Although this book mostly deals with different communication technologies allowing individual two-way communication, it is important to understand the role of unidirectional broadcast systems within future mobile communication scenarios. Typical broadcast systems, such as radio and television, distribute information regardless of the needs of individual users. As an addition to two-way communication technologies, broadcasting information can be very cost effective. Just imagine the distribution of a movie trailer to millions of potential customers and compare it with the abilities of 3G base stations to provide 10–20 simultaneous users with a 128 kbit/s video stream. The distribution of the trailer would block the whole mobile network for a long time even if tens of thousand base stations are assumed.

In the future, television and radio transmissions will be fully digital. Already several radio stations produce and transmit their programmes digitally via the internet or digital radio (see later sections in this chapter). Digital television is on its way. Besides transmitting video and audio, digital transmission allows for the distribution of arbitrary digital data, i.e., multimedia information can accompany radio and TV programmes at very low cost compared to individual wireless connections.

The following sections give a general introduction into asymmetric communication up to the extreme case of unidirectional broadcasting. One important issue is the cyclic repetition of data (as discussed in the sections about broadcast disks). Broadcasting systems which will be explained in detail are digital audio broadcasting (DAB) and digital video broadcasting (DVB). One interesting feature about data communication is the ability of DAB and DVB to carry multi-media information. In combination with satellite or terrestrial transmission and the use of the internet, these systems are able to deliver high bandwidth to individual customers at low cost (ETSI, 2002).

6.1 Overview

Unidirectional distribution systems or broadcast systems are an extreme version of asymmetric communication systems. Quite often, bandwidth limitations, differences in transmission power, or cost factors prevent a communication system from being symmetrical. **Symmetrical communication systems** offer the same
transmission capabilities in both communication directions, i.e., the channel characteristics from A to B are the same as from B to A (e.g., bandwidth, delay, costs).

Examples of symmetrical communication services are the plain old telephone service (POTS) or GSM, if end-to-end communication is considered. In this case, it does not matter if one mobile station calls the other or the other way round, bandwidth and delay are the same in both scenarios.

This symmetry is necessary for a telephone service, but many other applications do not require the same characteristics for both directions of information transfer. Consider a typical client/server environment. Typically, the client needs much more data from the server than the server needs from the client. Today’s most prominent example of this is the world wide web. Millions of users download data using their browsers (clients) from web servers. A user only returns information to the server from time to time. Single requests for new pages with a typical size of several hundred bytes result in responses of up to some 10 kbytes on average.

A television with a set-top box represents a more extreme scenario. While a high-resolution video stream requires several Mbit/s, a typical user returns some bytes from time to time to switch between channels or return some information for TV shopping.

Finally, today’s pagers and radios work completely one-way. These devices can only receive information, and a user needs additional communication technology to send any information back to, e.g., the radio station. Typically, the telephone system is used for this purpose.

A special case of asymmetrical communication systems are unidirectional broadcast systems where typically a high bandwidth data stream exists from one sender to many receivers. The problem arising from this is that the sender can only optimize transmitted data for the whole group of receivers and not for an individual user. Figure 6.1 shows a simple broadcast scenario. A sender tries to optimize the transmitted packet stream for the access patterns of all receivers without knowing their exact requirements. All packets are then transmitted via a broadcast to all receivers. Each receiver now picks up the packets needed and drops the others or stores them for future use respectively.

These additional functions are needed to personalize distributed data depending on individual requirements and applications. A very simple example of this process could be a user-defined filter function that filters out all information which is not of interest to the user. A radio in a car, for example, could only present traffic information for the local environment, a set-top box could only store the starting times of movies and drop all information about sports.

However, the problem concerning which information to send at what time still remains for a sender. The following section shows several solutions to this.
6.2 Cyclical repetition of data

A broadcast sender of data does not know when a receiver starts to listen to the transmission. While for radio or television this is no problem (if you do not listen you will not get the message), transmission of other important information, such as traffic or weather conditions, has to be repeated to give receivers a chance to receive this information after having listened for a certain amount of time (like the news every full hour).

The cyclical repetition of data blocks sent via broadcast is often called a broadcast disk according to the project in Acharya (1995) or data carousel, e.g., according to the DAB/DVB standards (ETSI, 2002). Different patterns are possible (Figure 6.2 shows three examples). The sender repeats the three data blocks A, B, and C in a cycle. Using a flat disk, all blocks are repeated one after another. Every block is transmitted for an equal amount of time, the average waiting time for receiving a block is the same for A, B, and C. Skewed disks favor one or more data blocks by repeating them once or several times. This raises the probability of receiving a repeated block (here A) if the block was corrupted the first time. Finally, multi-disks distribute blocks that are repeated more often than others evenly over the cyclic pattern. This minimizes the delay if a user wants to access, e.g., block A.
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It is only possible to optimize these patterns if the sender knows something about the content of the data blocks and the access patterns of all users.

EXAMPLE BROADCAST DISK

Let us assume that the broadcast sender is a radio station transmitting information about road conditions (block A), the weather report (block B), the latest events in town (block C) and a menu to access these and other topics (block D) in addition to music. The sender can now assume, knowing something about the importance of the data blocks, that block D is the most important to enable access to the other information. The second important block is A, then B and finally C. A possible broadcast disk for this scenario could now look as follows:

DADBDADCDADBDADC ...

It is now the receiver's task to cache data blocks to minimize access delay as soon as a user needs a specific type of information. Again, the receiver can only optimize caching if it knows something about the content of the data blocks. The receiver can store typical access patterns of a user to be able to guess which blocks the user will access with a higher probability. Caching generally follows a cost-based strategy: what are the costs for a user (caused by the waiting time) if a data block has been requested but is currently not available in the cache?

Considering the above example, the mobile device of the future (e.g., a radio in a car, an enhanced mobile phone) might remember that a user always checks the latest events in town in the evening, but the road conditions in the morning. The device will cache block A in the morning and block C in the evening. This procedure will generally reduce the waiting time for a user if he or she stays with this access pattern.

6.3 Digital audio broadcasting

Today's analog radio system still follows the basic principle of frequency modulation invented back in 1933. In addition to audio transmission, very limited information such as the station identification can accompany the program. Transmission quality varies greatly depending on multi-path effects and interference. The fully digital DAB system does not only offer sound in a CD-like quality, it is also practically immune to interference and multi-path propagation effects (ETSI, 2001a), (DAB, 2002).

DAB systems can use single frequency networks (SFN), i.e., all senders transmitting the same radio program operate at the same frequency. Today, different senders have to use different frequencies to avoid interference although they are transmitting the same radio program. Using an SFN is very frequency efficient, as a single radio station only needs one frequency throughout the whole country. Additionally, DAB transmission power per antenna is orders of
magnitude lower compared to traditional FM stations. DAB uses VHF and UHF frequency bands (depending on national regulations), e.g., the terrestrial TV channels 5 to 12 (174–230 MHz) or the L-band (1452–1492 MHz). The modulation scheme used is DQPSK. DAB is one of the systems using COFDM (see chapter 2) with 192 to 1536 carriers (the so-called ensemble) within a DAB channel of 1.5 MHz. Additionally, DAB uses FEC to reduce the error rate and introduces guard spaces between single symbols during transmission. COFDM and the use of guard spaces reduce ISI to a minimum. DAB can even benefit from multipath propagation by recombining the signals from different paths.

**EXAMPLE DAB ENSEMBLE**

The following is an ensemble transmitted at 225.648 MHz in southern Germany. The ensemble contains six radio programs and two data channels.

- SWR 1 BW 192 kbit/s, stereo
- SWR 2 192 kbit/s, stereo
- SWR 3 192 kbit/s, stereo
- Hit Radio Antenne 1 192 kbit/s, stereo
- DAS DING 160 kbit/s, stereo
- SWR traffic information 16 kbit/s, data
- SWR service information 16 kbit/s, data

Within every frequency block of 1.5 MHz, DAB can transmit up to six stereo audio programmes with a data rate of 192 kbit/s each. Depending on the redundancy coding, a data service with rates up to 1.5 Mbit/s is available as an alternative. For the DAB transmission system, audio is just another type of data (besides different coding schemes). DAB uses two basic transport mechanisms:

- **Main service channel (MSC):** The MSC carries all user data, e.g. audio, multimedia data. The MSC consists of common interleaved frames (CIF), i.e., data fields of 55,296 bits that are sent every 24 ms (this interval depends on the transmission mode (ETSI, 2001a)). This results in a data rate of 2.304 Mbit/s. A CIF consists of capacity units (CU) with a size of 64 bits, which form the smallest addressable unit within a DAB system.
- **Fast information channel (FIC):** The FIC contains fast information blocks (FIB) with 256 bits each (16 bit checksum). An FIC carries all control information which is required for interpreting the configuration and content of the MSC.

Two transport modes have been defined for the MSC. The stream mode offers a transparent data transmission from the source to the destination with a fixed bit rate in a sub channel. A sub channel is a part of the MSC and
comprises several CUs within a CIF. The fixed data rate can be multiples of 8 kbit/s. The packet mode transfers data in addressable blocks (packets). These blocks are used to convey MSC data within a sub channel.

DAB defines many service information structures accompanying an audio stream. This program associated data (PAD) can contain program information, control information, still pictures for display on a small LCD, title display etc. Audio coding uses PCM with a sampling rate of 48 kHz and MPEG audio compression. The compressed audio stream can have bit rates ranging from 8 kbit/s to 384 kbit/s. Audio data is interleaved for better burst tolerance.¹

Figure 6.3 shows the general frame structure of DAB. Each frame has a duration $T_F$ of 24, 48, or 96 ms depending on the transmission mode. DAB defines four different transmission modes, each of which has certain strengths that make it more efficient for either cable, terrestrial, or satellite transmission (ETSI, 2001a). Within each frame, 76 or 153 symbols are transmitted using 192, 384, 768, or 1,536 different carriers for COFDM. The guard intervals $T_d$ protecting each symbol can be 31, 62, 123, or 246 $\mu$s.

Each frame consists of three parts. The synchronization channel (SC) marks the start of a frame. It consists of a null symbol and a phase reference symbol to synchronize the receiver. The fast information channel (FIC) follows, containing control data in the FIBs. Finally, the main service channel (MSC) carries audio and data service components.

Figure 6.4 gives a simplified overview of a DAB sender. Audio services are encoded (MPEG compression) and coded for transmission (FEC). All data services are multiplexed and also coded with redundancy. The MSC multiplexer combines all user data streams and forwards them to the transmission multiplexer. This unit creates the frame structure by interleaving the FIC. Finally, OFDM coding is applied and the DAB signal is transmitted.

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¹ As the focus of this book is in data transmission, the reader is referred to ETSI (2001a) for more details about audio coding, audio transmission, multiplexing etc.
DAB does not require fixed, pre-determined allocation of channels with certain properties to services. Figure 6.5 shows the possibilities of dynamic reconfiguration during transmission. Initially, DAB transmits six audio programmes of different quality together with nine data services. Each audio program has its PAD. In the example, audio 1, 2, and 3 have high quality, 4 and 5 lower quality, while 6 has the lowest quality. Programmes 1 to 3 could, e.g., be higher quality classic transmissions, while program 6 could be voice transmissions (news etc.). The radio station could now decide that for audio 3 128 kbit/s are enough when, for example, the news program starts. News may be in mono or stereo with lower quality but additional data (here D10 and D11 – headlines, pictures etc.). The DAB multiplexer dynamically interleaves data from all different sources. To inform the receiver about the current configuration of the MSC carrying the different data streams, the FIC sends multiplex configuration information (MCI).
6.3.1 Multi-media object transfer protocol

A problem which technologies like DAB are facing is the broad range of different receiver capabilities. Receivers could be simple audio-only devices with single-line text displays or more advanced radios with extra color graphics displays. DAB receivers can also be adapters in multimedia PCs. However, all different types of receivers should at least be able to recognize all program-associated and program-independent data, and process some of this data.

To solve this problem, DAB defines a common standard for data transmission, the multi-media object transfer (MOT) protocol (ETSI, 1999a). The primary goal of MOT is the support of data formats used in other multi-media systems (e.g., on line services, Internet, CD-ROM). Example formats are multimedia and hypermedia information coding experts group (MHEG), Java, joint photographic experts group (JPEG), American standard code for information interchange (ASCII), moving pictures expert group (MPEG), hypertext markup language (HTML), hypertext transfer protocol (HTTP), bitmap (BMP), graphics interchange format (GIF).

MOT data is transferred in MOT objects consisting of a header core, a header extension, and a body (Figure 6.6).
Broadcast systems

- **Header core:** This seven byte field contains the sizes of the header and the body, and the content type of the object. Depending on this header information, the receiver may decide if it has enough resources (memory, CPU power, display etc.) available to decode and further process the object.

- **Header extension:** The extension field of variable size contains additional handling data for the object, such as, e.g., the repetition distance to support advanced caching strategies (see section 6.2), the segmentation information, and the priority of the data. With the help of the priority information a receiver can decide which data to cache and which to replace. For example, the index HTML page may have a higher priority than an arbitrary page.

- **Body:** Arbitrary data can be transferred in the variable body as described in the header fields.

Larger MOT objects will be segmented into smaller segments. DAB can apply different interleaving and repetition schemes to objects and segments (MOT data carousel):

- **Object repetition:** DAB can repeat objects several times. If an object A consists of four segments \((A_1, A_2, A_3, \text{ and } A_4)\), a simple repetition pattern would be \(A_1A_2A_3A_4A_1A_2A_3A_4A_1A_2A_3A_4\ldots\)

- **Interleaved objects:** To mitigate burst error problems, DAB can also interleave segments from different objects. Interleaving the objects A, B, and C could result in the pattern \(A_1B_1C_1A_2B_2C_2A_3B_3C_3\ldots\)

- **Segment repetition:** If some segments are more important than others, DAB can repeat these segments more often (e.g. \(A_1A_1A_2A_2A_2A_3A_4A_4\ldots\)).

- **Header repetition:** If a receiver cannot receive the header of an MOT, it will not be able to decode the object. It can be useful to retransmit the header several times. Then, the receiver can synchronize with the data stream as soon as it receives the header and can start decoding. A pattern could be \(HA_1A_2HA_3A_4HA_5A_6H\ldots\) with H being the header of the MOT object A.

Obviously, DAB can also apply all interleaving and repetition schemes at the same time.

### 6.4 Digital video broadcasting

The logical consequence of applying digital technology to radio broadcasting is doing the same for the traditional television system. The analog system used today has basically remained unchanged for decades. The only invention worth mentioning was the introduction of color TV for the mass market back in the 1960s. Television still uses the low resolution of 625 lines for the European PAL...
system or only 525 lines for the US NTSC respectively\(^2\). The display is interlaced with 25 or 30 frames per second respectively. So, compared with today’s computer displays with resolutions of \(1,280 \times 1,024\) and more than 75 Hz frame rate, non-interlaced, TV performance is not very impressive.

There have been many attempts to change this and to introduce digital TV with higher resolution, better sound and additional features, but no approach has yet been truly successful. One reason for this is the huge number of old systems that are installed and cannot be replaced as fast as computers (we can watch the latest movie on an old TV, but it is impossible to run new software on older computers!). Varying political and economic interests are counterproductive to a common standard for digital TV. One approach toward such a standard, which may prove useful for mobile communication, too, is presented in the following sections.

After some national failures in introducing digital TV, the so-called European Launching Group was founded in 1991 with the aim of developing a common digital television system for Europe. In 1993 these common efforts were named digital video broadcasting (DVB) (Reimers, 1998), (DVb, 2002). Although the name shows a certain affinity to DAB, there are some fundamental differences regarding the transmission technology, frequencies, modulation etc. The goal of DVB is to introduce digital television broadcasting using satellite transmission (DVB-S, (ETSI, 1997)), cable technology (DVB-C, (ETSI, 1998)), and also terrestrial transmission (DVB-T, (ETSI, 2001b)).

Figure 6.7 shows components that should be integrated into the DVB architecture. The center point is an integrated receiver-decoder (set-top box) connected to a high-resolution monitor. This set-top box can receive DVB signals via satellites, terrestrial local/regional senders (multi-point distribution systems, terrestrial receiver), cable, B-ISDN, ADSL, or other possible future technologies. Cable, ADSL, and B-ISDN connections also offer a return channel, i.e., a user can send data such as channel selection, authentication information, or a shopping list. Audio/video streams can be recorded, processed, and replayed using digital versatile disk (DVD) or multimedia PCs. Different levels of quality are envisaged: standard definition TV (SDTV), enhanced definition TV (EDTV), and high definition TV (HDTV) with a resolution of up to \(1,920 \times 1,080\) pixels.

Similar to DAB, DVB also transmits data using flexible containers. These containers are basically MPEG-2 frames that do not restrict the type of information. DVB sends service information contained in its data stream, which specifies the content of a container. The following contents have been defined:

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\(^2\) Only about 580 lines are visible in the PAL system, only 480 with NTSC. The horizontal resolution depends on transmission and recording quality. For VHS this results in 240 ‘pixels’ per line, terrestrial transmission allows up to 330 and high-quality TV sets up to 500 ‘pixels’. However, transmission is analog and, these ‘pixels’ cannot directly be compared with the pixels of computer monitors.
Network information table (NIT): NIT lists the services of a provider and contains additional information for set-top boxes.

Service description table (SDT): SDT lists names and parameters for each service within an MPEG multiplex channel.

Event information table (EIT): EIT contains status information about the current transmission and some additional information for set-top boxes.

Time and date table (TDT): Finally, TDT contains update information for set-top boxes.

As shown in Figure 6.8, an MPEG-2/DVB container can store different types of data. It either contains a single channel for HDTV, multiple channels for EDTV or SDTV, or arbitrary multi-media data (data broadcasting).

6.4.1 DVB data broadcasting
As the MPEG-2 transport stream is able to carry arbitrary data within packets with a fixed length of 188 byte (184 byte payload), ETSI (1999b) and ETSI (1999c) define several profiles for data broadcasting which can be used, e.g., for high bandwidth mobile Internet services.

Data pipe: simple, asynchronous end-to-end delivery of data; data is directly inserted in the payload of MPEG2 transport packets.

Data streaming: streaming-oriented, asynchronous, synchronized (synchronization with other streams, e.g., audio/video possible), or synchronous (data and clock regeneration at receiver possible) end-to-end delivery of data.
Multiprotocol encapsulation: transport of arbitrary data network protocols on top of the MPEG-2 transport stream; optimized for IP, support for 48 bit MAC addresses, unicast, multi-cast, and broadcast.

Data carousels: periodic transmission of data.

Object carousels: periodic transmission of objects; platform independent, compatible with the object request broker (ORB) framework as defined by CORBA (2002).

6.4.2 DVB for high-speed Internet access

Apart from this data/multi-media broadcasting, DVB can be also used for high-bandwidth, asymmetrical Internet access. A typical scenario could be the following (see Figure 6.9): An information provider, e.g., video store, offers its data to potential customers with the help of a service provider. If a customer wants to download high-volume information, the information provider transmits this information to a satellite provider via a service provider. In fixed networks this is done using leased lines because high bandwidth and QoS guarantees are needed. The satellite provider now multiplexes this data stream together with other digital TV channels and transmits it to the customer via satellite and a satel-
lite receiver. The customer can now receive the requested information with the help of a DVB adapter inside a multi-media PC. Typically, the information for the customer will be encrypted to ensure that only paying customers can use the information. The return channel for requests etc. can be a standard TCP/IP connection via the internet as this channel only requires a low bandwidth.

Typical data rates per user are 5–30 Mbit/s for the downlink via satellite and a return channel with 33 kbit/s using a standard modem, 64 kbit/s with ISDN, or several 100 kbit/s using DSL. One advantage of this approach is that it is transmitted along with the TV programs using free space in the transmitted data stream, so it does not require additional lines or hardware per customer. This factor is particularly important for remote areas or developing countries where high bandwidth wired access such as ADSL is not available. A clear disadvantage of the approach, however, is the shared medium ‘satellite’. If a lot of users request data streams via DVB, they all have to share the satellite’s bandwidth. This system cannot give hard QoS guarantees to all users without being very expensive.

6.5. Convergence of broadcasting and mobile communications

To enable the convergence of digital broadcasting systems and mobile communication systems ETSI (2000) and ETSI (1999d) define interaction channels through GSM for DAB and DVB, respectively. An interaction channel is not only common to DAB and DVB but covers also different fixed and mobile systems (UMTS, DECT, ISDN, PSTN etc.). 3G systems are typically characterized by very small cells, especially in densely populated areas. Although 3G systems offer higher data rates than 2G systems, their design has not fully taken into consideration the integration of
broadcast quality audio and TV services onto 3G terminals. This is true from a technical point of view (capacity per cell in bit/s) as well as from an economic point of view (very high deployment cost for full coverage, typically low return on invest for video services).

Figure 6.10 shows a scenario which benefits from the complementary characteristics of digital broadcast systems and 2.5G/3G mobile systems. High bandwidth audio and video is sent together with IP data via the broadcast channel. IP data could use multi-casting, data carousels etc. as described above. For example, IP data in a DVB-T carousel could contain the top hundred web pages of the ISP’s portal. Individual pages for single users are then additionally sent via GRPS or UMTS (DRiVE, 2002).

### 6.6 Summary

This chapter has presented two examples of broadcast technologies that somehow stand out from the other technologies presented in this book. DAB and DVB are most likely the successors of the traditional radio and television in many countries (probably not everywhere due to varying political and economic interests). In addition to the transmission of audio or video streams, these systems allow for the broadcasting of multimedia data streams. Although both technologies only support unidirectional communication, both will be an integral part of tomorrow’s mobile communication scenarios. DAB and DVB will be used to distribute mass data in a cost-effective manner and rely on other low bandwidth wireless technologies for the return channel if required. These technologies support the ongoing amalgamation of computer, communication, and entertainment industries by merging TV/radio data streams with personalized multi-media streams. We can imagine a scenario in which a movie is distributed to everyone, but for example, with individual commercials depending on the
user’s interests. The set-top box will merge both data streams and the user will, e.g., watch a soccer game with fully individualized billboards. Another feature, which makes DAB particularly attractive for mobile communication, is that it is the only commercial radio system suitable for high speeds and high data rates: up to 1.5 Mbit/s at 900 km/h! This makes it possible to install TV sets in for example, trains and other vehicles that would suffer from multi-path propagation using other technologies. Although DVB was not designed for very fast moving receivers, it has been shown in the MOTIVATE project that it still works at over 250 km/h (at reduced data rates; DVB, 2002, MOTIVATE, 2002).

As the aggregate capacity of a UMTS cell is limited (approx. 2 Mbit/s per 5 MHz bandwidth in the standard case) and shared between all active users, UMTS is preferably used for individual communication purposes. On the other hand, high bandwidth distribution of data in a point-to-multipoint fashion will be more efficient and economical on broadcast platforms such as DAB or DVB. However, as the capacity of a mobile DVB-T system is relatively small (about 10–15 Mbit/s per 8 MHz bandwidth), and cell size is large (>100 km²) this system may not efficiently provide individual data to many users. Both 3G and broadcast platforms, can be seen as complementary, not competitive. Table 6.1 compares the main features of UMTS, DAB and DVB.

Chapter 11 will show further scenarios integrating broadcast and other 4G systems.

<table>
<thead>
<tr>
<th></th>
<th>UMTS</th>
<th>DAB</th>
<th>DVB</th>
</tr>
</thead>
<tbody>
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<td>Spectrum bands</td>
<td>2000 (terrestrial), 2500 (satellite)</td>
<td>1140–1504, 220–228 (UK)</td>
<td>130–260, 430–862 (UK)</td>
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<td>Broadcast, licensed</td>
<td>Broadcast, licensed</td>
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<td>Effective throughput</td>
<td>30–300 kbit/s (per user)</td>
<td>1.5 Mbit/s (shared)</td>
<td>5–30 Mbit/s (shared)</td>
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<td>Low to high</td>
<td>Very high</td>
<td>Low to high</td>
</tr>
<tr>
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<td>High res. video, audio, push Internet</td>
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<td>Wide</td>
<td>Wide</td>
</tr>
<tr>
<td>Deployment cost for wide coverage</td>
<td>Very high</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 6.1. Comparison of UMTS, DAB and DVB
Mobile communications

6.7 Review exercises

1. 2G and 3G systems can both transfer data. Compare these approaches with DAB/DVB and list reasons for and against the use of DAB/DVB.

2. Which web pages would be appropriate for distribution via DAB or DVB?

3. How could location based services and broadcast systems work together?

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