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Evolution from 2G over 3G to 4G

In the past 15 years, fixed line and wireless telecommunication as well as the Internet have developed both very quickly and very slowly depending on how one looks at the domain. To set current and future developments into perspective, the first chapter of this book gives a short overview of major events that have shaped these three sectors in the previous one-and-a-half decades. While the majority of the developments described below took place in most high-tech countries, local factors and national regulation delayed or accelerated events. Therefore, the time frame is split up into a number of periods and specific dates are only given for country-specific examples.

1.1 First Half of the 1990s – Voice-centric Communication

Fifteen years ago, in 1993, Internet access was not widespread and most users were either studying or working at universities or in a few select companies in the IT industry. At this time, whole universities were connected to the Internet with a data rate of 9.6 kbit/s. Users had computers at home but dial-up to the university network was not yet widely used. Distributed bulletin board networks such as the Fidonet [1] were in widespread use by the few people who were online then.

It can therefore be said that telecommunication 15 years ago was mainly voice-centric from a mass market point of view. An online telecom news magazine [2] gives a number of interesting figures on pricing around that time, when the telecom monopolies where still in place in most European countries. A 10 min ‘long-distance’ call in Germany during office hours, for example, cost €3.25.

On the wireless side, first-generation analog networks had been in place for a number of years, but their use was even more expensive and mobile devices were bulky and unaffordable except for business users. In 1992, GSM networks had been launched in a number of European countries, but only few people noticed the launch of these networks.

Beyond 3G – Bringing Networks, Terminals and the Web Together: LTE, WiMAX, IMS, 4G Devices and the Mobile Web 2.0 Martin Sauter

1.2 Between 1995 and 2000: the Rise of Mobility and the Internet

Around 1998, telecom monopolies came to an end in many countries in Europe. At the time, many alternative operators were preparing themselves for the end of the monopoly and prices went down significantly in the first weeks and months after the new regulation came into effect. As a result, the cost of the 10 min long-distance call quickly fell to only a fraction of the former price. This trend continues today and the current price is in the range of a few cents. Also, European and even intercontinental phone calls to many countries, like the USA and other industrialized countries, can be made at a similar cost.

At around the same time, another important milestone was reached. About 5 years after the start of GSM mobile networks, tariffs for mobile phone calls and mobile phone prices had reached a level that stimulated mass market adoption. While the use of a mobile phone was perceived as a luxury and mainly for business purposes in the first years of GSM, adoption quickly accelerated at the end of the decade and the mobile phone was quickly transformed from a high-price business device to an indispensable communication tool for most people.

Fixed line modem technology had also evolved somewhat during that time, and modems with speeds of 30–56 kbit/s were slowly being adopted by students and other computer users for Internet access either via the university or via private Internet dial-up service providers. Around this time, text-based communication also started to evolve and Web browsers appeared that could show Web pages with graphical content. Also, e-mail leapt beyond its educational origin. Content on the Internet at the time was mostly published by big news and IT organizations and was very much a top-down distribution model, with the user mainly being a consumer of information. Today, this model is known as Web 1.0.

While voice calls over mobile networks quickly became a success, mobile Internet access was still in its infancy. At the time, GSM networks allowed data rates of 9.6 and 14.4 kbit/s over circuit-switched connections. Few people at the time made use of mobile data, however, mainly due to high costs and missing applications and devices. Nevertheless, the end of the decade saw the first mobile data applications such as Web browsers and mobile e-mail on devices such as Personal Digital Assistants (PDAs), which could communicate with mobile phones via an infrared port.

1.3 Between 2000 and 2005: Dot Com Burst, Web 2.0, Mobile Internet

Developments continued and even accelerated in all three sectors despite the dot com burst in 2001, which sent both the telecoms and the Internet industry into a downward spiral for several years. Despite this downturn, a number of new important developments took place during this period.

One of the major breakthroughs during this period was the rise of Internet access via Digital Subscriber Lines (DSL) and TV cable modems. These quickly replaced dial-up connections as they became affordable and offered speeds of 1 MBit/s and higher. Compared with the 56 kbit/s analog modem connections, the download times for web pages with graphical content and larger files improved significantly. At the end of this period, the majority of people in many countries had access to broadband Internet that allowed them to view more and more complex Web pages. Also, new forms of communication like Blogs and Wikis appeared, which quickly revolutionized the creator–consumer imbalance. Suddenly, users were no longer only consumers of content, but could also be creators for a worldwide audience. This is one of the main properties of what is popularly called Web 2.0 and will be further discussed later on in this book.

In the fixed line telephony world, prices for national and international calls continued to decline. Towards the end of this period, initial attempts were also made to use the Internet for transporting voice calls. Early adopters discovered the use of Internet telephony to make phone calls over the Internet via their DSL lines. Proprietary programs like Skype suddenly allowed users to call any Skype subscriber in the world for free, in many cases with superior voice quality. 'Free' in this regard is a relative term, however, since both parties in the call have to pay for access to the Internet, so telecom operators still benefit from such calls due to the monthly charge for DSL or cable connections. Additionally, many startup companies started to offer analog telephone to Internet Protocol (IP) telephone converters, which used the standardized SIP (Session Initiation Protocol) protocol to transport phone calls over the Internet. Gateways ensured that such subscribers could be reached via an ordinary fixed line telephone number and could call any legacy analog phone in the world. Alternative long-distance carriers also made active use of the Internet to tunnel phone calls between countries and thus offer cheaper rates.

Starting in 2001, the General Packet Radio Service (GPRS) was introduced in public GSM networks for the first time. When the first GPRS-capable mobile phones quickly followed, mobile Internet access became practically feasible for a wider audience. Until then, mobile Internet access had only been possible via circuit-switched data calls. However, the data rate, call establishment times and the necessity of maintaining the channel even during times of inactivity were not suitable for most Internet applications. These problems, along with the small and monochrome displays in mobile phones and mobile software being in its infancy, meant that the first wireless Internet services (WAP 1.0) never became popular. Towards 2005, devices matured, high-resolution color displays made it into the mid-range mobile phone segment and WAP 2.0 mobile Web browsers and easy-to-use mobile e-mail clients in combination with GPRS as a packet-switched transport layer finally allowed mobile Internet access to cross the threshold between niche and mass market. Despite these advances, pricing levels and the struggle between open and closed Internet gardens, which will be discussed in more detail later on, slowed down progress considerably.

At this point it should be noted that throughout this book the terms 'mobile access to the Internet' and 'mobile Internet access' are used rather than 'mobile Internet'. This is done on purpose since the latter term implies that there might be a fracture between a 'fixed line' and a 'mobile' Internet. While it is true that some services are specifically tailored for use on mobile devices and even benefit and make use of the user's mobility, there is a clear trend for the same applications, services and content to be offered and useful on both small mobile devices and bigger nomadic or stationary devices. This will be discussed further in Chapter 6.

Another important milestone for wireless Internet access during this timeframe was 3G networks going online in many countries in 2004 and 2005. While GPRS came close to analog modem speeds, UMTS brought data rates of up to 384 kbit/s in practice, and the experience became similar to DSL. Again, network operator pricing held up mass adoption for several years.

1.4 From 2005 to today: Global Coverage, VoIP and Mobile Broadband

From 2005 to today, the percentage of people in industrialized countries accessing the Internet via broadband DSL or cable connections has continued to rise. Additionally, many network operators have started to roll out ADSL2+, and new modems enable download speeds beyond 15 Mbit/s for users living close to a central exchange. VDSL and fiber to the curb/fiber to the home deployments offer even higher data rates. Another trend that has accelerated since 2005 is Voice over IP (VoIP) via a telephone port in the DSL or cable modem router. This effectively circumvents the traditional analog telephone network and traditional network fixed line telephony operators see a steady decline in their customer base.

At the time of publication, the number of mobile phone users has reached 3 billion. This means that almost every second person on Earth now owns a mobile phone, a trend which only a few people foresaw only five years ago. In 2007, network operators registered 1000 new users per minute [3]. Most of this growth has been driven by the rollout of second-generation GSM/GPRS networks in emerging markets. Due to global competition between network vendors, network components reached a price that made it feasible to operate wireless networks in countries with very low revenue per user per month. Another important factor for this rapid growth was ultra-low-cost GSM mobile phones, which became available for less than $50. In only a few years, mobile networks have changed working patterns and access to information for small entrepreneurs like taxi drivers and tradesmen in emerging markets [4]. GSM networks are now available in most parts of the world. Detailed local and global maps of network deployments can be found in [5].

In industrialized countries, third-generation networks continued to evolve and 2006 saw the first upgrades of UMTS networks to High Speed Data Packet Access (HSDPA). In a first step, this allowed user data speeds between 1 and 3 Mbit/s. With advanced mobile terminals, speeds are likely to increase further. Today, such high data rates are mainly useful in combination with notebooks to give users broadband Internet almost anywhere. In the mid term, it is likely that HSDPA will also be very beneficial for mobile applications once podcasts, music downloads and video streaming on mobile devices become mass market applications.

While 3G networks have been available for some time, take-up was sluggish until around 2006/2007, when mobile network operators finally introduced attractive price plans. Prices fell below €40–€50 for wireless broadband Internet access and monthly transfer volumes of around 5 Gbytes. This is more than enough for everything but file sharing and substantial video streaming. Operators have also started to offer smaller packages in the range of €6–15 a month for occasional Internet access with notebooks. Packages in a similar price range are now also offered for unlimited Web browsing and e-mail on mobile phones. Pricing and availability today still vary in different countries. In 2006, mobile data revenue in the USA alone reached a $15.7 billion, of which 50–60% is non-SMS revenue [6]. In some countries, mobile data revenues now accounts for between 20 and 30% of the total operator revenue, as shown in Figure 1.1.

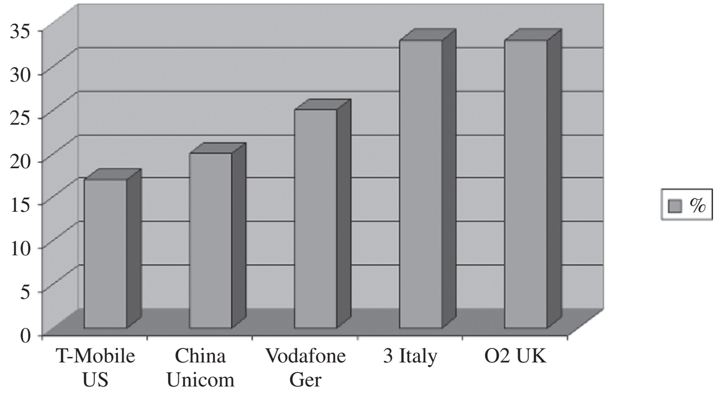

Figure 1.1 Percentage of data revenue of mobile operators in 2007 [6].

While wireless data roaming is still in its infancy, wireless Internet access via prepaid SIM cards is already offered in many countries at similar prices to those for customers with a monthly bill. This is another important step, as it opens the door to anytime and anywhere Internet access for creative people such as students, who favor prepaid SIMs to monthly bills. In addition, it makes life much easier for travelers, who until recently had no access to the Internet while traveling, except for wireless hotspots at airports and hotels. An updated list of such offers is maintained by the Web community on the prepaid wireless Internet access Wiki [7].

1.5 The Future – the Need for Beyond 3G Systems

When looking into the future, the main question for network operators and vendors is when and why Beyond 3G wireless networks will be needed. Looking back only a couple of years, voice telephony was the first application that was mobilized. The Short Message Service (SMS) followed some years later as the first mass market mobile data application. By today's standards comparably simple mobile phones were required for the service and little bandwidth. In a way, the SMS service was a forerunner of other data services like mobile e-mail, mobile Web browsing, mobile blogging, push-to-talk, mobile instant messaging and many others. Such applications became feasible with the introduction of packet-based wireless networks that could carry IP data packets and increasingly powerful mobile devices. Today, the capacity of current 3G and 3.5G networks is still sufficient for the bandwidth requirements of these applications and the number of users. There are a number of trends, however, which are already visible and will increase bandwidth requirements in the future:

- Rising use – due to falling prices, more people will use mobile applications that require network access.
- Multimedia content – while first attempts at mobilizing the Web resulted in mostly text-based Web pages, graphical content is now the norm rather than the exception.

A picture may paint a thousand words, but it also increases the amount of data that has to be transferred for a Web page. Video and music downloads are also becoming more popular, which further increases in bandwidth requirements.

- Mobile social networks – similar to the fixed-line Internet, a different breed of applications is changing the way people are using the Internet. In the past, users mainly consumed content. Blogs, podcasts, picture-sharing sites and video portals are now reshaping the Internet, as users no longer only consume content, but use the network to share their own ideas, pictures and videos with other people. Applications like, for example, Shozu [8] and Lifeblog [9] let users upload pictures, videos and Blog entries from mobile devices to the Web. In particular, picture, podcast and video transfers multiply the amount of data that users transmit and receive.
- Voice over IP – the fixed line world is rapidly moving towards VoIP. It is likely that, five years from now, many of today's fixed line circuit-switched voice networks will have migrated towards IP-based voice transmission. Likewise, on the network access side, many users will use VoIP as their primary fixed line voice service, for example over DSL or TV cable networks. The beginnings can already been observed today, as the circuit-switched voice market is under increasing pressure due to declining subscriber numbers. As a consequence, many operators are no longer investing in this technology. A similar trend can be observed in wireless networks. Here, however, the migration is much slower, especially due to the higher bandwidth requirements for transporting voice calls over a packet-switched bearer. This topic is discussed in more detail in Chapter 1.6.
- Fixed-line Internet replacement – while the number of voice minutes is increasing, revenue is declining in both fixed line and the wireless networks due to falling prices. In many countries, wireless operators are thus trying to keep or increase the average revenue per user by offering Internet access for PCs, notebooks and mobile devices over their UMTS/HSDPA or CDMA networks. Thus, they have started to compete directly with DSL and cable operators. Again, this requires an order of magnitude of additional bandwidth on the air interface.
- Competition from alternative wireless Internet providers – in some countries, alternative operators are already offering wireless broadband Internet access with Wi-Fi or WiMAX/802.16 networks. Such operators directly compete with traditional UMTS and CDMA carriers, who are also active in this market.
- The broadband Internet is not a socket in the wall – this statement combines all previous arguments and was made by Anssi Vanjoki, Executive VP of Nokia's Multimedia division [10], at a press conference. Today, many people already use Wi-Fi access points to create their personal broadband Internet bubble. Thus, broadband Internet is virtually all around them. In the future, people will not only use this bubble with desktop computers and notebooks, but also with smaller devices such as mobile phones with built-in Wi-Fi capabilities. Smaller devices will also change the way we perceive this Internet bubble. No longer is it necessary to sit down at a specific place, for example in front of a computer, in order to communicate (VoIP, e-mail, instant messaging), to get information or to publish information to the Web (pictures, Blog entries, videos, etc.). When the personal broadband bubble is left, mobile devices switch over to a cellular network. As we move into the future, the cellular network will extend into areas not covered today and available bandwidth will have to increase

to cope with the rising number of users and their connected applications. Moving between the personal Internet bubble at home and the larger external cellular network will become seamless as devices and services evolve.

A number of wireless technologies are currently under development or in the early rollout phase that are designed to meet these future demands: 3GPP's Long Term Evolution (LTE), HSPA+ and WiMAX. In addition, Wi-Fi is also likely to be an important network technology that is required to meet future capacity demands. All of these technologies will be further discussed in Chapter 2. The question that arises in this context is which of these technologies are 3G and which will be called 4G in the future?

The body responsible for categorizing wireless networks is the International Telecommunication Union (ITU). The ITU categorizes International Mobile Telecommunication (IMT) networks as follows:

- IMT-2000 systems – this is what we know as 3G systems today, for example UMTS and cdma2000. The list of all ITU-2000 systems is given in ITU-R M.1457-6 [11].
- Enhanced IMT-2000 systems – the evolution of IMT-2000 systems, for example HSPA, CDMA 1xEvDo and future evolutions of these systems.
- IMT-Advanced systems – systems in this category are considered to be 4G systems.

At this time, there is still no clear definition of the characteristics of future IMT-Advanced (4G) systems. The ITU-R M.1645 recommendation [12] gives first hints but leaves the door wide open:

> It is predicted that potential new radio interface(s) will need to support data rates of up to approximately 100 Mbit/s for high mobility such as mobile access and up to approximately 1 Gbit/s for low mobility such as nomadic/local wireless access, by around the year 2010 [...] These data rate figures and the relationship to the degree of mobility [...] should be seen as targets for research and investigation of the basic technologies necessary to implement the framework. Future system specifications and designs will be based on the results of the research and investigations.

When comparing current the WiMAX specifications to these potential requirements, it becomes clear that WiMAX does not qualify as a 4G IMT-Advanced standard, since data rates are much lower, even under ideal conditions.

3GPP's successor to its 3G UMTS standard, known as LTE, will also have difficulties fulfilling these requirements. Even with a four-way Multiple Input Multiple Output (MIMO) transmission, data rates in a 20 MHz carrier would not exceed 326 Mbit/s. It should be noted at this point that this number is already a long stretch, since putting four antennas in a small device or on a rooftop will be far from simple in practice.

It is also interesting to compare these new systems with the evolution of current 3G systems. The evolution of UMTS is a good example. With HSDPA and HSUPA, user speeds now exceed the 2 Mbit/s that was initially foreseen for IMT-2000 systems. The evolution of those systems, however, has not yet come to an end. Recent new developments in 3GPP Release 7 and 8 called HSPA+, which include MIMO technology and other enhancements, bring evolved UMTS technology to the same capacity and bandwidth levels as currently specified for LTE on a 5 MHz carrier. HSPA+ is also clearly not a 4G IMT-Advanced system, since it enhances a current 3G IMT-2000 radio technology. Thus, HSPA+ is categorized as an 'enhanced IMT-2000 system'.

To meet the likely requirements of IMT-Advanced, the WiMAX and LTE standards bodies have started initiatives to further enhance their technologies. On the WiMAX side, the 802.16m task group is working on standardizing an even faster radio interface. On the LTE side, a similar working program has become known as LTE+ or Enhanced LTE.

Current research indicates that the transmission speed requirements described in ITU-R M.1645 can only be achieved in a frequency band of 100 MHz or more. This is quite a challenge, both from a technical point of view and also due to a lack of available additional spectrum. Thus, it is somewhat doubtful whether these requirements will remain in place for the final definition of 4G IMT-Advanced.

In practice, several different network technologies will coexist and evolve in the future to meet the rising demands in terms of bandwidth and capacity. It is also likely that a combination of different radio systems, like for example LTE together with Wireless LAN, will be used to satisfy capacity demands.

From a user and service point of view, it does not matter if a network technology is considered 3.5G, 3.9G or 4G. Thus, this book uses the term 'Beyond 3G systems' (B3G), which includes all technologies which will be able to satisfy future capacity demands and which either evolve out of current systems or are a new development.

1.6 All Over IP

While on the radio network side it is difficult to foresee which mix of evolved 3G and 4G technologies will be used in the future, the future of fixed and mobile core networks is much easier to predict. One of the main characteristics of 3G networks is the support for circuit-switched and packet-switched services. The circuit-switched part of the core network and circuit-switched services of the radio network were specifically designed to carry voice and video calls. Service control rests with the Mobile Switching Center (MSC), the main component of a circuit-switched network. As subscribers can roam freely in a mobile network, a database is required to keep track of the current location of the subscriber in addition to the subscription information. This database is referred to as the Home Location Register (HLR). To establish a call, a mobile phone always contacts the MSC. The MSC then uses the destination's telephone number to query the HLR for the location of the destination subscriber. The call is then routed to this MSC, which in turn informs the destination subscriber of the incoming call. This process is called signaling. For the speech path, a transparent circuit-switched channel is established between the two parties via the MSCs switching matrix. The signaling required for the call is transferred over an independent signaling network, as the circuit-switched channel only transports the speech signal.

In recent network designs, MSCs are split into an MSC Call Server component that handles the signaling and a media gateway that is responsible for forwarding the voice call as shown in Figure 1.2. Instead of fixed connections, media gateways use packet-switched ATM (Asynchronous Transfer Mode) or IP connections to forward the call. This removes the necessity to transport the voice data via circuit-switched connections in the core network.

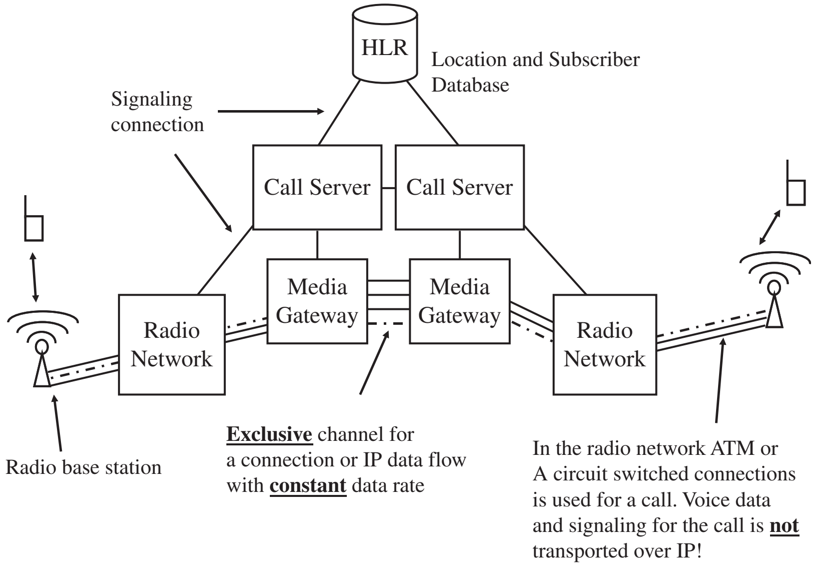

Figure 1.2 Circuit switching with dedicated network components.

While this approach is ideally suited to carry voice and video calls with a constant bandwidth and delay requirements, it performs poorly for a connection to the Internet. Here, all data is transported in data packets. Furthermore, data packets are not only exchanged between two endpoints while a connection is established, but usually between many. An example is a Web browsing session during which a user visits several Web sites, sometimes even simultaneously. While a Web page is transferred, it is desirable to use as much bandwidth as is currently available, rather than be limited to a circuit-switched channel that is designed to carry a digitized narrowband voice or video stream. An Internet connection is often also idle for a substantial duration. During this time, resources are best given to other users. This is also not possible with a circuit-switched connection, because it is an exclusive channel that offers a fixed amount of bandwidth between two parties while it is established.

For these reasons, 3G networks contain a separate core network to forward data packets rather than circuits. This is shown in Figure 1.3. The radio network serves both the circuit-switched and the packet-switched network and the kind of connection established to a user over the air depends on whether a circuit-switched connection or a packet-switched connection is required. Some systems such as UMTS even allow devices to simultaneously use packet and circuit connections so a phone call can be made while being connected to the Internet and transferring data.

Traditional fixed line networks use a similar split for simultaneous voice telephony and Internet access. Since DSL became popular, analog voice service and DSL use the same physical line to the customer's home. A splitter is then used to separate the analog telephone signal from the DSL service as they operate in different frequency bands. In the central exchange office, a similar splitter is used to connect the line of the subscriber to

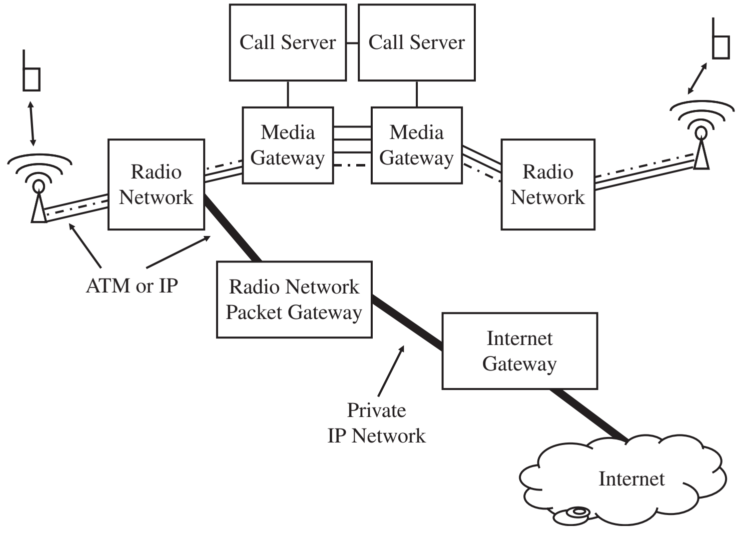

Figure 1.3 Typical circuit-switched and packet-switched dual architecture of 3G networks. The location and subscriber database is not shown.

the local circuit-switched exchange for voice calls and additionally to a DSL Access Multiplexer (DSLAM) for Internet connectivity. Telephone exchanges are then interconnected via circuit-switched connections, while the DSLAM connects to a packet-switched backbone. In the meantime, however, there is a clear shift to transporting telephone calls over the Internet connection as well. Instead of connecting the analog phone to the splitter, the DSL access device is equipped with a jack for the phone. The DSL access device digitizes the voice signal and sends it as IP packets over the DSL connection. In many cases, an IP-based SIP server and RTP (Real Time Transport Protocol) replace the local circuit-switched telephone exchange. There are several advantages of this approach:

- Only a single type of core network is needed, as the circuit-switched telephone exchanges and the circuit-switched network between them are no longer necessary.
- Using an IP network for voice calls makes it a lot easier for companies other than the local telephone carrier to offer telephony services, as the controlling network element no longer needs to be at the local exchange.
- Voice services can be combined with other services. Since there is more bandwidth available, users can, for example, exchange pictures with each other while being engaged in a voice call or add video at any point during the conversation.

While the trend to VoIP is already fully underway in fixed-line networks, wireless networks have not yet caught up. Here, things are moving more slowly for a number of reasons. The main reason is that 3G mobile networks did not have the necessary bandwidth to support VoIP, which requires a higher data rate than circuit-switched voice calls. The gap has been somewhat reduced by the introduction of 3.5G networks. However, only B3G networks (evolved IMT-2000 and IMT-Advanced) will have enough capacity and an optimized radio network to support VoIP on a large scale.

The challenges are significant, but none of the new B3G network architectures discussed in Chapter 2 have a circuit-switched core network. To be successful, it is essential for B3G wireless network operators to have a fully functioning VoIP solution in place in the future that is able to seamlessly transfer the call to a circuit-switched wireless connection when the user roams out of network coverage. This is discussed in more detail in Chapter 4.

1.7 Summary

This chapter presented how fixed and wireless networks evolved in the past 15 years from circuit-switched voice-centric systems to packet-switched Internet access systems. Due to the additional complexity of wireless systems, enhancements are usually introduced in fixed-line systems first and only some years later in wireless systems as well. To date, fixed-line networks offer data rates to the customer premises of several megabits per second, in some cases already going beyond this. Wireless 3.5G networks are capable of data rates in the order of several megabits per second. In the future, more bandwidth and capacity will be achieved by evolving current wireless network technologies (evolved IMT-2000) and by designing new access networks (IMT-Advanced). This book therefore not only concentrates on 4G systems, but also discusses the evolution of 3G systems. Another important development is the use of packet-switched networks for transporting telephone calls, which is referred to as VoIP. This trend is already fully underway in fixed-line networks and will inevitably also happen in B3G networks, as systems such as WiMAX and LTE have been designed without a circuit-switched core network dedicated to voice calls.

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