

## Chapter 2

# Digital Terrestrial Broadcasting Systems

The success story of radio and television was originally based on terrestrial transmission. At a suitable location a transmitter was erected that would broadcast radio and TV signals using corresponding equipment and antennas. The listener or viewer was expected to make a certain reception effort. In the case of television, he or she was to erect an antenna on top of the roof of the house with a sufficiently high directivity. Most of the stationary receivers were fed by correspondingly adopted antenna systems.

At the end of the twentieth century the supremacy of terrestrial broadcasting over other distribution paths was definitely lost. Other distribution forms like cable and satellite had significantly overrun the terrestrial platform in many countries. Also, consumption of audio and video content across the Internet has gained ground. However, there are still many regions around the globe where terrestrial broadcasting constitutes the primary means to deliver radio and television programmes to the listeners and viewers.

When it comes to distribution the situation is different in several aspects for television and radio. Today, terrestrial broadcasting is still the most important way to deliver audio programs to the listeners. This is mainly due to the fact that listening to radio is something people do while being involved in other activities such as driving in a car, being at work or during leisure time. Most of these activities can be described by mobile or portable reception conditions using simple portable receivers. The dominance of mobile and portable consumption of radio services is to some extent in contradiction with the planning principles for FM transmission which has not been designed for mobile reception in a vehicle. Originally, only fixed reception using a roof top antenna was foreseen. However, the technological development of new receivers allowed to provide FM services also under portable and mobile receiving conditions.

Analogue terrestrial broadcasting of both radio and television services got under pressure due to two fundamental problems. Firstly, with the advent of digital media such as CDs customers got used to high audio and video quality. This could not always be provided across terrestrial distribution platforms. Moreover, the lack of spectrum did not allow to provide a greater variety of programmes. Hence, more

efficient spectrum usages became an important issue. This was certainly one of the reasons for the development of digital terrestrial broadcasting systems. To this end, primary objectives were a resource saving usage of radio frequencies, high transmission quality, and a large enough data capacity to allow for a sufficient number of attractive programs. In the case of radio, the possibility for mobile reception even at high velocities was an important issue in order to reach in particular vehicles moving on highways and also high velocity trains.

Over the last two decades several digital terrestrial broadcasting systems have been developed. Even though they might target at different services under different conditions, they exhibit several common technical features. Usually, multi-carrier technology is employed and psycho-acoustic or psycho-visual effects are exploited to significantly reduce the amount of data that needs to be transmitted in order to maintain a certain level of quality of the audio or video signals. Furthermore, the transmission is protected against perturbation by the application of sophisticated error protection mechanisms. In the following section some important systems will be described very briefly.

## 2.1 Digital Terrestrial Radio Systems

Many different digital terrestrial broadcasting systems have been proposed for the delivery of radio content over the last 20 years. Since audio content requires only limited data rate between 48 and 192 kBits/s radio content has often been provided piggyback on television systems if spare data rate was available. However, radio and television programmes quite often have different coverage and reception targets. Therefore, it is reasonable to develop broadcasting systems that are optimized for distribution of radio programmes. The three most important systems currently being implemented or already in operation are briefly sketched in the following subsections.

### 2.1.1 *The DAB-Family*

The digital terrestrial broadcasting system known as Digital Audio Broadcast – Terrestrial (T-DAB) has been drafted around 1990 in the framework of the European research and development program Eureka 147 [EUR96]. It has been standardized in 1997 [ETS97a] and rests on four basic pillars, namely an appropriate source coding technology (MPEG-1, layer II [ISO93] also known as MUSICAM), special channel coding algorithms (punctured convolutional codes[Pro89]), multiplexing of several programs, and coded orthogonal frequency division multiplex (COFDM) as the modulation scheme (MS) for the signal transmission.

Originally, the intention was to develop a radio broadcasting system that could become a successor of FM radio in Band II, i.e. 87.5–108.0 MHz. The idea was to

**Table 2.1** The four possible operation modes for T-DAB

|                                   | Mode I | Mode II | Mode III | Mode IV |
|-----------------------------------|--------|---------|----------|---------|
| Number of carriers                | 1536   | 384     | 192      | 768     |
| Carriers spacing $\Delta f$ (kHz) | 1      | 4       | 8        | 2       |
| Symbol length $T_S$ ( $\mu s$ )   | 1246.0 | 311.5   | 155.75   | 623.0   |
| Guard interval $T_G$ ( $\mu s$ )  | 246.0  | 61.5    | 30.75    | 123.0   |

fade out FM transmissions and use the released spectrum for T-DAB. However, it turned out that this was not feasible due to the simple fact that broadcasters were not willing to shut down any analogue FM stations on which their entire business models rely and take the risk of introducing a digital system. Fortunately, T-DAB was designed to be used in Band III (174–230 MHz) and the L-Band (1452–1479.5 MHz) as well. These are actually the primary frequency bands for T-DAB today. However, it seems that even the L-Band is no longer attractive to be used for T-DAB network implementation.

The COFDM of T-DAB utilizes a nominal bandwidth of 1.75 MHz for the generation of the T-DAB signals. Since T-DAB has been designed for mobile reception in the first place a very robust modulation scheme was mandatory. Therefore, the differential modulation DQPSK<sup>1</sup> has been chosen.

Each T-DAB signal is built by a sequence of successive COFDM symbols. A number of 76 symbols is grouped to build a so-called T-DAB frame which is preceded by the null symbol. During the duration of the null symbol there is no power output of the transmitter at all. It allows a first rough synchronization of the receiver. The null symbol is followed by the phase reference symbol whose carrier phases are known to the receiver. This constitutes a repeated starting point for the calculation of the phase differences of the carriers of successive symbols.

Four different sets of COFDM parameters can be selected in order to adapt T-DAB to different coverage environments and coverage targets. Table 2.1 gives an outline of the four sets of allowed COFDM parameters.

The usage of a guard interval allows operating T-DAB in a single frequency network (SFN) mode. This means that all transmitters in a network providing the same content can make use of the same frequency. In areas where signals from several transmitters are received better reception can be provided in contrast to analogue system where under the same conditions harmful interference would result. More information on SFN planning can be found in [Beu04a] and [Beu08].

The integration of four different system variants in the DAB standard enables T-DAB networks for different purposes. The standard mode, mode I, allows the implementation of networks for large area coverage on the basis of few high power transmitters. Preferably, these should not be separated by more than 73 km. This distance corresponds exactly to the route electromagnetic waves can travel within the period of a guard interval of 246.0  $\mu s$ . Inter-transmitter distances beyond this

<sup>1</sup>DQPSK means *Differential Quadrature Phase Shift Keying*.

limit will then give rise to so-called self-interference. More details concerning different aspect of T-DAB technology can be found in [Wor11].

The system design of T-DAB was optimized with respect to providing audio services (plus additional data) for portable and mobile reception conditions. This determined the choice of COFDM parameters but also had an influence on coding schemes and error protection mechanisms employed. T-DAB allows to transmit pictures or figures but it is not foreseen to broadcast movies or video clips.

Since the early days of T-DAB there has been discussion about the system capabilities. It was argued that even for the broadcasting of audio content only the source coding employed for T-DAB would not be efficient enough. Clearly, T-DAB has been standardized almost two decades ago. Therefore, in recent years the argument was repeatedly put forward that MPEG-1, layer II is outdated. As a consequence and since efficient coding schemes had been introduced in the meantime, an enhancement of T-DAB which is called DAB+ was standardized in 2007 [ETS07].

There are two significant changes in comparison to T-DAB. Firstly, MUSICAM was substituted by the more advanced coding scheme HE AAC v2 [ISO05a]. An overview about this coding scheme can be found e.g. in [Mel06]. This allows higher data reduction rates compared to T-DAB. Secondly, the channel coding has been enhanced as well by adding Reed-Solomon coding in order to make the transmission more robust [Ree60].

The audio program is transmitted as a standard T-DAB data stream after having been encoded by HE AAC v2 and Reed-Solomon. This is actually the reason why in principle it is possible to combine DAB and DAB+ content. In other words, a DAB+ multiplex can be build from audio programs coded with MPEG-1, layer II, i.e. standard T-DAB content, together with others that employ HE AAC v2 [Wor11]. The system is very flexible in that respect.

DAB+ has been optimized to carry audio content rather than video. This is reflected in the fact that video codecs are not supported. Furthermore, all features incorporated into T-DAB like packet mode or the possibility to include program associated data are fully maintained. This would allow broadcasters to continue the production of broadcasting content without any change in case T-DAB is to be substituted by DAB+.

The fact that DAB/DAB+ do not support the distribution of video content has been considered as a major drawback by many people, in particular, as access to video content has become more and more important in recent years. Customers are keen to consume audio and video programs while on the road or in trains. Consequently, the idea emerged to build a system that would allow to satisfy exactly this demand. Digital Multimedia Broadcasting (DMB) as an extension of T-DAB has been developed for that purpose.

For the transmission of audio and video programs to portable and mobile receivers most likely being equipped only with rather small screen and limited storage capacity, a mixture of difference source coding schemes has been employed in T-DMB. Since video transmission calls for higher data rates, better coding algorithms than MPEG-1 layer II are needed. Once MPEG-4 was available the door was open for this. In T-DMB, video content is compressed on the basis of MPEG-

4/AVC [ISO05b] while audio programs are encoded with the help of HE AAC v2 [ISO05a]. This choice reflects the fact that T-DMB has been optimized to broadcast television content. Even though, in principle, audio programs can be broadcast as well via DMB, this is usually not recommended.

### ***2.1.2 Digital Radio Mondiale***

Terrestrial radio broadcasting can make use of several different frequency ranges. The DAB family of standards described above is intended to be put into operation in the frequency band III and the L-Band, i.e. 174–230 MHz and 1452–1479.5 MHz respectively. T-DAB systems are considered as broadband systems because they occupy a bandwidth of 1.75 MHz.

Many broadcasters have not been very fond of T-DAB at all. In particular, many commercial broadcasters were and still are reluctant to subscribe to the idea of putting their programmes in a multiplex together with their direct competitors. In a FM world radio services are provided on the basis of the philosophy of “one frequency – one station – one programme”. This gives rise to unique coverage areas and associated quality of service for particular receiving conditions. As a matter of fact, this creates a situation where a direct comparison between different programmes in terms of covered population or area is not straightforward. In relation to negotiations with the advertising industry this can be an advantage.

However, if programmes are bundled into multiplexes all contained programmes have the identical coverage area and they can be received at the same quality of service throughout this area. If a particular programme has more listeners than another one, the difference can no longer be disguised. This may lead to problems when it comes to attract advertisement partners. Certainly, this is one of the reasons why in some countries commercial broadcasters are reluctant to switch to DAB.

A system that follows more closely the traditional analogue philosophy of using spectrum is called Digital Radio Mondiale (DRM). It is a COFDM system like T-DAB, too. According to the standard [ETS05] DRM can be used below 30 MHz, i.e. in the short and medium wave regime. In the first place, DRM is a digital terrestrial broadcasting system which is meant to substitute the analogue AM transmissions. Therefore, it employs a bandwidth of 9 or 10 kHz only. Compared to the T-DAB family of standards this is very narrowband. However, such a bandwidth has been chosen to fit DRM into the existing AM channel raster.

Based on the coding scheme MPEG-4 HE AAC v2 [ISO05a] a bandwidth of 10 kHz allows to obtain between 8 kBits/s and 20 kBits/s depending on the amount of data capacity that needs to be dedicated to achieve a certain degree of ruggedness against propagation perturbations. HE AAC v2 is the right choice for audio content. For speech programs other coding schemes like MPEG-4 CELP or MPEG-4 HVXC (which are both part of the MPEG-4 family) can be utilized. These coding schemes are particularly adapted to these kinds of input signals.

Similar to T-DAB the several program input streams can be bundled into one multiplex but this is not mandatory. Channel coding to protect the transmission

against propagation errors is added, too, as well as time interleaving. In order to allow the receiver to synchronize to the signal pilot carriers are included as well. A very detailed description of the DRM system can be found on the website of the DRM forum [DRM11].

AM broadcasting is still very important in many parts of the world. Countries such as Russia, China, India, Brazil, and many African countries need to cover very large areas. This is where AM transmissions are very well suited due to the far reaching wave propagation conditions in the AM frequency bands. Furthermore, in comparison to analogue AM transmissions DRM offers a quantum leap in terms of quality of service. Typically, DRM in the AM bands can provide radio services with a quality sometimes almost as good as FM in Band II depending on the circumstances.

For Europe AM is no longer a very attractive option. The operational costs of AM networks are high and since the coverage is far reaching the system does not very well suit the needs of regional or local radio broadcasters. However, what is attractive is that like FM one broadcaster could make use of one station, using one frequency to broadcast a single programme.

Therefore, the DRM standard was extended in 2009 to the broadcasting frequency bands up to 174 MHz [ETS09]. This frequency range includes the broadcasting bands I and II, i.e. 45–85 MHz and 87.5–108 MHz. Instead of creating a new standard it was decided to add an additional mode, mode E, which corresponds to the DRM variant to be used at higher frequencies. Mode E of the DRM standard is usually addressed as DRM+.

The most important change is the extension of the occupied bandwidth to 100 kHz. All COFDM parameters are adapted appropriately. This was done in order to make DRM+ compatible with the existing European frequency raster in Band II which is 100 kHz. Therefore, subject to the definition of corresponding sharing and compatibility criteria with FM services DRM+ could be used to migrate from analogue to digital broadcasting also in Band II.

The development and standardization of DRM+ constitutes a large step forward on the way to the digital switch-over for terrestrial radio services. At the beginning of this process T-DAB and DRM+ were considered as competing systems. In the meantime, however, it became clear that they rather should be seen as complements in the sense that DRM+ could build the bridge across which commercial broadcasters could go to digital terrestrial broadcasting because it might better suit their special needs.

Due to the fact that the Band II frequency range is overcrowded in most countries in Europe it was proposed to even further extend the spectrum range for DRM+. The idea is to include the entire Band III range for broadcasting, i.e. 174–230 MHz. The process has been initiated and it can be expected that in the coming years the DRM standard will be modified correspondingly.

### 2.1.3 HD Radio

In the USA, a proprietary standard for a digital terrestrial radio broadcasting system, called HD Radio, has been developed. It can be employed in the AM and FM bands. The development was governed by the intention to support simultaneous operation of legacy analogue services, while allowing for gradual transition to digital services. Currently, the system is implemented in the USA and it is considered in some other countries. The technical specification of the system can be found at [NRS11]. Details about the roll-out can be found in [HDR11] or at [iBi11].

The basic idea of HD Radio is to transmit one or two digital signals alongside with an analogue AM or FM signal. The digital signals employ COFDM modulation techniques. In the FM case, the digital blocks are located at  $\pm 150$  kHz from the centre frequency of the analogue FM signal. In principle, any frequency separation could be used. However, both the US frequency raster of 200 kHz (in contrast to the European 100 kHz raster) and system design aspects suggest such a separation. Adjusting the power levels of the digital side lobes appropriately, i.e. requesting for example a power reduction of 23 dB with respect to the analogue signal, results in a signal configuration which does not lead to unacceptable interference in a typical US frequency environment.

HD Radio can be operated in several different modes. In principle, the analogue signal can be accompanied by one or two digital COFDM components each occupying a bandwidth of optionally 70 or 100 kHz. Therefore, a maximum bandwidth of 400 kHz is occupied. If analogue and digital signals are broadcast in parallel, the system is said to work in hybrid mode. However, at a certain point in time the broadcaster can decide to cease the analogue–digital simulcast and switch off the analogue part in the middle. The released centre spectrum can re-used by transmitting a third COFDM block instead. This would constitute the full digital mode of HD Radio. In hybrid mode, a bit rate of the digital part of 96 kBit/s can be achieved. This allows for up to three digital programmes to be broadcast. One of these, however, has to be identical to the analogue FM programme. In the all-digital mode, the bit rate is up to 300 kBit/s.

Designing HD Radio the way it is known today was driven by the wish to support new digital receivers while retaining backward compatibility with existing analogue receivers under US regulation. Furthermore, existing equipment and infrastructure of radio stations should be utilizable as much as possible in order to minimize conversion costs. Finally, HD Radio should allow for a potential migration to all-digital services when conditions are favorable (e.g. when digital receiver penetration is sufficient).

In particular for public service broadcasters, it is important to note that HD-Radio is a proprietary system that requires annual license fees to be paid by broadcasters.



## 2.2 Digital Terrestrial Television Systems

Several digital terrestrial broadcasting systems for the distribution of television services have been developed and rolled-out in different parts of the world. Some of them are briefly introduced here.

### 2.2.1 *Digital Video Broadcasting (DVB-T)*

In the beginning of the 1990s digital video broadcasting (DVB-T) was developed. Several international organizations like the European Telecommunications Standards Institute (ETSI) [ETS11], the European Committee for Electrotechnical Standardization (CENELEC) [CEN11], and the European Broadcasting Union (EBU) [EBU11] have been actively involved in the development process. DVB-T constitutes an open standard as does T-DAB.<sup>2</sup>

Obviously, television broadcasting has a different focus than audio broadcasting. In the first place, a significantly larger technical effort is necessary than in the case of audio broadcasting. This is related to the data capacities that are required to provide a satisfying television service. They exceed those of typical audio programs by an order of magnitude. This did not change in the digital age either. Furthermore, the acceptable error rates for television broadcasting are significantly smaller at the same time.

Analogue television has been planned for fixed roof top reception. Even though portable analogue reception might be feasible in the vicinity of a transmitter, mobile reception does usually not work. On the contrary, DVB-T was designed to allow reception of television content also under portable and mobile receiving conditions. Portable can refer to both indoor and outdoor portable reception. For mobile reception it might be necessary to foresee a larger receiving effort to be taken such as multiple antennas.

As in the case of T-DAB several television programmes are bundled to form a programme multiplex. A programme consists of video signals, audio signals and pure data. All three types of data undergo data reduction procedures based on MPEG-2. MPEG-2 offers the freedom to assign different data rates to each of the programs in the multiplex in an independent manner. This means the data rate for each of the programs can be adapted to comply with predefined coverage targets. Once the data reduction is accomplished for the video, audio, and data part of a single television program, they are bundled into a sub-multiplex. Together with further programs and service information the DVB-T multiplex is subsequently built.

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<sup>2</sup>There are different definitions of the term open standard. However, publication of all details of the standard accessible to anybody free of royalty fees are common elements of all definitions.



**Table 2.2** Potential COFDM parameters for DVB-T [ETS97b]

| Bandwidth of TV channel [MHz]      | 2k mode |      |       | 8k mode |      |       |
|------------------------------------|---------|------|-------|---------|------|-------|
|                                    | 6       | 7    | 8     | 6       | 7    | 8     |
| Evaluation window $T_W$ [ $\mu$ s] | 298     | 256  | 224   | 1194    | 1024 | 896   |
| Carrier spacing $\Delta f$ [Hz]    | 3348    | 3906 | 4464  | 837     | 977  | 1116  |
| DVB-T bandwidth $B$ [MHz]          | 5.72    | 6.66 | 7.612 | 5.71    | 6.66 | 7.609 |

Channel coding is the next step. Several mechanisms are applied for that purpose. Reed–Solomon and punctured convolutional codes are employed in order to make the transmitted data more rugged against transmission errors. In order to further enhance the Reed–Solomon coding a bit interleaving step is introduced before the convolutional coding is carried out. Finally, the baseband signal is generated by a COFDM modulator. Details of the whole process can be found in [Rei01] or in the standard of DVB-T itself [ETS97b].<sup>3</sup>

One additional important difference between T-DAB and DVB-T is worth mentioning. In the case of T-DAB, the data reduction and channel coding are applied before the multiplex is generated, while for DVB-T the protection against propagation influences is added only after the multiplex has been built. As a consequence, for T-DAB there is no need to decode the entire signal in order to access a particular programme. This is different for DVB-T where first the entire data stream needs to be decoded before the information relating to a particular programme can be further processed.

In Europe, there are several channel rasters used in the spectrum ranges allocated to television broadcasting. Basically, the spectrum bands are subdivided into 8 MHz channels. This holds in particular for the UHF range. In VHF, there are countries, in particular European countries, which use a 7-MHz bandwidth. In other parts of the world, there are also channel rasters based on a 6-MHz spacing. The standardization of DVB-T took account of this and consequently DVB-T can be operated on the basis of the channel bandwidths 6, 7 or 8-MHz, respectively. The system has been designed initially for the 8 MHz case only. Values for system parameters connected to a bandwidth of 6 or 7 MHz can be derived from the 8 MHz values by a corresponding scaling of the underlying system clock by a factor 6/8 and 7/8, respectively.

Apart from the basic decision which bandwidth is to be utilized there are two fundamental system configurations that can be implemented. They differ by the number of carriers employed for the COFDM modulation. It is possible to use either 1705 or 6817 carriers. They are called 2k or 8k mode, respectively. Depending on the used bandwidth different durations of the evaluation window  $T_W$  and the carrier spacing  $\Delta f$  result. Table 2.2 summarizes the most important parameters.

<sup>3</sup>DVB-T has been adopted by the International Telecommunications Union (ITU) as well. In the ITU world it is referred to as system B described in [ITU09].

For the two modes a total of six different guard intervals  $T_G$  have been defined. The four values  $T_G = 224, 112, 56$ , and  $28 \mu s$  can be used in 8k mode while for the 2k mode  $T_G = 56, 28, 14$ , and  $7 \mu s$  are allowed. So, the values  $56 \mu s$  and  $28 \mu s$  are available for both modes. If two transmitters in a DVB-T SFN are separated by more than a distance  $\Delta r = c * T_G$  self-interference can result. The quantity  $c$  denotes the velocity of light. This has a direct impact on the network implementation. As DVB-T is a COFDM system making use of a guard interval large area coverage can be provided in terms of a single frequency network. However, in order to avoid self-interference the only viable option is to employ the 8k mode together with  $T_G = 224 \mu s$ .

In contrast to T-DAB, it is possible to employ several different modulation schemes. Either QPSK, 16-QAM or 64-QAM can be applied.<sup>4</sup> The amount of data that can be transmitted increases from QPSK to 64-QAM. On the other hand, the transmission becomes less rugged at the same time. In fact, from QPSK to 64-QAM an increasing protection ratio between the useful and the unwanted signal contributions has to be taken into account. As a matter of fact, more elaborate network structures might be needed. Fortunately, DVB-T offers the possibility to adjust different error protection levels (EPL). This can be used to counterbalance the consequences of higher MSs.

DVB-T does not use a differential MS. Therefore, it is necessary to dedicate a fraction of the total data capacity for synchronization purposes. A subset of the total number is utilized as pilot carriers. They have precisely defined amplitudes and phases which are known to the receiver. There exist two types of pilots. The first type has fixed positions within the used bandwidth. Furthermore, there are pilots which change their position within the spectrum from one symbol to the next. The way they change their position is purely deterministic and also known to the receiver. This offers additional protection for the synchronization against degradation caused by narrow band fading as a consequence of multi-path propagation conditions.

The net data rate of DVB-T is independent of the chosen mode. Both 2k as well as 8k allow the transmission of the same amount of data per second. It is true that the 8k mode employs four times more carriers than in the 2k case. But, at the same time the symbol length is four times as large for 8k variants, so that after all the data capacity remains the same. The crucial factors determining the data capacity are the MS applied, the EPL, the duration of the guard interval and the bandwidth used. By varying these parameters a huge variety of different operational system variants can be put into practice. Table 2.3 presents the most important possibilities. For a more profound discussion it is referred to [Rei01].

The total data capacity of DVB-T allows to broadcast a multiplex containing 4–6 television programmes in standard quality. However, in principle, it is also possible to utilize the available capacity to broadcast 1–2 programs in HDTV quality. More information on HDTV can be found for example in [Woo06]. Even though from

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<sup>4</sup>QPSK means *Quadrature Phase Shift Keying* whereas QAM stands for *Quadrature Amplitude Modulation*.

**Table 2.3** Net data rates for different DVB-T operation modes in the case of an 8-MHz TV channel[ETS97b]

| MS    | EPL | Net bit rate (Mbits/sec) |                 |                  |                  |
|-------|-----|--------------------------|-----------------|------------------|------------------|
|       |     | $T_G/T_W = 1/4$          | $T_G/T_W = 1/8$ | $T_G/T_W = 1/16$ | $T_G/T_W = 1/32$ |
| QPSK  | 1/2 | 4.98                     | 5.53            | 5.85             | 6.03             |
| QPSK  | 2/3 | 6.64                     | 7.37            | 7.81             | 8.04             |
| QPSK  | 3/4 | 7.46                     | 8.29            | 8.78             | 9.05             |
| QPSK  | 5/6 | 8.29                     | 9.22            | 9.76             | 10.05            |
| QPSK  | 7/8 | 8.71                     | 9.68            | 10.25            | 10.56            |
| 16QAM | 1/2 | 9.95                     | 11.06           | 11.71            | 12.06            |
| 16QAM | 2/3 | 13.27                    | 14.75           | 15.61            | 16.09            |
| 16QAM | 3/4 | 14.93                    | 16.59           | 17.56            | 18.10            |
| 16QAM | 5/6 | 16.59                    | 18.43           | 19.52            | 20.11            |
| 16QAM | 7/8 | 17.42                    | 19.35           | 20.49            | 21.11            |
| 64QAM | 1/2 | 14.93                    | 16.59           | 17.56            | 18.10            |
| 64QAM | 2/3 | 19.91                    | 22.12           | 23.42            | 24.13            |
| 64QAM | 3/4 | 22.39                    | 24.88           | 26.35            | 27.14            |
| 64QAM | 5/6 | 24.88                    | 27.65           | 29.27            | 30.16            |
| 64QAM | 7/8 | 26.13                    | 29.03           | 30.74            | 31.67            |

a technical point of view this is certainly feasible it has to be borne in mind that HDTV via DVB-T will then result in a demand for frequencies similar to that of analogue television.

### 2.2.2 Digital Video Broadcasting-Handheld (DVB-H)

Portable and mobile reception is becoming a more and more important issue both for network providers as well as for providers of any kind of telecommunication services including broadcasters. This led to the demand that also television services should be receivable under these conditions. DVB-T as it has been standardized in [ETS97b] is not the appropriate system. Under certain conditions, e.g. using antenna diversity in order to boost the antenna gain, it is possible to achieve mobile reception for DVB-T, too. But it is not a very efficient way to provide mobile television. In principle, T-DMB could be employed for this (see Sect. 2.1.1). However, the data rates that can be reached might not be sufficient.

Therefore, a variant of DVB-T has been designed which should be able to provide television services in particular for portable and mobile usage with acceptable quality. This means that in the first place a handheld receiver has to be targeted at. This includes multimedia mobile phones with color displays as well as personal digital assistants or pocket PC types of receivers. All these devices have one thing in common, namely that they are rather small, having only light weight and – very important – are energized by batteries. Apart from that, portable and mobile reception naturally includes indoor reception, sometimes even deep indoor, i.e. in

**Table 2.4** COFDM parameters for DVB-H

|                                    | 2k mode    | 4k mode      | 8k mode       |
|------------------------------------|------------|--------------|---------------|
| Number of carriers                 | 1705       | 3409         | 6817          |
| Evaluation window $T_W$ [ $\mu$ s] | 224        | 448          | 896           |
| Guard intervals $T_G$ [ $\mu$ s]   | 7;14;28;56 | 14;28;56;112 | 28;56;112;224 |
| Carrier spacing $\Delta f$ [Hz]    | 4464       | 2232         | 1116          |

basements or deep inside concrete buildings. This requirement is however in conflict with the small dimensions of the receiving devices since handheld devices employ built-in antennas. These usually have rather poor receiving characteristics both in terms of antenna gain as well as directivity. A multi-antenna diversity approach to improve the receiving characteristics is all but impossible under such conditions.

In November 2004, the digital video broadcasting – handheld (DVB-H) standard has been published by ETSI [ETS04a]. DVB-H is to large extent compatible with DVB-T. This has been explicitly taken care of when designing the system because one of the requirements in particular of broadcasters was to be able to implement DVB-H networks with the help of existing DVB-T networks, too.

Nevertheless, several major changes in relation to DVB-T have been introduced. The energy problem linked to battery operation of receiving devices has been tackled by introducing a special power-saving mechanism called time slicing. In the case of DVB-T, the whole data stream has to be decoded before individual programs can be accessed. This poses a severe problem for handheld devices powered by batteries due to high power consumption. For the DVB-H standard this problem has been resolved by transmitting the data associated with a particular service not continuously but only throughout dedicated time slices. In between these slices when other DVB-H services are broadcast the receiver switches to a power-saving mode [ETS04b].

Furthermore, an enhanced error-protection scheme has been incorporated. It is called “multi-protocol-encapsulation – forward error correction” (MPE-FEC). A prerequisite of this is that in contrast to DVB-T where the DVB transport stream is based on MPEG-2, DVB-H is based on IP. This is accomplished by adapting the DVB Data Broadcast Specification to allow for the “Multi-Protocol-Encapsulation” [ETS04b]. On the level of MPE additional forward error protection is added which is MPE-FEC. It basically consists of a special Reed–Solomon code together with a block interleaver. MPE-FEC imposes a frame structure which is aligned with the time slicing technology of DVB-H. More details can be found, for example, in [Kor05] or [Far06].

A further modification of the DVB-T standard for DVB-H relates to the incorporation of an additional COFDM mode. DVB-T allows to use either the 2k or the 8k mode. DVB-H can be operated in terms of a 4k mode as well. Table 2.4 shows the differences of the three modes for some COFDM parameters for the case of a 8-MHz channel.

The 4k mode has been introduced in order to allow for network structures which can benefit from both DVB-T modes, namely 2k and 8k. Due to larger guard

intervals in comparison to 2k mode, 4k-DVB-H operated in SFN mode allows for a less denser network, i.e. the inter-transmitter distance can be increased without causing self-interference. Moreover, the susceptibility to Doppler shift is reduced compared to the 8k mode. This is particularly important in relation to providing services for mobile reception.

### ***2.2.3 Second Generation DVB (DVB-T2)***

An ever increasing demand for capacity, for example to provide higher quality, has triggered the development of a second generation digital terrestrial system called second generation DVB (DVB-T2). Similar to the situation of T-DAB also for DVB-T there has been a discussion about the source coding technology MPEG-2. The DVB-T standard has been issued in 1997 and hence the employed source coding could no longer be considered state-of-the art by 2005. Other algorithms had been developed in the meantime. In particular, MPEG-4 is currently the favored machinery to prepare audio and video data for distribution via terrestrial broadcasting systems. Consequently, DVB-T has been extended to make use of MPEG-4 in order to achieve higher data rates.

More capacity can be used to provide more television content in the first place. On the other hand, having more data capacity available opens the door to transmit services of a higher quality such as HDTV. Furthermore, it is also important that part of the additional data rate can be utilized to increase the amount of redundant information in the digital signal and therefore leads to more robustness against propagation influences. In any case, increasing the data rate by applying better source coding algorithms is certainly a big step forward in terms of more efficient usage of spectrum.

DVB-T2 employs also a COFDM scheme similar to DVB-T. However, additional configurations have been included to better adapt the signal robustness versus data rate to particular coverage targets and propagation conditions. Several options are available such as the number of carriers, guard interval sizes and pilot signals, so that the administrative overheads can be optimized for any target transmission channel.

Apart from the different MSs the most significant modification is certainly the incorporation of more advanced error correction capabilities. Instead of convolutional coding together with Reed–Solomon codes, low density parity check (LDPC) coding combined with Bose–Chaudhuri–Hocquengham (BCH) coding is applied. In addition, rotated constellations provide significant additional robustness under difficult propagation conditions.

Further new technologies have been added as well. One of the new features DVB-T2 offers is called multiple physical layer pipes (PLP). Multiple PLPs enable service-specific robustness. For example, a single DVB-T2 transmission multiplex could carry a mixture of high definition services aiming at household television sets fed by rooftop aerials as well as some low-bit rate, more rugged services aiming at portable television receivers or even radio services. Extended interleaving, including

**Table 2.5** Comparison of DVB-T and DVB-T2

|                  | DVB-T   | DVB-T2   |
|------------------|---|--|
| Error correction | Convolutional coding<br>+ Reed-Solomon,<br>1/2, 2/3, 3/4, 5/6,<br>7/8 | LDPC + BCH,<br>1/2, 3/5, 2/3, 3/4,<br>4/5, 5/6     |
| Modes            | QPSK, 16QAM,<br>64QAM   | QPSK, 16QAM,<br>64QAM, 256QAM                      |
| Guard interval   | 1/4, 1/8, 1/16, 1/32  | 1/4, 19/128, 1/8,<br>119/256, 1/16, 1/32,<br>1/128 |
| FFT Size         | 2k, 8k  | 2k, 4k, 8k, 16k, 32k                               |
| Scattered pilots | 8% of total carrier   | 1%, 2%, 4%, 8% of<br>total carrier                 |
| Continual pilots | 2.6% of total carrier   | 0.35% of total carrier                             |
| Max. data rate   | 29 MBit/s   | 47.8 MBits/s                                       |

bit, cell, time and frequency interleaving have become part of the specification, too. Table 2.5 summarizes these new features by comparing DVB and DVB-T2.

The DVB-T2 specification was approved in 2008 and published by ETSI in September 2009 [ETS09a]. More information and further references on the DVB-T2 system can be found at [DVB11a].

### **2.2.4 Next Generation Handheld DVB (DVB-NGH)**

DVB-H has been a commercial success in only a very limited number of countries. Therefore, DVB Project [DVB11] initiated the development of a successor system which is called Digital Video Broadcast-Next Generation Handheld (DVB-NGH). It should be more efficient than DVB-H in order to cope with the expected increase of media consumption. The standardization process has been started in spring 2010 and the DVB Project targets the publication of the related ETSI standard(s) in 2011. Under optimistic assumptions the first commercial NGH devices could then become available in 2013.

DVB-NGH is based on DVB-T2 which has already been designed to operate in an mobile environment. However, with DVB-NGH emphasis has been put on the investigation of the possibility to adopt further new technologies which are specific for a mobile scenario. Among possible new approaches under study the most important are the so-called multiple input–multiple output (MIMO) techniques. This means to employ multiple antenna systems in order to improve the performance thanks to spatial diversity. In contrast to DVB-T2 where MIMO is envisaged only on the transmitter side it is foreseen to integrate several antennas into the receivers for DVB-NGH as well.

For video encoding, the scalable video coding (SVC) profile of H.264/AVC standard is under study. It divides the signal stream in two or more quality levels, with different transmission protection, decreasing for higher levels. This ensures, even in the most critical reception (indoor), a minimum quality of service, increasing with more favorable reception conditions (outdoor). It is expected that this way more robustness can be achieved under mobile receiving conditions with velocities of upto 350 km/h.

Another important issue concerning mobile reception is power consumption and thus battery run-time. This has been a particular area of effort during the specification of the system. More details can be found at [DVB11b] and the references given there. Whether DVB-NGH is a successful step forward towards attractive mobile television in view of the developments on the mobile communication side remains to be seen.

### ***2.2.5 Integrated Service Digital Broadcasting (ISDB-T)***

In the 1990s, the development of a digital terrestrial broadcasting system for television was started in Japan. Two basic constraints had to be taken into consideration during the system design. Firstly, as it is commonplace in many locations around the planet also in Japan spectrum is considered a scarce resource. Therefore, a new digital terrestrial television system had to make use of the available spectrum in an efficient manner. Secondly, HDTV had been an issue in Japan for quite a long time already in contrast to Europe where this has become a hot topic in recent years only. At the same time standard definition quality broadcasting was very successful in Japan. Therefore, any new system would need to be able to accommodate SD and HD services side by side.

The 1990s did also see the take-off of the Internet. Forecasts predicted a dramatic growth of this kind of electronic communication. Hence, data cast capabilities have been integrated from the very beginning. Also, it was recognized that portable and mobile reception would become more and more important in the future. This was explicitly taken into consideration when defining the system parameters



**Table 2.6** COFDM parameters for ISDB-T

|                         |   |
|-------------------------|---|
| Modulation              | QPSK, DQPSK, 16QAM, 65QAM                                   |
| Error correction coding | Convolutional coding, Reed-Solomon, 1/2, 2/3, 3/4, 5/6, 7/8 |
| Guard interval          | 1/4, 1/8, 1/16, 1/32  |
| Interleaving            | Time, frequency, bit, byte                                  |

of integrated service digital broadcasting (ISDB-T). The Japanese digital terrestrial broadcasting system was standardized in 2001 [ARI01].<sup>5</sup> Since 2003, ISDB-T services are operational in Japan.

ISDB-T is a COFDM system like DVB-T. Actually, both are very similar apart from some fundamental differences. ISDB-T can only employ 6 MHz channels. However, more flexibility is offered in the way the occupied bandwidth is used. In the case of ISDB-T, the entire bandwidth of 6 MHz is subdivided into 13 frequency segments. These segments can be independently allocated to different services such as HDTV, SDTV or mobile TV. So, 13 segments can be used for 1 HD (12 segments) plus 1 mobile TV offer (1 segment) or 3 SDTV programmes ( $3 \times 4$  segments). It has to be noted, however, that this organization of spectrum usage differs from the way DVB-T combines several programmes. In both cases, the transmitted signal contains several programmes. However, in DVB-T programmes are multiplexed on the level of sources while in ISDB-T different COFDM blocks are allocated to different programmes. A subset of system parameters are shown in Table 2.6.

Concerning the source coding ISDB-T employs MPEG-2 for audio and video coding even though also MPEG-4/H.264 AVC can be used in the case of one segment utilized to carry programmes targeting at portable and mobile receiving devices. An overview and further references on ISDB-T are to found at [ISD11].

In 2007, an enhancement development to ISDB-T has been standardized which is called ISDB-T International. The main difference between the two systems is that ISDB-T International employs MPEG-4/H.264 AVC also for SDTV and HDTV. More information can be found at [ISD11a].

### 2.2.6 Advanced Television System Committee (ATSC)

Almost at the same time as the development of a digital terrestrial broadcasting system for television was started in Europe and Japan an effort was made to develop such a system also in the US. Starting from the existing regulatory framework and US market conditions a system was put forward that fundamentally differs

<sup>5</sup>ISDB-T has been adopted by the ITU as well. In the ITU world it is referred to as system C described in [ITU09].

from DVB-T and ISDB-T. It is called Advanced Television System Committee (ATSC) as the organization in charge, i.e. the ATSC. A set of standards are bundled under the ATSC heading in order to define a digital broadcasting system [ATS11]. The standards have been adopted by the FCC in 1996.<sup>6</sup>

ATSC uses TV channels of 6 MHz bandwidth. The first striking difference between ATSC and DVB-T or ISDB-T is that ATSC is not a COFDM system. In contrast to multi-carrier systems ATSC employs a single carrier. This carrier is AM modulated with a baseband signal onto which the broadcasting content has been modulated in terms of a so-called 8VSB modulation. More information on the technical details of the modulation scheme can be found on [ATS11a]. In the 6-MHz channel used for broadcast ATSC, 8VSB carries a gross bit rate of 32 MBit/s, and a net bit rate of 19.39 MBit/s of usable data. The net bit rate is lower due to the addition of forward error correction codes.

The usage of a single carrier system has incontestable disadvantages compared to COFDM systems. First of all, spectrum cannot be used as efficiently as it is possible with the systems described in the preceding sections since the option to deploy SFN networks is not available. Moreover, SFN mode operation rests on the COFDM modulation together with a carefully chosen guard interval. Consequently, such a system is rather robust against interference caused by multi-path propagation conditions which are typically encountered in urban areas.

On the other hand, 8VSB modulation gives rise to better signal-to-noise ratios which is an advantage in terms of ruggedness but also in terms of power consumption both on the side of the transmitter as well as on the receiver side. Using the same transmit power a significant larger area can be covered by ATSC than with a COFDM system. Actually, this was one of the reasons why 8VSB was chosen instead of COFDM because in the US there are large area to be covered with very low population density.

ATSC allows to broadcast up to six SDTV programmes within the bandwidth of a 6-MHz TV channel or a single  $1,920 \times 1,080$  HDTV programme. In 2009, the standard of ATSC was revised in order to include H.264/AVC video coding. Furthermore, ATSC can broadcast 5.1 Dolby Surround sound using Dolby's AC-3 audio coding. The broadcasting content can be enriched by adding several auxiliary datacast services.

It can be noted that the situation is similar to the radio case when comparing Europe and the US. Also, here a system, i.e. HD Radio, has been designed which perfectly fits into the US regulation framework and market but cannot easily be deployed in other environments as well.

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<sup>6</sup>ATSC has been adopted by the ITU as well. In the ITU world, it is referred to as system A described in [ITU09].



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