UNIT-1

Introduction to Mobile Computing

- The process of computation on a mobile-device.
- In mobile computing, a set of distributed computing systems or service provider servers participate, connect, and synchronise through mobile communication protocols
- Provides decentralized (distributed) computations on diversified devices, systems, and networks, which are mobile, synchronized, and interconnected via mobile communication standards and protocols.
- Mobile device does not restrict itself to just one application, such as, voice communication
- Offers mobility with computing power
- Facilitates a large number of applications on a single device
- Also called pervasive computing *when a set of computing devices*, systems, or networks have the characteristics of *transparency*, application-aware *adaptation*, and have an *environment* sensing ability

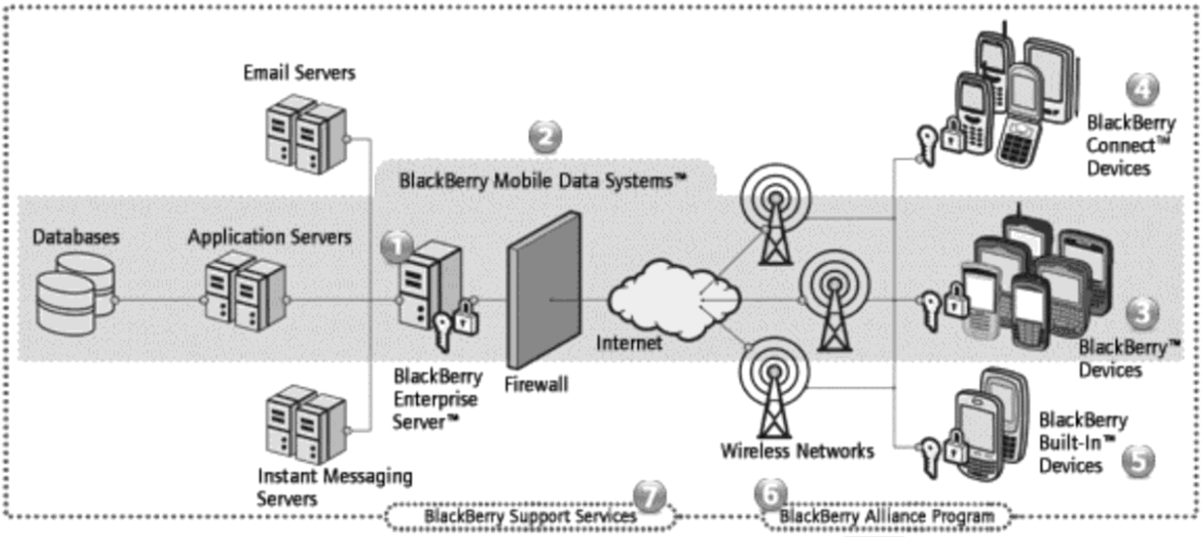
Novel applications:

SmartPhone Feature Example.

- A mobile phone with additional computing functions so as to enable multiple applications
- SMS (short message service), MMS (multimedia messaging service), phone, e-mail, addres book, web browsing, calender, task-to-do list, pad for memos.
- Compatibility with popular Personal Information Management (PIM) software
- Integrated attachment viewing.
- SureType keyboard technology with QWERTY-style layout.
- Dedicated Send and End keys.
- Bluetooth® capability for hands-free talking via headset, ear buds, and car kits
- EvDO* support enabling the device as a wireless modem use for laptop or PC.
- Speaker phone
- Polyphonic ring tones
- 64 MB memory
- Bright, high-resolution display, supporting over 65,000 colors

Enterprise Solutions

- Enterprises or large business networks
- Huge database and documentation requirements
- Business solutions for corporations or enterprises



Mobile Computing application to Music and Video

- Example─ Apple iPods enables listening to one's favourite tunes anytime and anywhere
- View photo albums
- Slide shows
- Video clips

Mobile Commerce

- Stock quotes in real time or on demand.
- The stock purchases or selling
- Bank transactions
- Retail purchases
- Supply chain management
- e-Ticketing─ booking cinema, train, flight, and bus tickets

Limitations to mobile computing

- Resource constraints: Battery
- Interference: the quality of service (QoS)
- Bandwidth: connection latency
- Dynamic changes in communication environment: variations in signal power within a region, thus link delays and connection losses
- Network Issues: discovery of the connection-service to destination and connection stability
- Interoperability issues: the varying protocol standards
- Security constraints: Protocols conserving privacy of communication

UNIT-1: Introduction to mobile computing, GSM, MAC.

Mobile Computing Architecture

- Programming languages used for mobile system software
- Operating system functions to run the software components onto the hardware
- Middleware components deployment
- Layered structure arrangement of mobile computing components
- Protocols and layers used for transmission and reception

Programming Languages

- Java— J2SE.
- J2ME (Java2 Micro edition)
- JavaCard (Java for smart card)
- The Java enterprise edition (J2EE) used for web and enterprise server based applications of mobile services
- C and C++ ,Visual C++ ,Visual Basic.

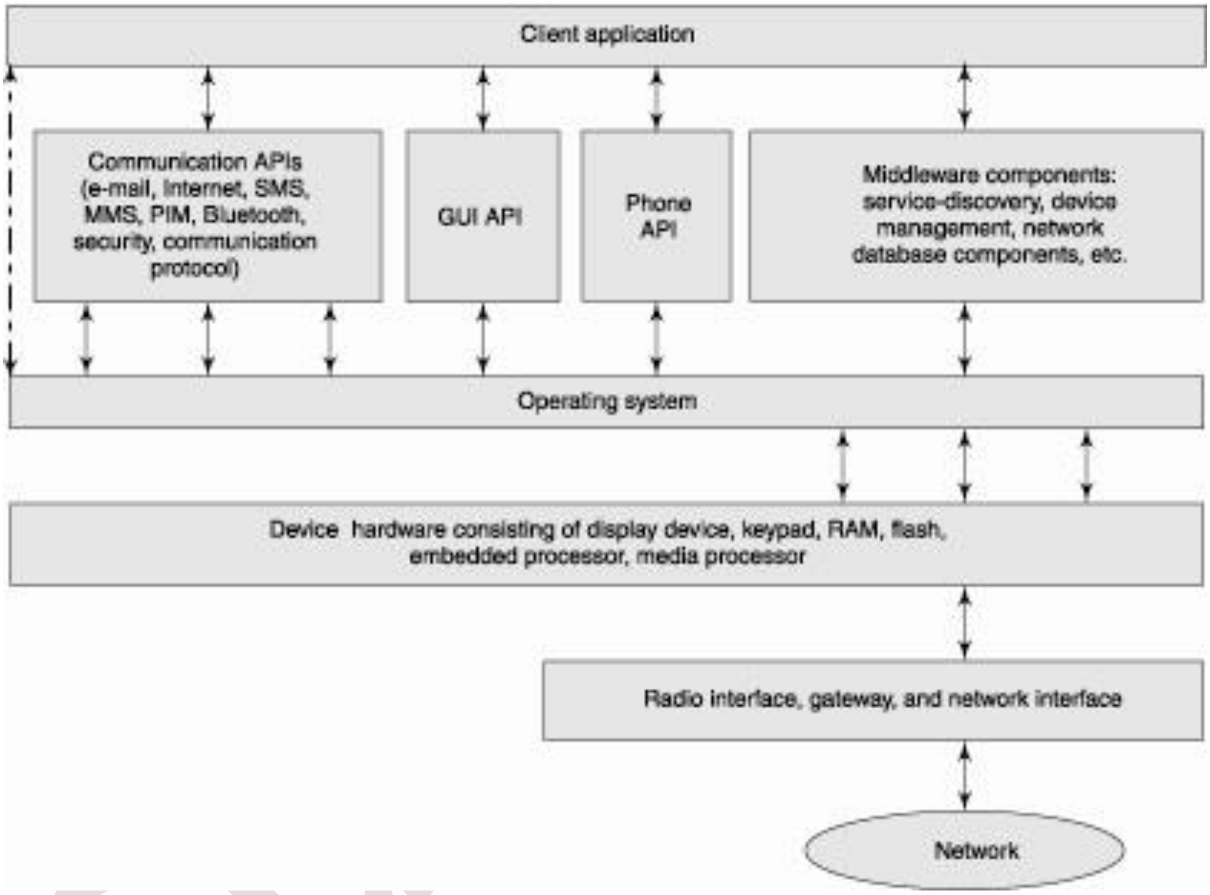
Operating System

- Symbian OS, Window CE, Mac OS…
- Offers the user to run an application without considering the hardware specifications and functionalities
- Provides functions which are used for scheduling the multiple tasks in a system
- Provides the functions required for the synchronization of multiple tasks in the system
- Multiple threads synchronization and priority allocation
- Management functions (such as creation, activation, deletion, suspension, and delay) for tasks and memory .
- Provides Interfaces for communication between software components at the application layer, middleware layers, and hardware devices
- Facilitates execution of software components on diversified hardware.
- Provides Configurable libraries for the GUI (graphic user interface) in the device.
- Provides User application's GUIs, VUI (voice user interface) components, and phone API
- Provides the device drivers for the keyboard, display, USB, and other devices

Middleware for Mobile Systems

- Software components that link the application components with the network-distributed components
- To discover the nearby device such as Bluetooth

- To discover the nearby hot spot
- For achieving device synchronization with the server or an enterprise server
- For retrieving data (which may be in Oracle or DB2) from a network database
- For service discovery at network
- For adaptation of the application to the platform and service availability



Mobile computing services Protocols

- Such as GSM 900, GSM900/1800/1900, UMTS, and I-Mode
- WPAN protocols─ Bluetooth, IrDA, and Zigbee)
- WLAN protocols ─for example, 802.11a and 802.11b)
- WAP

Mobile Computing system Layers

- Physical for sending and receiving signals (for example, TDMA or CDMA coding)
- Data-link (for example, multiplexing)
- Networking (for linking to the destination)
- Wireless transport layer security (for establishing end-to-end connectivity)

- Wireless transaction protocol
- Wireless session protocol
- Wireless application environment (for running a web application, for example, mobile e-business)

GSM (global system for mobile communications):

GSM is the most successful digital mobile telecommunication system in the world today. It is used by over 800 million people in more than 190 countries. In the early 1980s, Europe had numerous coexisting analog mobile phone sys-tems, which were often based on similar standards (e.g., NMT 450), but ran on slightly different carrier frequencies. To avoid this situation for a second genera-tion fully digital system, the **groupe spéciale mobile (GSM)** was founded in 1982. This system was soon named the **global system for mobile communications (GSM)**, with the specification process lying in the hands of ETSI (ETSI, 2002), (GSM Association, 2002).

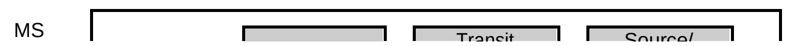
GSM is a typical second generation system, replacing the first generation analogy systems, but not offering the high worldwide data rates that the third generation systems, such as UMTS, are promising. GSM has initially been deployed in Europe using 890–915 MHz for uplinks and 935–960 MHz for downlinks – this system is now also called GSM 900 to distinguish it from the later versions. These versions comprise GSM at 1800 MHz (1710–1785 MHz uplink, 1805–1880 MHz downlink), also called DCS (digital cellular system) 1800.

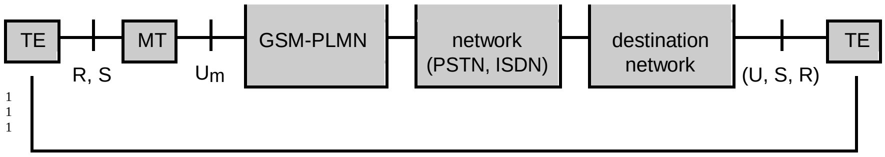
The following section describes the architecture, services, and protocols of GSM that are common to all three major solutions, GSM 900, GSM 1800, and GSM 1900.

Mobile services:

GSM permits the integration of different voice and data services and the inter-working with existing networks. Services make a network interesting for customers. GSM has defined three different categories of services: bearer, tele, and supplementary services. These are described in the following subsections. Figure 4.3 shows a reference model for GSM services. A **mobile station MS** is connected to the **GSM public land mobile network (PLMN)** via the U_m inter-face. (GSM-PLMN is the infrastructure needed for the GSM network.) This network is connected to transit networks, e.g., **integrated services digital net-work (ISDN)** or traditional **public switched telephone network (PSTN)**. There might be an additional network, the source/destination network, before another **terminal TE** is connected. **Bearer services** now comprise all services that enable the transparent transmission of data between the interfaces to the network.

- **i)Bearer services**





Bearer services permit transparent and non-transparent, synchronous or asynchronous data transmission. **Transparent bearer services** only use the functions of the physi-cal layer to transmit data. Data transmission has a constant delay and throughput if no transmission errors occur. The only mechanism to increase.

Figure 4.3 Bearer and tele services reference model

transmission quality is the use of **forward error correction (FEC)**, which codes redundancy into the data stream and helps to reconstruct the original data in case of transmission errors.. **Non-transparent bearer services** use protocols of layers two and three to implement error correction and flow control. These services use the transparent bearer services, adding a **radio link protocol (RLP)**. This protocol comprises mechanisms of **high-level data link control (HDLC)**.

- **ii)Tele services**

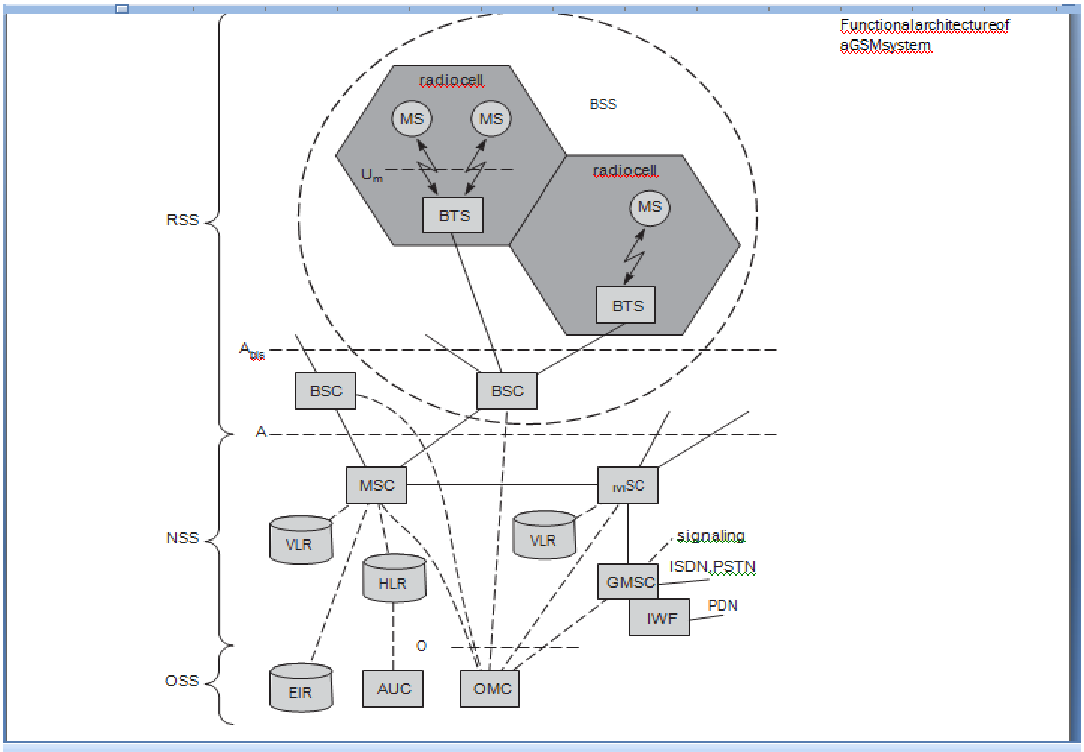
GSM mainly focuses on voice-oriented tele services. These comprise encrypted voice transmission, message services, and basic data communication with termi-nals as known from the PSTN or ISDN.Another service offered by GSM is the **emergency number**. This service is mandatory for all providers and free of charge. This connection also has the highest priority, possibly pre-empting other connections. A useful service for very simple message transfer is the **short message ser-vice (SMS)**, which offers transmission of messages of up to 160 characters. The successor of SMS, the enhanced message service (EMS), offers a larger message size (e.g., 760 characters, concatenating several SMs), formatted text. EMS never really took off as **the multimedia message service (MMS) was** avail-able..

- **iii)Supplementary services**

Services are user **identification**, call **redirection**, or **forwarding** of ongoing calls. Standard ISDN features such as **closed user groups** and **multi-party** communication may be available.

<u>System architecture:</u>

A GSM system consists of three subsystems, the **radio sub system (RSS)**, the **network and switching subsystem (NSS)**, and the **operation subsystem (OSS)**.



i) Radio subsystem

As the name implies, the **radio subsystem (RSS)** comprises all radio specific entities, i.e., the **mobile stations (MS)** and the **base station subsystem (BSS)**. Figure 4.4 shows the connection between the RSS and the NSS via the **A inter-face** (solid lines) and the connection to the OSS via the **O interface** (dashed lines).

● **Base station subsystem (BSS)**: A GSM network comprises many BSSs, each controlled by a base station controller (BSC). The BSS performs all functions necessary to maintain radio connections to an MS, coding/decoding of voice, and rate adaptation to/from the wireless network part. Besides a BSC, the BSS contains several BTSs.

● **Base transceiver station (BTS)**: A BTS comprises all radio equipment, i.e., antennas, signal processing, amplifiers necessary for radio transmission. A BTS can form a radio cell or, using sectorized antennas, several cells (see sec-tion 2.8), and is connected to MS via the **U_m interface** (ISDN U interface for mobile use), and to the BSC via the **A_{bis} interface**. The U_m interface contains all the mechanisms necessary for wireless transmission (TDMA, FDMA etc.) and will be discussed in more detail below. The A_{bis} interface consists of 16 or 64 kbit/s connections.

● **Base station controller (BSC)**: The BSC basically manages the BTSs. It reserves radio frequencies, handles the handover from one BTS to another within the BSS, and performs paging of the MS. The BSC also multiplexes the radio channels onto the fixed network connections at the A interface.

● **Mobile station (MS): The MS comprises all user equipment and software needed for communication with a GSM network. An MS consists of user** independent hard- and software and of the **subscriber identity module (SIM)**, which stores all user-specific data that is relevant to GSM.[3] While an MS can be identified via the **international mobile equipment identity (IMEI)**, a user can personalize any MS using his or her SIM. Without the SIM, only emergency calls are possible. The SIM card contains many identifiers and tables, such as card-type, serial number, a list of subscribed services, a **personal identity number (PIN)**, a **PIN unblocking key (PUK)**, an **authentication key** K_i, and the **inter-national mobile subscriber identity (IMSI)** (ETSI, 1991c). The PIN is used to unlock the MS. Using the wrong PIN three times will lock the SIM. In such cases, the PUK is needed to unlock the SIM.

ii) Network and switching subsystem

The "heart" of the GSM system is formed by the **network and switching sub-system (NSS)**. The NSS connects the wireless network with standard public networks, performs handovers between different BSSs, comprises functions for worldwide localization of users and supports charging, accounting, and roaming of users between different providers in different countries. The NSS consists of the following switches and database

● **Mobile services switching center (MSC)**: MSCs are high-performance digi-tal ISDN switches. They set up connections to other MSCs and to the BSCs via the A interface, and form the fixed backbone network of a GSM system. Typically, an MSC manages several BSCs in a geographical region. A **gateway MSC (GMSC)** has additional connections to other fixed networks, such as **PSTN** and **ISDN**. Using additional **interworking functions (IWF)**, an MSC

Home location register (HLR): The HLR is the most important database in a GSM system as it stores all user-relevant information. This comprises static information, such as the **mobile subscriber ISDN number (MSISDN)**, sub-scribed services (e.g., call forwarding, roaming restrictions, GPRS), and the **international mobile subscriber identity (IMSI)**. Dynamic information is also needed, e.g., the current **location area (LA)** of the MS, the **mobile sub-scriber roaming number (MSRN)**, the current VLR and MSC. As soon as an MS leaves its current LA, the information in the HLR is updated.

Visitor location register (VLR): The VLR associated to each MSC is a dynamic database which stores all important information needed for the MS users currently in the LA that is associated to the MSC.). If a new MS comes into an LA the VLR is respons-ible for, it copies all relevant information for this user from the HLR.

iii) Operation subsystem

The third part of a GSM system, the **operation subsystem (OSS)**, contains the necessary functions for network operation and maintenance.

Operation and maintenance center (OMC): The OMC monitors and con-trols all other network entities via the O interface (SS7 with X.25). Typical OMC management functions are traffic monitoring, status reports of net-work entities, subscriber and security management, or accounting and billing.

Authentication centre (AuC): As the radio interface and mobile stations are particularly vulnerable, a separate AuC has been defined to protect user identity and data transmission. The AuC contains the algorithms for authentication as well as the keys for encryption and generates the values needed for user authentication in the HLR

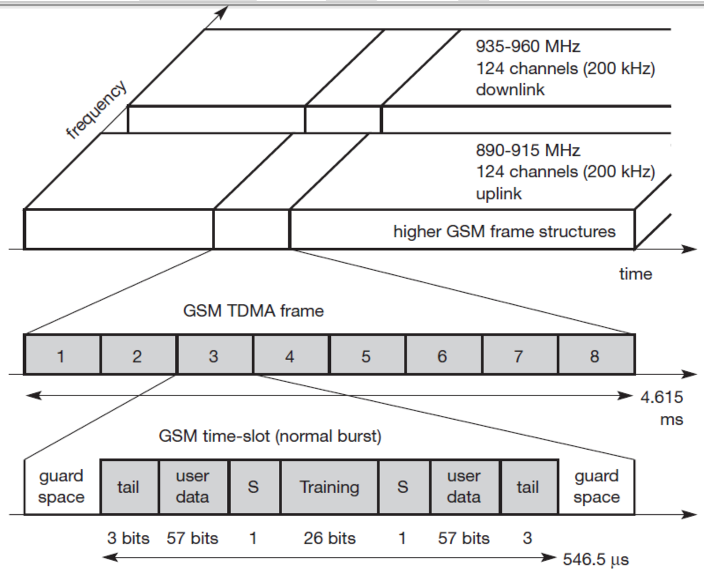
Equipment identity register (EIR): The EIR is a database for all IMEIs, i.e., it stores all device identifications registered for this network. As MSs are mobile, they can be easily stolen.the EIR also contains a list of valid IMEIs (white list), and a list of malfunctioning devices (gray list).

Radio interface:

Data is transmitted in small portions, called bursts. Figure 4.5 shows a so-called normal burst as used for data transmission inside a time slot (user and signaling data). In the diagram, the burst is only 546.5 μs long and contains 148 bits. The remaining 30.5 μs are used as guard space to avoid overlapping with other bursts due to different path delays and to give the transmitter time to turn on and off.

The first and last three bits of a normal burst (**tail**) are all set to 0 and can be used to enhance the receiver performance. The **training** sequence in the middle of a slot is used to adapt the parameters of the receiver to the current path propa-gation characteristics and to select the strongest signal in case of multi-path propagation. A flag **S** indicates whether the **data** field contains user or network control dataa **frequency correction** burst allows the MS to correct the local oscillator to avoid interference with neighboring channels, a **synchroniza-tion burst** with an extended training sequence synchronizes the MS with the BTS in time, an **access burst** is used for the initial connection setup between MS and BTS, and finally a **dummy burst** is used if no data is available for a slot.

Figure 4.5
GSM TDMA frame, slots, and bursts



i) **Logical channels and frame hierarchy;**

- GSM specifies two basic groups of logical channels, i.e., traffic channels and control channels
- **Traffic channels (TCH)**: GSM uses a TCH to transmit user data (e.g., voice, fax). Two basic categories of TCHs have been defined, i.e., **full-rate TCH (TCH/F)** and **half-rate TCH (TCH/H).**
- **Control channels (CCH)**: Many different CCHs are used in a GSM system to control medium access, allocation of traffic channels or mobility man-agement.

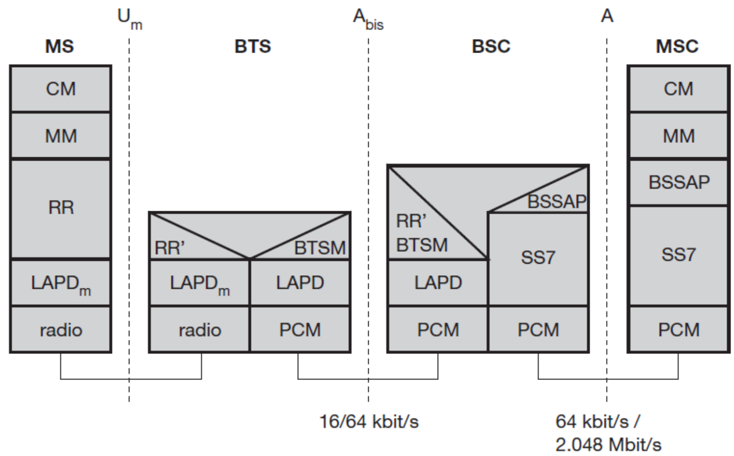
- **Broadcast control channel (BCCH)**: A BTS uses this channel to signal information to all MSs within a cell. Information transmitted in this channel, e.g., the cell identifier.
- The BTS sends information for frequency correction via the frequency correction channel (FCCH) and information about time synchronization via the synchronization channel (SCH), where both channels are subchannels of the **BCCH.**

- **Common control channel (CCCH):**
- All information regarding connec-tion setup between MS and BS is exchanged via the CCCH. For calls toward an MS, the BTS uses the **paging channel (PCH)** for paging the appropriate MS. If an MS wants to set up a call, it uses the **random access channel (RACH)** to send data to the BTS. The RACH implements multiple access (all MSs within a cell may access this channel) using slot-ted Aloha. The BTS uses the **access grant channel (AGCH)** to signal an MS that it can use a TCH or SDCCH for further connection setup.
- **Dedicated control channel (DCCH):**
- following channels are bidirectional. As long as an MS has not established a TCH with the BTS, it uses the **stand-alone dedicated control channel (SDCCH)** with a low data rate (782 bit/s) for signalling.
- This can comprise authentication, registration or other data needed for setting up a TCH. Each TCH and SDCCH has a **slow associated dedicated control channel (SACCH)** associated with it.
- GSM uses a **fast asso-ciated dedicated control channel (FACCH)**. The FACCH uses the time slots which are otherwise used by the TCH.

Protocols:

- Figure 4.7 shows the protocol architecture of GSM with signalling protocols, interfaces.

Figure 4.7 Protocol architecture for signaling



The main interest lies in the U_m interface, as the other interfaces occur between entities in a fixed network. **Layer 1**, the physical layer, handles all **radio**-specific functions. This includes the creation of bursts according to the five different formats, **multi-plexing** of bursts into a TDMA frame, **synchronization** with the BTS, detection of idle channels, and measurement of the **channel quality** on the downlink. The physical layer at U_m uses GMSK for digital

modulation and performs **encryption/decryption** of data, i.e., encryption is not performed end-to-end, but only between MS and BSS over the air interface.

Synchronization also includes the correction of the individual path delay between an MS and the BTS. All MSs within a cell use the same BTS and thus must be synchronized to this BTS. The BTS generates the time-structure of frames, slots.

LAPD$_m$ protocol has been defined at the U$_m$ interface for **layer two**. LAPD$_m$, as the name already implies, has been derived from link access procedure for the D-channel (**LAPD**) in ISDN systems. LAPD$_m$ offers reliable data transfer over connections, re-sequencing of data frames, and flow control (ETSI, 1993b), (ETSI, 1993c).. defined for the U$_m$ interface. Further services provided by LAPD$_m$ include segmentation and reassembly of data and acknowledged/unacknowledged data transfer.

The network layer in GSM, **layer three**, comprises several sublayers as Figure 4.7 shows. The lowest sublayer is the **radio resource management (RR)**. Only a part of this layer, **RR**', is implemented in the BTS, the remainder is situ-ated in the BSC. The functions of RR' are supported by the BSC via the **BTS management (BTSM)**. The main tasks of RR are setup, maintenance, and release of radio channels. RR also directly accesses the physical layer for radio information and offers a reliable connection to the next higher layer.

Mobility management (MM) contains functions for registration, authentica-tion, identification, location updating, and the provision of a **temporary mobile subscriber identity (TMSI)** that replaces the **international mobile subscriber identity (IMSI).**

Finally, the **call management (CM)** layer contains three entities: **call con-trol (CC)**, **short message service (SMS)**, and **supplementary service (SS)**. SMS allows for message transfer using the control channels SDCCH and SACCH.

Data transmission at the physical layer typically uses pulse code modulation (PCM) systems. . LAPD is used for layer two at **Abis**, BTSM for BTS management.

Signaling system No. 7 (SS7) is used for signalling between an MSC and a BSC. This protocol also transfers all management information between MSCs, HLR, VLRs, AuC, EIR, and OMC. An MSC can also control a BSS via a **BSS application part (BSSAP)**.

Localization and calling:

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

Mobile station international ISDN number (MSISDN): The only important number for a user of GSM is the phone number. Remember that the phone number is not associated with a certain device but with the SIM, which is personalized for a user. The MSISDN follows the ITU-T standard E.164 for addresses as it is also used in fixed ISDN networks. This number consists of the **country code (CC)** (e.g., +49 179 1234567 with 49 for Germany), the **national destination code (NDC)** (i.e., the address of the network provider, e.g., 179), and the **subscriber number (SN)**.

International mobile subscriber identity (IMSI): GSM uses the IMSI for internal unique identification of a subscriber. IMSI consists of a **mobile country code (MCC)** (e.g., 240 for Sweden, 208 for France), the **mobile network code (MNC)** (i.e., the code of the network provider), and finally the **mobile subscriber identification number (MSIN)**.

Temporary mobile subscriber identity (TMSI): To hide the IMSI, which would give away the exact identity of the user signaling over the air inter-face, GSM uses the 4 byte TMSI for local subscriber identification. TMSI is selected by the current VLR and is only valid temporarily and within the location area of the VLR.

MSRN contains the current **visitor country code (VCC)**, the **visi-tor national destination code (VNDC)**, the identification of the current MSC together with the subscriber number. The MSRN helps the HLR to find a subscriber for an incoming call.

i)Mobile Terminated Call:

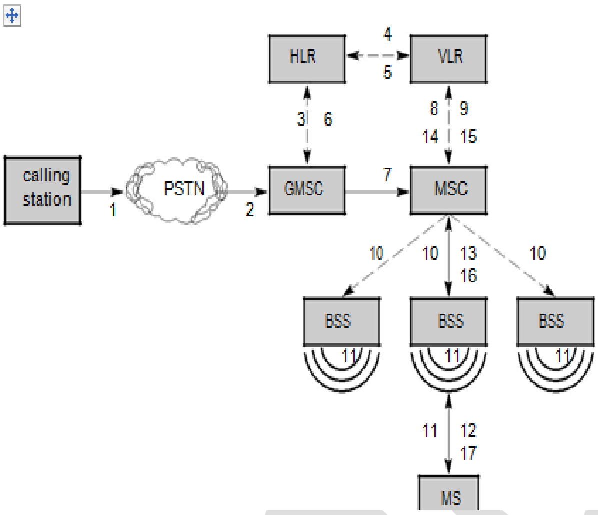


Figure 4.8 Mobile terminated call (MTC)

- 1: calling a GSM subscriber
- 2: forwarding call to GMSC
- 3: signal call setup to HLR
- 4, 5: request MSRN from VLR
- 6: forward responsible MSC to GMSC
- 7: forward call to
- current MSC
- 8, 9: get current status of MS
- 10, 11: paging of MS
- 12, 13: MS answers
- 14, 15: security checks
- 16, 17: set up connection

ii)MOBILE ORIGINATED CALL (MOC):

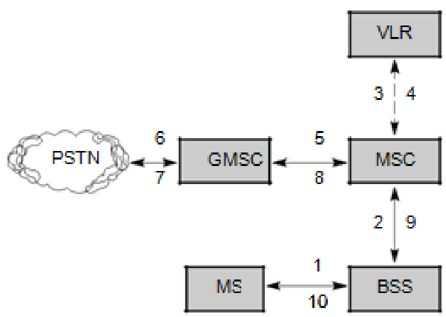
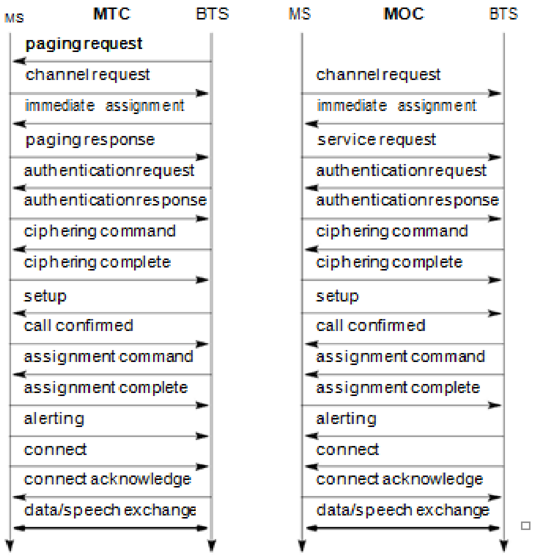


Figure 4.9 Mobile originated call (MOC)

- 1, 2: connection request
- 3, 4: security check
- 5-8: check resources (free circuit)
- 9-10: set up call

Figure 4.10
Message flow for MTC and MOC



In addition to the steps mentioned above, other messages are exchanged between an MS

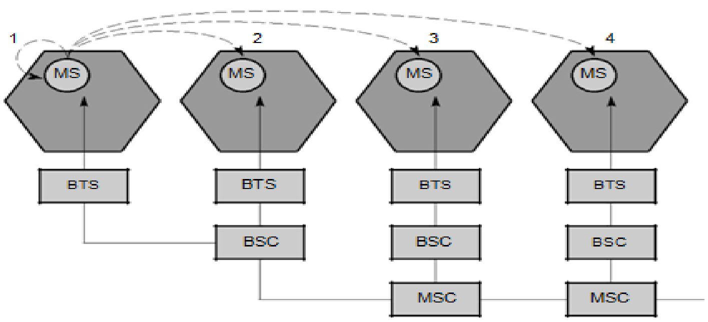
<u>Handover</u> :

Cellular systems require **handover** procedures, as single cells do not cover the whole service area, but, e.g., only up to 35 km around each antenna on the countryside and some hundred meters in cities The smaller the cell size and the faster the movement of a mobile station through the cells (up to 250 km/h for GSM), the more handovers of ongoing calls are required. Figure 4.11 shows four possible handover scenarios in GSM:

- **Intra-cell handover:** Within a cell, narrow-band interference could make transmission at a certain frequency impossible. The BSC could then decide to change the carrier frequency (scenario 1).
- **Inter-cell, intra-BSC handover:** This is a typical handover scenario. The mobile station moves from one cell to another, but stays within the control of the same BSC. The BSC then performs a handover, assigns a new radio channel in the new cell and releases the old one (scenario 2).
- **Inter-BSC, intra-MSC handover:** As a BSC only controls a limited number of cells; GSM also has to perform handovers between cells controlled by differ-ent BSCs. This handover then has to be controlled by the MSC (scenario 3). This situation is also shown in Figure 4.13.

Inter MSC handover: A handover could be required between two cells belonging to different MSCs. Now both MSCs perform the handover together (scenario 4)

Figure 4.11
Types of handover in GSM



Security:

GSM offers several security services using confidential information stored in the **AuC** and in the individual SIM

- **Access control and authentication:** The first step includes the authentication of a valid user for the SIM. The user needs a secret PIN to access the SIM. The next step is the subscriber authentication.
- **Confidentiality:** All user-related data is encrypted. After authentication, BTS and MS apply encryption to voice, data, and signaling. This confidentiality exists only between MS and BTS, but it does not exist end-to-end or within the whole fixed GSM/telephone network.

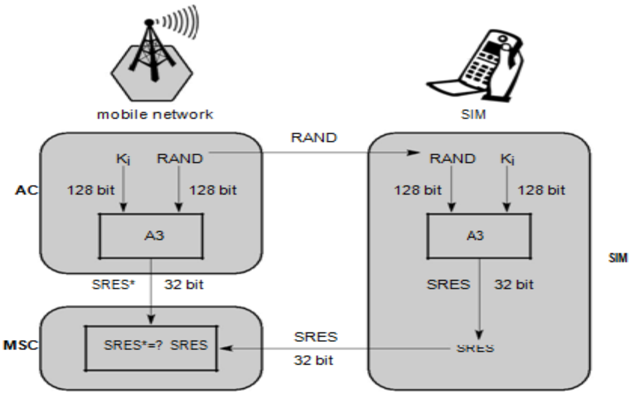
Anonymity: To provide user anonymity, all data is encrypted before trans-mission, and user identifiers (which would reveal an identity) are not used over the air. Instead, GSM transmits a temporary identifier (TMSI), which is newly assigned by the VLR after each location update. Additionally, the VLR can change the TMSI at any time.

- **Security services**
  - **access control/authentication**
    - user Õ SIM (Subscriber Identity Module): secret PIN (personal identification number)
    - SIM Õ network: challenge response method
  - **confidentiality**
    - voice and signaling encrypted on the wireless link (after successful authentication)
  - **anonymity**
    - temporary identity TMSI (Temporary Mobile Subscriber Identity)
    - newly assigned at each new location update (LUP)
    - encrypted transmission
- **3 algorithms specified in GSM**
  - **A3 for authentication (“secret”, open interface)**
  - **A5 for encryption (standardized)**
  - **A8 for key generation (“secret”, open interface)**

i) Authentication

Before a subscriber can use any service from the GSM network, he or she must be authenticated. Authentication is based on the SIM, which stores the **individual authentication key K_i**, the **user identification IMSI**, and the algorithm used for authentication **A3**.

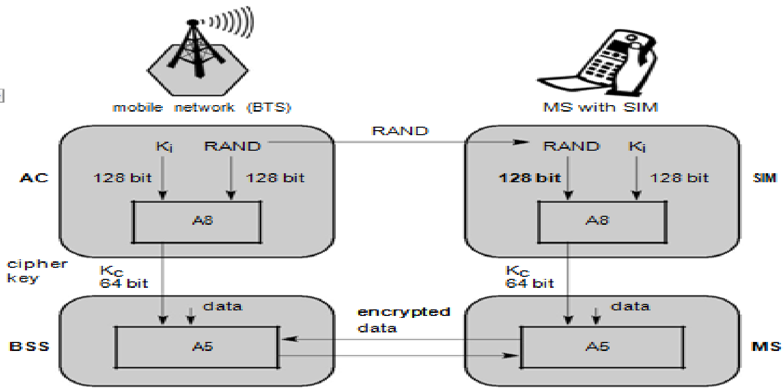
Figure 4.14
Subscriber
authentication



ii) Encryption

To ensure privacy, all messages containing user-related information are encrypted in GSM over the air interface. After authentication, MS and BSS can start using encryption by applying the cipher key K_c (the precise location of security functions for encryption, BTS and/or BSC are vendor dependent). K_c is generated using the individual key K_i and a random value by applying the algo-rithm A8. Note that the SIM in the MS and the network both calculate the same K_c based on the random value RAND. The key K_c itself is not transmitted over the air interface.

Figure 4.15
Data encryption



MS and BTS can now encrypt and decrypt data using the algorithm A5 and the cipher key K_c. As Figure 4.15 shows, K_c should be a 64 bit key – which is not very strong, but is at least a good protection against simple eavesdropping. However, the publication of A3 and A8 on the internet showed that in certain implementations 10 of the 64 bits are always set to 0, so that the real length of the key is thus only 54 consequently, the encryption is much weaker.

- Data transmission standardized with only 9.6 kbit/s
  - advanced coding allows 14.4 kbit/s
  - not enough for Internet and multimedia applications
- HSCSD (High-Speed Circuit Switched Data)
  - already standardized
  - bundling oft/s us several time-slots to get higher AIUR

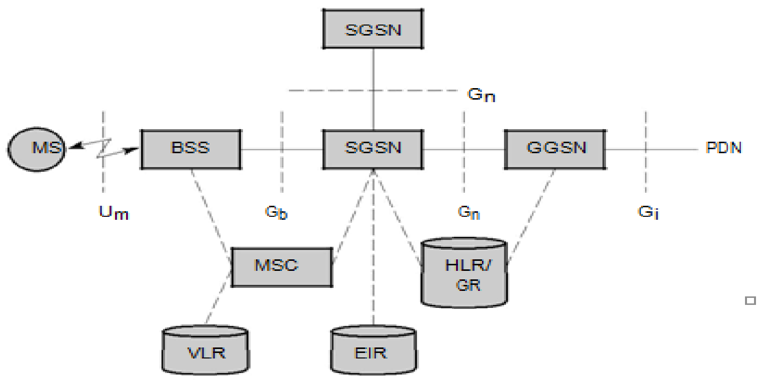
- advantage: ready to use, constant quality, simple
- disadvantage: channels blocked for voice transmission

➢ **GPRS (General Packet Radio Service)**

- **packet switching**
- **using free slots only if data packets ready to send standardization 1998**
- **advantage: one step towards UMTS, more flexible**
- **disadvantage: more investment needed**
- **GPRS network elements**
- **GSN (GPRS Support Nodes): GGSN and SGSN**
- **GGSN (Gateway GSN)**
- interworking unit between GPRS and PDN (Packet Data Network)
- **SGSN (Serving GSN)**
- supports the MS (location, billing, security)
- **GR (GPRS Register)**
- user addresses

GPRS architecture and interfaces:

Figure 4.16
GPRS architecture reference model



The **GPRS architecture** introduces two new network elements, which are called **GPRS support nodes (GSN)** and are in fact routers.

The **gateway GPRS support node (GGSN)** is the inter-working unit between the GPRSnetwork and external **packet data networks (PDN)**.**serving GPRS support node (SGSN)** which supports the MS via the G_b interface

GPRS protocol architecture:

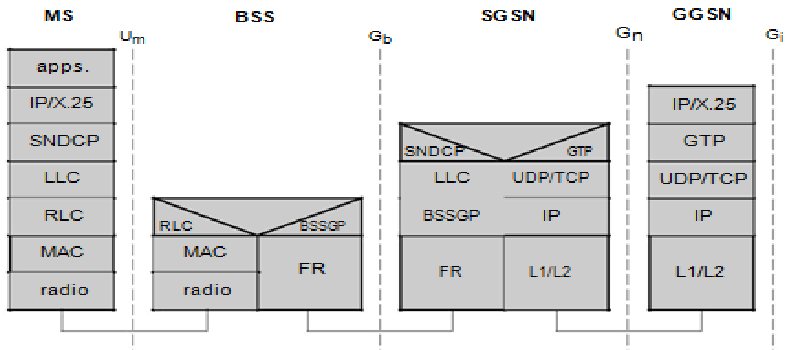


Figure 4.17
GPRS transmission plane protocol reference model

A **base station subsystem GPRS protocol (BSSGP)** is used to convey rout-ing and QoS-related information between the BSS and SGSN.

The **radio link protocol (RLC)** provides a reliable link.

while the **MAC** controls access with signaling procedures for the radio channel and the mapping of LLC frames onto the GSM physical channels

. The **radio interface** at U_m needed for GPRS does not require fundamental changes compared to stan-dard GSM.

All data within the GPRS backbone, i.e., between the GSNs, is transferred using the **GPRS tunnelling protocol (GTP)**. GTP can use two different transport proto-cols, either the reliable **TCP** (needed for reliable transfer of X.25 packets) or the non-reliable **UDP** (used for IP packets). The network protocol for the GPRS back-bone is **IP** (using any lower layers). To adapt to the different characteristics of the underlying networks, the **subnetwork dependent convergence protocol (SNDCP)** is used between an SGSN and the MS.

<u>Medium access control:</u>

MAC belongs to layer 2, the **data link con-trol layer (DLC)**. Layer 2 is subdivided into the **logical link control (LLC).**

Motivation for specialized MAC :

- **Can we apply media access methods from fixed networks?**
- Example CSMA/CD
  - Carrier Sense Multiple Access with Collision Detection
  - send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)
- **Problems in wireless networks**
  - signal strength decreases proportional to the square of the distance
  - the sender would apply CS and CD, but the collisions happen at the receiver
  - it might be the case that a sender cannot "hear" the collision, i.e., CD does not work

furthermore, CS might not work if, e.g., a terminal is "hidden**.**

Motivation - hidden and exposed terminals:

- **Hidden terminals**
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a "free" medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)

- ❑ A is "hidden" for C

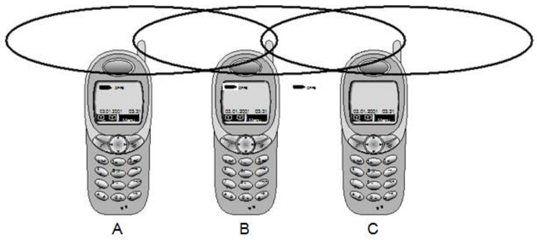


Figure 3.1
Hidden and exposed terminals

- **Exposed terminals**
  - ❑ B sends to A, C wants to send to another terminal (not A or B)
  - ❑ C has to wait, CS signals a medium in use
  - ❑ but A is outside the radio range of C, therefore waiting is not necessary

C is "exposed" to B.

Motivation - near and far terminals:

- ❑ Terminals A and B send, C receives
- ❑ signal strength decreases proportional to the square of the distance
- ❑ the signal of terminal B therefore drowns out A's signal
- ❑ C cannot receive A

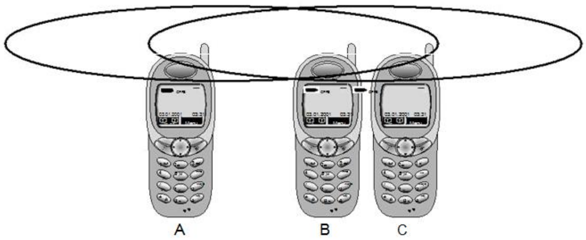


Figure 3.2
Near and far terminals

- ❑ If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- ❑ Also severe problem for CDMA-networks - precise power control needed!

Access methods SDMA/FDMA/TDMA:

- **SDMA (Space Division Multiple Access)**
  - ❑ segment space into sectors, use directed antennas
  - ❑ cell structure

➢ FDMA (Frequency Division Multiple Access)

- ❑ assign a certain frequency to a transmission channel between a sender and a receiver
- ❑ permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- ❑ Here the two partners typi-cally establish a **duplex channel**, i.e., a channel that allows for simultaneous transmission in both directions. The two directions, mobile station to base sta-tion and vice versa are now separated using different frequencies. This scheme is then called **frequency division duplex (FDD)**.

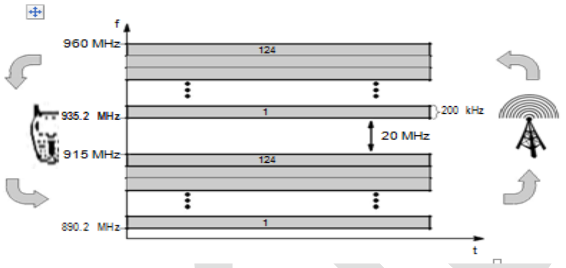


Figure 3.3 Frequency division multiplexing for multiple access and duplex

- ❑

➢ TDMA (Time Division Multiple Access)

- ❑ assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

- **Fixed TDM:**
  - ✓ The simplest algorithm for using TDM is allocating time slots for channels in a fixed pattern.
  - ✓ . Assigning different slots for uplink and downlink using the same frequency is called **time division duplex (TDD)**.

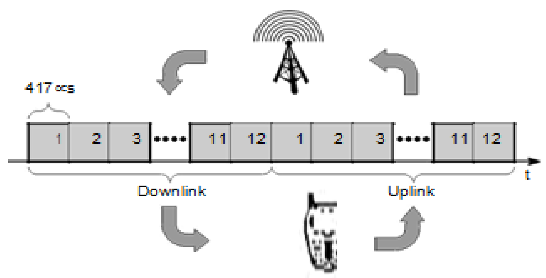


Figure 3.4 Time division multiplexing for multiple access and duplex

- As shown in the figure, the base station uses one out of 12 slots for the downlink, whereas the mobile station uses one out of 12 different slots for the uplink. Uplink and downlink are separated in time. Up to 12 different mobile stations can use the same frequency without interference using this scheme. Each connection is allotted its own up- and downlink pair.

- **Classical Aloha:**
- a scheme which was invented at the University of Hawaii and was used in the ALOHANET for wireless connection of several stations. Aloha neither coordinates medium access nor does it resolve contention on the MAC layer. random, distributed (no central arbiter), time-multiplex. If two or more stations access the medium at the same time, a **collision** occurs and the transmitted data is destroyed. Resolving this problem is left to higher layers

Figure 3.5 Classical Aloha multiple access

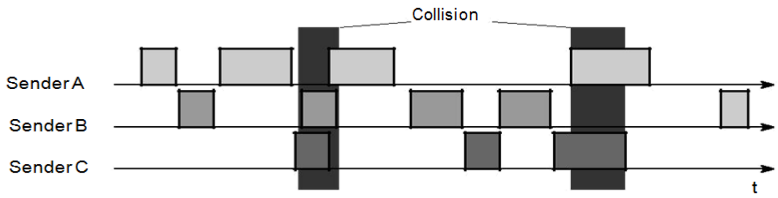
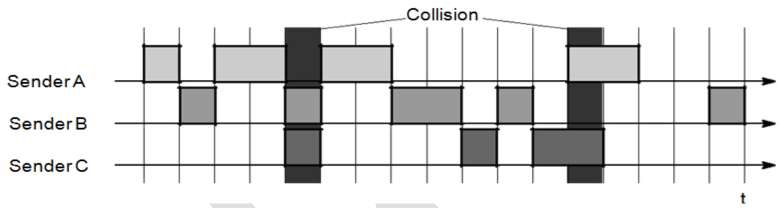


Figure 3.6 Slotted Aloha multiple access



- **slotted aloha:**
  - The first refinement of the classical Aloha scheme is provided by the introduc-tion of time slots (**slotted Aloha**). In this case, all senders have to be **synchronized**, transmission can only start at the beginning of a **time slot**
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- **Carrier sense multiple access:**
  - Sensing the carrier and accessing the medium only if the carrier is idle decreases the probability of a collision. hidden terminals cannot be detected, so, if a hidden terminal transmits at the same time as another sender, a collision might occur at the receiver.
  - In non-persistent CSMA, stations sense the carrier and start sending immediately if the medium is idle. If the medium is busy, the station pauses a random amount of time before sensing the medium again and repeating this pattern. In p-persistent CSMA systems nodes also sense the medium, but only transmit with a probability of p, with the station deferring to the next slot with the probability 1-p, i.e., access is slotted in addition. In 1-persis-tent CSMA systems, all stations wishing to transmit access the medium at the same time, as soon as it becomes idle.
  -

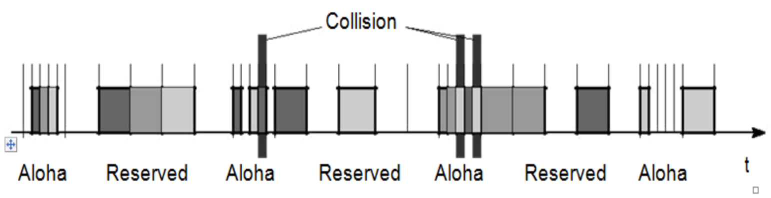
- ## Demand assigned multiple access
  - Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)
  - Reservation can increase efficiency to 80%
    - sender *reserves* a future time-slot
    - sending within this reserved time-slot is possible without collision
    - reservation also causes higher delays
    - typical scheme for satellite links
  - Examples for reservation algorithms:
    - Explicit Reservation according to Roberts (Reservation-ALOHA)
    - Implicit Reservation (PRMA)
    - Reservation-TDMA

- ## Explicit Reservation (Reservation Aloha):

Twomodes:

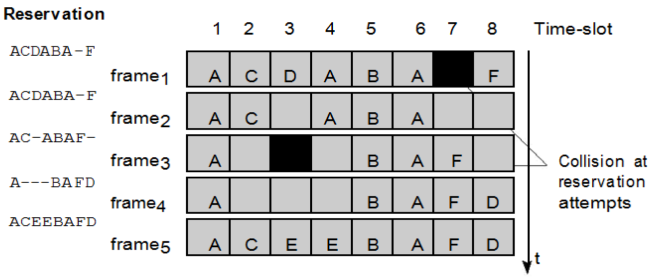
- **reserved mode** for data transmission within successful reserved slots (no collisions possible)
- **aloha mode** for reservation :competition for small reservation slots, collisions possible
- **it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time**
-

Figure 3.7
Demand assignment multiple access with explicit reservation



- ## Implicit reservation (PRMA - Packet Reservation MA):
  - a certain number of slots form a frame, frames are repeated
  - stations compete for empty slots according to the slotted aloha principle
  - once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
  - competition for this slots starts again as soon as the slot was empty in the last frame

Figure 3.8
Demand assignment multiple access with implicit reservation



- **Reservation Time Division Multiple Access**
  - every frame consists of N mini-slots and x data-slots
  - every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

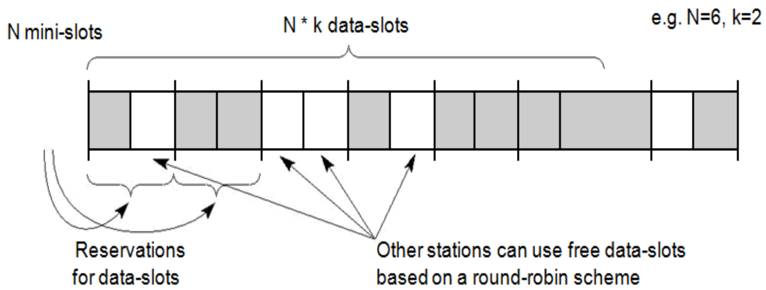
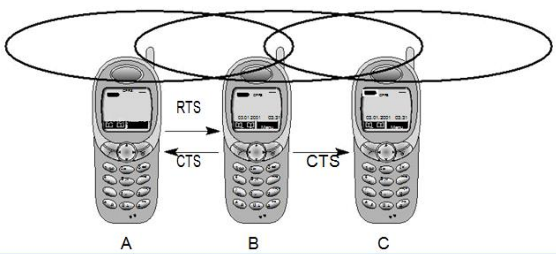


Figure 3.9
Reservation TDMA access scheme

- **MACA - collision avoidance:**
  - MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
    - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
    - CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
  - Signaling packets contain
    - sender address
    - receiver address
    - packet size
  - **MACA avoids the problem of hidden terminals**

Figure 3.10
MACA can avoid hidden terminals



- A and C want to send to B

  - A sends RTS first
  - C waits after receiving CTS from B
- **MACA avoids the problem of exposed terminals**
  - B wants to send to A, C to another terminal
  - now C does not have to wait for it cannot receive CTS from A

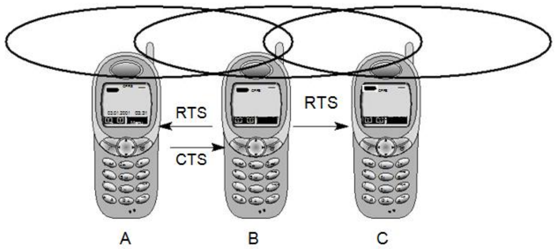


Figure 3.11
MACA can avoid exposed terminals

- The sender is idle until a user requests the transmission of a data packet. The sender then issues an RTS and waits for the right to send. If the receiver gets an RTS and is in an idle state, it sends back a CTS and waits for data. The sender receives the CTS and sends the data. Otherwise, the sender would send an RTS again after a time-out (e.g., the RTS could be lost or collided). After transmission of the data, the sender waits for a positive acknowledgement to return into an idle state. The receiver sends back a positive acknowledgement if the received data was correct. If not, or if the waiting time for data is too long, the receiver returns into idle state. If the sender does not receive any acknowledgement or a negative acknowledgement, it sends an RTS and again waits for the right to send. Alternatively, a receiver could indicate that it is currently busy via a separate RxBusy.

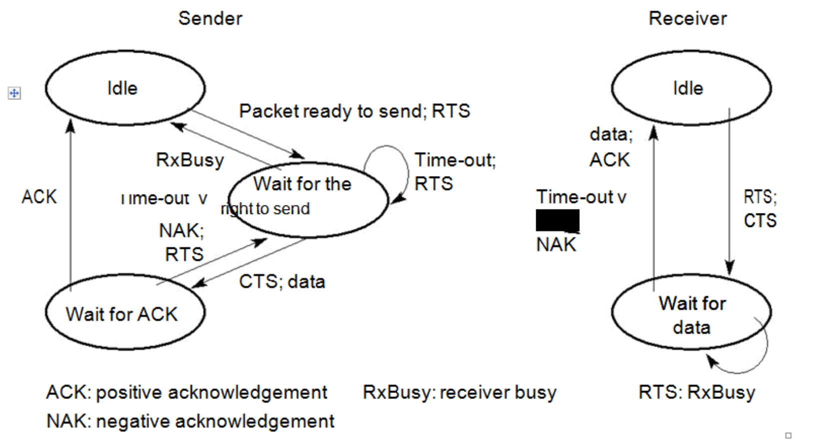
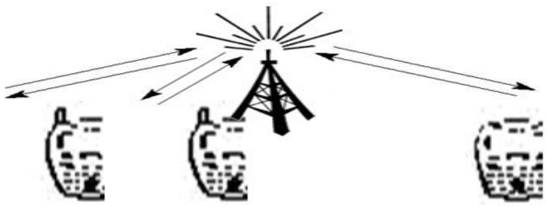


Figure 3.12
Protocol machines for multiple access with collision avoidance

- ## Polling mechanisms:
  - If one terminal can be heard by all others, this "central" terminal (a.k.a. base station) can poll all other terminals according to a certain scheme

  - now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)
  - **Example: Randomly Addressed Polling**
  - base station signals readiness to all mobile terminals
  - terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
  - the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
  - the base station acknowledges correct packets and continues polling the next terminal
  - this cycle starts again after polling all terminals of the list
- **ISMA (Inhibit Sense Multiple Access):**
  - Current state of the medium is signaled via a "busy tone"
  - the base station signals on the downlink (base station to terminals) if the medium is free or not
  - terminals must not send if the medium is busy
  - terminals can access the medium as soon as the busy tone stops
  - the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach.

Figure 3.13 Inhibit sense multiple access using a busy tone

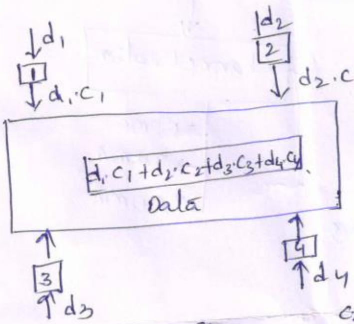


- **CDMA (Code Division Multiple Access)**

CDMA:

Let us assume we have four stations 1,2,3,& 4 Connected to same channel. The data from station 1 are d_1, from station 2 are d_2 and so on. The code assigned to the first station is c_1, to the second is c_2, and so on. assigned Codes have two properties

1. if we multiply each Code by another, we get 0.
2. if we multiply each code by itself, we get 4.



data is $= (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1$

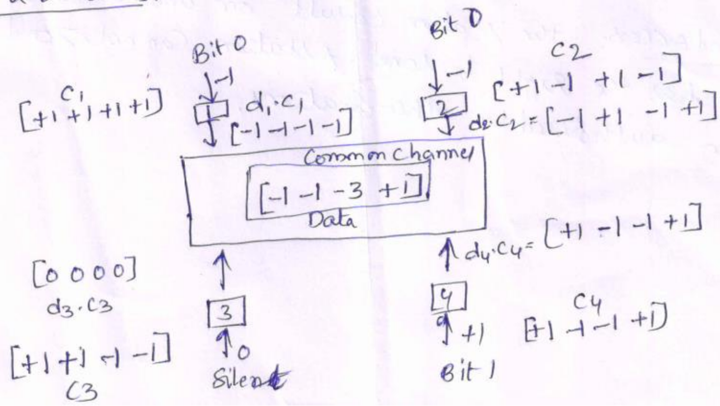
$= d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1$

$= 4 \times d_1$

Chip sequence: c_1 [+1 +1 +1 +1] c_2 [+1 -1 +1 -1] c_3 [+1 +1 -1 -1] c_4 [+1 -1 -1 +1]

Data representation: Data bit 0 → -1 Data bit 1 → +1 Silence → 0

Encoding & Decoding:



The sequence of on the channel is the sum of all four sequences. Now station 3, which we said is silent, is listening to station 2. Station 3 multiplies the total data on the channel by the code for station 2, which is [+1 -1 +1 -1] to get.

$$[-1\ -1\ -3\ +1] \cdot [+1\ -1\ +1\ -1] = \frac{-4}{4} = -1 \Rightarrow \text{bit } 1$$

Multiple-access protocols

- Random Access Protocols
  - ALOHA
  - CSMA
  - CSMA/CD
  - CSMA/CA
- Controlled Access
  - Reservation
  - Polling
  - Token passing
- Channelization
  - FDMA
  - TDMA
  - CDMA

Channelization: is a multiple access method in which the available bandwidth of link shared in time, frequency, or through code, between different stations.

Controlled Access: the station consult one another to find which station has the right to send. A station can not send unless it has been authorized by other stations.

➢ SAMA - Spread Aloha Multiple Access

- Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha

Figure 3.19 Spread Aloha multiple access