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Wireless Communications

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Contents

Preface

During the last year of the study Business Mathematics and Computer Science, the student performs a literature research. The goal is to perform a literature study in these fields. This study can be on any subject.

This subject attracted me because wireless is a hot event nowadays. And I am interested in what kind of wireless technology is offered. Luckily, I know from an earlier assignment that Prof. Dr. Rob van der Mei, is an expert in this field. So I was glad that he got an assignment for me. But, due to his busy schedule, he had no time to guide me.

In this report, I will try to give an overview of some of the wireless technologies offered. The report includes four chapters. In the first chapter, we make a distinction between mobile telephony and wireless computing. For mobile telephony the GSM, GPRS and UMTS standards are discussed. And for the wireless computing, WLAN and WATM will be discussed. The chapter includes a comparison of the mobile phone technology as well. In the second chapter, we will discuss the services offered by the mobile operators and the costs of having a mobile phone or to do wireless computing. In the third chapter, a mathematical model of GSM is proposed, which enables the computation of metrics of interest. Finally, chapter 4 concludes the report.

I would like to thank my supervisor Dr. Sara Alouf for her advice, guidance and critics. Also I would like to thank her for her patience and showing me the wireless world. I would also like to thank Prof. Dr. Rob van der Mei for giving me this assignment.

Introduction

The future
You are riding in a car with your colleague who is driving. Suddenly, your handheld device comes on, asking if you can take a video conference call from your team to discuss a project you are working on. You take the call and as you watch them explain the topic, you decide they need one of the spreadsheets you have in your laptop, which is in the trunk of the car. Using your Bluetooth technology, you are able to transfer the file to your handheld device and send it to your team during this videoconference. A few seconds later your team will receive and open your spreadsheet and you can start discussing options with them.

Everything described above will be soon available. As technology improves each day, it certainly makes life easier.

Chapter 1
An Overview of Wireless Technologies and Cellular Systems

Introduction

To get an overview about wireless technology nowadays offered, a couple of technologies are discussed. I divided the wireless technologies into two groups, based on the distinction between connection-oriented and connectionless communications.

In connection-oriented telecommunications, the devices use a preliminary protocol to set up an end-to-end connection before any data can be sent. So in this case one has a physical path reserved only for him and the other person he is talking with. Nobody will be allowed crossing this physical path. If one ends the conversation, the physical path will be free for others to use.

In connectionless communications, there is no physical path reservation. The device at one end of the communication transmits data to the other, without first ensuring that the recipient is available and ready to receive the data. The device sending a message simply sends it addressed to the intended recipient. The package that is being sent is routed through the system until it reaches its destination.
One technology, that is connection-oriented and very familiar to the public, is the mobile telephony whereas the technology used for wireless computing is based on connectionless communications.

First, the technologies of the mobile phone will be discussed, these include GSM, GPRS and UMTS. Then a comparison of GSM, GPRS and UMTS will be given. Finally a couple of techniques used by the wireless computing will be discussed.

1.1 Mobile telephony

In this section three mobile technologies will be discussed. These three, GSM, GPRS and UMTS, are the technologies used in Europe.

1.1.1 GSM – Global System for Mobile Communications

The development of the GSM started in the early 1980s. It was set to be a standard for Europe's mobile communication infrastructure for the 1990s and referred to as 2G. This started in 1985 when the Conference of European Post and Telegraphs (CEPT) formed a group called Groupe Spécial Mobile (GSM) to develop a set of common standards for a future pan-European cellular network.
By 1987, the GSM members agreed upon an important standard, the digital standard would be chosen over the analog standard (known as 1G, first generation), for its several advantages like, improved spectrum efficiency, better quality transmission and new services with enhanced features including security. Finally, since GSM is

purely digital, it can easily interface with existing networks like Integrated Services Digital Network (ISDN).
GSM operates in the frequency 900-Mhz and a variation of it operates in the 1800-Mhz and is known as GSM DCS 1800.
In 1991, GSM services have started and the original french name Groupe Spécial Mobile was later changed to Global System for Mobile Communications.
The key features of the GSM are:

- International roaming – This feature lets the user to use the mobile phone and number in countries who operates a GSM network worldwide.
- Sound Quality – With digital, sound quality is much better than the existing analog cellular technology. The sound quality is sharp and clear.
- High security level – Everything that is send through the digital network is safe and secure.
- Great convenience – With a digital technology, there is also a better battery life, this means that the talk time is doubled for each battery charge compared to an analog technology. Also, the digital service handles more calls at any one time.
- New services, such as call holding, call forwarding, Short Message Service (SMS), Fax Service.

So how does the GSM-network works?
To understand how the GSM network works it is important to understand about the parts in the network. A GSM network can be divided into three parts. The Mobile Station (MS), the Base Station Subsystem (BSS) and the Network Subsystem.

Mobile Station

The mobile station consists of a mobile equipment (ME), usually a mobile phone, and a SIM card. The SIM (Subscriber Identity Module) card provides the mobile phone with a unique identity through the use of the International Mobile Subscriber Identity (IMSI). This IMSI is used to identify the subscriber to the system, contains a secret key for authentication, and contain other information. The SIM card is also capable of storing phone numbers and SMS messages.

Base Station Subsystem

The Base Station Subsystem is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC).
The Base Transceiver Station (BTS) is in direct contact with the mobile phones, the BTS consists of a radio transceiver with antenna that covers a single cell. The BTS is linked to the BSC.
The Base Station Controller (BSC) controls the allocation and release of radio channels. One BSC can control many BTSs, so the BSC also monitors each call and decides when to handover the call from one BTS to another.

Network Subsystem

The main part of the Network Subsystem is the Mobile Switching Center (MSC). As the BSC controls many BTSs, the MSC also controls many BSCs. The MSC routes calls to and from mobile stations. The GMSC – Gateway Mobile Switching Center performs calls between mobile users and the fixed network. The MSC is responsible for generating billing records, authentication, location updating of user and routing between the subscribers. To handle this, the MSC uses four databases. These are the

Home Location Register (HLR), the Visitor Location Register (VLR), the Equipment Identity Register (EIR) and the Authentication Center (AuC).

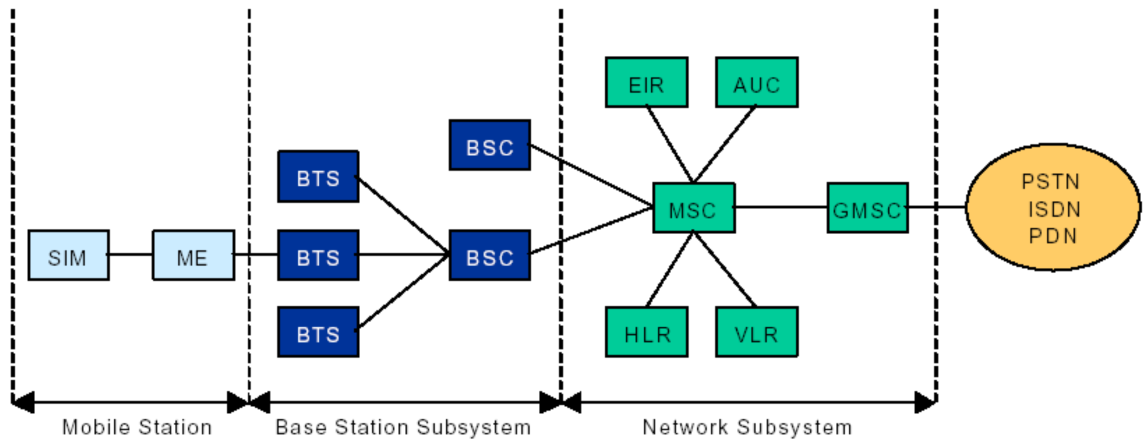

Fig. 1.1 GSM architecture

After this explanation, it is time to explain how GSM network works. See Fig. 1.1.
When you turn your mobile phone (MS) on, it will try to connect to the network. It will look for the nearest Base Transceiver Station (BTS) to connect. While you are moving it is possible that another BTS gives a better signal. In that case the Base Station Center (BSC) will make the phone connect to the other BTS. If the newer BTS is controlled by the same BSC the BSC will make the handover. If the newer BTS is controlled by another BCS, the BCS will let the MCS take care of this.
With the databases HLR and the VLR, MSC is able to tell where a phone is. So if someone makes a call, MSC is able to route this call correctly. Thus, you can connect with someone else and talk to him [4].
In short:

MS $\rightarrow$ BTS $\rightarrow$ BSC $\rightarrow$ MSC $\rightarrow$ (other MSC) $\rightarrow$ (other) BSC $\rightarrow$ (other) BTS $\rightarrow$ MS

1.1.2 GPRS – General Packet Radio Service

GPRS is an enhancement to the GSM mobile communications system that supports data packets. GPRS is a packet-switched protocol for applications such as the Web, in which the user spends most of the time reading information and data is transferred only when necessary. GPRS enables a continuous flow of IP data packets over the system for such applications as Web browsing and file transfer. GPRS is also referred to as 2.5G.

This data overlay network provides packet data transport at rates from 9.6 to 171 kbps. Additionally, multiple users can share the same air-interface resources. GPRS attempts to reuse the existing GSM network elements as much as possible, but in order to effectively build a packet-based mobile cellular network, some new network elements, interfaces, and protocols that handle packet traffic are required.

GPRS enhances GSM data services significantly by providing end-to-end packet switching data connections. This is particularly efficient in Internet/intranet traffic. Because there is no real end-to-end connection to be established, setting up a GPRS call is almost instantaneous and users can be continuously online. This means that a given amount of radio bandwidth can be shared efficiently and simultaneously among many users. Users have the additional benefit of paying for the actual data transmitted, rather than for connection times.

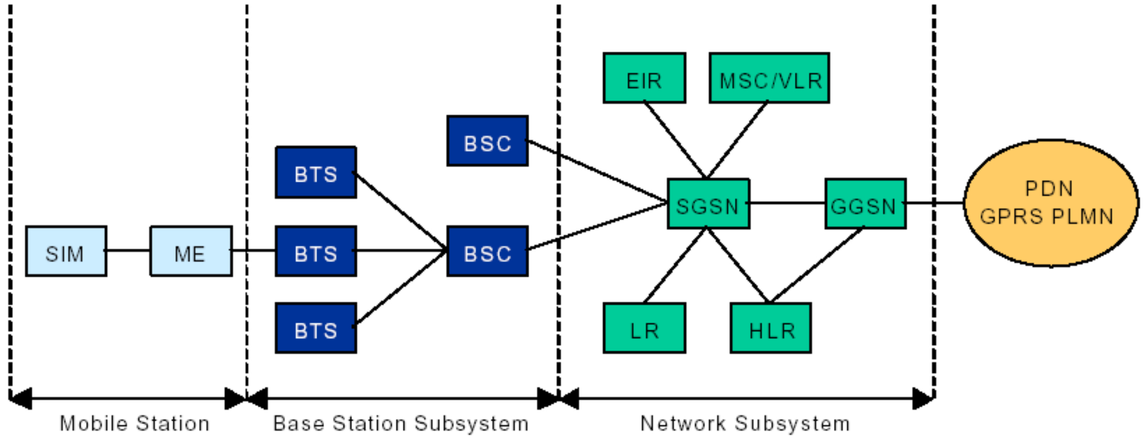

Fig. 1.2 GPRS system architecture

In Fig. 1.2, the GPRS architecture is outlined. In this architecture, the GSM architecture's existing MS, BSS, MSC, VLR, and HLR are all modified. For example, the HLR is enhanced with GPRS subscriber information. Two new network nodes are introduced in GPRS. The Serving GPRS Support Node (SGSN) is the GPRS equivalent to the MSC. The Gateway GPRS Support Node (GGSN) provides internetworking with external packet-switched networks, and is connected with SGSNs via an IP-based GPRS backbone network.

The SGSN represents the mobile's point of attachment to the core network and provides the following specific functions for the data services:

- Handling of call control signaling with data services location registers,
- Providing mobility management such as tracking of mobile's routing area and serving cell,
- User authentication and verification,
- Billing data collection,
- Handling of the actual user's traffic and conversion between the IP core and radio network,
- Standard interfaces to the HLR for management of end user subscriber data.

GGSNs are used as interfaces to external IP networks such as the public Internet, other mobile service providers' GPRS services, X.25 networks, and enterprise intranets. GGSN contains routing information for attached GPRS users. The routing information is used to tunnel the protocol data units (PDUs) to the MS's current point of attachment, i.e., the SGSN node [14].

1.1.3 UMTS - Universal Mobile Telecommunications System

UMTS, also known as 3G, is the third generation of access technology for cellular network, promising advanced features such as high data rates and improved quality of service. UMTS will give GSM operators the potential for a whole range of mobile multimedia services. Electronic postcards, Web surfing, access to corporate LANs, and e-mail from a mobile terminal, are just a few of the things people will be able to do from a handset. UMTS also promises to revolutionize networks with better frequency efficiency and lower transport costs by utilizing asynchronous transfer mode (ATM) for both voice and data services.

GSM is currently very popular worldwide, and the coming technology will need to support technologies currently deployed. The UMTS network architecture provides full support for existing technologies -- that is, for GSM and GPRS. The combination of both of these technologies, and the addition of a few more software and hardware pieces, makes UMTS a very robust and effective architecture.
UMTS will operate in the frequency ranges 1920-1980 and 2110-2170 MHz.
Fig. 1.3 shows the architecture of UMTS. The GPRS support nodes and GSM network nodes still function under UMTS. The new architecture includes an added node: UTRAN (universal terrestrial radio access network), which is an enhancement of GSM's existing BSS.

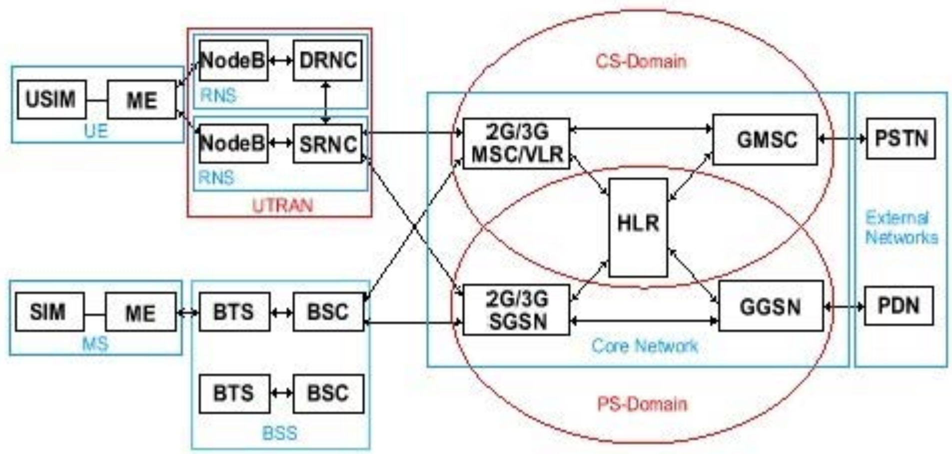

Fig. 1.3 UMTS architecture

UTRAN takes onboard the high-speed switching capabilities of ATM and the evolvable support for both W-CDMA and TDMA, and also delivers standard open interfaces within the radio network.

A UMTS mobile station can operate in one of three modes of operation. The different UMTS mobile station operation modes are defined as follows:
PS (Packet Switched) mode: The MS is attached to the PS domain only and may only operate services on the PS domain. However, this does not prevent the offering of CS-like services over PS (e.g., voice over IP).
CS (Connection Switched) mode: The MS is attached to the CS domain only and may only operate services of the CS domain. However, this does not prevent the offering of PS-like services over CS.
PS/CS mode: The MS is attached to both the PS and CS domains, and the MS is capable of simultaneously operating both PS and CS services. All combinations of different operation modes as described for GSM and UMTS MSs will be allowed for GSM and UMTS multisystem terminals [15].

1.2 Comparison GSM/GPRS/UMTS

This section will explain the differences between the technologies described above. First, the protocol stack of the three will be presented. Then, a summary of the main differences will be discussed.

1.2.1 GSM protocol stack

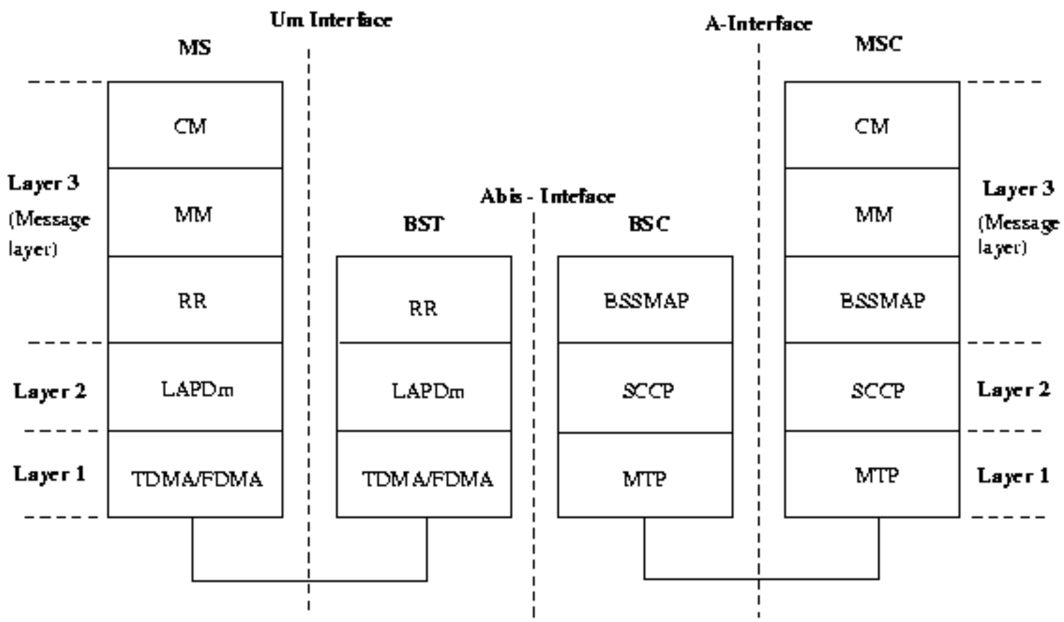

Fig. 1.4 GSM protocol stack

In Fig. 1.4, the GSM protocol architecture is given. This architecture consists of three layers, the physical layer, the data link layer and the Layer 3.

Physical layer
This layer is the lowest layer in the architecture and provides functions to transfer bit streams over the physical radio links. The method to divide up the bandwidth among the users is a combination of Time and Frequency Division Multiple Access (TDMA/FDMA).

Data link layer
This layer provides a radio link between the MS and the BSS and uses a LAPDm protocol, which is a modified version of the LAPD (Link Access Protocol for the ISDN D-channel) protocol.

Layer 3
Layer 3 is divided in three sub-layers: Radio Resource Management (RR), Mobility Management (MM), Call Control Management (CCM or CM).

Radio Resource Management
This sublayer is responsible for the establishment, operation and release of a dedicated radio channel.

Mobility Management
This sublayer manages problems that arise from mobility of the subscriber, like location update, handovers and registration procedures, as well as security and authentication.

Connection Management
This sublayer establishes, maintains and terminates a circuit switched call. It consists of entities like call-related supplementary services, SMS, and call independent supplementary services support [5].

1.2.2 GPRS protocol stack

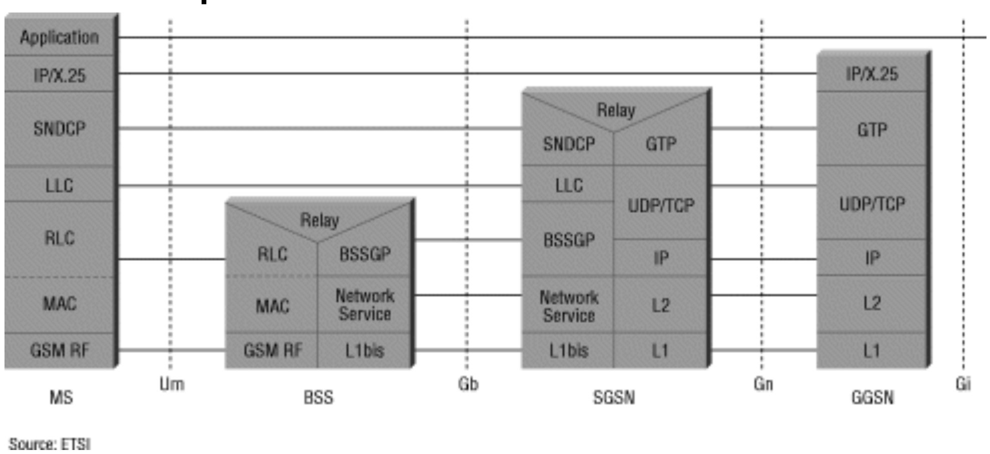

Fig. 1.5 GPRS protocol stack

In Fig. 1.5, one can see that the protocol stack looks very similar to the GSM one.

- In fact at the physical layer GPRS is compatible with GSM.
- At the link layer of the air interface, the GSM system uses LAPDm whereas GPRS uses a logical link control (LLC) and radio link control (RLC)/medium access control (MAC).
  - -LLC is an adapted version of LAPDm.
  - -RLC/MAC meets the demands of packet oriented transmissions. It ensures the concurrent access to radio resources in a more flexible way compared to the TDMA structure of GSM.
- GPRS uses Subnetwork-Dependent-Convergence Protocol (SNDCP) instead of CM, MM and RR used in GSM. SNDCP is used to multiplex several connections at the network layer.
- UDP/TCP: These are the backbone network protocols used for transporting user data.
- IP is the Internet protocol. IP provides the routing function across multiple networks.
- The GPRS tunneling protocol (GTP) is specifically designed to tunnel IP and X.25 packets which are not supported by GSM. More details can be found in [10].

1.2.3 UMTS protocol stack

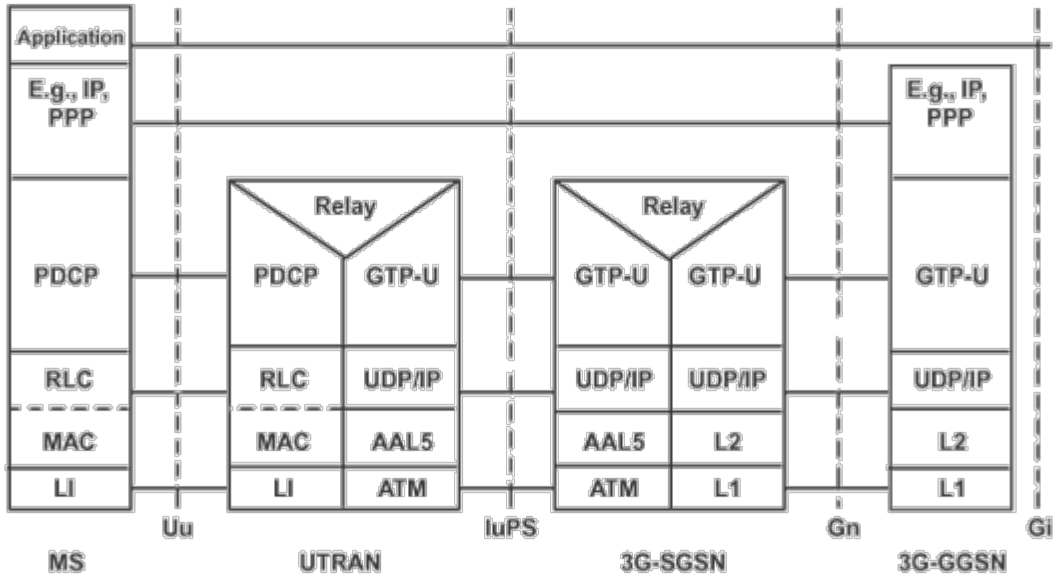

Fig. 1.6 UMTS protocol stack

In Fig. 1.6, it can be seen that some layers are the same as GPRS layers. The new layers are explained below:

- Asynchronous Transfer Mode (ATM): The information to be transmitted is divided into fixed-size cells (53 octets), multiplexed, and transmitted.
- ATM Adaptation Layer 5 (AAL5): This adaptation layer protocol provides support for variable bit rate connection-oriented, or connectionless data and services.
- Packet Data Convergence Protocol (PDCP): This transmission functionality maps higher-level characteristics onto the characteristics of the underlying radio-interface protocols. PDCP supports IPv4, PPP, and IPv6, among other protocols.
- GPRS Tunnelling Protocol for the User Plane (GTP-U): This protocol tunnels user data between UTRAN and the 3G-SGSN, and between the GSNs in the backbone network.

So in short:
GSM compared to GPRS

- GPRS is an extension of the GSM Architecture,
- GPRS shows that certain additions are needed to be implemented on GSM, to be able to support both data and voice packets at a higher rate,
- The major differences with respect to architecture are the two nodes, SGSN and GGSN,
- The two systems use the same air interface,
- New protocols like GTP, SNDCP, LLC and RLC/MAC were introduced [10].

GPRS compared to UMTS

- The Multiple access scheme used by UMTS enables it to obtain higher data rates: air interface rate for UMTS is over 14 times as high as GSM and GPRS,
- Efficiency of UMTS depends on its mode of operation, Frequency Division Duplex (FDD) or Time Division Duplex (TDD),
- UMTS's data rates enable the development of a whole new class of services [11].

You can see in Table 1.1 that each technology is much faster than the older one.

Standard	**GSM**
Frequency wavelength	900 MHz, 1800 MHz, 1900 MHz[1]
Data bandwidth	9.6 kbps

Standard	**GPRS**
Frequency wavelength	900 MHz, 1800 MHz, 1900 MHz[1]
Data bandwidth	9.6 kbps to 171.2 kbps

Standard	**UMTS**
Frequency wavelength	1920-1980 and 2110-2170 MHz
Data bandwidth	144 kbps at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in a stationary environment.

Table 1.1 Frequency and speed of GSM, GPRS and UMTS

[1] The 1900 MHz frequency is used in the United States only and is known as PCS 1900.

1.3 Wireless network

Everybody is familiar with the word wireless, controlling one device with another device without a wire between them. Think about the remote control of the television. There is no discussion about it that one ‘controlling’ the television using the remote is a wireless event.

There are two ways to be wireless networking. The first one is networking without infrastructure. In this case there is no fixed infrastructure. One can think like wireless networking anywhere and anyplace, known as ad hoc network. The other way is wireless networking with infrastructure. Actually this kind of networking is an extension of the wired networking infrastructure. It creates a network by sending/receiving radio-frequency signals between a wireless base station or "access point" and router from/to a personal computer.

Wireless networking can make networking extremely easy. It also makes it a whole lot simpler to move computers around. This means that if you have a laptop with a wireless network card you are completely portable throughout the house.

There are several technologies to do wireless networking but unlike the remote control, security is very important in a wireless network. Compared to the wired network, the wireless network is very insecure, as data sent over the wireless network can easily be broken. This means that unless you take some precautions, it is very unsafe to send critical data (passwords, personal informations, or money transactions) over a wireless network.

So the big advantage you get is that you will not be wired and walk with your laptop or handheld in a given area. But unfortunately there are also some disadvantages like the speed and the security.

1.3.1 Wireless ad hoc network

An ad-hoc network is a dynamic multi-hop wireless network that is established by a group of mobile devices without the aid of any pre-existing network infrastructure or centralized administration. Thus they remain connected in a decentralized way.

An ad-hoc network is relatively mobile compared to a wired network. Hence it makes this kind of network dynamic. This creates many challenging research issues since the objectives of how routing should take place is often unclear.

One type of wireless ad hoc network is mobile ad hoc network (MANET).
A MANET is an autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links. Since the nodes are mobile, the network topology may change rapidly and unpredictably over time.

To get a better understanding about how ad hoc networks work, an example is illustrated below.

Consider four people with a laptop each. Each person is 10 meters far from each other. So if person 1 start at 0 meter, person 2 will be 10 meters further, person 3 will be 20 meters far from person 1, etc. The laptop can send a signal up to 12 meters. Suppose person 1 wants to communicate with person 4. If person 4 is within range than that should be no problem. Unfortunately person 4 is 40 meters far from person 1. The following will happen in an ad hoc network: person 1 will send a signal to person 2, person 2 will send a signal to person 3 and person 3 will send a signal to person 4, this is the so-called multi-hop. It takes multiple trips until it reaches the destination. See Fig 1.7.

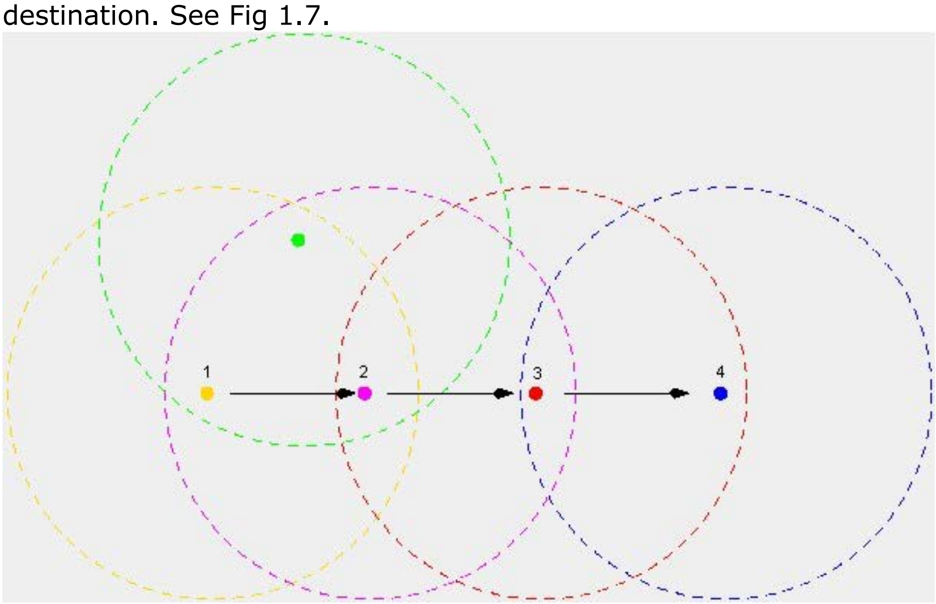

Fig. 1.7 Multi hopping within an ad hoc network

As they are mobile, errors can occur. For instance, if someone is moving he/she might become out of range. In Fig. 1.8 one can see that person 3 has moved in such a way that he is out of range for person 2. It is not surprising that in this situation person 1 cannot communicate with person 4.

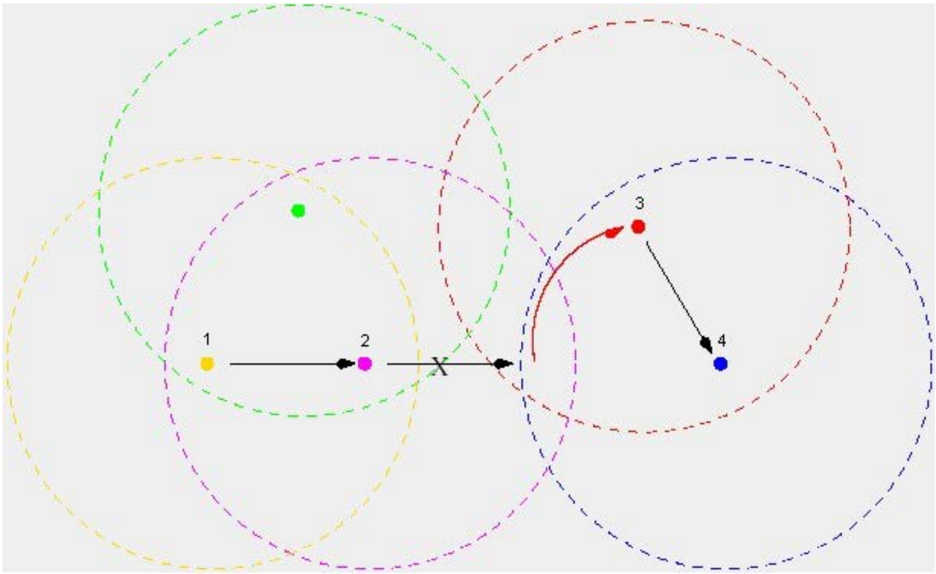

Fig. 1.8 Person 3 is moving

Fortunately, in an ad hoc network it is not necessary that person 2 has to be connected with person 3, as there is no fixed line. In Fig. 1.9 a new person (say person 5) has come within range of person 2. Thus person 2 can send a signal to person 5, person 5 sends a signal to person 3 and finally person 3 will send a signal to person 4.

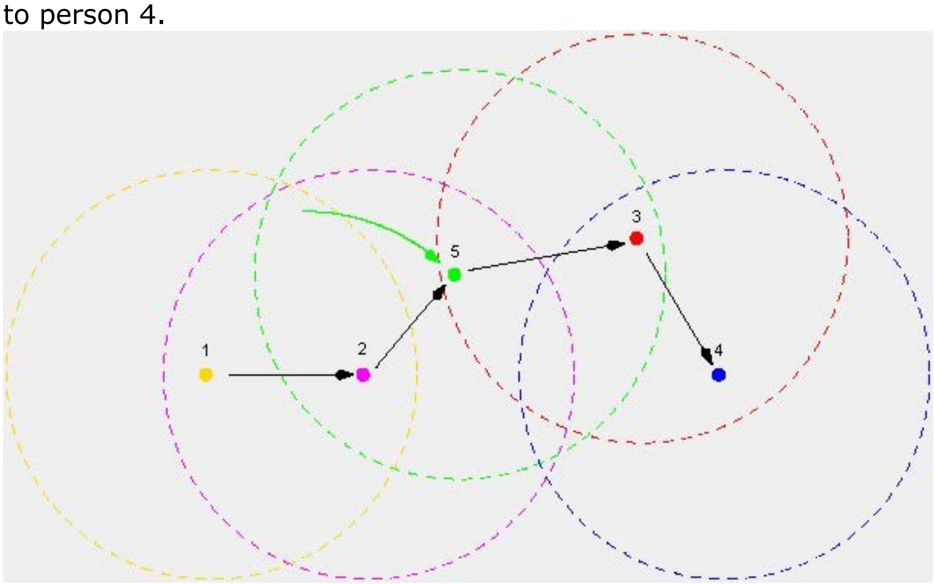

Fig. 1.9 New person comes within range

It will be clear that in the example above there is no pre-existing network used and all devices are mobile. Ad hoc networks can be used for conferencing, emergency services, home networking, battlefields, disaster areas, etc.

1.3.2 Bluetooth

History

Bluetooth was originally designed for cable replacement, because computer and cellular telephone users view this process as inconvenient. In 1994, Ericsson Mobile Communications started a study to examine alternatives to the cables that linked its mobile phones with accessories. Mobile hands-free devices and other accessories were limited in that they need a wire to connect to the wireless phone. This technology uses radio technology. As radio is omni-directional it has obvious advantages over the infrared technology, which needs a “face to face” communication between devices.

The name Bluetooth is named after Harald Blatand (Blatand is Danish for Bluetooth), a Danish Viking king who lived in 940-985 and was the one who united and controlled Denmark and Norway. The name Bluetooth is used because Bluetooth is expected to unify the telecommunications and computing industries [24].

There are many requirements for the study, these included the following:
Low Power. In order to install an application in any device, the power drain from the radio chip had to be very low.
Low Cost. In order to make most consumers buy an electronic device, the cost had to be very low. At least it cannot be much more expensive than a cable or nobody will buy it. This amount is around $5[1].
Small Footprint. As Bluetooth is used for small devices it is not permitted to make a large chip.
Speech and data transmission. It had to enable both speech and data transmission, preferably at the same time.
Worldwide capability. It had to work around the world.

In 1998, Ericisson, Intel, IBM, Toshiba and Nokia formed the Bluetooth Special Interest Group (SIG). The group started to create standardization for the short-range radio and software. In 1999 four large companies have joined the group, these are, Microsoft, Lucent, 3Com and Motorola.

Any incorporated company willing to sign the Bluetooth SIG membership agreement can join the SIG as a Bluetooth adopter company. Members are granted a free license to build products using the Bluetooth technology. This offer proved so attractive that it has now more than 2000 SIG members. For more detail, see [2].

As Bluetooth is designed to communicate between different devices, it’s the ideal ‘bridge’ between a mobile phone and computers.

Fig 1.10 shows the protocol architecture of Bluetooth. Major components of the protocol stack are the Link Manager (LM), the Logical Link Control and Adaptation Protocol (L2CAP), the Host Control Interface (HCI), the Service Discovery Protocol (SDP), Audio/Telephony Control, RFCOMM, Human Interface Device (HID), TCP/IP, and other high level protocols. For more details see [25].

[1] A cable is around $10. 1 cable for 2 devices ⇒ each device is $5.

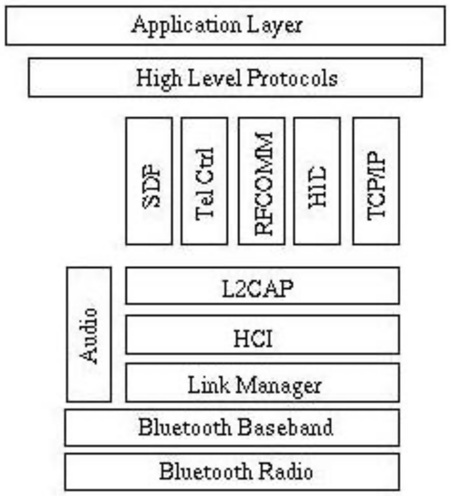

Fig. 1.10 Protocol architecture of Bluetooth

1.3.3 Wireless Local Area Network (WLAN)

A WLAN is a flexible data communication system implemented as an extension of or as an alternative for a wired LAN. Using radio frequency (RF) technology, WLANs transmit and receive data over the air, minimizing the need for wired connections. Several laptops can communicate through a single access point sharing the available bandwidth, thus individual performance is affected by the number of other people using the network through that access point, as all the users share a slice of radio frequency spectrum in the 2.4 GHz range.

The basic requirement for wireless LAN are:

-LAN adapter
-Access point
-Outdoor LAN bridges

The technologies available for use in WLANs are infrared, Ultra High Frequency (UHF) and spread spectrum implementation.

Infrared technology. Infrared is an invisible band of radiation that exists at the lower end of the visible electromagnetic spectrum. This type of transmission is most effective when a clear line-of sight exists between the transmitter and the receiver.

UHF Narrowband. UHF wireless data communication systems have been available since the early 1980s. These systems normally transmit in the 430-470 MHz frequency range, with rare systems using segments of the 800-MHz range. The lower portion of this band (430-450 MHz) is referred to as the protected (licensed band). In the unprotected band, RF licenses are not granted for specific frequencies and anyone is allowed to use any frequency, giving customers some assurance that they will have complete use of that frequency.

Spread-Spectrum Technology. Most WLAN systems use spread-spectrum technology, a wideband radio frequency technique that uses the entire allotted spectrum in a shared fashion as opposed to dividing it into discrete private pieces as with narrowband. In commercial applications, spread-spectrum techniques currently offer data rates up to 2 Mbps. There are two modulation schemes that are commonly used to encode spread-spectrum signals, direct-sequence spread-spectrum (DSSS) and frequency hopping spread-spectrum (FHSS) [3].

Although there are several standards used for wireless networking, the international standard used is the 802.11-network card. The most common in use is the 802.11b. The theoretical speed of the 802.11b standard can go up to 11 megabits per second, which is enough if you use it for email, internetting, chatting and printing to local printers. Wireless networking is not suitable if you are planning to use it for streaming audio/video or download very large files. This theoretical speed will usually not be achieved, due to the number of users, the range between access points and laptops and physical obstacles. Although it may occasionally slow down, 802.11b keeps the network stable and very reliable. The 802.11b standard defined two spread-spectrum radio techniques and a diffuse infrared specification. The original 802.11b standard defines data rates of 1 Mbps and 2 Mbps via radio waves using FHSS or DSSS. FHSS and DSSS are two different kinds of mechanisms and will not interoperate with one another.

FHSS

Frequency hopping works very much like its name implies. It takes the data signal and modulates it with a carrier signal that hops from frequency to frequency as a function of time over a wide band of frequencies. With frequency hopping spread spectrum, the carrier frequency changes periodically. The frequency hopping technique reduces interference because an interfering signal from a narrowband system will only affect the spread spectrum signal if both are transmitting at the same frequency at the same time. Thus, the aggregate interference will be very low, resulting in little or no bit errors. A frequency hopping radio, for example, will hop the carrier frequency over the 2.4 GHz frequency band between 2.4 GHz and 2.483 GHz. A hopping code determines the frequencies the radio will transmit and in which order. To properly receive the signal, the receiver must be set to the same hopping code and listen to the incoming signal at the right time and correct frequency. If the radio encounters interference on one frequency, then the radio will retransmit the signal on a subsequent hop on another frequency. Because of the nature of its modulation technique, frequency hopping can achieve up to 2 Mbps data rates. Faster data rates are susceptible to an overwhelming number of errors.

DSSS

Direct sequence spread spectrum combines a data signal at the sending station with a higher data rate bit sequence, which many refer to as a *chipping code* (also known as processing gain). A high processing gain increases the signals resistance to interference. In comparison to frequency hopping, direct sequence can achieve much higher than 2 Mbps data rates. Direct sequence spread spectrum sends a specific string of bits for each data bit sent. A chipping code is assigned to represent logic 1 and 0 data bits. As the data stream is transmitted, the corresponding code is actually sent. For example, the transmission of a data bit equal to 1 would result in the sequence 00010011100 being sent [9].

In Fig. 1.11 the physical layer and the link layer of the WLAN is given.

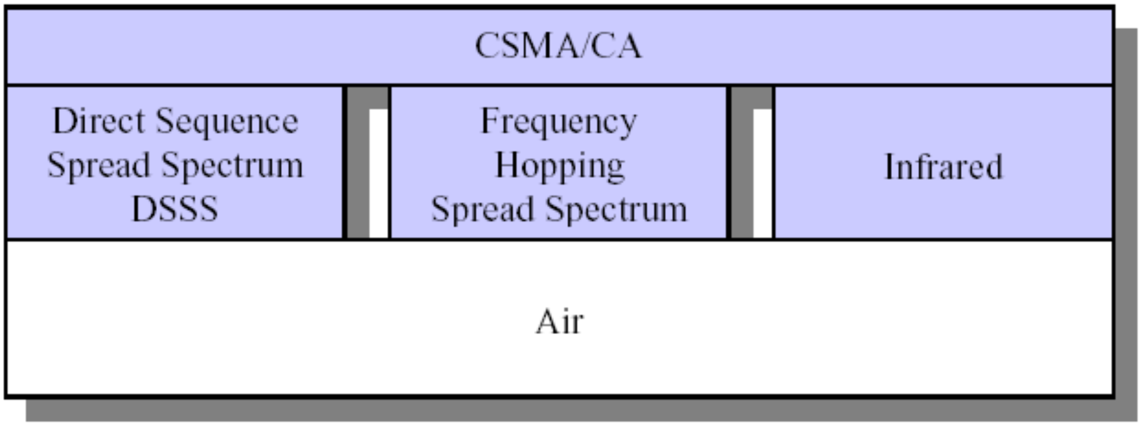

Fig. 1.11 Physical layer and the link layer of the WLAN

1.3.4 Wireless ATM

The Asynchronous Transfer Mode (ATM) is a data transport technology that supports a single high-speed infrastructure for integrated broadband communications involving voice, data and video. In ATM networks, the data is transported in small cells, each having a fixed length of 53 bytes. Each cell contains a 5-bytes header and 48 bytes of the actual data. ATM is a high-speed packet based scheme, it can have bit rates about 155 Mbps or about 600 Mbps.

The explanation for why the payload of an ATM cell is 48 bytes is an interesting one. As the ATM standard was evolving, the US telephone companies were pushing a 64-byte cell size, while the European companies were advocating 32-byte cells. The reason the Europeans wanted the smaller size is that since the countries they served were of a small enough size, they would not have to install echo cancellors. Thirty-two byte cells were adequate for this purpose. In contrast, the US is a large enough country that the phone companies had to install echo cancellors anyway, and so the larger cell size reflected a desire to improve the header-to-payload ratio. It turns out that averaging is a classic form of compromise--48 bytes is simply the average of 64 bytes and 32 bytes [22].

Wireless ATM provides wireless broadband access to a fixed ATM network. WATM provide users with high-speed capacity with Quality of Service (QoS). To support this mobility, new mechanisms are needed, such as handover, routing, and location management. As WATM is an evolving technology, no standards have been defined yet.

Fig. 1.12 shows the protocol architecture for a wireless and mobile ATM network. In this architecture the lowest three layers are related to the radio link i.e. the radio physical layer, the medium access control (MAC) and the data link control (DLC).

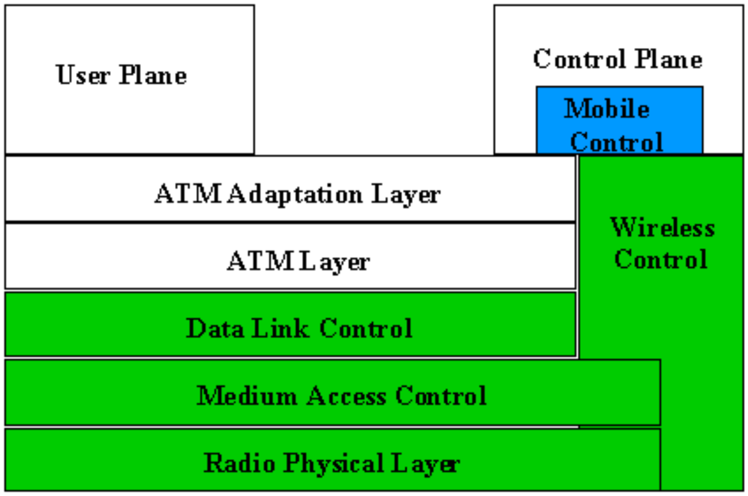

Fig. 1.12 Protocol architecture for wireless mobile ATM.

1.4 Conclusion

In this chapter, we have seen several of wireless technologies. To get a better overview, I have divided these into two groups, the connection-oriented and the connectionless communications. For the connection-oriented communications I have discussed about the GSM, GPRS and UMTS technology. Each technology is more promising and better than the technology before. GPRS is more suitable for data packets transfer than GSM. UMTS has such a high speed that it is able to transfer video and sound at an acceptable rate. As for the connectionless communications one can see that there are many ways to build wireless networks. The two common known technologies are: Bluetooth and WLAN. Note that I just discussed those technologies, which are well known by the public. But there are also a lot of other wireless technologies that I have not described.

Chapter 2
Cost of Being Wireless

Introduction

In this chapter, an overview and comparison of the mobile operators will be given. This only includes those who are operating in the Netherlands. In Section 2.1 informations about the different companies are given. The list of operators therein overviewed is not exhaustive. In Section 2.2, the services offered by the operators are discussed. And finally, the cost of being wireless/mobile is discussed in Section 2.3.

2.1 Overview of mobile operators

2.1.1 KPN-Mobile

KPN owns 97 percent of KPN Mobile. The remaining 3 percent is owned by KPN's strategic partner NTT DoCoMo. KPN Mobile also owns German mobile operator E-Plus and Belgian mobile operator KPN Orange. KPN-Mobile is started in 1994. KPN believes that there is a shift taking place from voice to data communication. Their vision is based on the belief that communication is a basic need in our lives, and that customers want the freedom to choose where, when, how and with whom they communicate. That’s why they have introduced i-mode, this trend -- sometimes described as from "ear to eye" -- has become clearly visible in the demand for mobile services.

2.1.2 Vodafone

Since the foundation of Libertel in June 1995, Vodafone is the biggest shareholder of Libertel. With 107.5 million clients, the Vodafone Group is the largest mobile operator. To emphasize that, Libertel has changed its name into Vodafone since 28 January. The company Vodafone Libertel N.V. is since 15 June 1999 member of the stock list of Euronext in Amsterdam.

2.1.3 T-Mobile

T-Mobile is a name that has been introduced recently. The shareholder of T-Mobile (used to be BEN) is T-Mobile international, which is 100% owned by Deutsche Telekom. T-Mobile operates mainly in Europe and the United States.

In February 1999, they started offering mobile services. In April 2000, they announced land covering. In December 2001, they are the first offering GPRS services. In September 2002, T-Mobile was the first to offer MMS (Multimedia Message Service).

2.1.4 Orange

In the beginning of January 1999, Orange (used to be Dutchtone) has started with offering mobile telephone services. In October 1999, the network of Orange is land covering, which means that at least 95% of the people can call and be called with Orange. Not only the normal people are customers of Orange but also the Dutch government is a customer of Orange. After a European selection procedure, Orange has been selected as supplier of the Dutch government.

Vision
Orange makes it possible for people to communicate whenever, wherever and in whatever way they want.

Mission
Orange's aim is to provide products and services that:
- are easy to use,
- offer specific and tangible advantages,
- are valuable,
- are geared to the future.

2.1.5 O_2

O_2 has started in 1997 by a joint venture of the British Telecom and the Nederlandse Spoorwegen. In 2000, British Telecom is 100% the owner of Telfort. Telfort was split into mobile communications and fixed communications in 2001. The mobile sector goes further with the name mmO_2 plc in the Exchange of London and New York. Finally, in 2002, Telfort has changed its name into O_2.

O_2 is the only mobile operator who offers just one kind of subscription. The standard version costs €7.50 and with €5 more, one can call up to 500 minutes to O_2 numbers or the fixed line.

Vision
To be the essential wireless brand by enriching people's lives, whatever they're doing, wherever they are.

Mission
To build an inseparable relationship with the customers by understanding their needs, and delivering wireless solutions that they truly value.

2.2 Services offered

All the operators offer (almost) the same kind of supplementary services. Think of Call Forward - On Busy, Call Forward - On No Reply, Call Forward - On Not Reachable, Barring All Calls, Multi Party Calling, etc. Also all the operators offer SMS [29]. This is not surprising because GSM was designed to do all this. This has changed when the GPRS technology became available, because GPRS allows for packet switching internetting with the mobile phone. WAP is used for this and nowadays all the operators offers WAP.

In September 2002, T-Mobile was the first to offer MMS (Multimedia Message Service). This is an upgrade version of the SMS, where one can send pictures instead of just text. Since January 2003, KPN offers I-mode, where one can email, download pictures, watch news and other things. A couple of months later, Vodafone started offering Vodafone Live!, where one also can email, play games, get info, etc. These services use the GPRS technology. KPN and Vodafone claim that these services are not the same, but I do not see any differences. These are the latest services using the GPRS technology.

The great experience one will get is when UMTS will become available. All of the five operators have an UMTS license, so they can offer UMTS. But why is UMTS still not available?
The biggest problem is the high cost that comes around with the installation of the UMTS network. First they need to pay a lot for the UMTS license. In the Netherlands, the operators have paid for a total of $2.5 billion for the licenses. They also need to build a new network capable of using UMTS. So it is not surprising that it takes such a long time until UMTS is available. In the Netherlands, UMTS is planned to be available in the last quarter of 2003.

2.3 Economic value

If someone buys a product, he (most of the time) wants to know how much the product costs, before buying it. In this section, I have put a small overview of the costs coming with the mobile telephony and the wireless computing.

2.3.1 Cost of having a mobile phone

In order to make a phone call with a mobile phone, you will need a mobile phone and a subscription by an operator to do that. You can buy a prepaid phone or pay a monthly fee. With a prepaid phone you have not the obligation to pay a monthly fee. The prices of prepaid phone are ranging from € 69 to € 239. With a subscription, it is hard to tell what the total cost is, because there are different prices for the many combinations, like buying a mobile phone and taking a subscription apart or buying a phone in combination with a subscription. In order to give an overview of the cost, I have just put a small part of the subscription costs. Table 2.1 lists the cheapest, the average and the most expensive subscription proposed by the operators.

Name	Free minutes	Cost per month (€)
KPN Mobile 60	60	16.5
KPN Mobile 240	240	36
KPN Mobile 1200	1200	142.5
Vodafone Budget	0	9.5
Vodafone 240	240	35
Vodafone 1500	1500	156.5
T-Mobile 30	30	10
T-Mobile 300	300	35
T-Mobile 1200	1200	120
Orange 20[1]	71	20

Orange 40	200	40
Orange 80	500	80
O_2 zuiver[2]	0	7.5
O_2 zuiver +500	500	12.5

Table 2.1 Overview of subscription of the operators

[1] For Orange you will not get any free minutes because the subscription also includes calling and sending SMS. Because the price of calling to a fixed line and calling to a mobile phone is different it is hard to tell how much calling minutes you will get. The calling minutes you see in the table is what you get if you are only calling to a mobile phone.

[2] O^2 only offers one kind of subscription in two versions, the basic version and the extended version. With the basic version you will not get any free calling minutes, and every call/SMS you make will cost €0.15. With the extended version, you can call up to 500 minutes to other O^2 numbers or the fixed line.

2.3.2 Cost of having a wireless LAN

Wireless computing is a technology that is very popular lately. For a company who moves to a new pawn where there is no fixed wire, wireless networking could be cheaper than the fixed one. Also wireless computing could be interesting for companies who have a lot of flexible workers or employers who work a lot "outside".

To have a wireless LAN you need the following components: access point/router and a wireless PC-card. The cost of having these is:
AccessPoint / Router:
Cheap: €100 to €250.
High end: €700 to €800.

Wireless PC-Card
Cheap: €70 to €100.
High end: €150.

A fast calculating learns that with €170 you can have wireless computing and just one terminal. Although this does not look that much, one should consider the cost of having a fixed network or a wireless network. As for companies, financial and organizational aspects should be considered. To compare wireless with fixed network a price/performance proportion could be considered.

2.3.3 Public wireless access point

In the Netherlands, there are public wireless access points, where one can access the Internet with a laptop. One organisation that offers this is hubhop.com. Hubhop offers two kinds of wireless access. One is the Premium Hotspot network and the other one is the Personal Network Community. The Personal Network Community is available for everyone having a wireless Access Point himself and is signed as member of MiWiFi. MiWiFi is a community for people who have a wireless access points. It lets the access point be available to other MiWiFi members. In exchange, one can access all other access points of the MiWiFi members which are through all the Netherlands. On the other hand, the Premium Hotspot network grants access to wireless internetting against a subscription or a pay-per-use fee. This concerns the wireless access on special locations like in hotels, restaurants, parks, stations, etc [32].

2.4 Conclusion

There are five mobile operators in the Netherlands. So one could say that there are a lot of operators to choose, each one offering a different kind of subscription than the other ones. It is hard to say which one is best. It depends on what you want to do, just calling to a fixed line, just SMS, only want to be accessible, etc. But all of them offer services that are available for the GSM. They all have an UMTS license. So I think we can expect some competing between those operators when UMTS will be available.

As for the wireless networking, I have just put the cost of one wireless technology, just to give an impression of how much it costs to build a wireless network. It seems that for about €170 one can already do wireless networking and for the expensive case an amount of €950 have to be paid before wireless networking is possible. Also one should note that these are only the cost of having the equipment. If you want for instance, internetting, one should also consider the cost of having a subscription to internet. But it is not necessary to have a subscription, one can alternatively use a public network and pay per use.

Chapter 3
Basics of Cellular Systems

Introduction

In this chapter, the relationship between the reuse ratio (q) and the cluster size (N) for a hexagonal cell will be discussed. Also, a numerical example will be provided to give a better understanding of the equations.

3.1 Hexagon structure

In order to allow frequency reuse at much smaller distances in a cellular system, it is important to make efficient use of the available channels. Cellular systems are designed to operate with groups of lower-power base stations spread out over the geographical service area. Each group of base stations serves mobile units, which are located near them. The area served by each base stations is called a cell.
The ideal shape of a cell is circular. However, in reality, the cell coverage is an irregularly shaped circle. The exact coverage of the cell depends on the terrain and other factors. For design convenience, we assume that the coverage areas are regular polygons. Any regular polygon, such as an equilateral triangle, a square, or a hexagon, can be used. The hexagon is used for two reasons: first, a hexagonal layout requires fewer cells and therefore, fewer transmitter sites and second, a hexagonal cell layout is less expensive compared to square and triangular cells.

Fig. 3.1 illustrates the concept of frequency reuse distance. There are two sets of 7 cells. The set of frequencies used by cell 1 of one set is reused by the cell 1 of the second set. And the frequencies of cell 2 of one set is reused by cell 2 of the second set, and so on. These cells must maintain a minimum geographical distance, which is referred to as the frequency reuse distance and is denoted by D.

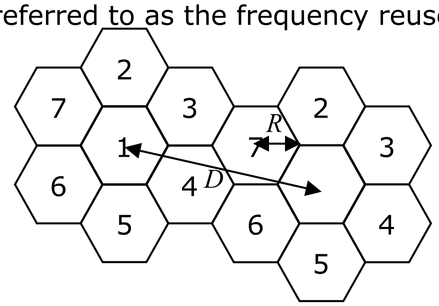

Fig. 3.1 Frequency reuse distance D and center-to-vertex distance R

A cluster is a group of cells that share the total allocated spectrum to the system.
Because of the geometry of the hexagon there are only certain cell layouts and cluster sizes that are possible in order to *tesselate* (without leaving gaps in between the cells). The numbers of cells per cluster, N, can only have values, which satisfy the following equation

$$N = i^2 + ij + j^2 \qquad (1.1)$$

where i and j are integer values. To find the nearest co-channel neighbors of a particular cell, one must do the following:

1. Move i cells along any straight chain of hexagons.
2. Turn 60 degrees counter-clockwise and move j cells.

Fig. 3.2 illustrates this process with i=2, j=1 and N=7. So in this example, one cluster contains 7 cells. To find the nearest cluster, one should move 2 cells, turn 60 degrees counter-clockwise and then move 1 cell.

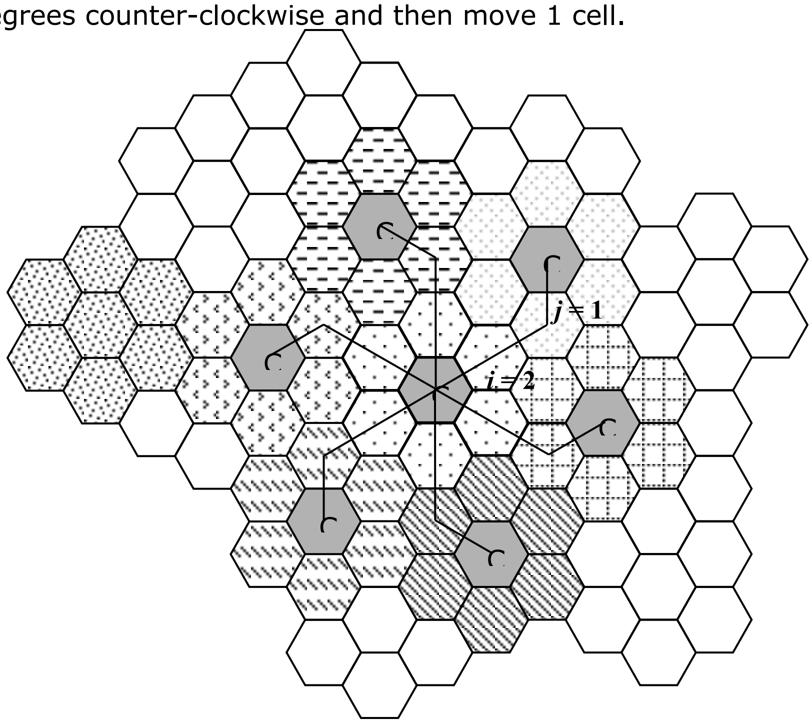

Fig. 3.2 Pattern of reuse frequency with N=7 and C=center of cluster

The co-channel interference is a function of q where $q = D/R$. If there are only two interfering cells, then the signal to interference ratio would be $S/I = q^{-\gamma}$, where γ is the propagation path-loss slope. The relation between D, R and N is given in Eq. (1.2)

$$\frac{D}{R} = q = \sqrt{3N} \qquad (1.2)$$

where D = Distance between the cells using the same frequency,
R = Center to vertex distance,
N = Cluster size,
q = Reuse frequency.

In Table 3.1 the values i and j and the accompanying cluster size and reuse frequency are given.

i	j	N	q=D/R or q= $\sqrt{3N}$
1	0	1	1.73
1	1	3	3.00
2	0	4	3.46
2	1	7	4.58
3	0	9	5.20
4	1	21	7.94

Table 3.1 Relations between D, R and N

3.2 Co-channel interference

Co-channel interference is produced by users who transmit in the same frequency channel. Signal-to-interference ratio (S/I) is defined to express the co-channel interference faced in frequency reuse.

This ratio is given by:

$$\frac{S}{I} = \frac{S}{\sum_{k=1}^{6} I_k}. \quad (1.3)$$

In a hexagonal-shaped structure there are always six co-channel interfering cells in the first tier. In a small cell system, interference will be the dominating factor and thermal noise can be neglect. Thus the S/I can also be written as:

$$\frac{S}{I} = \frac{1}{\sum_{k=1}^{6} \left(\frac{D_k}{R}\right)^{-\gamma}} \quad (1.4)$$

where

S/I = Signal to interference ratio at the desired mobile receiver,
S = desired signal power,
I = Interference power,
$2 \le \gamma \le 5$ is the propagation path-loss slope and γ depends on the terrain environment.

If we assume, for simplification, that D_k is the same for the six interfering cells[2], i.e., $D = D_k$, then the formula above becomes:

$$\frac{S}{I} = \frac{1}{6(q)^{-\gamma}} = \frac{q^{\gamma}}{6} \quad (1.5)$$

$$q = \left[6\left(\frac{S}{I}\right)\right]^{\frac{1}{\gamma}}. \quad (1.6)$$

For analog systems using frequency modulation, normal cellular practice is to specify an S/I ratio to be 18 dB or higher based on subjective tests. An S/I of 18 dB is the measured value for the accepted voice quality from the present-day cellular mobile receivers.

Using an S/I ratio equal to 18dB ($10^{18/10} = 63.1$) and γ =4 in the equation above, then

$$q = [6 \times 63.1]^{0.25} = 4.41. \quad (1.7)$$

Substituting q from Eq. (1.7) into Eq. (1.2) yields

$$N = \frac{(4.41)^2}{3} = 6.49 \approx 7. \quad (1.8)$$

Eq. (1.8) indicates that a 7-cell reuse pattern is needed for an S/I ratio of 18 dB.

[2] Under the assumption that there is full coverage, so there are six interfering cells.

To give a better understanding of the equation given above, a numerical example is shown below.

Example
Consider a cellular system with 395 total allocated voice channel frequencies. The traffic is uniform with an average call holding time of 120 seconds and the call blocking during the system busy hour is 2%.
I will calculate the following:
a) the number of calls per cell site per hour;
b) the mean S/I ratio for cell size equal to 4,7 and 21.

Solution
For a cell size N=4, the number of voice channels per cell site is 395/4 ≈ 99 and $q = \sqrt{3 \times 4} = 3.5$. Using the Erlang-B[3] traffic table for 99 channels with 2% blocking probability, we find a traffic load of 87 Erlangs. See Table A.1, 3rd column, 4th row. Erlangs can be calculated with the equation shown below

$$\frac{\text{Seconds of traffic in the hour}}{\text{Total time in seconds}} = \text{Erlangs}$$

$$\frac{\text{Number of calls per cell site per hour x 120}}{60 \text{ x } 60 = 3600} = 87$$

Number of calls per cell site per hour = 87 x (3600/120)= 87 x 30 = 2610.
Using Eq. (1.5) we can calculate the mean S/I ratio as
$S/I = (3.5)^4/6 = 25$, or equivalently S/I =10 log(25) = 14 dB.

Table 3.2 reports all the result regarding different values of N.

N	q	Voice Channels per cell	Calls per cell per hour	Mean S/I in dB
4	3.5	99	2610	14.0
7	4.6	56	1376	18.7
21	7.94	19	369	28.2

Table 3.2 Cell reuse factor vs mean S/I ratio and call capacity

It is evident from the results in Table 3.2 that, by increasing the cell size from N=4 to N=21, the mean S/I ratio is increased from 14 dB to 28.2 dB (a 101% improvement). However, the call capacity of the cell is reduced from 2610 to 369 calls per hour (a reduction of 86%).

In real life, the frequency reuse depends on the following factors:

1. The power of the transmitted signal,
2. The frequencies used,
3. The type of antenna,
4. The height of the antenna,
5. The weather,
6. The terrain over which the signal is sent.

[3] See appendix A for an introduction about Erlang-B.

3.3 Conclusion

For cellular systems it is common to use a hexagon cell to make computations easier. Due to the hexagon structure only some cluster sizes, like 1, 3, 4, 5, 7, are allowed. So, for N=1, the reuse frequency is 1.73 and for N=4 it is 3.46. By reducing q the number of cells per cluster is reduced. If the total frequency is constant, then the number of channels per cell is increased, thereby increasing the system traffic capacity. The reverse is true, an increase in q reduces co-channel interference and also the traffic capacity of the cellular system.

For a company it is important to find an optimum cluster size and acceptable voice quality. It is shown that for an adequate accepted voice quality of 18 dB a 7-cell cluster and a reuse frequency of q=4.6 is adequate.
Still, this is just theory, in real life, the frequency reuse depends on many factors.

Chapter 4
Conclusions

In this report, I have presented some wireless technologies nowadays offered. For the mobile telephony, UMTS is the newest technology which will be available soon. All mobile operators have paid a huge amount of money, in order to get an UMTS license. They all expect that UMTS will be the future for mobile telephony. Still it is uncertain how the public will react to UMTS. In order to check whether UMTS is really such promising as they announce, we will have to wait until UMTS is available. As for mobile telephony, wireless technology is also improving. New standards are in progress, or are already available. Regarding wireless computing, the 802.11b standard is commonly used.

Being wireless is very attractive for the consumers nowadays, because this is more convenient. For example, most people have a mobile phone, so if someone wants to make a call, he will use his mobile phone instead of finding the nearest public phone. Thus the public phone at street is slowly being replaced by the mobile phone.
Still there are a lot of public phones outside, why are those still there if everyone can go wireless? I think the main reason is still the costs of being wireless. For people who are not calling that much, a mobile phone is still expensive compared to not having a mobile phone. And of course not everybody *needs* to be wireless. Thus leaving a 'market' for the supplier of the fixed telephones at street (in the Netherlands this supplier is KPN).

For consumers who like to be wireless, the future looks very promising. As each technology improves it will also (probably) improve speed, quality, security, etc. But as (almost) each technology improvement, the cost is much more expensive than the existing one. It should be nice if they improve something where the cost is not rising.

It is always 'easy', for instance, to call wireless. But when you are going 'backstage', you will be amazed and surprised that such an easy thing is in fact very complicated. There are a lot of requirements in order to let you call wireless. It is very interesting for me to know how something works. Still, being a user, I am happy that I do not need to know '*how*' it works, and like many users, I am satisfied that *it* works.

Appendix A

The unit named the Erlang is a statistical measure of telecommunication traffic used in telephony. It is named after the Danish telephone engineer A.K. Erlang, the originator of queueing theory.

In Erlang-B, we assume that, when traffic arrives in the system, it either is served, or is lost to the system. A customer attempting to place a call therefore either will see a call completion or gets a busy and hangs up. This assumption is acceptable for low blocking probabilities.

Strictly speaking, an Erlang represents the continuous use of one voice path. In practice, it is used to describe the total traffic volume of one hour.

The blocking probability is given by the following formula:

$$P_{Blocking} = \frac{\frac{E^n}{n!}}{\frac{E^N}{n!} + \frac{E^{n-1}}{(n-1)!} + \frac{E^{n-2}}{(n-2)!} + \ldots + \frac{E^2}{2!} + E + 1}$$

where $P_{Blocking}$ is the probability of blocking or call rejection,

E is the number of Erlangs and

n is the number of lines.

The formula to calculate the number of Erlangs is :

$$\frac{\text{Seconds of traffic in the hour}}{\text{Total time in seconds}} = \text{Erlangs}$$

For example, if a group of users made 30 calls in one hour, and each call had an average call duration of 5 minutes, then the number of Erlangs is computed as follows [28]:

Minutes of traffic in the hour = number of calls x duration
Minutes of traffic in the hour = 30 x 5
Minutes of traffic in the hour = 150
Hours of traffic in the hour = 150 / 60
Hours of traffic in the hour = 2.5
Traffic figure = 2.5 Erlangs

In Table A.1 some values, which are used in chapter 3, are listed. The blocking probability is the probability that one is willing to be blocked. For example 0.1 would mean 10% of the calls are blocked. One should read the table like this: the top row of the table tells that 19 lines can handle 11.24 Erlangs if the blocking percentage is 1%. If you tolerate 10% of blocking, 19 lines can handle 16.58 Erlangs.

Number of lines	Blocking probabilities		
	0.01	0.02	0.1
19	11.241	12.341	16.580
20	12.041	13.188	17.614
56	43.317	45.877	56.059
99	83.125	87.004	103.013
100	84.065	87.972	104.110

Table A.1 the number of Erlangs of offered traffic that can be handled by a given number of lines at a given percentage of blocked calls for the Erlang-B Model.

List of Abbreviations

A	
AAL5	ATM Adaptation Layer 5
ATM	Asynchronous Transfer Mode
AuC	Authentication Center
B	
bps	bits per second
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
C	
CM	Control Management
CDMA	Code Division Multiple Access
CEPT	Conférence Européenne de Postes et Télécommunications
CS	Connection Switched
D	
DLC	Data Link Control
DRNC	Drift Radio Network Controller
DSSS	Direct Sequence Spread Spectrum
E	
EIR	Equipment Identity Register
E-mail	Electronic mail
F	
FDD	Frequency Division Duplex
FDMA	Frequency-Division Multiple Access
FH	Frequency Hopping
FHSS	Frequency Hopping Spread Spectrum
G	
GGSN	Gateway GPRS Support Node
GHz	Gigahertz
GMSC	Gateway Mobile Switching Center
GOS	Grade of Service
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GTP	GPRS Tunneling Protocol
GTP-U	GPRS Tunnelling Protocol for the User Plane
H	
HCI	Host Control Interface
HLR	Home Location Register
HID	Human Interface Device

I

ID	Identification
IEEE	Institute of Electrical and Electronic Engineers
IMEI	International Mobile station Equipment Identity
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
ISDN	Integrated Service Digital Network

K

kbps	kilobits per second

L

L2CAP	Logical Link Control and Adaptation Protocol
LAN	Local Area Network
LAPD	Link Access Protocol for the ISDN D-channel
LLC	Logical Link Control
LM	Logical Manager

M

MAC	Medium Access Control
MANET	Mobile Ad hoc Network
Mbps	Megabits per second
ME	Mobile Equipment
MHz	Megahertz
MM	Mobility Management
MMS	Multimedia Message Service
MS	Mobile Station
MSC	Mobile Switching Center

P

PDCP	Packet Data Convergence Protocol
PDN	Public Data Network
PDU	Protocol Data Units
PIN	Personal Identification Number
PPP	Point-to-Point Protocol
PS	Packet Switched
PSTN	Public Switched Telephone Network

Q

QoS	Quality of Service

R

RF	Radio Frequency
RLC	Radio Link Control
RR	Radio Resource management

S

SDP	Service Discovery Protocol
SGSN	Serving GPRS Support Node
S/I	Signal to Interference
SIG	Special Interest Group

SIM	Subscriber Identity Module
SMS	Short Message Service
SNDCP	Subnetwork-Dependent-Convergence Protocol
SRNC	Serving Radio Network Controller
T	
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time-Division Multiple Access
U	
USIM	UMTS Subscriber Identity Module
UDP	User Datagram protocol
UE	User Equipment
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal Terrestrial Radio Access Network
V	
VLR	Visitor Location register
W	
WAP	Wireless Application Protocol
WATM	Wireless Asynchronous Transfer Mode
W-CDMA	Wideband Code-Division Multiple Access
WLAN	Wireless Local Area Network

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