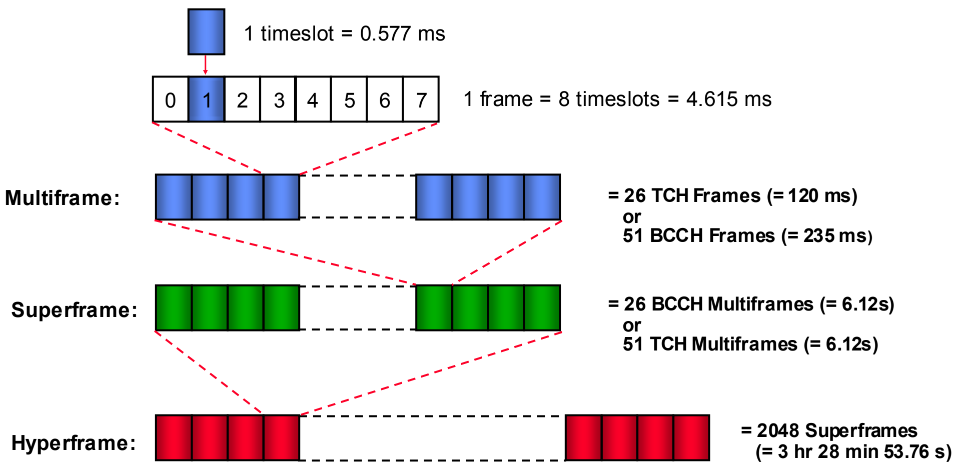
FACCH is used for purposes that require instant access such as a handover command message from the base station. When this is needed, FACCH uses a TCH burst and sets a 'stealing flag' in the burst to show that it is not a traffic channel burst.

Control channel multiframes always consist of 51 timeslots and are generally allocated to timeslot 0 (TS0) in the frame.

The example shown is for TS0 of the BCCH carrier. It includes 9 blocks of CCCH, which will be used for PCH and AGCH. It is possible to replace some CCCH blocks with SDCCH forming a combined multiframe. If more SDCCH is required than can be allocated in this way, then a second timeslot is used (generally TS0 of another carrier) leaving the BCCH as the non-combined multiframe shown above.

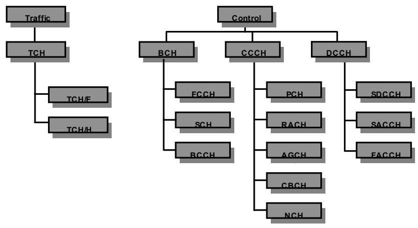
The structure of control channel multiframes and the methods of calculating the allocation required for a particular cell are dealt with in course G103 (Advanced GSM Cell Planning).

Frame Hierarchy



The synchronisation channel (SCH) transmits a frame number (FN) which enables a mobile to synchronise with the base station. The FN is a 22 bit number which resets after each hyperframe, i.e. after 2048 x 26 x 51 = 2715648 frames.

Summary



- Modulation techniques:
  - Analog: AM, FM
  - Digital: PCM, FSK, PSK, GMSK
- Multiple access techniques:
  - FDMA, TDMA, CDMA
- Physical and Logical Channels: Timeslots
- GSM Logical Channels: Traffic and control channels
- Frames and multiframes: Mapping logical channels

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Section 4 Self-Assessment Exercises

Exercise 4.1 - Logical Channels for Mobile Terminated Call

The following logical channels are used in setting up a call to a mobile in a cell (i.e. mobile is receiving the call):

TCH, SDCCH, PCH, FACCH, AGCH, RACH

Write down the order in which these channels would be used in setting up the call and briefly describe what each one does in the process.

Channel	What it does

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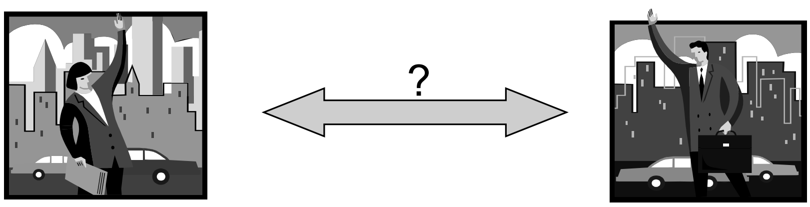
5. Protocols

5.1 Introduction

This section provides a very brief introduction to the topic of protocols and the OSI 7 layer model.

Protocols

- **A protocol is a set of rules, agreed by both sides, to allow meaningful communication to take place**
- **Protocols are needed whenever systems need to pass information from one to another**



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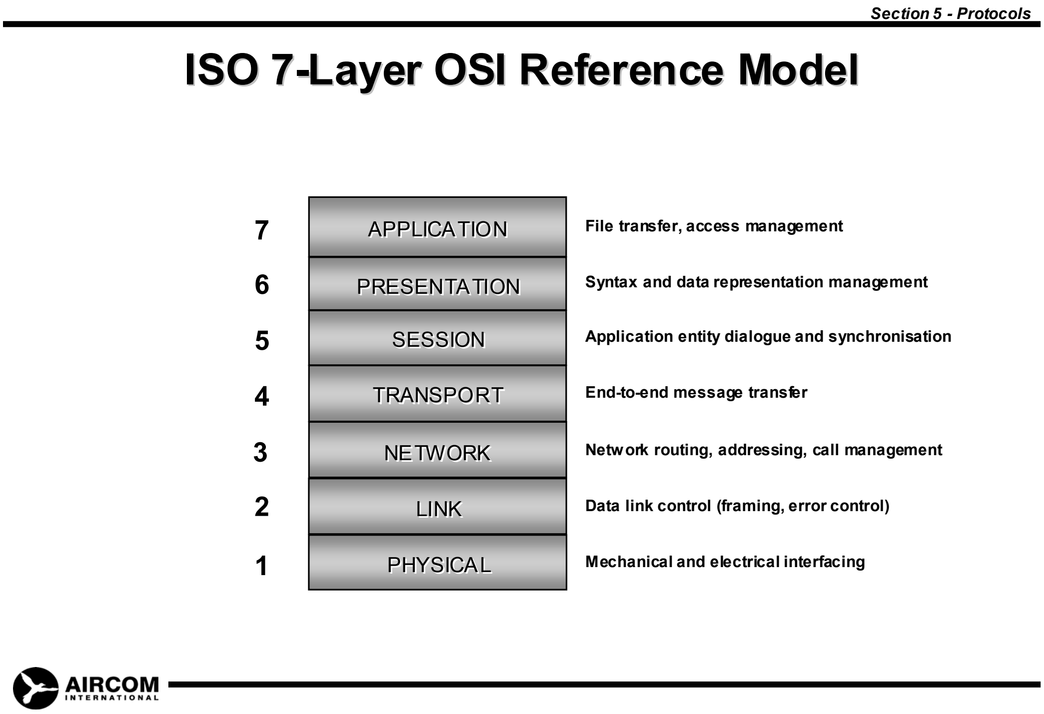
5.2 The ISO 7-Layer OSI Model

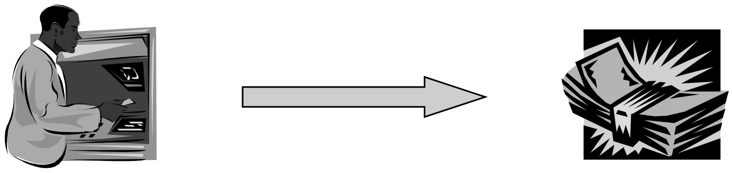


Development of the Open Standards Interconnection (OSI) reference model was started in 1983 by an number of major computer and telecommunications companies. It was eventually adopted as an international standard by the International Standards Organisation (ISO) and is currently embodied within the ITU-TS X.200 Recommendation.

The model comprises 7 layers which define various functions involved in establishing an end-to-end communications circuit.

Layer 7 - Application Layer

- What the system actually does for the user
  - e.g. Bank dispenser
    - Provides money and services to the bank customer

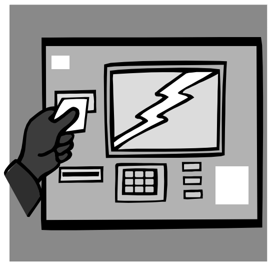


Layer 6 - Presentation Layer

- Converts the semantics into syntax

Takes the abstract user view of the system and produces machine readable instructions

Which buttons do you have to press to get the money?



Layer 5 - Session Layer

- Controls the session, logs calls, checks passwords
  - Network requires username and password

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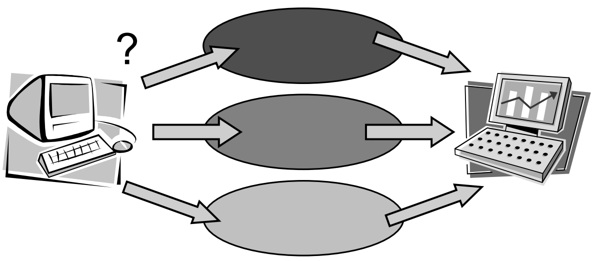
Layer 4 - Transport Layer

- Concerned with getting the information from source to destination
- Which network to use?



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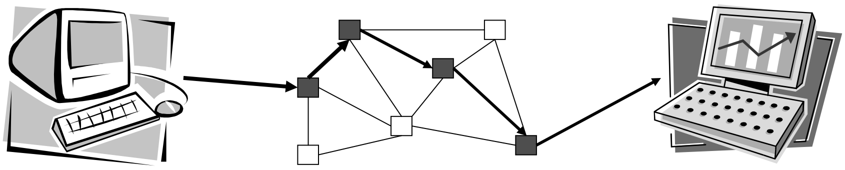
Layer 3 - Network Layer

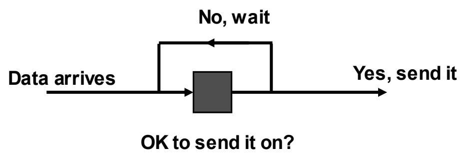
- Makes sure the information gets across the network from source to destination correctly e.g.
  - Error checking and routing
  - Which way through the network?



Section 5 - Protocols

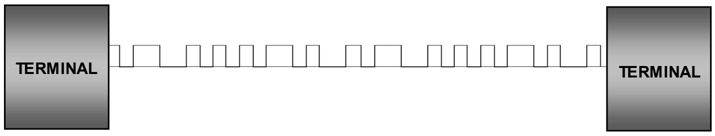
Layer 2 - Data Link Layer

- Controls the flow of information between nodes in the network and handles congestion and retransmission



Layer 1 - Physical Layer

- Determines the means of communications
  - Voltage, frequency, speed
  - Type of medium wire, fibre, radio



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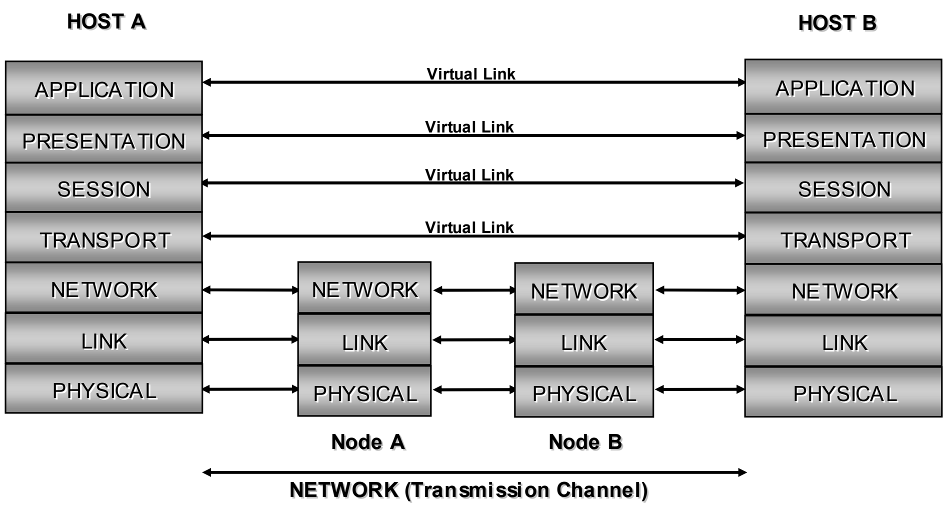
5.3 Vertical and Horizontal Communications

Horizontal (Peer-to-Peer) Communication



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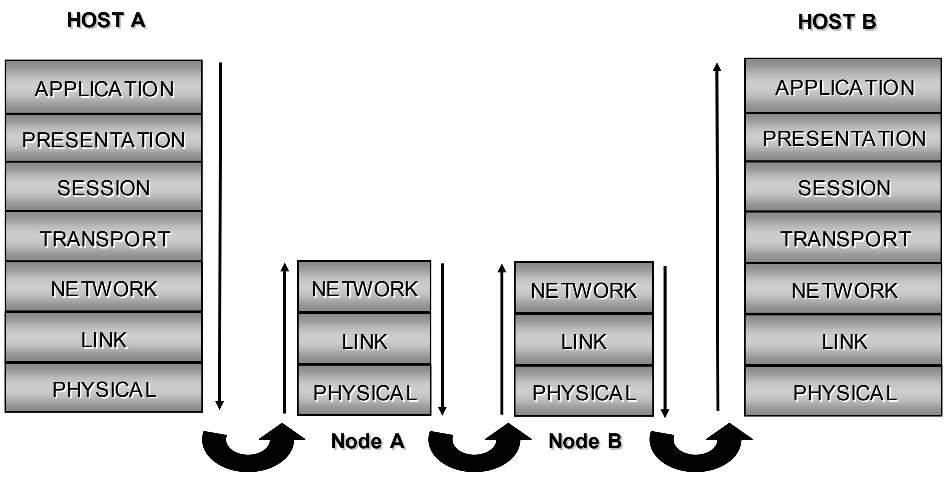
Vertical (Entity-to-Entity) Communication



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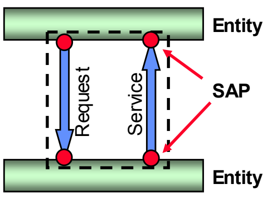
Vertical (Entity-to-Entity) Communication

- Each layer requests a service from the layer below
- The layer below responds by providing a service to the layer above
- Each layer can provide one or more services to the layer above
- Each service provided is known as a service 'Entity'
- Each Entity is accessed via a Service Access Point (SAP) or a 'gate'.
- Each SAP has a unique SAP Identifier (SAPI)



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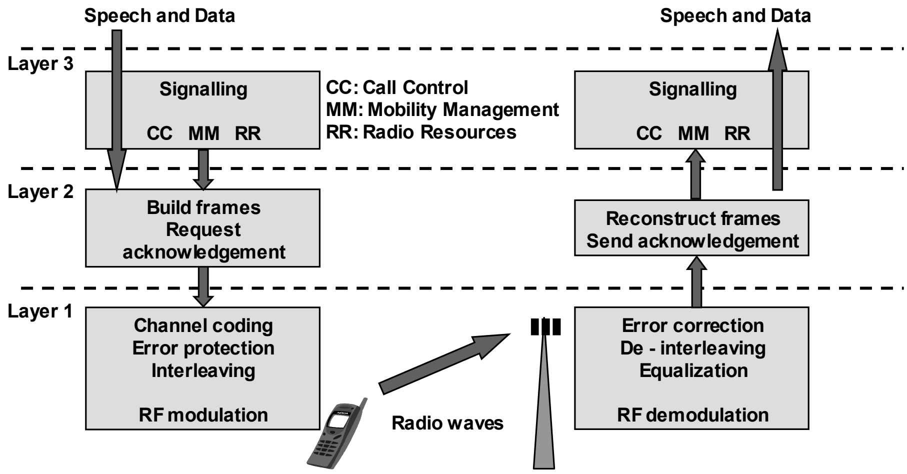
5.4 GSM Air Interface Protocols

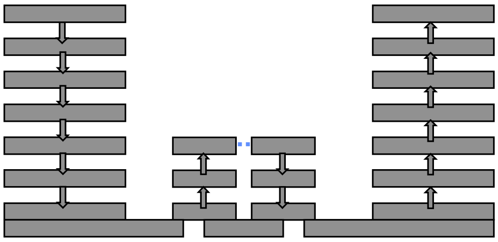
Protocols on the GSM Air Interface



Section 5 - Protocols

Summary

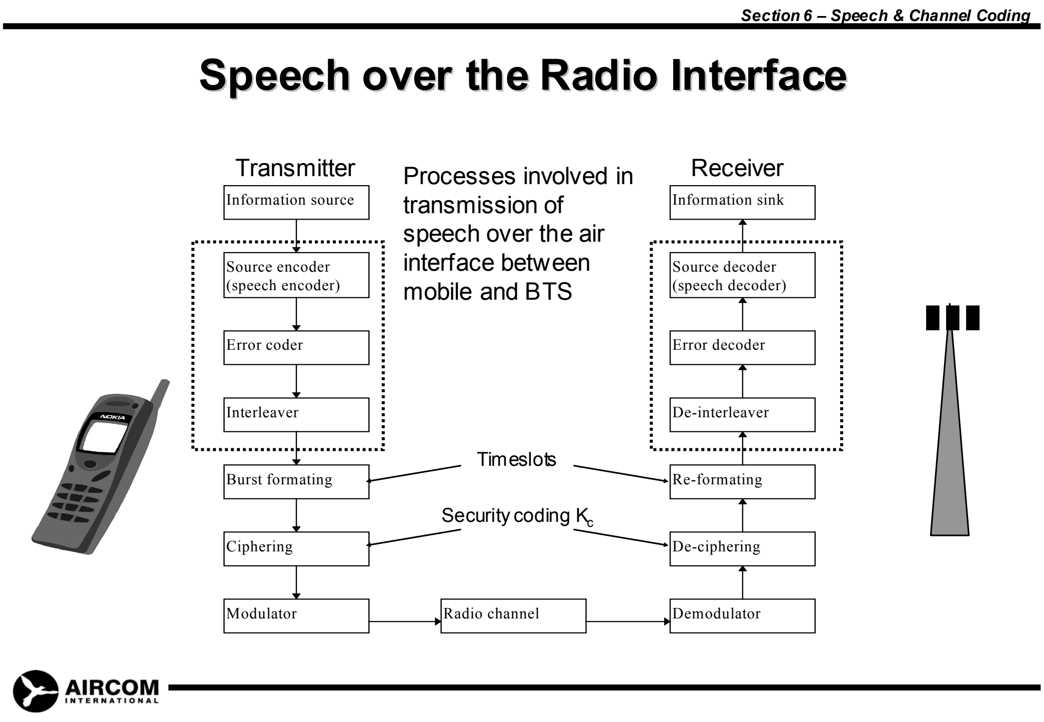
- The need for protocols: communications between systems
- OSI 7 layer model: Physical, Data link, Network, Transport, Session, Presentation, Application
- Communications via protocols: Horizontal, Vertical, Service Access Points
- GSM protocol layers: Layer 1 - 3, Layer 3 - CC, MM, RR



6. Speech and Channel Coding

6.1 Introduction

Here we will consider the speech encoding used by GSM. PCM which was covered earlier requires too much bandwidth for the air interface.

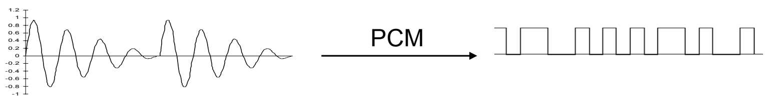


6.2 Speech Coding

Section 6 – Speech & Channel Coding

Speech Coding

- GSM transmits using digital modulation - speech must be converted to binary digits
- Coder and decoder must work to the same standard
- Simplest coding scheme is Pulse Code Modulation (PCM)
  - Sampling every 125 μs
  - Requires data rate of 64 kbps
- This is too high for the bandwidth available on the radio channels



Sample analog signal at 8 kHZ

Digital pulse train at 64 kbps

Several approaches to modelling human speech which requires less data than PCM have been attempted.

Section 6 – Speech & Channel Coding

Advanced Speech Coding

- We cannot send the 64 kbps required by PCM
- We need alternative speech encoding techniques
- Estimates are that speech only contains 50 bits per second of information
- Compare time to speak a word or sentence with time to transmit corresponding text

- Attempts to encode speech more efficiently:
  - speech consists of periodic waveforms - so just send the frequency and amplitude
  - model the vocal tract - phonemes, voiced and unvoiced speech
- Vocoder - synthetic speech quality

Speech obviously contains far more information than the simple text transcription of what is being said. We can identify the person speaking, and be aware of much unspoken information from the tone of voice and so on.

Early vocoders which reduced the voice to just simple waveform information lacked the human qualities which we need to hold a meaningful communication.

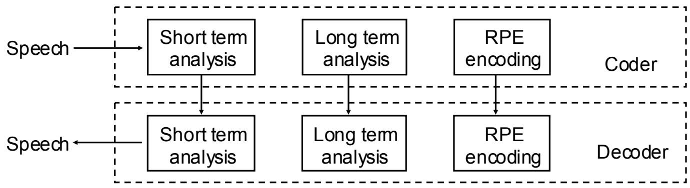
Hybrid encoders give greater emphasis to these qualities by using regular pulse excitation which encodes the overall tone of the voice in great detail.

Section 6 – Speech & Channel Coding

GSM Voice Coder

- Hybrid model using *multi-pulse excitation linear predictive coding*
- Regular Pulse Excitation - Long Term Prediction (RPE-LTP)
- Divides speech into three parts:
  - Short term prediction
  - Long term prediction

    sent as frequency and amplitude
  - Residual periodic pulse - sent as coded waveform - improves quality



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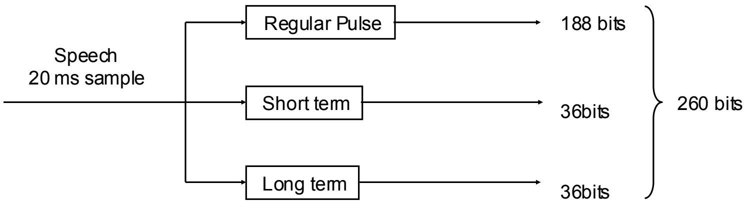
The long and short term prediction waveforms are encoded as frequency and amplitude information, while the regular pulse is sampled in a similar manner to PCM, which is why this requires more bits than the other two parts. This is to ensure that the characteristic tone of the voice is reproduced well.

The resulting data rate of 13 kbps is suitable for the bandwidth available on the air interface.

GSM Voice Coder - Output Rate

- Speech is divided into blocks of 20 ms
- Each block of 20 ms is represented by a pattern of 260 bits:



- 260 bits every 20 ms, gives an output rate of : $260 / 20 \times 10^{-3}$ = 13 kbps

6.3 Error Correction Coding

The speech decoding process is very sensitive to errors in the transmitted bits and attention must be paid to checking and correcting errors in transmission. Procedures for addressing this problem are covered in this section

Section 6 – Speech & Channel Coding

Error Correction Coding

- To reproduce speech, decoder needs bit error rate no more than 0.1%
- Radio channel typically gives error rate of 1% - need error correction
- Two approaches to error correction:
    - Backward error correction
    - Forward error correction

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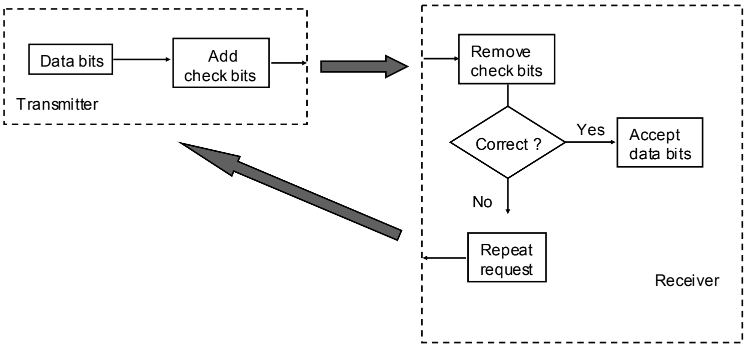
Backward Error Correction

- Backward error correction - Automatic Repeat Request:



- Suitable for data transmission - not speech

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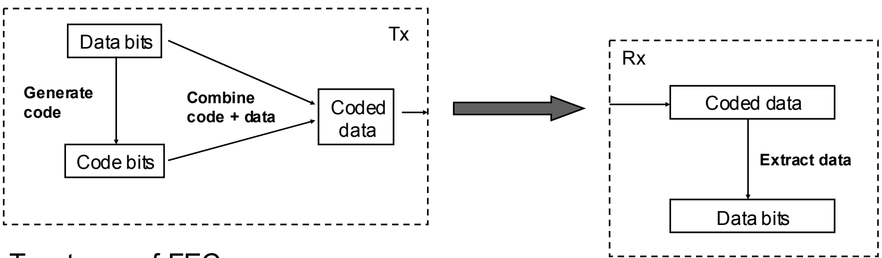
In backward error correction, we assume that if the known check bits have been transmitted correctly, the rest of the data is correct. If the check bits do not match what is expected, the system asks for re-transmission.

Automatic Repeat Request (ARQ) is not suitable for speech as the timing could become unintelligible if several repeats were necessary. However, in normal conversation, we naturally apply backward error correction by asking the person to repeat something we have not understood.

Forward Error Correction

- Coding is added to the information bits which enable the original to be reconstructed even if there are errors - redundancy
- Repeat transmission is not required - suitable for speech



- Two types of FEC:
  - Block codes
  - Convolutional codes
- GSM uses a combination of both code types

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In forward error transmission, the original data can be reconstructed from the received bits in several ways, allowing the system to make a best estimate of what the data should be, without requiring re-transmission.

Because we are sending more bits than there are in the original data, there is said to be redundancy in the system.

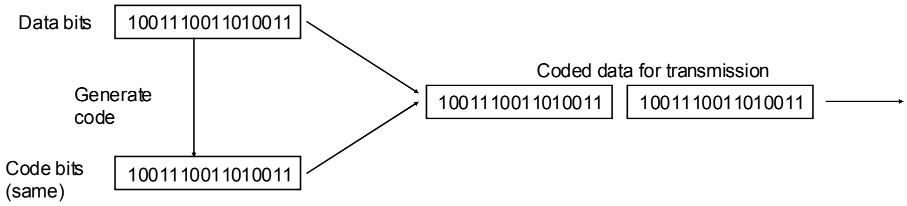
Block Codes:
Using block codes, the current data block (that which is about to be transmitted) is used to generate a code. This code is sent along with the original data bits. In the simple example illustrated, the code is just a repeat of the original data. Realistic schemes are calculated to give the best chance of recovering the data when errors occur.

Convolutional Codes:
Convolutional coding, uses not just the current bit pattern, but a sequence of three consecutive patterns, which are combined using bitwise logical operations to generate the code. Only the coded result is sent, not the original bits.

The scheme used in GSM is based on a convolutional coding technique developed by Andrew Viterbi, co-founder of Qualcomm. A web based tutorial on Viterbi coding can be found at the web site:
http://pw1.netcom.com/~chip.f/Viterbi.html

Block Codes

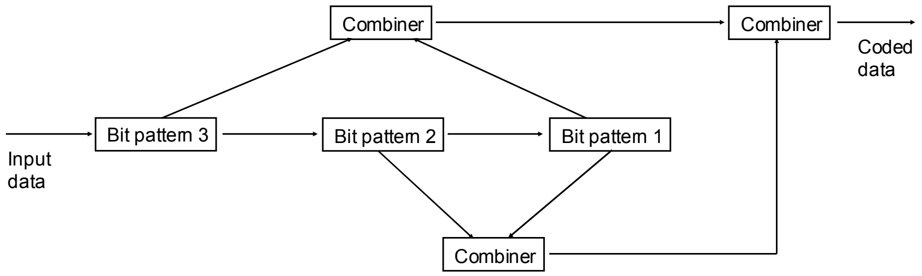
- Block codes are generated from just the current bit pattern
- Simplest scheme would be to duplicate the pattern and send it twice



- More complex block code schemes include:
  - RS (Reed - Solomon)
  - Golay
  - BCH (Bose - Chaundhuri - Hocquenghem)

Convolutional Codes

- Convolutional codes are generated from several sequential data bit patterns



- GSM uses a Viterbi convolutional coding scheme

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Convolutional Codes

- Rate of coding describes the amount of redundancy in the coded data:
  - 1/2 rate code transmits twice as many bits as actual data
  - Data rate is halved
- Convolutional coding cannot directly detect when an error has occurred - block coding can
- If the error rate is high, convolutional codes can make it worse
- Convolutional codes are slightly more efficient than block codes
  - i.e. reduction in error rate for given increase in bits transmitted

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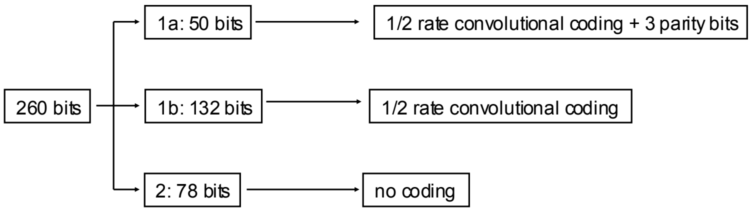
Typical rates of convolutional coding are1/2 rate used in GSM and 1/3 rate used in GPRS. GPRS also makes use of 'puncturing' in which some bits are deliberately removed before transmission in order to fit the coded data into the burst.
The decoding algorithm attempts to recover the best estimate of the original data from what is received. When the error rate is high, this algorithm can introduce more errors.
The algorithm is not able to detect when errors have occurred.

The GSM coding scheme is described as ‘concatenated’. It divides the data into three prioritised sections and applies different levels of coding to each, as shown in the slide. The resultant code is then put together (concatenated) for transmission.

Section 6 – Speech & Channel Coding

GSM Error Correction Scheme

- Full rate traffic channel (TCH/F) uses the most complex scheme:
- 260 bits from voice coder are divided into 3 classes, according to their importance for speech reproduction:



- This concatenated scheme allows bad blocks to be corrected, but keeps complexity to a minimum

6.4 Interleaving

The algorithms used to recover the data are based on an assumption that errors will be randomly distributed. In practice errors tend to clump together as the mobile passes in and out of fade regions.

To overcome this, the data bursts are not sent in their natural order, but are interleaved according to a pseudo-random pattern among a set of timeslots within the multiframe.

Interleaving is applied after error coding and removed at the receiver before the decoding. Thus the coding algorithm has a more random distribution of errors to deal with.

Interleaving

- Error correction codes work best when the errors are randomly distributed
- Fading of signal due to multi-path propagation (Rayleigh fading) causes errors to occur in bursts
- To randomise the errors, the interleaver takes the data bursts (timeslots) to be transmitted and rearranges them within the multiframe

Blocks to be sent: 1 2 3 4 5 6 7 8

Interleaver sends: 1 5 2 6 3 7 4 8

- At the receiver, the blocks must be re-assembled into the correct order

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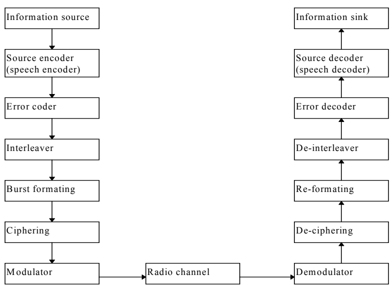
Summary

- The processes involved in sending speech over the radio interface:
- Methods of speech encoding: PCM, vocoder, hybrid coder, RPE-LTP
- Error correction coding: Backward, Forward, Block code, Convolutional code, GSM scheme
- Interleaving: randomising errors



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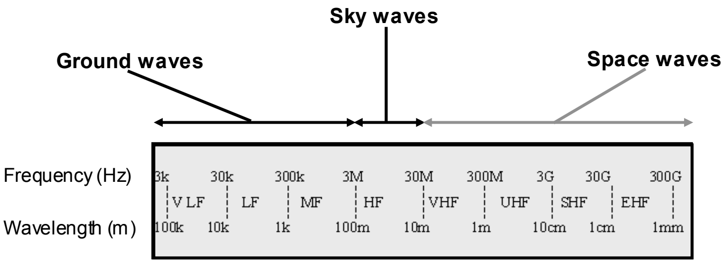
7. Radio Propagation

7.1 Introduction

Errors in transmission across the air interface are partly due to the multiple paths, which the radio waves can take. This causes fading effects and time delays, which need to be dealt with. Propagation of radio waves from other base stations leads to interference which another major source of errors.

Categories of Radio Wave

- Radio waves can be classified as:



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7.2 Propagation Characteristics

Section 7 – Radio Propagation

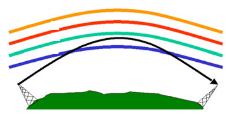
Ground and Sky Wave Propagation

Ground waves:

- Frequencies below 3 MHz - VLF,LF
- Wave propagation follows the contours of the earth surface
- Antennas and power levels need to be large
- Ranges of several hundred miles are possible

Sky Waves:

- Frequencies 3 MHz to 30 MHz (HF)
- Relatively high angle radiation reflects from ionosphere
- Low TX power and small antennas
- World wide coverage possible
- Ionosphere is unstable - change TX frequency often for reliable communication



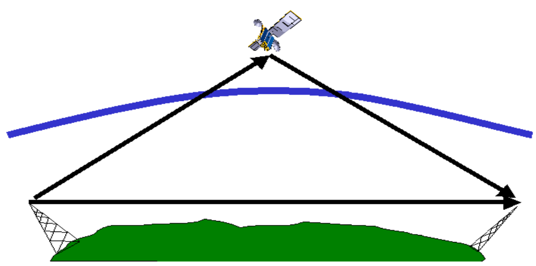
The general propagation characteristics of radio waves vary with frequency and the three categories shown here can be distinguished. For GSM we will only be concerned with space wave propagation.

Section 7 – Radio Propagation

Space Wave Propagation

Space waves:

- Frequencies above 30 MHz (VHF,UHF,SHF)
- Travel in troposphere - lowest layer of atmosphere
- Not reflected by ionosphere
- Generally follow line of sight
- Range of several tens of kilometres possible

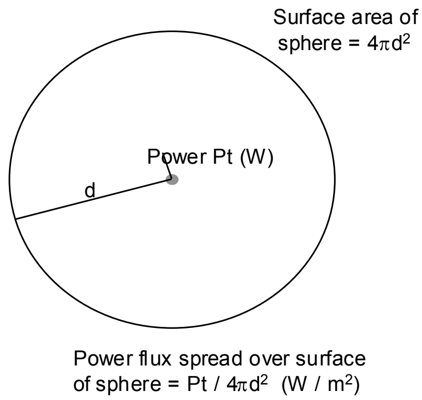


Free Space Propagation

- In free space propagation the wave is not reflected or absorbed
- Attenuation is caused by spreading the power flux over greater areas
- Inverse Square Law
- Isotropic antenna - power transmitted equally in all directions

- Power flux at distance d from antenna:

$$P = P_t / 4\pi d^2 \quad (W / m^2)$$



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This is an ideal propagation model based on transmission and reception between isotropic antennas with only empty space between. The path loss formula depends on distance and frequency, two fundamental parameters in all path loss models.

Free Space Path Loss

- Power flux is power per unit area
- Actual power received by antenna depends on its receiving area
- Effective area of an isotropic antenna is:

$$A_e = \lambda^2 / 4\pi$$

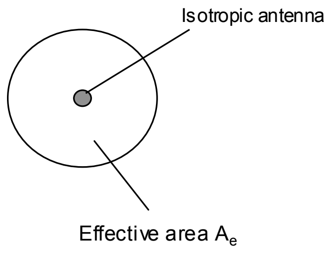
- Power received: $P_r = P \times A_e$

$$P_r = (P_t / 4\pi d^2) \times (\lambda^2 / 4\pi)$$
$$= P_t \times (\lambda / 4\pi d)^2$$

This leads to a path loss formula in dB:

$$L = 20 \log (4\pi d / \lambda) \quad dB$$

$$L = 32.5 + 20 \log d + 20 \log f \quad dB$$



Units for path loss formula:
d in km f in MHz

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For frequencies in GHz (microwaves) the constant in the path loss formula is 92.4 rather than 32.5.

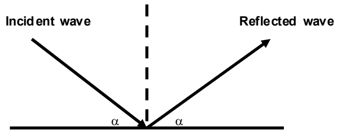
Effect of Environment

- Wavelengths of GSM radio waves:

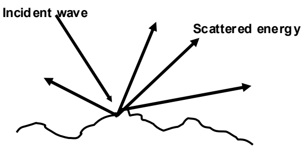
  900 MHz: about 30 cm   1800 MHz: about 15 cm

  The waves will be affected by people, buildings, furniture etc.

- Reflection - from smooth surfaces



- Scattering - multiple reflections from rough surfaces

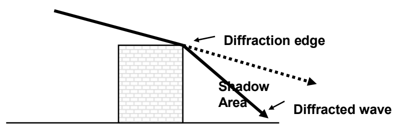


Practical propagation models must allow for many effects the environment on the wave. In practice, such models are based on actual measurements as described in Section 8.

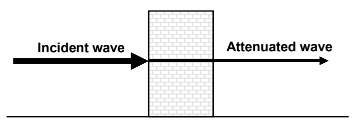
Section 7 – Radio Propagation

Effect of Environment

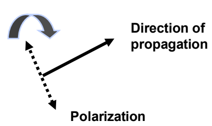
- Diffraction - wave passes over an edge or through a gap. Greater when wavelength is similar to size of object.



- Attenuation - reduction in power as wave passes through an obstacle

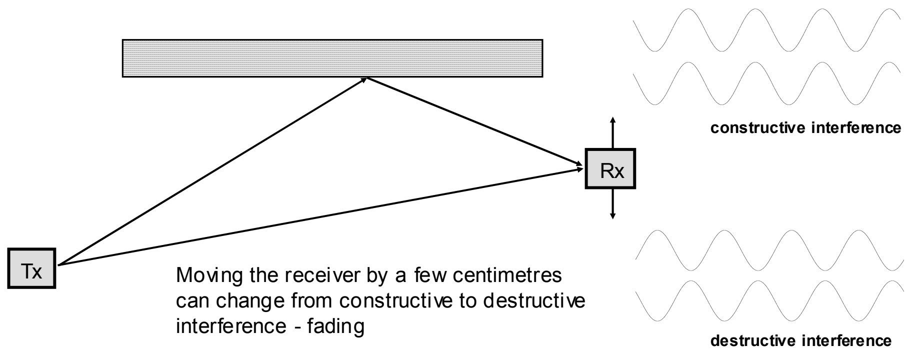


- Rotation of the plane of polarization - may be caused by atmospheric and geomagnetic effects.



Multipath Propagation

- GSM is a 'multipath environment'
- Received signal arrives via many different routes
- Phase differences produce interference effects



Due to scattering, there is actually a continuous spread of paths which the radio wave can take between transmitter and receiver. The simple example here shows constructive and destructive interference caused by just two wave paths. In practice statistical approaches are needed to handle the distribution of possible paths.

7.3 Fading Characterisitics

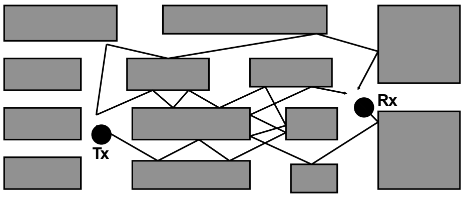
Rayleigh Fading

Rayleigh statistics describe the distribution of the radio waves when there is no dominant line of sight path. All possible paths are equally significant in contributing to fading effects.

The received signal level may vary by 20 to 30 dB over short distances as shown in the graph.

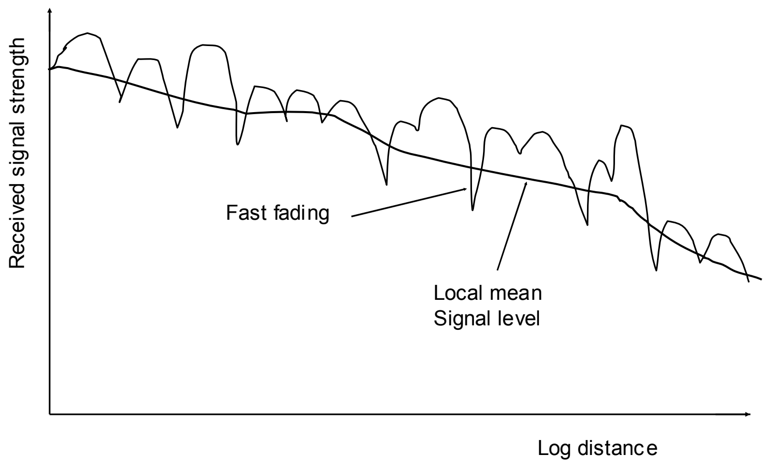
Fast Fading - Rayleigh

- Typically no LOS between Tx and Rx in GSM environment



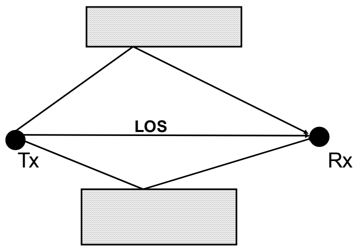
- Use statistical distribution of signal strengths and phases
- Rayleigh distribution
- Fading can be very deep: 20 to 30 dB

Fast Fading



Rice Fading

- Rice distribution of signals arriving at Rx
- One line of sight signal dominates the other contributions



- Fast fading occurs but becomes less deep the more the LOS contribution dominates

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If there is line of sight between transmitter and receiver, the contribution from this will dominate others from reflected waves. The statistical distribution, which is appropriate to describe this, is due to Rice. Fast fading still occurs but the variation in received levels is not as great as for Rayleigh fading.

7.4 Time Dispersion Effects

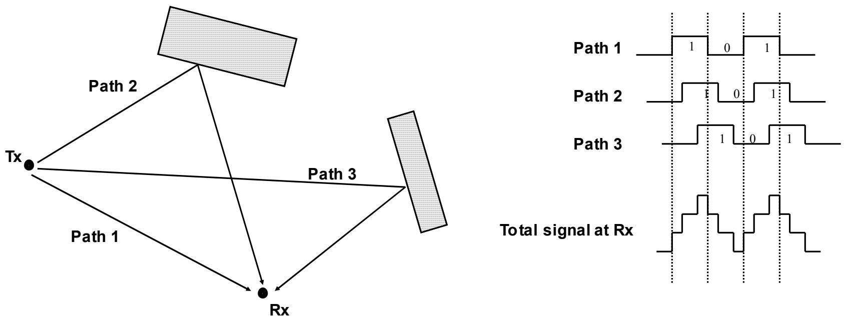
The effect of multipath propagation considered so far concerns the power level at the receiver resulting from interference between the waves.

However each of the multipath contributions is carrying the base band data signal and each contribution will take a different time to reach the receiver. Many versions of the data stream will thus arrive spread over a certain time period.

If the time dispersion is comparable with the bit period, it may become impossible to resolve the individual data bits. This is known as intersymbol interference and will cause errors in the received bits.

Time Dispersion

- Signals which follow different paths to the Rx have different propagation times
- Recovered digital baseband signals are shifted relative to each other in time



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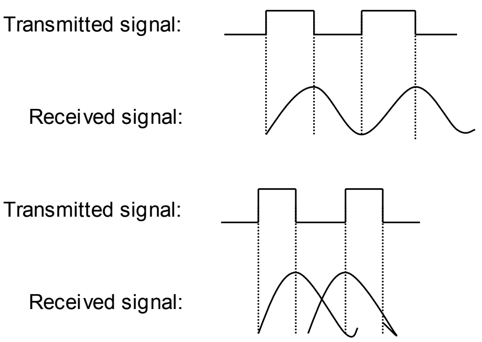
Intersymbol Interference

- With many paths, the received signal is rounded:



In this case, individual peaks corresponding to transmitted symbols can be distinguished

If the bit rate is increased, the peaks overlap, producing intersymbol interference

The individual bits can no longer be distinguished

- Intersymbol interference (ISI) can lead to unacceptable Bit Error Rates (BER)

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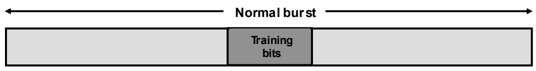
Equalization

- Equalization attempts to overcome time dispersion delay spread
- Equalization process:
  - A training sequence of 26 bits is sent in the middle of each burst
  - This is used to tune filters which then allow the rest of the burst to be
  - interpreted



- The GSM equalizer can accommodate delay spreads up to 16 μs
- This delay corresponds to 4 bits or a path difference of 4.5 km
- If the equalizer can realign the data, a form of diversity can be achieved

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To reduce intersymbol interference, the receiver includes an equalizer. This uses a known sequence of training bits which is sent in the middle of each burst of data. The equalizer filters the received signals and adjusts the tuning of this filtering to align the signals and produce the training bit sequence. The data before and after this in the burst should then also be correctly aligned.

Diversity reception (covered in Section 9) refers to methods of receiving a signal in several ways in order to produce gain and reduce fading effects. Here the equalizer produces a type of diversity reception, since many signals are being combined.

While equalization provides one way of reducing time dispersion, it is also possible to improve the situation by sensible base station positioning. The aim is to avoid strong signals with a large time delay, which could for example be produced by reflection from a distant hill.

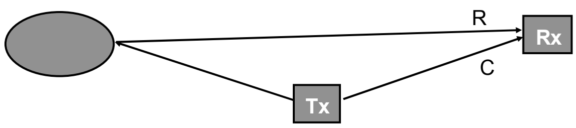
The strength of such reflections is expressed in a C/R ratio. It may be possible to improve C/R by using a directional antenna with a small lobe in the direction of the reflector.

The time delay can be reduced by careful siting of the base station relative to the reflector.

These points are illustrated on the following three slides.

Cell Planning to Reduce Delay Spread

- In situations such as hilly terrain, the delay spread may be more than the 16 μs that the equalizer can deal with
- Problem occurs when the reflected signal is strong relative to the direct signal



- This is expressed as **Carrier to Reflection ratio (C/R)**

C/R = 10 log (Pd / Pr)

Pd = Power of direct path   Pr = Power of reflected path

- GSM recommends C/R should be 9 dB or greater

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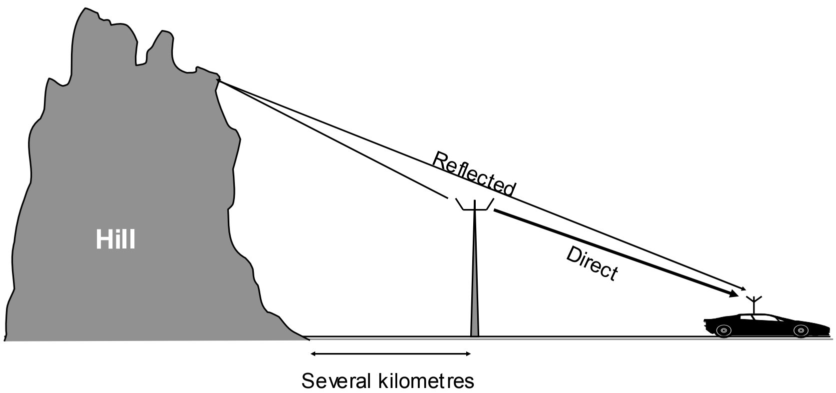
Section 7 – Radio Propagation

Reducing Delay Spread

- Site the base antenna closer to the hill to reduce the time difference between direct and reflected signal



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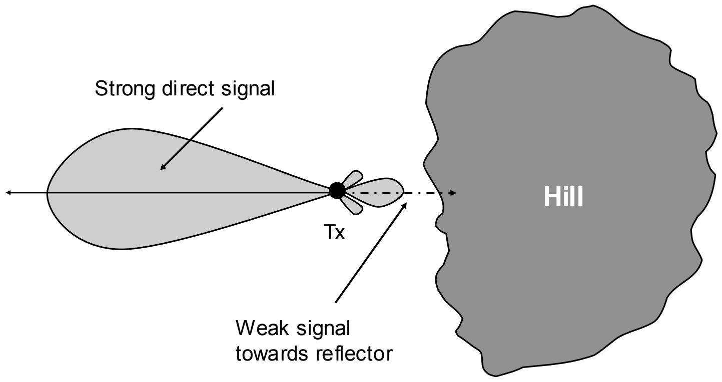
Reducing Delay Spread

- Use a directional antenna to give weak signals on the potential reflecting path



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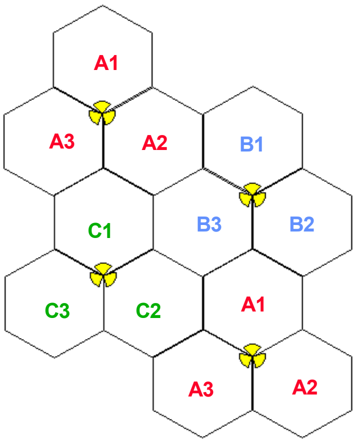
7.5 Interference Effects

Interference

- Cellular structure allows frequency re-use
- Required to cater for traffic levels
- Leads to mobiles receiving same frequency from two base stations
- This is **co-channel interference**

- It is also likely that a mobile receiving a signal on channel number N (ARFCN) will experience interference from channels N + 1 and N - 1
- This is **adjacent channel interference**



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Cellular planning involves finding a compromise between traffic capacity and interference. High traffic capacity requires several carrier frequencies (TRXs) in each cell. However, carriers are limited so this implies re-using frequencies more often which gives worse interference.

The most serious form of interference is co-channel, that is from another signal using the same frequency as the wanted signal. This measured in terms of the ratio C/I.

The other form of interference which must be considered is adjacent channel in which the interfering signal is separated by one carrier from the wanted signal. This is measured by the ratio C/A.

A range of techniques exist to reduce the effect of interference, including frequency hopping, base station power control and discontinuous transmission.

Co-Channel Interference

- Co-channel interference is measured by the carrier to interference ratio:

C / I

$$C / I = 10 \log (P_C / P_I) \quad \text{dB}$$

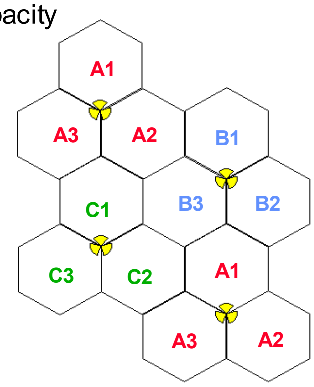
P_C = wanted signal power
P_I = signal power from the interfering transmitter

- GSM specification for minimum working C/I:
  - 12 dB if frequency hopping is not used
  - 9 dB if frequency hopping is used

- Operators generally plan for higher C/I values

C/I Considerations

- **Compromise between:**
  - greater frequency re-use to increase capacity
  - lower C/I values
- **Effect of low C/I:**
  - Unacceptable BER
  - Dropped calls
- **Possible measures to overcome low C/I:**
  - Frequency hopping
  - BTS power control
  - Discontinuous transmission (DTX)



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Adjacent Channel Interference

- Adjacent channel interference is measured by the carrier to adjacent channel ratio: **C / A**

$$C/A = 10 \log (P_C / P_A) \quad dB$$

P_C = Power from wanted channel

P_A = Power from adjacent channel

- GSM specification for minimum working C/A: - 9 dB
- Some operators plan for C/A as high as 3 dB
- Ways of improving C/A:
  - More selective receivers
  - Greater distance between adjacent TX frequencies

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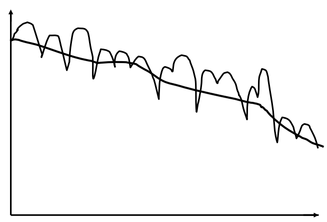
Summary

- Categories of radio propagation: Ground, Sky and Space waves
- Free space propagation: Inverse square law, effective antenna area, Path loss equation: **$L = 20 \log (4\pi d / \lambda)$ dB**
- Causes of multipath propagation: wavelength of GSM signals, reflection, scattering, diffraction, attenuation
- Effects of multipath propagation:, fast fading, no LOS - Rayleigh, LOS dominates - Rice
- Time delay effects: time dispersion, intersymbol interference, equalisation, cell planning to reduce delay spread
- Interference: frequency re-use, co-channel (C/I), adjacent channel (C/A)



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Section 7 Self-Assessment Exercises

Exercise 7.1 - Free Space Path Loss

1. A 900 MHz antenna is transmitting a signal at 30 dBm

For reliable reception, a signal of at least -90 dBm is needed at the mobile.

Assuming only free space path loss, what radius of cell does this give?

2. Two rival operators have GSM networks in an area. One uses only GSM 900 equipment, the other only DCS 1800.

What does this tell you about the investment in equipment required by the operators to give equal coverage?

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8. Cell Planning Principles

8.1 Introduction

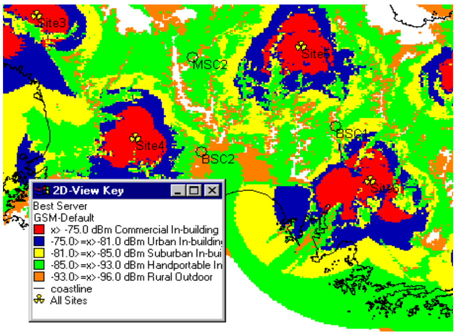
In this overview course we look briefly at the principles of cell planning which are covered in more depth in the AIRCOM courses G101 (Radio Planning Fundamentals) and G103 (Advanced GSM Cell Planning). Toppics covered in this section include:

- Coverage Prediction
- Network Dimensioning
- Traffic Capacity
- Frequency Planning
- Dual Band Systems

8.2 Coverage Prediction

Coverage Prediction

- Coverage: areas in which the radio signal is strong enough to be used
- Level of signal needed depends on the user's environment, e.g.:
  - Commercial in building
  - Urban in building
  - Suburban in building
  - Hand portable in car
  - Rural Outdoor
- These levels can be assigned to particular power levels (dBm) required to provide service in such areas



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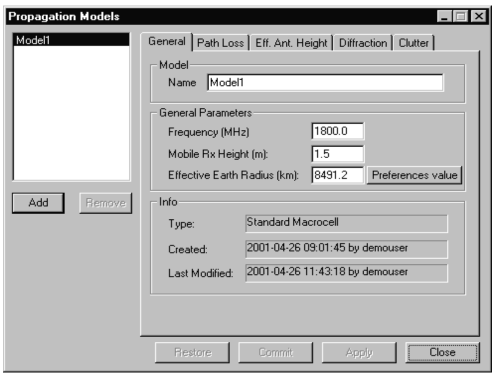
In using coverage predictions you must allow for local (fast) fading and penetration losses for in-building coverage.

Propagation Model

- To predict coverage from an antenna, we need to model how the radio waves are affected by the environment through which they are passing
- Factors to be considered are:
  - Path loss due to distance
  - Clutter in the area
  - Diffraction
- In Asset, the parameters for this model are entered in the Propagation Model editor



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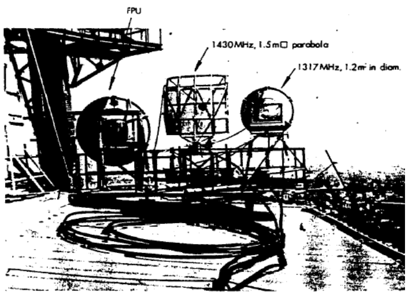
Path losses occur due to scattering from and absorption by clutter such as vegetation and buildings. Diffraction occurs over and around buildings. These effects were first studied practically by Okumura.

Path Loss

- Predictions of path loss are based on a combination of theory and practical testing
- In 1960s, Okumura, a Japanese engineer, made many measurements of signal strength around test transmitters near Tokyo
- His results showed that the signal dropped off much more rapidly than free space path loss predicts
- Numerous mathematical equations have been worked out to fit his data



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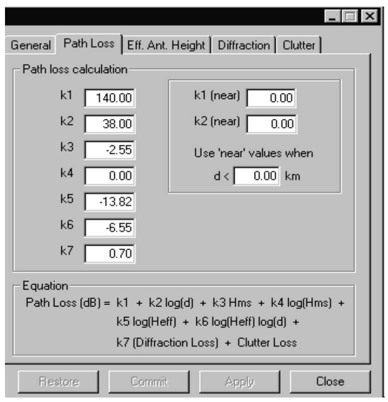
Path Loss Models

- Some of the models that have been set up to fit Okumura's results are:
  - Hata
  - COST 231 - Hata
  - Walfisch-Ikegami
  - Sakagami Kuboi
- Each equation contains a series of terms involving distance, antenna heights, frequency etc.
- Asset uses a similar model with several k factors that can adjusted to tune the model



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Path loss models simply try to find an empirical equation that fits the measured data. There is no attempt to explain the loss theoretically. Asset's model is similar to the COST 231 Hata model.

The terms in the equation (shown in the slide above) relate to distance from base station (d), height of mobile station (Hms) and effective height of the antenna (Heff).

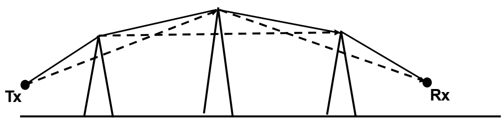
The diffraction loss is a correction for diffraction around the sides of buildings. Diffraction over the top of buildings is dealt with by the diffraction loss calculation method selected on the following screen.

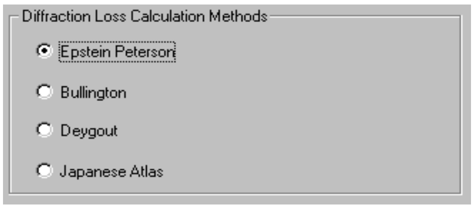
Each of these terms is weighted by a 'k – factor'. The job of model tuning is to find the optimum values for the k – factors which make the equation fit the data measured by drive testing.

Section 8 – Cell Planning Principles

Diffraction Loss

- As the radio wave passes over buildings and other obstacles it is diffracted, which leads to a loss as the wave spreads out
- There are well established theories of diffraction at a single flat obstacle (knife edge)
- Diffraction loss models treat the obstacles as a series of knife edges and combine the losses in different ways



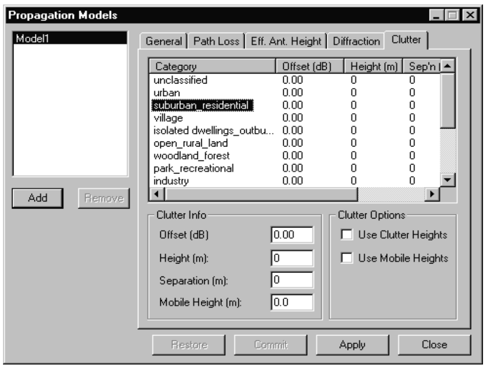


Diffraction methods treat buildings, hills and so on as a series of knife-edges and finds the combined loss due to diffraction over these. Some methods (such as Epstein Peterson) add up the effects of many knife edges, while others (such as Bullington) find one effective knife edge.

The final term in the path loss model is clutter loss which can be set as an offset for different clutter types. For example some models include a 3 dB loss offset term for dense urban clutter.

Clutter Loss

- Some models assign an offset loss for certain types of clutter, such as urban
- In Asset, each category of clutter in the map data can be given an offset value for loss
- This loss is added to the main loss equation when dealing with those clutter types



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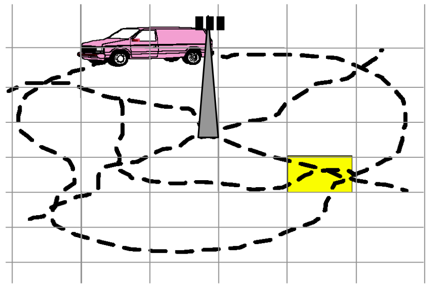
<u>Drive Testing and Model Tuning</u>

The propagation model must be 'tuned' in order to be usable in any particular area. This involves drive testing the area to obtain many thousands of radio signal measurements and then adjusting the k – factors in the model to find the best fit to these measurements.
Drive testing at this stage is also known as CW analysis (CW meaning carrier or continuous wave) as the signal which is used is a pure radio wave unmodulated by any baseband information.

Drive Testing (CW Analysis)

- To be of practical use, the propagation model must be tuned to suit the area for which the cell plan is being made
- Drive testing is carried out to measure signal strength around a test transmitter
- The test transmitters should be sited to closely model the proposed network
- The routes of the drive test must be carefully planned to cover all clutter types in the area equally



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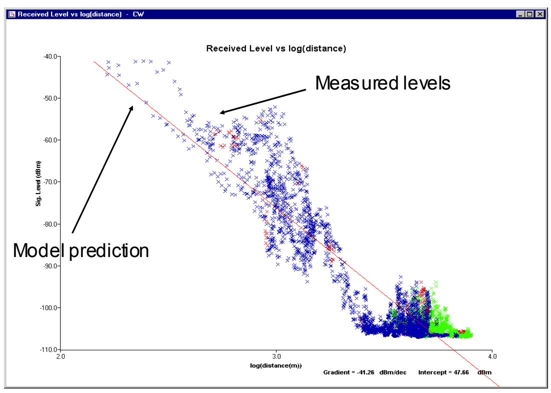
This drive testing should not be confused with test-mobile drive testing (using Neptune) which is carried out on an established live network to assess its performance for optimisation.

CW analysis results, recorded in SIGNIA, are loaded into Asset. By looking at the mean and standard deviation of the error between the model and the measurements, it is possible to adjust the k – factors to produce the best possible fit. A practical exercise on this process is included as part of course G101 (Radio Planning Fundamentals).

Model Tuning

- The result of the drive test is a set of values which are imported into the program
- The parameters k1 etc. are then adjusted so that the path loss predicted by the model is as close as possible to the measured results



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8.3 Network Dimensioning

At some point the path loss model is taken to be as well tuned as it can be and is then used as an input to the power budget. The path loss is the major factor in the power budget, however, many other gains and losses due to the equipment must be taken into account.

Section 8 – Cell Planning Principles

Link Budget

- Link budget or power budget tracks the gains and losses in the radio signal between the base station and the user's mobile
- This makes use of path loss predictions from the model
- One result of the link budget analysis is to establish the maximum area of coverage that the base station can provide
- This gives the area of a cell in the network

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The power budget gives an estimate of cell radius and area, which can then be used to find the number of cells that will be needed to provide coverage. The calculation should be done for each type of environment (rural, suburban, urban and so on) that the network is to serve.

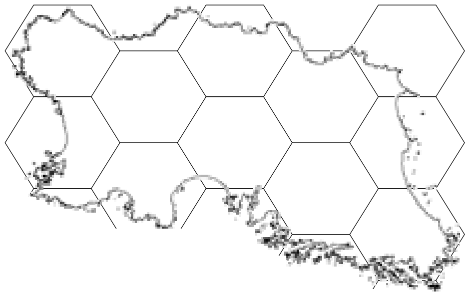
This initial network dimensioning, based on coverage, must also be backed up by an analysis of traffic capacity requirements to obtain a reliable estimate of the number of cells. In some areas, such as cities, capacity will determine the number of cells, while in sparsely populated areas, coverage will dominate the calculation.

Network Dimensioning for Coverage

- Simple approach to finding the number of base stations needed in the network:
- For a particular environment (e.g. urban, rural)

Number of cells needed =

$$\frac{\text{Total area of environment}}{\text{Area of a cell in the environment}}$$



- This calculation is typically carried out using a spreadsheet so the link budget and geographic parameters can easily be altered

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Dimensioning for Traffic

- Another important consideration when dimensioning the network is capacity
- Capacity is the ability of the network to handle traffic, i.e. calls made by subscribers
- Traffic theory is based on the concept of trunking, where the links between potential callers are routed through a limited number of channels or trunks
- Trunking is necessary in any telecommunications network because it would be impossible to provide for every possible link between subscribers separately
- This leads to the concepts of blocking and grade of service which must be considered when dimensioning the channels

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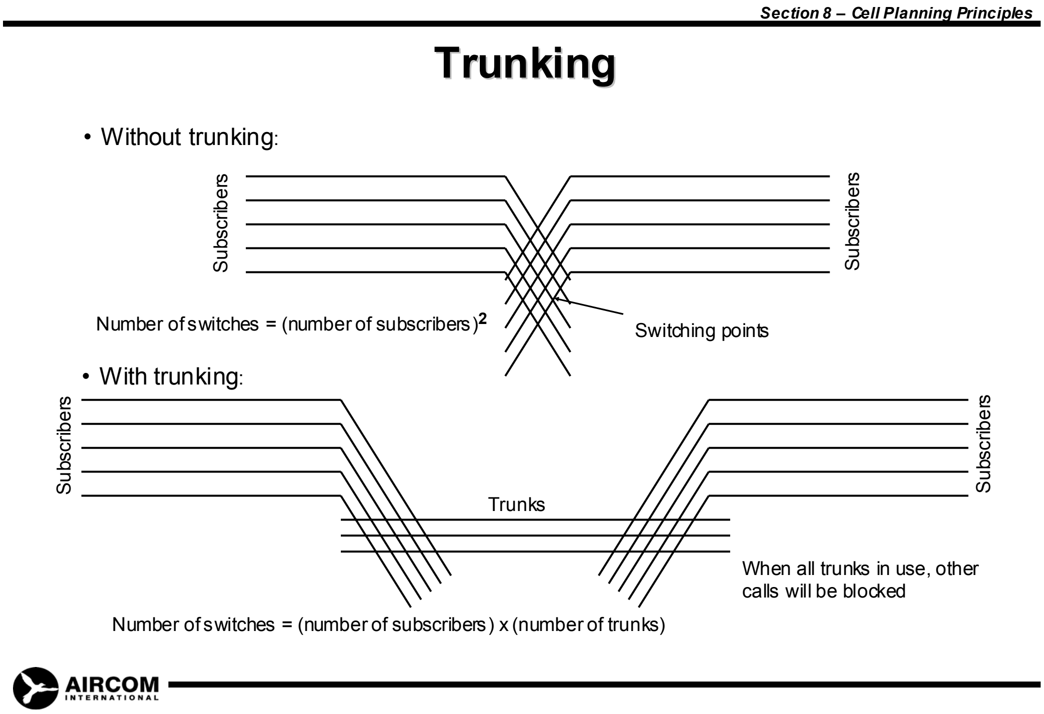
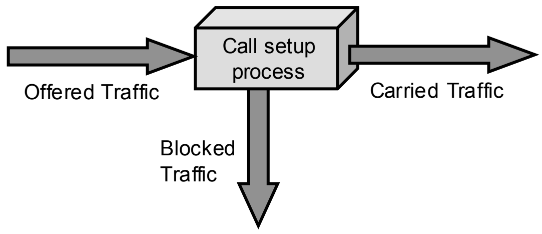
8.4 Traffic Capacity



This slide demonstrates the need for trunking in any practical network. Connecting only 5 pairs of subscribers without trunking requires 25 switches. Trunking reduces this requirement to a manageable size for practical numbers of subscribers, but introduces the concept of blocking. On the GSM air interface, trunks correspond to traffic channels.

Blocking

- Since there are fewer trunks (channels) than potential calls, some calls will be blocked
- % of calls blocked is called the Grade of Service
- So a low figure for Grade of Service is good for the subscriber
- Low Grade of Service may not be good for the network, as channels will be under-used at times



- Trunking efficiency describes the percentage usage that is made of the channels

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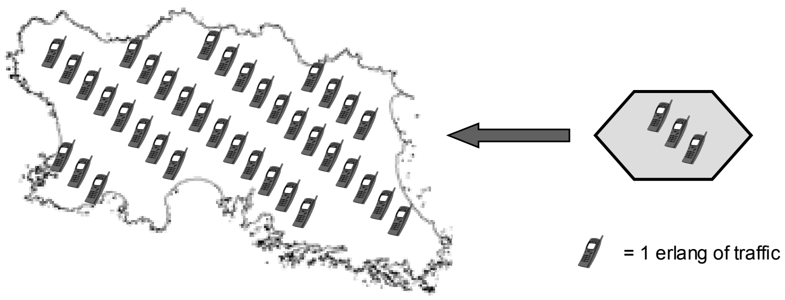
Traffic Channel Dimensioning

- Traffic is measured in erlangs: 1 erlang = 1 channel used continuously
- To dimension the network for traffic capacity:
  - Find the total traffic generated by the subscribers in the network area
  - Find the traffic that can be handled by one TRX at a base station
  - Divide to find the number of base station TRXs needed



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Traffic theory allows us to calculate (dimension) the number of channels required to handle a given traffic level at a required grade of service, using tables based on traffic models worked out by Agner Erlang in his 1909 paper *The Theory of Probability and Telephone Conversations*.

Detailed calculations for both traffic and control channels are dealt with in AIRCOM Advanced GSM Cell Planning course.

8.5 Frequency Planning

Before looking at typical frequency planning techniques, we should be aware of the types of cell sites that form a network. The main distinctions are between size of site and sectored as opposed to omni sites.

Section 8 – Cell Planning Principles

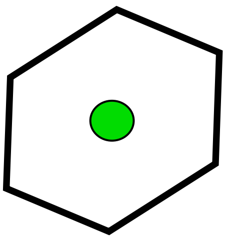
Types of Cell Site

- A network may contain several types of cell to provide service in different regions
- Types of cell:
  - Macrocell - large base station antenna giving wide area coverage
  - Microcell - small antenna mounted in street, giving local coverage
  - Picocell - very small antenna giving coverage in part of a building

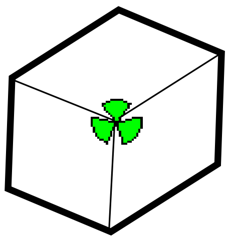
Section 8 – Cell Planning Principles

Omni and Sectored Sites

- Initially many macrocell sites are installed using omni antennas giving coverage around the base station
- To cater for more traffic as the network grows, sites can be sectored to give more carriers from one tower



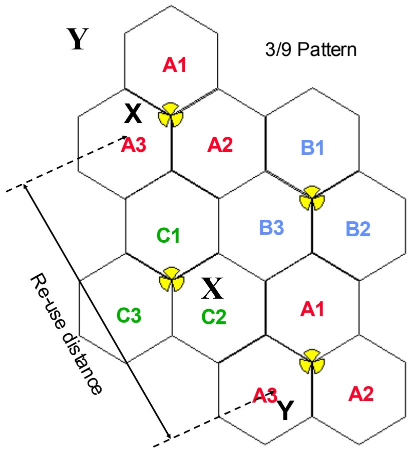
Omni site



Sectored site

Frequency Planning

- In GSM, frequency planning is important to minimise interference between cells while giving the coverage and capacity required
- Operators generally have a very limited number of carrier frequencies, several of which may be needed in each cell
- Important parameter is the re-use distance, which depends on the re-use pattern
- Common frequency re-use pattern is 3/9, in which a cluster is formed of 3 sites, each sectored into 3 cells, giving 9 cells in total

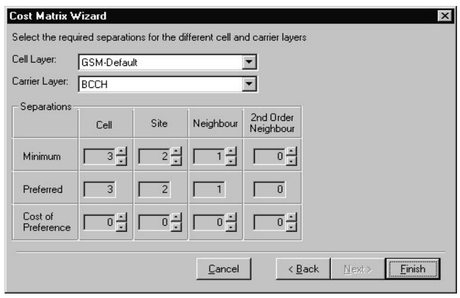


A simple group frequency plan (3/9) is illustrated here. This is based on sectored cells. Sectoring reduces interference across the network since the interference is not mutual. If one cell (X) is producing interference in a second cell (Y), cell Y will cause less interference in X because of the directional nature of the transmission.

Section 8 – Cell Planning Principles

Frequency Planning with ILSA

- Intelligent Local Search Algorithm
- Define cost matrix:
  - Preferred separations between carrier frequencies for same cell, same site, neighbour site and next nearest neighbour
  - Set 'costs' for breaking these constraints



Simple group planning assumes a homogeneous network in which cells are equal sized and regularly spaced. Real networks are more complex and require a software tool to find the optimum frequency plan.

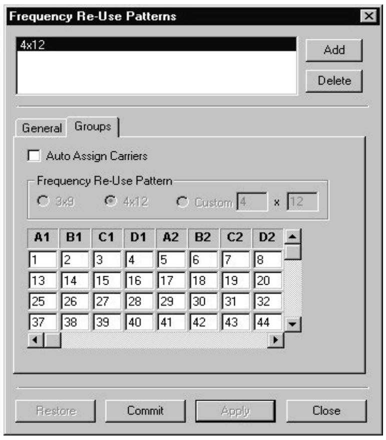
In ILSA, the user sets preferences for the plan, such as the carrier spacing to be used for neighbour cells. When the program tests a possible plan, it adds a cost value for each one of these preferences which is not met. It then looks for a plan which minimises this cost.

The cost and interference levels can be examined graphically for a series of iterations during the run of the program.

If required, group planning can also be incorporated.

Re-use Pattern in ILSA

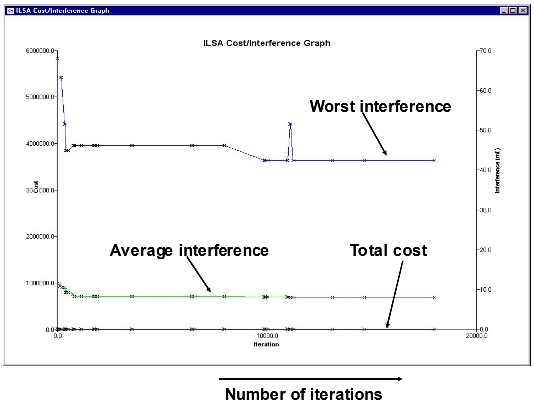
- The frequency plan can be (optionally) constrained to a particular re-use pattern
- A 4/12 pattern set up is shown as:



Running ILSA

- ILSA runs continuously through thousands of iterations, trying to minimise the total 'cost' of the frequency plan

- You can display a graph of its progress showing:
  - worst interference
  - average interference
  - total cost

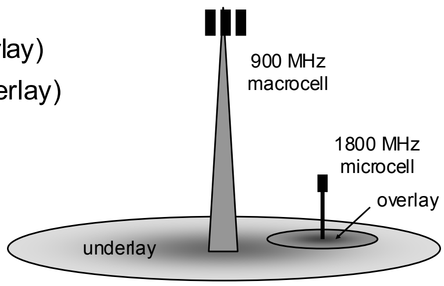


Dual Band Systems

- Dual band systems use a combination of 900 MHz and 1800 MHz cells to provide flexible coverage
- A 900 MHz cell is generally larger than an 1800 one
  - free space path loss increases with frequency

- System may consist of:
  - large macrocells on 900 MHz (underlay)
  - smaller microcells on 1800 MHz (overlay)

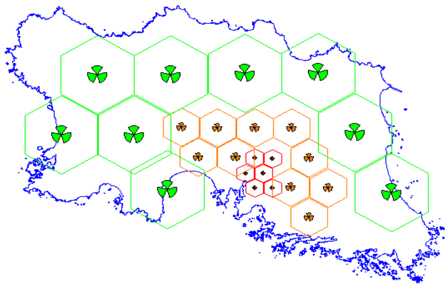
- There may be several layers:
  - street level microcells
  - mini cells just above roof tops
  - macrocells with high antennas



Microcell layers are generally introduced to improve traffic capacity in urban areas and to fill in coverage in shadow regions (such as streets). Frequency planning and control of admission to these cells is dealt with in course G103 (Advanced GSM Cell Planning).

Planning Dual Band Systems

- Larger cells only in rural areas - little traffic capacity required
- Smaller overlaid cells in areas of greater population:
  - low power, low interference
  - allow more frequency re-use, giving higher capacity
- Larger underlay cells provide control channel carriers for setting up calls (paging, random access)
- When call is established, it is handed over to an overlay cell



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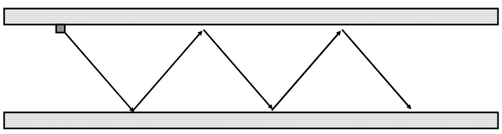
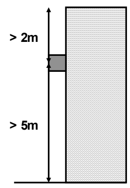
Section 8 – Cell Planning Principles

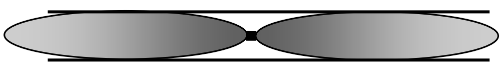
Microcell Planning

- Microcell antennas mounted below roof top height
- Energy is contained within the streets by the canyon effect - using streets as a waveguide

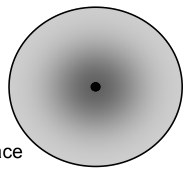




- Directional or omni antennas may be used according to the situation



Long straight road



Open space

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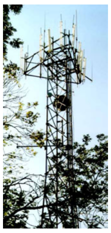
Summary

- Predicting coverage: propagation models, path loss, diffraction, clutter, model tuning
- Network dimensioning: coverage, capacity
- Traffic capacity: trunking, blocking
- Frequency planning: omni, sectored cells, re-use patterns, ILSA
- Dual band systems: macrocells, microcells, underlay, overlay

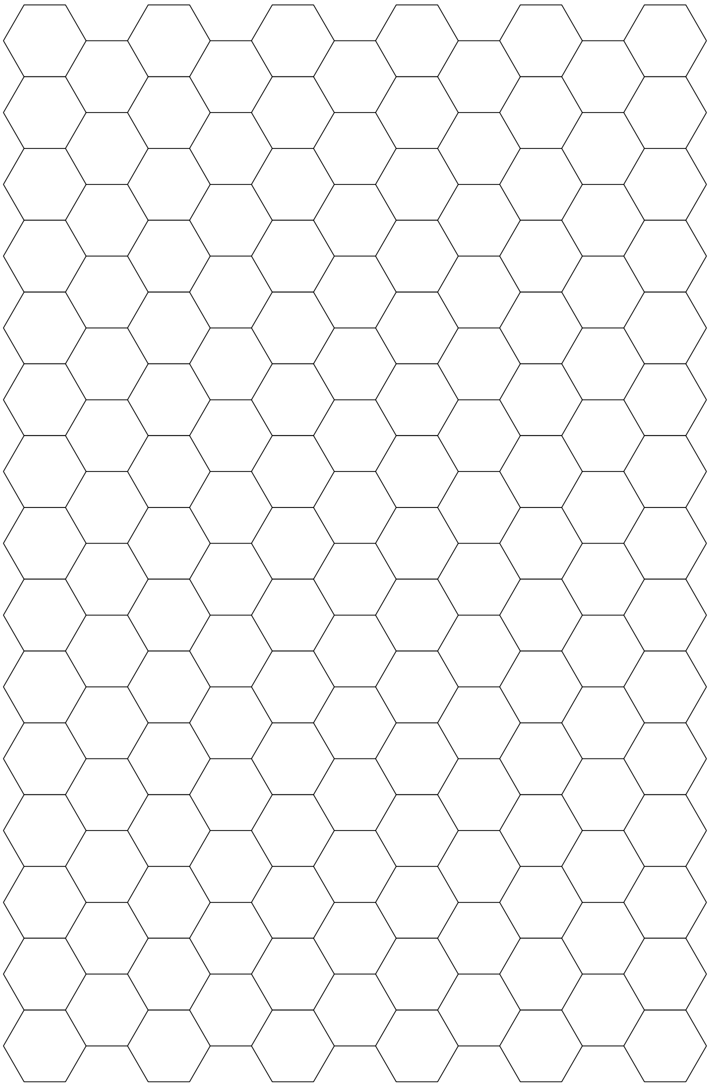


Section 8 Self-Assessment Exercises

Exercise 8.1 - Frequency Planning

On the grid below, show a group of 3 sites using a 3/9 frequency pattern.

Another common pattern is 4/12 in which 4 sites in a group are each tri-sectored, giving a cluster of 12 cells each using a different carrier. Show this scheme on the grid.



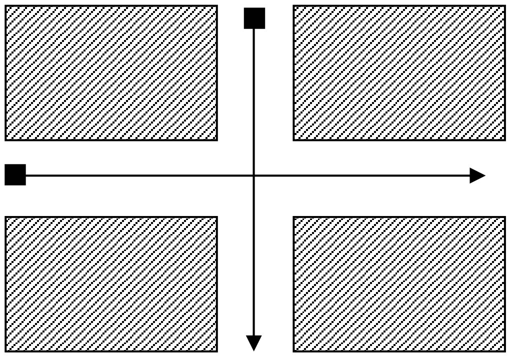
Indicate the re-use distance for each scheme.
How would this affect interference in each scheme?

Compare the traffic per cell capacity offered by each scheme if the operator has a total of 36 carriers available.

Exercise 8.2 - Microcell Planning

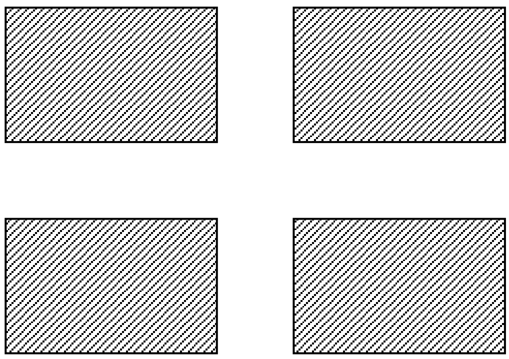
You need to place microcells in order to give coverage at a cross roads surrounded by high buildings.

One suggestion is to place directional antennas as shown:



What possible problem would this cause?

Suggest an alternative on the diagram below.



9. Cell Planning Options

9.1 Introduction

The cell planning options described in this section may be implemented in particular cells in order to improve performance. The options described include:

Frequency Hopping (FH)
Diversity Reception
Discontinuous Transmission (DTX)

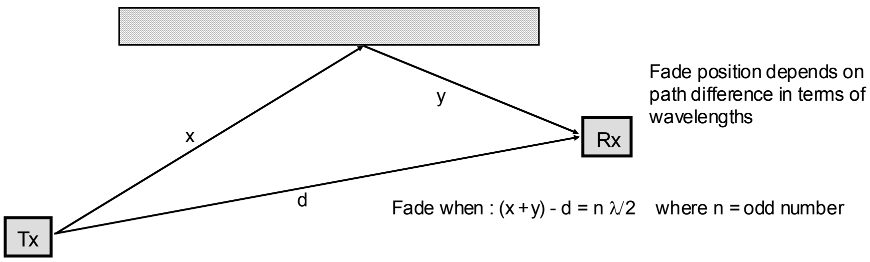
The cell planning options described in this section may be implemented in particular cells in order to improve performance.

9.2 Frequency Hopping

Section 9 – Cell Planning Options

Reasons for Frequency Hopping (1)

- GSM radio signals are affected by multi-path interference, causing fading
- Changing frequency (wavelength) moves the position of the fade
- Frequency hopping cycles through many fade positions
- This reduces the effect of the fades when the mobile is moving slowly



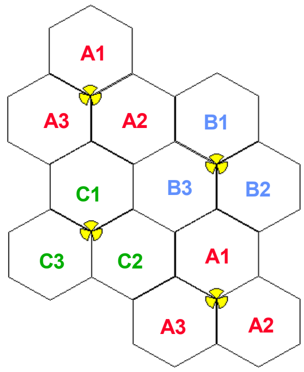
Frequency hopping and discontinuous transmission (DTX), together with base station power control are typically used to reduce interference.

Frequency hopping has little effect on the fading problem for fast moving mobiles.

If frequency hopping is to be used to reduce interference, many more carriers will be required.

Reasons for Frequency Hopping (2)

- Cells are subject to interference from other cells using the same carriers at the re-use distance
- If the cells hop through a set of frequencies in different sequences, the effect of this interference is reduced
- C/I ratio is increased



Section 9 – Cell Planning Options

Frequency Hopping

- When using frequency hopping, the actual carrier frequency used by a TRX changes on each frame (8 timeslots)
- The frequency follows either a sequential or pseudo-random pattern:

Frames cycle through carriers 1 to 6 :

1	3	4	2	6	5	1	3	4	2	6	5	1	3	4	2

Hopping sequence

- One frame is 4.6 ms long
- Rate of hopping = 1/ (4.6 x 10^{-3}) = 217 hops / second

- This is also known as Slow Frequency Hopping (SFH) to distinguish it from Fast Frequency Hopping which is a method of implementing CDMA

In FFH, the frequency changes more rapidly than the symbol rate. FH-CDMA can use either slow or fast FH.

Frequency hopping is optional for any particular base station.

Frequency Hopping at the BTS

- If the BTS has implemented SFH:
  - TRXs used only for traffic channels will hop through set sequences
  - TRX used for the BCCH carrier will not hop - mobiles must be able to access this for neighbour cell power level measurements
- 64 hopping sequences are available in GSM:
  - 1 sequence is cyclic - 1,2,3 …, 1,2 …
  - 63 others are pseudo random patterns
- Hop Sequence Number (HSN) defines the sequence in use
- The set of carrier frequencies assigned to the sequence (Mobile Allocation) must be different for each TRX

Frequency Hopping at the Mobile

- Base stations need not implement frequency hopping
- Mobile must be capable of SFH in case it enters a cell in which it is implemented
- In addition to hopping in step with the BTS, the mobile must also make measurements on adjacent cells
- This is why the rate of hopping is limited to SFH in GSM
- The mobile needs to know:
  - Frequencies used for hopping (Mobile Allocation)
  - Hop Sequence Number (HSN)
  - Start frequency (Mobile Allocation Index Offset, MAIO)

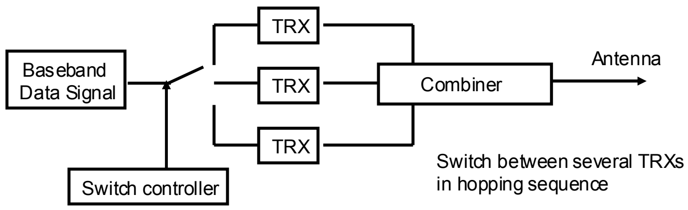
The frequency hopping information above is included in the handover message when a mobile enters a cell that is using frequency hopping.

The mobile must be able to cope with the different possibilities of being handed to or from cells where frequency hopping is or is not in use. This is controlled by the handover command which is sent by the base station to the mobile as part of the handshaking sequence of signals that pass between the MS, BTSs, BSCs and MSCs involved in the handover.

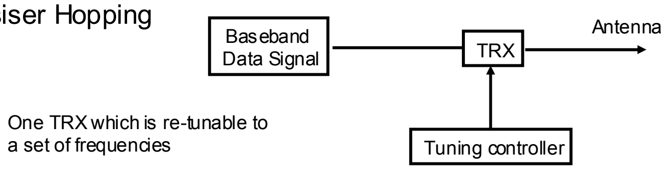
An example of this sequence is given in the AIRCOM Advanced GSM Cell Planning course.

Implementing Frequency Hopping

- Two methods are used at the BTS to achieve frequency hopping:
  - Baseband Hopping



  - Synthesiser Hopping



Baseband Hopping

The data signal which is to be modulated onto the radio wave is rapidly switched (217 times per second) between a set of TRXs. The outputs of these TRXs are passed through a combiner before being sent to the antenna. Each TRX output is a single carrier bandwidth (200 kHz).

Synthesiser Hopping

The baseband signal is modulated by a single TRX which is tuned to each of the frequencies in the hopping sequence by software. The resulting output of the TRX has a broader bandwidth since it hops between several carrier frequencies.

The difference in bandwidth produced by baseband and synthesiser hopping has implications for the type of combiner equipment that can be used at the base station. This is discussed fully in the AIRCOM Advanced GSM Cell Planning course.

9.3 Diversity Reception

Diversity reception gives extra gain on the uplink by reducing fading at the base station antenna.

Section 9 – Cell Planning Options

Diversity Reception

- Diversity reception is a way to improve the quality and strength of the signal arriving at the base station, by receiving it in several independent ways
- Two forms of diversity reception often employed are:
  - Polarisation diversity
  - Space diversity
- Frequency hopping is sometimes referred to as frequency diversity

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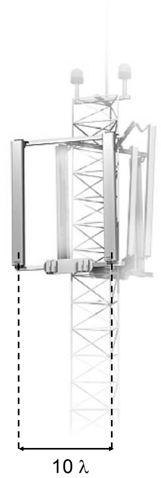
Diversity reception introduces a gain into the uplink power budget typically of about 5dB. A base station may use one or other method of diversity, but would not generally use both.

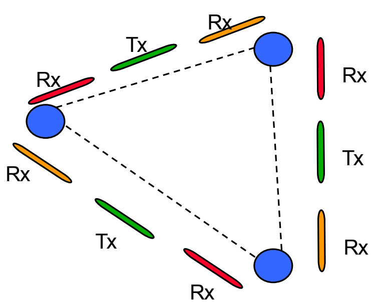
Space Diversity

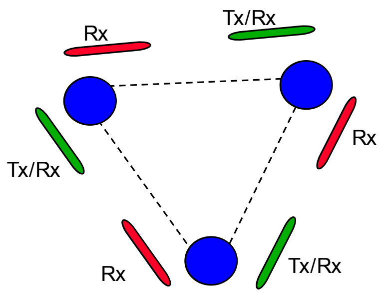
- Two receiving antennas are used at the base station
- If they are far apart, the received signals will be independent of each other
  - If one has suffered fading, the other may not
- A suitable distance is generally about 10 wavelengths
- GSM 900, 10λ = 3 metres
- Better isolation between the two signals can also be obtained by mounting the antennas at different heights on the tower



Space Diversity Antenna Systems

- Plan views of two possible tri-sectored site antenna systems

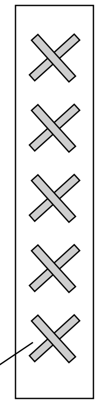




This diagram illustrates the reduction in space required on the tower by using a duplexer. This allows one receive antenna to be combined with the transmit antenna in each sector. A duplexer uses filters to direct the uplink and downlink signals to and from the antenna. This introduces a loss of 1 or 2 dB into the power budget.

Polarisation Diversity

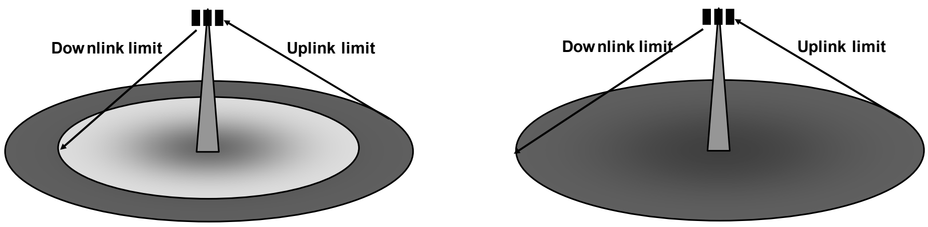
- As the radio signal undergoes multiple reflections and scattering, the plane of polarisation is rotated randomly
- This can be used to provide diversity reception by designing antennas with dipoles crossed to receive different components of the polarisation
- The preferred method is to cross the dipoles at 45°
- This gives good coverage of vertical polarisation and strong components of rotated signals



Section 9 – Cell Planning Options

Diversity Gain and System Balance

- Combining signals from space or polarisation diversity receivers increases the gain of the uplink signal - MS cannot have space diversity
- This affects the uplink power budget calculation but not the downlink
- Asymmetric terms like this in the power budgets must be balanced so that limit of coverage for uplink and downlink is the same - a balanced system



Unbalanced system

Balanced system

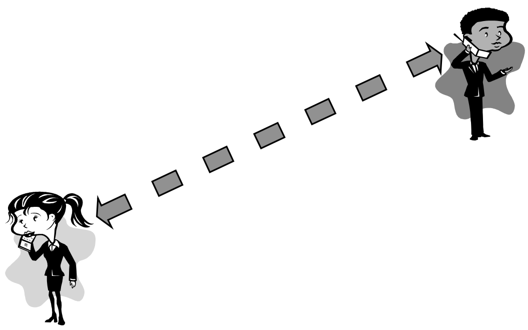
Handover algorithms used by the BSS take uplink and downlink power and quality levels into account. If the system were unbalanced, the information would be inconsistent and handovers would not be correctly implemented.

Uplink and downlink power budget equations and their use in deriving the system balance condition are described in detail in the AIRCOM Advanced GSM Cell Planning Course

9.4 Discontinuous Transmission (DTX)

Discontinuous Transmission (DTX)

- In a conversation, a person generally only speaks for about 30% to 40% of the time
- DTX makes use of this by stopping transmission when no voice signal is detected
- VAD - Voice Activity Detection unit
- Advantages:
  - Reduces interference
  - Prolongs battery life of mobile



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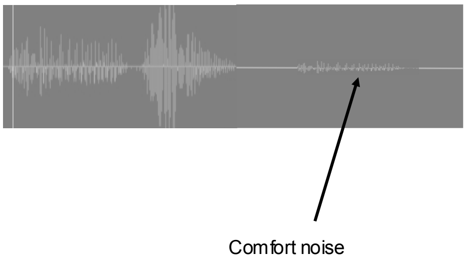
Under the control of the VAD, the mobile either transmits encoded speech or a signal to instruct the receiver to generate comfort noise. If a speech frame is corrupted, a Bad Frame Indicator (BFI) causes the receiver to generate a suitable waveform based on the previous frames.

Silence Descriptor (SID)

- Silence Description Frames (SID) are sent at the end of a speech frame - prevents sudden cut off of sound
- SID frames also sent periodically during periods of silence
- Receiver produces 'comfort noise' for the listener
- If speech frames are lost, they can be extrapolated from previous frame to fill the gap



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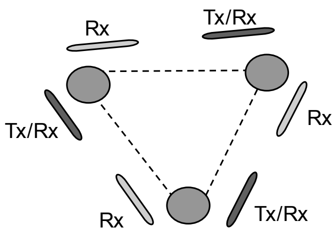
Summary

- Frequency Hopping: reduces fading, interference, SFH, sequences, HSN, SFH at the mobile, baseband, synthesiser hopping
- Diversity Reception: space, polarisation, diversity gain
- Discontinuous Transmission: DTX, VAD, SID



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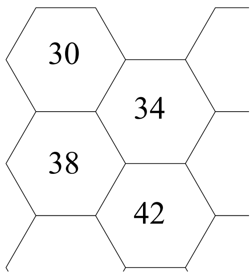
Section 9 Self-Assessment Exercises

Exercise 9.1 - Frequency Hopping

In one area of a network, a group of 4 neighbouring cells uses carriers 30, 34, 38 and 42 with one TRX in each cell.



To increase capacity in each cell, a planner suggests putting 4 TRXs in each cell.

Each TRX will hop through a sequence of 30, 34, 38 and 42 in a different order so that no two TRXs in a cell use the same frequency simultaneously.

Each of the four cells will use the same four carriers but with different hopping sequences.

In this way the planner intends to quadruple the capacity.

Is this a viable solution to the problem, or does it have a fatal flaw?

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10. GSM Evolution

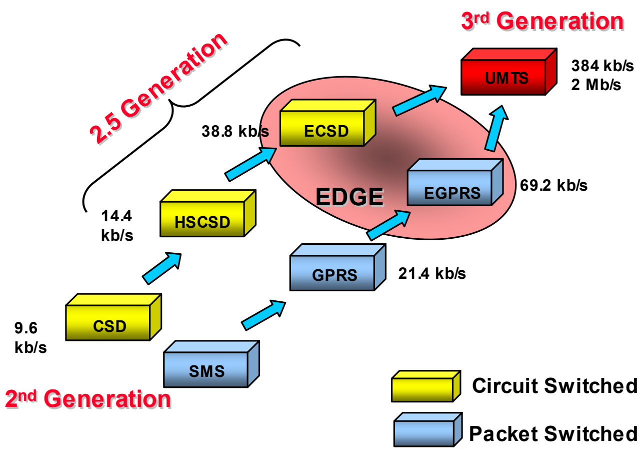
10.1 Introduction

This final section of the course looks briefly at the developments within GSM that are leading towards third generation technology and the high data rates which this is intended to offer. These technologies are collectively known as 2.5 or 2 ½ Generation GSM technologies and include:

- High Speed Circuit-Switched Data (HSCSD)
- General Packet Radio Service (GPRS)
- Enhanced Data for GSM Evolution (EDGE)

2.5 Generation GSM

- Evolution of GSM towards 3G systems
- Main requirement is for increased data rates
- Mobile access to:
  - Internet
  - E-mail
  - Corporate networks



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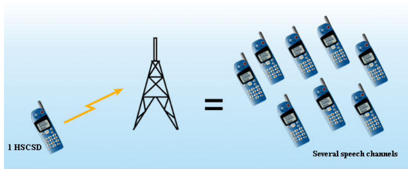
10.2 HSCSD

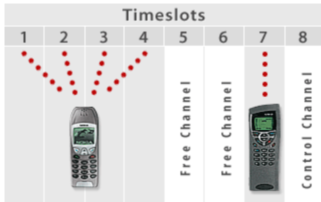
Section 10 – GSM Evolution

HSCSD

- Increases bit rate for GSM by a mainly software upgrade
- Uses multiple GSM channel coding schemes to give 4.8 kb/s, 9.6 kb/s or 14.4 kb/s per timeslot
- Multiple timeslots for a connection e.g. using two timeslots gives data rates up to 28.8 kb/s
- Timeslots may be symmetrical or asymmetrical, e.g. two downlink, one uplink, giving 28.8 kb/s downloads but 14.4 kb/s uploads.



Maximum data rate quoted as 115 kb/s = 14.4 x 8



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The main new concept in HSCSD is that of multiple timeslots per handset. Current handsets are limited practically to a maximum of 4 timeslots.

Section 10 – GSM Evolution

HSCSD Mobile Equipment

- HSCSD handsets are typically limited to 4 timeslots, allowing:
  - 2 up / 2 down (28.8 kb/s in both directions)
  - 3 down and 1 up (43.2 kb/s down 14.4 kb/s up)
- This limitation arises because the handset operates in half duplex and needs time to change between transmit and receive modes
- Nokia cardphone (PCMCIA card for laptops) uses HSCSD (Orange network)
  - quotes data downloads at 28.8 kb/s

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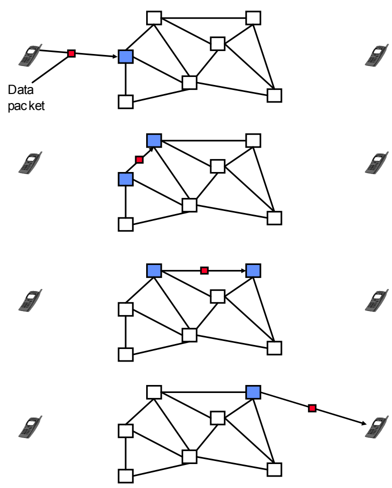
10.3 GPRS

GPRS

- General Packet Radio Service
- Packet switching:
  - Data divided into packets
  - Packets travel through network individually
  - Connection only exists while packet is transferred from one node to next
  - When packet has passed a node, the network resources become available for another packet
- User sees an 'always on' virtual connection through the network



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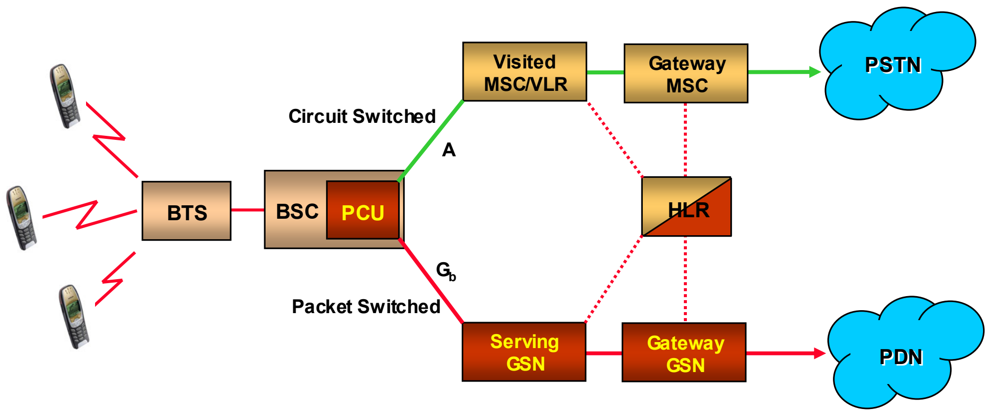
This is a very brief look at GPRS, for a more in depth introduction, see the AIRCOM GPRS System Overview course.

Circuit/Packet Data Separation



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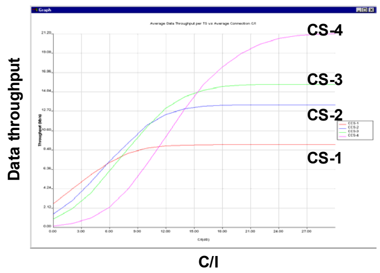
GPRS Air Interface

- New 'Packet' logical channels defined - PBCCH, PDTCH etc.
- New multiframe structure based on 'radio blocks' of 4 timeslots
  - Allows up to 8 mobiles to share a timeslot
- For high data rates, several physical channels may be allocated to one user
- 4 levels of channel coding schemes (CS-1 to CS-4):
  - Decreasing level of error checking
  - Greater data throughput rates
  - Scheme selected according to interference level (C/I)



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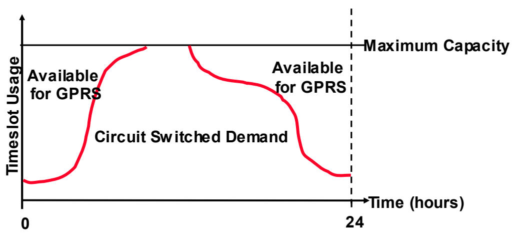
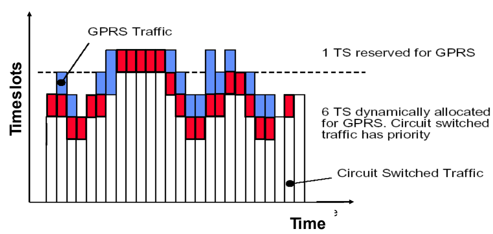
Section 10 – GSM Evolution

Using Spare GSM Capacity

- GPRS can use traffic capacity on the GSM network away from the busy hour for non time critical data transfers
- Even during the busy hour, there is spare capacity that GPRS can make use of:
  - Voice calls starting and finishing at random times, leave short periods when channels are unused
  - Packets of data can be sent when these channels become available - dynamic allocation





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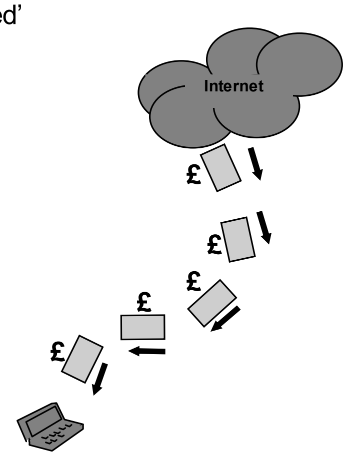
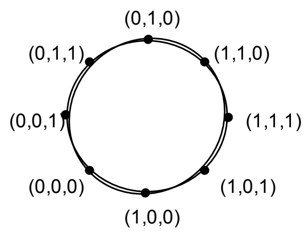
Charging for GPRS Services

- GPRS allows the user to be 'always connected' - charging by time is not appropriate
- Some possible methods of charging are:
  - By volume of data transferred
  - Flat rate for Internet access
  - By Quality of Service
  - For content - operator may provide own pages (value added services)
- Quality of Service parameters:
  - Service Precedence (priority)
  - Reliability
  - Delay
  - Throughput



10.4 EDGE

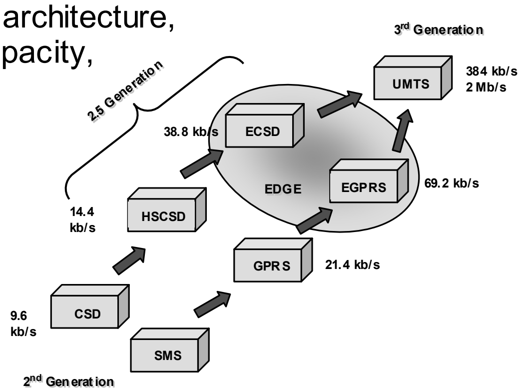
EDGE



- Enhanced Data rates for GSM Evolution
  - Use 8 Phase-Shift Keying (8PSK) modulation - 3 bits per symbol
  - Improved link control allows the system to adapt to variable channel quality - leads to slightly reduced coverage area
  - Applied to GSM, EDGE allows a maximum data rate of 48 kb/s per timeslot, giving the quoted figure of 384 kb/s per carrier (8 timeslots)
- EDGE can be applied to HSCSD (ECSD) and GPRS (EGPRS)
- EDGE will be expensive for operators to implement:
  - Each base station will require a new EDGE transceiver
  - Abis interface between BTS and BSC must be upgraded

Summary

- 2.5 G: move from GSM towards 3G, higher data rates
- HSCSD: circuit switched, multiple timeslots
- GPRS: packet switched, new architecture, new channels, using spare capacity, charging methods
- EDGE: 8PSK



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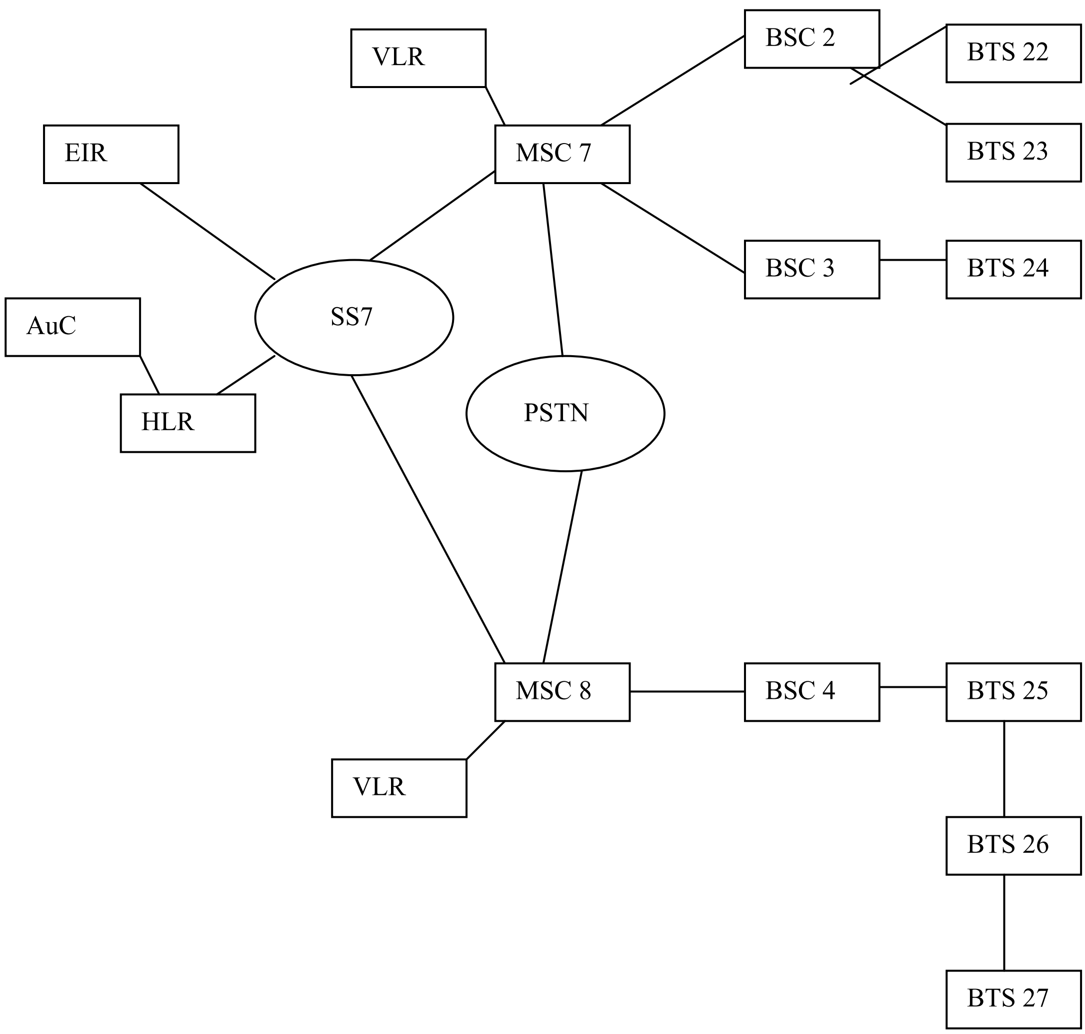
Appendix A
Solutions to Self-Assessment Exercises

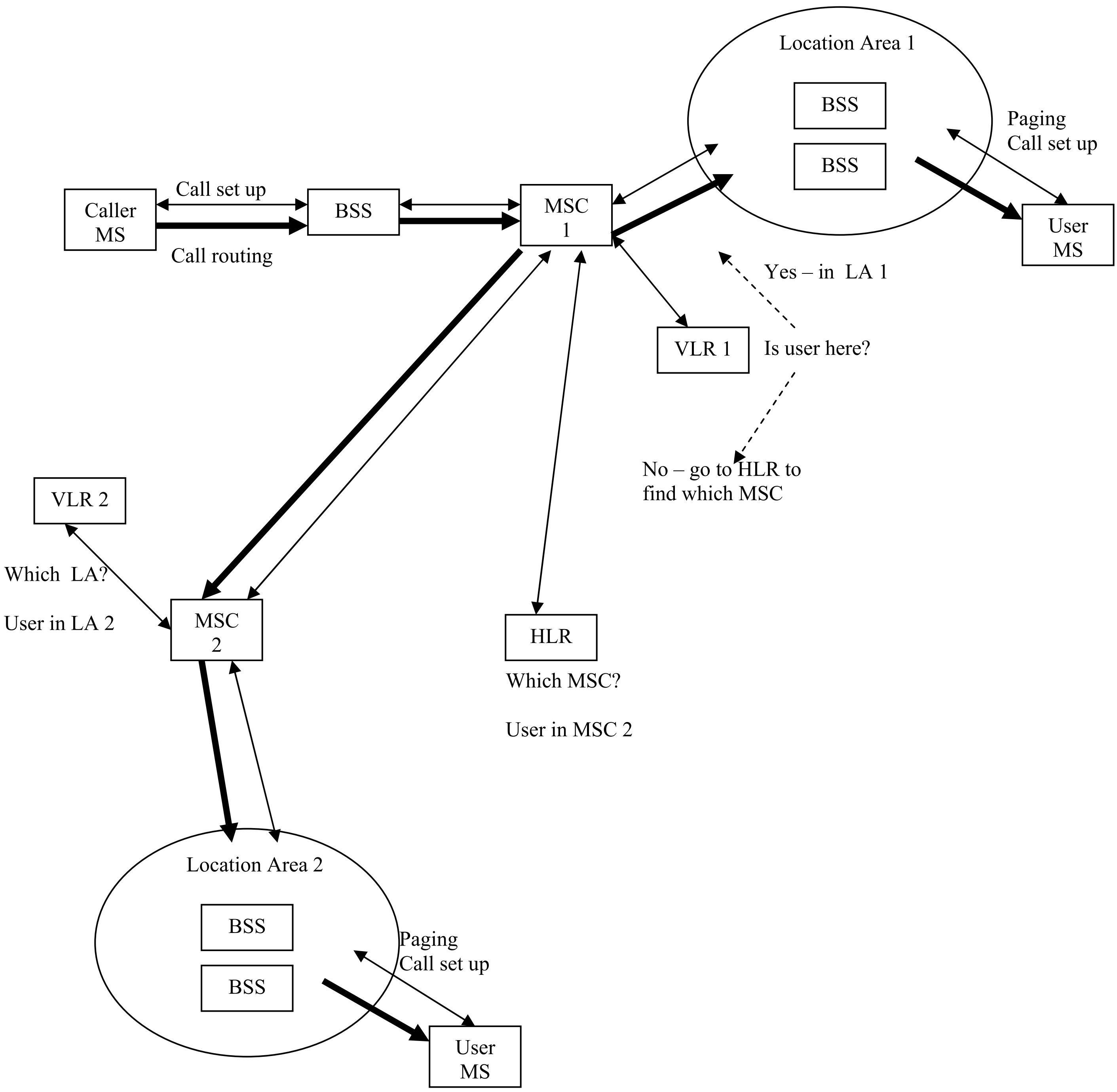
Section 1

Exercise 1.1 - GSM Network Architecture



Section 2

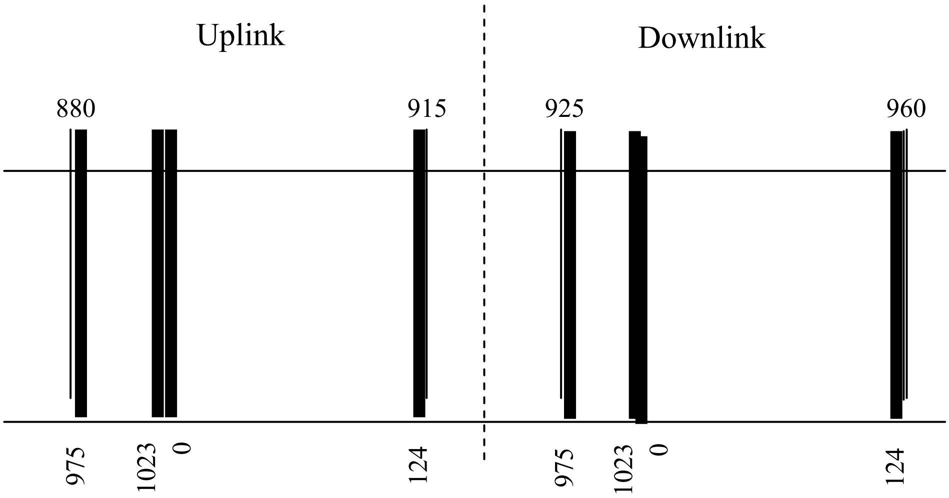
Exercise 2.1 - Mobile Originated Call



Section 3

Exercise 3.1 - Radio Spectrum Allocation

1.



For E-GSM:

Fu(n) = 890 + 0.2 n

n = 0 : Fu(1) = 890 + 0.2 x 0 = 890 MHz

n = 124 : Fu(124) = 890 + 0.2 x 124 = 914.8 MHz

Fu(n) = 890 + 0.2 (n –1024)

n = 975 : Fu(n) = 890 + 0.2 x (975 – 1024) = 880.2 MHz

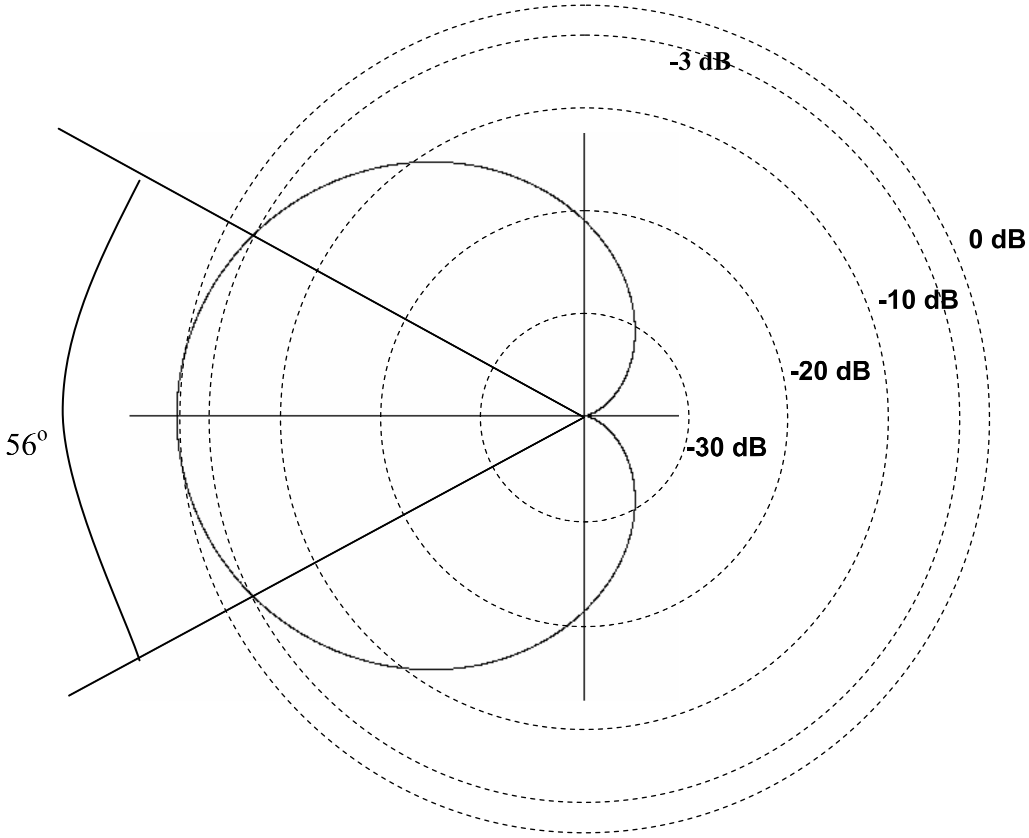
n = 1023 : Fu(n) = 890 + 0.2 x (1023 – 1024) = 889.8 MHz

The downlink frequencies are found by adding 45 MHz to each of these.

2.
For DCS-1800 , Fu(n) = 1710.2 + 0.2 (n – 512)

n = 601, Fu(601) = 1710.2 + 0.2 x (601 – 512) = 1728 MHz
n = 625, Fu(625) = 1710.2 + 0.2 x (625 – 512) = 1732.8 MHz

Exercise 3.2 - Antenna Beam Width



Estimate position of – 3dB level.

Find points where radiation pattern crosses – dB level.

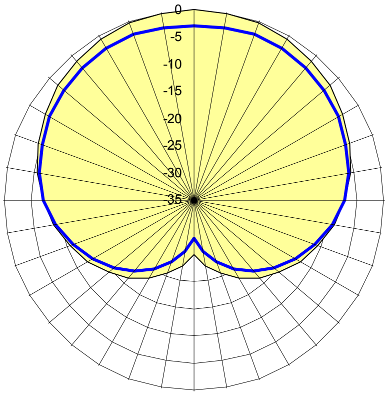
Draw lines to these points from antenna.

Angle is approximately 56° .

Exercise 3.3 - Antenna Tilting

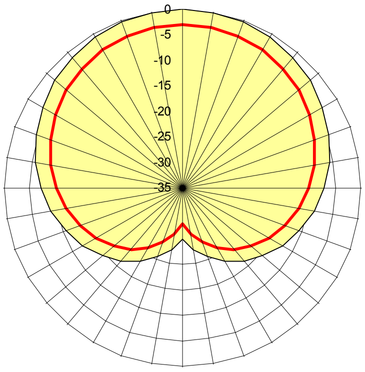
Mechanical down tilt:

Reduction mainly in forward direction.



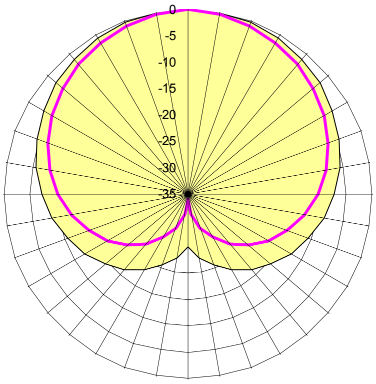
Electrical down tilt:

Reduction in all directions.



Electrical down tilt + mechanical up tilt:

Tilt is compensated in forward direction, but enhanced in backward direction.



Section 4

Exercise 4.1 - Logical Channels for Mobile Terminated Call

Channel	What it does
PCH	Base station pages the mobile
RACH	Mobile responds and requests a channel
AGCH	BTS assigns a SDCCH channel
SDCCH	Authentication process BTS assigns traffic channel (TCH)
FACCH	FACCH acknowledges TCH assignment Produces ring tone Sends connect message to BTS
TCH	Speech traffic

Section 7

Exercise 7.1 - Free Space Path Loss – Possible Solutions

1.

Required signal = - 90 = 30 – 32.5 – 20 log d - 20 log 900

20 log d = 90 + 30 + 32.5 – 20 log 900

20 log d = 28.415

d = 26.35

Radius of cell is approximately 26 km.

2.

1800 MHz suffers greater path loss than 900 MHz (doubling frequency gives an extra 6 dB path loss).

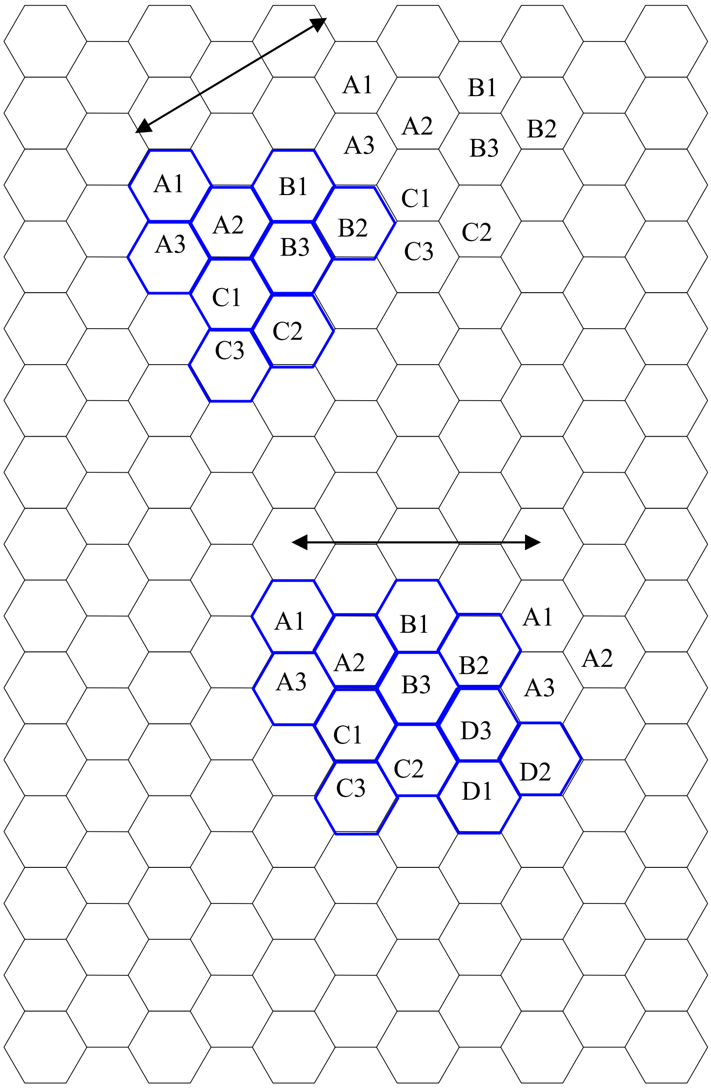
Repeating the previous calculation gives half the radius for the cell (13 km).

1800 operator will require much greater investment in base station equipment (BTSs, TRXs, antennas etc.) than the 900 operator.

Section 8

Exercise 8.1 - Frequency Planning

3/9



4/12

Notice the numbering of the D group of cells.

This ensures A1 and D3 which are adjacent carriers are not physically next to each other.

Re-use distance is greater for 4/12.

Less co-channel interference, also less adjacent channel interference as adjacent frequencies can also be planned further apart

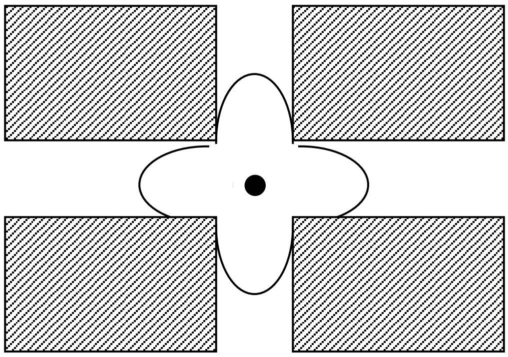
Only 36 carriers available, so 3/9 gives 4 carriers per cell, 4/12 gives 3 carriers per cell.
3/9 has greater traffic capacity per cell.

Exercise 8.2 - Microcell Planning

By crossing the coverage of the two antennas, mobiles will handover to the other microcell and then back to the first microcell as they pass through the junction.

This will place an unnecessary burden on radio resources.

An alternative solution is to place an omni-directional cell near the centre of the junction. The coverage will be confined by the buildings to the crossroads and streets:



Section 9

Exercise 9.1 - Frequency Hopping – Comments

Although each cell is using four different frequencies at any one time, the neighbouring cells are also using the same four frequencies at the same time.

There are only four frequencies available, so at any moment all the cells are trying to use all the frequencies. This would produce unacceptable interference.

To use frequency hopping, each cell must hop through a different set of frequencies than its neighbours so that interference is not caused.

Appendix B
Glossary of Terms

A3	Authentication algorithm
A5	Ciphering algorithm
A8	Ciphering key computation
A	Interface between MSC and BSC
Abis	Interface between BSC and BTS
ACK	Acknowledgement protocol
ADM	Adaptive delta modulation
ADPCM	Adaptive differential pulse-code modulation
ADSL	Asymmetric Digital Subscriber Line. A technique for dramatically increasing the data rates available on copper wiring.
AMPS	Analog Mobile Phone System. The US analogue cellular standard.
ARFCN	Absolute Radio Frequency Channel Number
ARQ	Automatic repeat request
ATM	Asynchronous Transfer Mode
AuC	Authentication Centre. The part of the GSM system responsible for authenticating the mobiles and providing ciphering keys.
BCCH	Broadcast Control Channel. A GSM logical control channel providing information to the mobile as to the channel configuration in the cell.
BER	Bit error rate
BP	Burst Period. The duration of a single burst, when one mobile transmits within the GSM framing structure.
BS	Base station. The part of the radio system which transmits the signal to the mobile.
BSC	Base Station Controller. The part of the GSM system responsible for controlling the base stations.
BSS	Base Station Sub-system. The combination of the BTS and BSC.
BSSMAP	BSS Management Part. The protocol used for BSS management on the Abis interface.
BT	Bandwidth-Time product. A means of measuring the amount of filtering applied to the pulse during the modulation process.
BTS	Base Transceiver Station. Another name for BS.
CAI	Common air interface – as in CT2 standard.
CDMA	Code Division Multiple Access. The use of different codes to allow users to access the same spectrum at the same time.
CC	Call Control. The protocol layer within GSM responsible for overall control of the call.
CELP	Code-excited linear prediction, vocoder.
CEPT	European Committee for Post and Telecommunications. The European body responsiblefor radio spectrum management.
COST	Co-operation in Science and Technology programme (Europe).
COST 231	COST committee dealing with future mobile system.

CT-0	The original analogue VHF/LF cordless phone technology as used in UK, France and elsewhere.
CT-1	Cordless Telephone Generation One – 900MHz analogue FM cordless Technology standardised by CEPT.
CT-2	Cordless Telephone Generation 2. An early UK digital cordless standard.
CT-3	Early Swedish (Ericsson) digital cordless standard.
CTM	Cordless terminal mobility – an application concept and an ETSI project.
DCS	Digital cellular system (eg DCS1800).
DECT	Digital European Cordless Telephone. The European cordless telephone standard.
Downlink	Transmission path from radio fixed part to portable part.
Duplex	Simultaneous two-way conversation.
DTAP	Direct Transfer Application Part. The protocol used on the Abis interface to Distinguish between messages for mobiles and for BTSs.
DTX	Discontinuous transmission
EDGE	Enhanced Data rates for GSM Evolution. Method of increasing data rates in GSM by using 8PSK modulation
8PSK	Eight Phase Shift Keying. Modulation techniques encoding 3 bits to each symbol.
EIR	Equipment Identity Register. Part of the GSM system responsible for keeping details of the mobile units and their status.
ETR	ETSI technical report.
ETS	ETSI technical standard.
ETSI	European Telecommunications Standards Institute.
FACCH	Fast Associated Control Channel. A logical channel used for sending emergency information to the mobile by suppressing traffic information.
FCCH	Frequency Control Channel. A logical control channel within GSM used to allow the mobile to lock onto the transmitted signal.
FDMA	Frequency Division Multiple Access. The division of the radio frequency into narrow slots, each one being given to a different user.
FEC	Forward error correction.
FH	Frequency Hopping. Changing rapidly from frequency to frequency to avoid problematic propagation effects.
FPLMTS	Future Public Land Mobile Telecommunications Service. The US name for third generation radio systems.
FSK	Frequency-shift keying.
FT	Fixed termination.
GAP	Generic access profile of DECT.
GFSK	Gaussian-filtered FSK modulation.
GIP	GSM interworking profile of DECT.
G-MSC	Gateway Mobile Switching Centre. The part of the GSM system providing the link into the PSTN.
GMSK	Gaussian Minimum Shift Keying. The modulation technique used in GSM, a form of phase modulation.
GoS	Grade of service.
GPRS	General Packet Radio Service.
GSM	Global System for Mobile telecommunications. *also* Groupe Speciale Mobile

Handoff	Procedure whereby communications between a mobile handset and a base station is automatically routed via an alternative base station when necessary to maintain or improve communications.
Handover	Another term for handoff.
HLR	Home Location Register. The part of the GSM system responsible for holding records about mobiles and for keeping track of the parent MSC area.
HSCSD	High Speed Circuit Switched Data. 2.5 G enhancement to GSM giving higher data rates
IAP	ISDN access profile for DECT.
ISI	Inter-Symbol Interference. A radio propagation effect whereby echoes of received signals cause previous symbols transmitted to interference with current symbols.
IMEI	International Mobile Equipment Identity. The GSM number given to each mobile.
IMSI	International Mobile Subscriber Identity. The phone numbering system used within GSM.
IMT2000	International Mobile Telecommunications system for the year 2000.
IN	Intelligent Network.
IP	Internet Protocol, a layer 3 network protocol
IS54	US digital AMPS standard.
IS95	US CDMA digital cellular standard.
ISDN	Integrated Services Digital Network. A protocol for sending digital information over copper landlines.
ITU	International Telecommunications Union. The international body responsible for spectrum management.
IWP	Inter-working profile.
IWU	Inter-working unit.
LA	Location Area
LAC	Location Area Code
LAI	Location Area Identity
LAPD	Link Access Protocol on interface D. Part of the ISDN protocol stack also used in GSM.
LEO	Low Earth Orbiting satellite system. A proposed communications system based on up to 66 satellites.
LLME	Lower layer management entity (DECT).
LNA	low noise amplifier.
LOS	Line-Of-Sight
LPC	Linear Predictive Coding.
MAC	Medium Access Control. The means whereby mobiles access radio channels which are not permanently reserved for their own particular use.
MAP	Mobile Application Part. Part of the SS7 protocol dealing with mobile services.
MM	Mobility Management. The protocol layer within GSM responsible for keeping track of mobiles and performing security functions.
MoU	Memorandum of Understanding
MS	Mobile Station.
MSC	Mobile Switching Centre. The part of the GSM system responsible for switching calls.

MSISDN	Mobile Subscriber Integrated Services Digital Number. The numbering system used to contact GSM mobiles from other networks.
MSK	Minimum shift keying modulation.
MTP	Message Transfer Part. Part of the SS7 protocol stack.
NADC	North American Digital Cellular
NCC	National Colour Code
NMT	Nordic Mobile Telephone system. The Nordic analog cellular standard.
O&M	Operations and maintenance
OAM	Operations, administration and maintenance.
OMC	Operations and Maintenance Centre. The part of the GSM system responsible for monitoring network function.
PABX	private automatic branch exchange.
PAGCH	Paging and Access Grant Channel. A GSM logical control channel providing paging information and allowing mobiles to make access attempts.
PBX	Private Branch Exchange (today has same meaning as PABX).
PCM	Pulse Code Modulation. A simple form of speech coding.
PCN	Personal communications network.
PCS1900	Personal Communications System at 1900 MHz. A variant of GSM working at 1900MHz designed for the US.
PDC	Personal Digital Cellular. The Japanese cellular standard.
PHL	Physical layer – lowest protocol layer.
PHS	Personal Handiphone System. The Japanese cordless telephone standard.
PLMN	Public Land Mobile Network.
PMR `	Private (*or Professional*)Mobile Radio. A radio system owned by the users typically large companies.
POTS	Plain old telephone service.
PP	Portable part.
PSK	Phase shift keying modulation.
PSTN	Public Switched Telephone Network.
PT	Portable termination.
QPSK	Quadrature Phase Shift Keying. A form of modulation whereby orthogonal carriers are used to gain the maximum information from the channel.
Quantisation	A process of representing samples of an analogue waveform by the nearest whole number of predefined voltage steps.
RACH	Random Access Channel. A GSM logical control channel used for making uplink access attempts.
RAP	Radio access profile for DECT.
RAN	Radio Access Network
RFP	Radio fixed part.
RIL	Radio Interface Layer. The protocol within GSM responsible for maintenance of the radio interface.
RLAN	Radio local area network.
RLL	Radio local loop.
RPE-LTP	Regular pulse excitation – long term predictor – speech coder user in GSM.
RR	Radio Resource. The protocol layer within GSM responsible for providing a service over the air interface.
RSSI	Received signal strength indication.
SACCH	Slow Associated Control Channel. A logical channel used alongside a traffic

	channel to send signalling information to and from the mobile.
SCCH	Synchronisation Control Channel. A GSM logical control channel providing synchronisation to the mobile.
SCCP	Signalling Control and Connection Part. Part of the SS7 protocol stack.
SID	Silence Descriptor
SIM	Subscriber Identity Module. A small card within GSM mobiles which contains the subscriber identity.
Simplex	One-way communication.
SMS	Short Message Service. A feature within GSM whereby messages of up to 160 characters can be transmitted to mobiles.
SMS-SC	SMS Service Centre. The part of the GSM system which handles short messages.
SRES	Signed RESult . Produced by authentication algorithm.
TA	Timing Advance
TACS	Total Access Communications System. The UK (and other European countries) analogue cellular standard.
TBR	Technical basis for regulation – ETSI standards.
TCH	Traffic Channel. The channel used in GSM to send subscriber information.
TCAP	Transaction Capability Application Part. Part of the SS7 protocol stack.
TDD	time division duplex.
TDM	Time division multiplex.
TDMA	Time Division Multiple Access. A system where users access all the frequency but only for a limited time.
TETRA	TErrestrial Trunk RAdio
TMN	Telecommunications Management Network. The concept of managing the network from a single point using a networked operations and maintenance system.
TMSI	Temporary Mobile Subscriber Identity. A GSM number given to the mobile during an encrypted call to prevent eavesdroppers being able to located the mobile.
TRAU	Transcoder Rate Adapter Unit
TRX	Transmit/Receiver module. The GSM term for a single carrier card within a BTS.
UMTS	Universal Mobile Telecommunications Service. One name for the third generation mobile radio system.
Uplink	Communications path from portable part to fixed part.
UPT	Universal Personal Telecommunications. The fixed network equivalent of third generation systems.
VAD	Voice Activity Detection
VLR	Visitors Location Register. The part of the GSM system responsible for keeping track of a mobile's position to the nearest location area.
VSAT	Very Small Aperture Terminal. A satellite communication system based on dishes around 1m across.
WAP	Wireless Application Protocol
WLL	Wireless Local Loop. The use of radio to replace copper wiring as a means of connecting the home to the PSTN.
WPABX	Wireless PABX.
WPBX	Wirelexx PBX.

WRC	World Radio Conference. The bi-annual international conferences to determine the use of the radio spectrum.
WRS	Wireless relay station.