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BASIC CONCEPTS OF DIGITAL TERRESTRIAL TELEVISION TRANSMISSION SYSTEM

1.1 INTRODUCTION AND HISTORIC REVIEW

Television is a word of Latin and Greek origin meaning “far sight.” In Greek, *tele* means “far” while *visio* is “sight” in Latin. A television (TV) system transmits both audio and video signals to millions of households through electromagnetic waves and is one of the most important means of entertainment as well as information access. With the never-ending technological breakthroughs and the continuously increasing demands of audio and video services, the TV system has evolved over generations with several important developmental periods in less than a century.

1.1.1 Birth and Development of Television Black-and-White TV Era

In the mid-1920s, the Scottish inventor John Logie Baird demonstrated the successful transmission of motion images produced by a scanning disk with the resolution of 30 lines, good enough to discern a human face. In 1928, the first TV signal transmission was carried out in Schenectady, New York, and the world’s first TV station was established by the British Broadcasting Corporation in London eight years later. After World War II, the black-and-white TV era began. Detailed technical and implementation specifications of TV service, including photography, editing, production, broadcasting, transmission, reception, and networking, were gradually formulated. With the ever-growing popularity of TV viewers, the color TV with better watching experience was invented to simulate the real world.

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1.1.2 Analog Color TV Era

In 1940, Peter Carl Goldmark with CBS (Columbia Broadcasting System) Lab invented a color TV system known as the field-sequential system. This system occupied an analog bandwidth of 12 MHz and was carried by 343 lines (~100 lines less than that of the black-and-white TV) at different field scan rates, and hence was incompatible with black-and-white TV. The system started field trial broadcast in 1946, and this is the dawn of the color TV age.

In the 1950s, a color TV signal system called NTSC (National Television Standards Committee) was developed in the United States that was compatible with the black-and-white TV. This scheme uses a luminance–chrominance encoding scheme with red, green, and blue (RGB) primary signals encoded into one luminance signal (Y) and two quadrature-amplitude-modulated color (or chrominance) signals (U and V), and all are transmitted at the same time. An NTSC TV channel occupies 6 MHz bandwidth with the video signal transmitted between 0.5 and 5.45 MHz baseband. The video carrier is 1.25 MHz and the video carrier generates two sidebands, similar to most amplitude-modulated signal, one above the carrier and one below. The sidebands are each 4.2 (5.45–1.25) MHz wide. The entire upper sideband will be transmitted while only 1.25 MHz of the lower sideband (known as a vestigial sideband, VSB) is transmitted. The color subcarrier is 3.579545 MHz above the video carrier and quadrature amplitude modulated with the suppressed carrier while the audio signal is frequency modulated. The NTSC system was deployed in most of North America, parts of South America, Myanmar, South Korea, Taiwan, Japan, the Philippines, and some Pacific island nations and territories. This invention is considered as the landmark of the second stage of the development—the analog color TV era.

A group of French researchers started their work in parallel and this led to the invention of the Sequential Color with Memory (SECAM) system in 1956, and the system was successfully demonstrated in 1961. In the SECAM system, two color difference signals are transmitted alternately (line by line) and frequency modulated by the color subcarrier. This system was adopted by France, the Soviet Union, Eastern European countries (except for Romania and Albania), and Middle East countries and was the first color TV standard in Europe. In 1962, Walter Bruch, a German engineer at Telefunken, put forward the Phase Alternate Line (PAL) system based on the NTSC system in the Federal Republic of Germany. This system performs line-by-line phase inversion of the quadrature component of the chrominance signal in the NTSC system and can effectively offset the phase error and increase the tolerance for differential phase error from ±12° to ±40° in the NTSC system. This new system was adopted by more than 120 countries successively, and in 1972 China decided to adopt it as well.

In the first 70 years of the twentieth century, even though the development of TV had gone through two different phases (black and white and color), the fundamental characteristics of TV signal transmission was unchanged, that is, the TV signal was continuous, or analog, and hence why both black-and-white and color TVs were called analog. In analog TV signal transmission, the amplitude, frequency, phase, or a combination of these parameters of the carrier are changed in accordance with the contents to be transmitted. Linear modulation as well as transmission are therefore achieved in one step. Though simple and straightforward, the analog TV system has the following issues in practice [1]:

1. In terms of the quality, long-term storage, and dissemination of the video programs, the analog TV program source suffers from color–luminance interference, large-area flicker, and poor image definition, and it is difficult to replicate the content for too many times.
2. In terms of signal transmission efficiency, the analog TV network is largely restricted by the bandwidth available. For example, the PAL system can accommodate only one analog video signal and one analog audio signal in 8 MHz bandwidth, and the spectral efficiency is low. In addition, due to cochannel and adjacent-channel interference in neighboring areas, different analog channels have to be used to carry the same programs to different areas to avoid mutual interference. Therefore, the spectral efficiency is further decreased, and it is very difficult to introduce new programs by assigning additional channels in the same region due to the limited available spectrum.
3. In terms of the quality of the signal transmission, the analog TV signal may suffer from "ghosts" from terrestrial broadcasting due to its poor anti-multipath interference ability, which severely affects the viewer's experience. In addition, if the analog TV signal needs to be amplified for a longer transmission distance, the noise accumulation will make the signal quality very poor due to the deteriorating signal-to-noise ratio.
4. In terms of the circuitry, network equipment, and terminals of the analog TV system, the geometric distortion of images is inevitable due to the nonlinearity of the circuitry while the phase distortion of the amplifiers would cause color deviation, aggravating the Ghost phenomenon. In addition, the analog TV system suffers from poor stability, time-domain aliasing, low degree of integration, difficulty in calibration, automatic control, and monitoring.

1.1.3 Digital TV Era

People's demands for better audio and video quality of the TV signal has always been a tremendous driving force for the broadcasting industry, and this led to the invention of the digital television (DTV). Also, due to significant technical breakthroughs in the digital signal processing field (including signal acquisition, recording, compression, storage, distribution, transmission, and reception), the semiconductor industry, and other related industries in the past half century, the broadcasting industry is now embracing the third important stage in its history, i.e. the DTV era.

The visual information received by human eyes in daily life is always analog, and the mission of both the first and second generation of TV broadcasting systems (black and white or color) is to transmit these analog signals to the numerous TV sets with the highest possible quality. Although the definition or the structure of the different DTV systems may be slightly different, the core definition or the major functional blocks are the same. They must include the sampling, quantization, and encoding of analog TV programs to convert them into digital format before they are further processed, recorded, stored, and distributed. The sequence segmentation, scrambling, forward error correction coding, modulation, and up conversion are done in the baseband to form the DTV radio frequency (RF) signals after up conversion at the transmit side. At the receive side, after achieving the system synchronization and signal equalization based on accurate channel estimation, inverse operations on the received signal to that at the transmit side will be performed before the final program can be finally displayed on the TV screen. Digital broadcasting technologies not only provide better reception and display performances compared to its analog counterpart but also introduce new functions that are not available with the analog broadcasting technologies. Considering all the advantages digital technology can provide over its analog counterpart, it is obvious that a DTV system can offer high-quality audio visual experiences and more comprehensive services for consumers. Given all these featured services the DTV system can support, digitization is widely considered a fundamental change and new landmark in the TV broadcasting industry, after the introduction of the black-and-white TV and the color TV.

The advantages of DTV over the traditional analog TV can be summarized as follows:

1. *Better Anti-Interference Ability, No Noise Accumulation, and High-Quality Signals.* After digitization, the analog signal is changed into a binary (two-level) sequence. Unless the amplitude of the noise exceeds a certain level, noise introduced during processing or transmission can be effectively eliminated. Error-free transmission can also be achieved by means of forward error correction coding. During transmission of the DTV signal, the quality of the image and sound received by the users in the coverage is almost identical to that originally transmitted from the TV station. Thus the quality of programs in DTV would not be degraded if the system is well designed, whereas the processing or transmission of the analog TV signals may introduce additional noise which is difficult to remove, and the quality of the image and sound will thus be gradually degraded due to the noise accumulation.
2. *Higher Transmission Efficiency and More Flexibility in Multiplexing.* Digital TV broadcasting can utilize the precious spectrum resources more efficiently. Using terrestrial broadcasting as an example, DTV can use the so-called taboo channel, which is not allowed in analog TV systems, and adopt the single-frequency network (SFN) technology. When SFN is adopted, the same DTV channel can be used to carry the same TV programs with different transmitters to cover a very large area (even the countrywide SFN is possible). Depending on the video coding compression scheme used in a DTV system, one analog TV channel can at least contain one HDTV (high-definition TV) program, or ~10 SDTV (standard-definition TV) programs, or more than 20 DTV programs with VHS quality. Digital TV technology helps reduce the bandwidth requirement for each program, and the spectrum efficiency increases greatly. With the

spectrum saving from DTV broadcasting, broadcasters can use the saved spectrum to either provide more TV programs or offer new services.

3. *Easy to Encrypt and Support Interactive Services.* DTV systems can be extended from a point-to-multipoint broadcasting system to a point-to-point interactive system to support value-added services so that the user can either watch TV programs or search/exchange information based on personal preferences. Digitization in the whole process also facilitates the encryption, and existing encryption techniques can be easily used in the DTV system.
4. *Easy to Store, Process, and Distribute under Network Environment.* The advantage of a DTV signal over its analog counterpart is that it is easy to store, process, and exchange. This facilitates the integrated transmission of images, data, and voice as well as TV program sharing under the network environment.

In summary, the introduction of the DTV concept relies on the latest technical breakthroughs from video compression and information transmission/processing. The digital video compression coding technique is applied to the video source to minimize redundancy with high compression ratio at no (or almost no) loss in quality. The transmission data rate for any TV program is therefore reduced and the transmission efficiency of the whole system is improved. Using error correction coding technology which introduces certain redundancy to the compressed information sequence and the highly efficient digital modulation technologies, better transmission performance in the presence of noise, interference, and other nonperfect conditions can be achieved. Also, due to the latest development in drive and display technologies, DTV systems can surely offer better viewer experience, including sharper images, better color, and more exquisite sound quality, all with improved spectral efficiency.

Looking forward, ultrahigh-definition TV (UHDTV) with UHDTV-1, representing 4K of 3840 × 2160, and UHDTV-2, representing 8 K of 7680 × 4320, systems have been proposed by NHK Science & Technology Research Laboratories and are accepted by the International Telecommunication Union (ITU) [2]. Definitely UHDTV will be one development trend from the display point of view, while three-dimensional (3D) TV technologies following the recent popularity of 3D movies will be another clear trend for the display. From the users' experience point of view, intelligent TV systems will surely attract more and more people due its great simplicity and interactive capability. With the massive development of DTV networks and the increasing number of DTV users, various systems and applications for DTV have been and will continue to be introduced.

There are three types of TV broadcasting networks regardless of whether they are analog or digital: terrestrial (also known as over the air), cable, and satellite TV networks, as shown in Figure 1-1. Satellite TV broadcasting provides coverage of a large area, especially in rural areas with sparse population while cable TV broadcasting uses the coaxial cable to deliver information to the home, with an emphasis on serving densely populated areas. As the most commonly used method of TV broadcasting, the terrestrial system uses transmitting stations to send radio waves over the air to cover certain service areas and users can receive TV programs by all

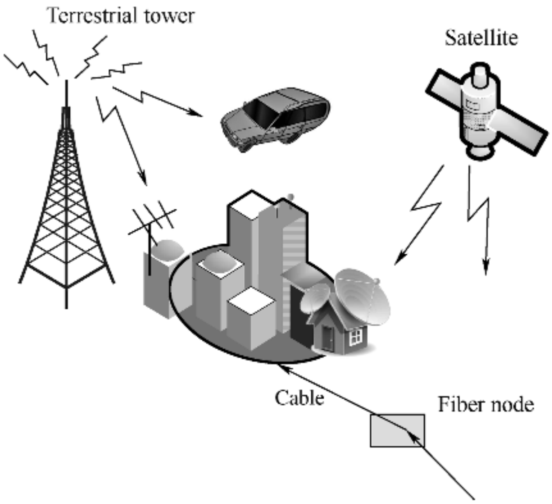

FIGURE 1-1 Classifications of DTV infrastructure.

kinds of receiving antennas and various terminals. This makes it the most direct and reliable approach to reach people nationwide in case of emergency. Statistics show that most people in the world still rely on terrestrial broadcasting networks to receive TV programs, with the percentage in China over 60%. This book mainly focuses on the core technologies and performance of the DTV terrestrial transmission system, which lay down the foundation for the various applications of DTV systems. The key video compression concepts will also be introduced in this chapter.

It is generally acknowledged that the transmission environment for a satellite or cable channel is very similar to the ideal additive white Gaussian noise (AWGN) channel, and adoption of both advanced channel coding and modulation can make the performance of both satellite or cable broadcasting approach the theoretical limit. Being the most commonly used DTV networks worldwide, the Digital Television Terrestrial Broadcasting (DTTB) networks support the largest number of users. The term digital terrestrial television (DTTV or DTT) is also used to refer to the DTTB system, and they are used interchangeably within this book. The terrestrial broadcasting channel, however, presents the harshest transmission conditions due to the high degree of interference, especially with rapid changes in both time delay and amplitude of the multipath interference. This channel is far more complicated compared to that of either satellite or cable networks. The transmission environment for a terrestrial DTV broadcasting channel is obviously not an AWGN channel, and this presents a great challenge for the DTTB system designer. Laboratory test results for DTTB system performance under an AWGN environment may be significantly different from that in the real world. In another words, the coding scheme with decent gain for an AWGN channel may not be applicable to the actual transmission environment. Therefore, system performance should be carefully evaluated when choosing the appropriate transmission scheme not only in an AWGN channel but also in a multipath channel. Another important issue that needs to be addressed is interference from the terrestrial broadcasting network itself. With the inevitable coexistence of both analog and digital terrestrial TV services during the transition period, the system must have strong capability to deal with both adjacent and cochannel interference from the analog transmission and also minimize its interference to the existing broadcasting systems (both analog and digital). This helps guarantee the overall reception performance for all end users.

1.2 MAJOR INTERNATIONAL AND REGIONAL DTV ORGANIZATIONS [3]

Almost all countries and regions have been or are now seriously considering the deployment of DTV broadcasting networks based on the advantages the DTV system can provide. Countries such as the United States, Canada, United Kingdom, Germany, Japan, Netherlands, Finland, Switzerland, South Korean, and Sweden have successfully completed their DTV transition (also known as the digital switch-over or analog switch-off) for their TV broadcast networks, while many countries in the world are still in the process of transitioning their TV broadcasting networks from analog to digital.

1.2.1 International DTV Broadcasting Standards

Even though the application scenarios for terrestrial DTV broadcasting are very similar, different international transmission standards for DTTB systems have been proposed, including ATSC (Advanced Television Systems Committee) by the United States, DVB-T (Digital Video Broadcasting-Terrestrial) by Digital Video Broadcasting organization, ISDB-T (Integrated Service Digital Broadcasting-Terrestrial) by Japan, and DTMB (Digital Terrestrial Television Multimedia Broadcasting) by China. All four DTTB standards have been accepted by the ITU, and they have already been commercialized in many countries and regions worldwide.

In the United States, the Federal Communications Commission (FCC) developed its own DTV broadcasting standard in 1987, which is required to be compatible with the existing NTSC TV standard. In 1992, the ATSC, consisting of members who passed its qualification and obtained authentication, was founded with the aim of creating advanced TV system standards. In the same year, ATSC put forward four candidate proposals, and eventually integrated them into a unified standard by Grand Alliance (GA) in 1995. This standard includes the AC-3 standard for multichannel audio source coding and the MPEG-2 standard for video source coding, system information, and multiplexing. The ATSC/8VSB describes a single-carrier system for terrestrial broadcasting with a throughput of 19.39 Mbps when the system bandwidth is 6 MHz. The ATSC/16VSB is a standard for digital cable TV systems with total throughput of 38.78 Mbps. The ATSC standard is generally believed to have a higher spectral efficiency and power efficiency but usually requires a better receiving environment. The FCC adopted ATSC as the DTV standard for the United States on December 24, 1996, and revised it in 2009. H.264/AVC video coding was introduced to the ATSC system in 2008. All terrestrial TV broadcasters are required to deliver over-the-air TV programs using the ATSC standard, and even cable operators are requested to carry ATSC signals from terrestrial broadcasters. By June 12, 2009, the United States had successfully replaced almost all analog NTSC TV system with ATSC. Canada and South Korea decided to use ATSC as well.

The European Launching Group (ELG) was founded in 1991 with the help of the German government. The ELG realized that mutual respect and trust had to be established between members and became the Digital Video Broadcasting (DVB) program in September 1993. Currently the DVB organization has more than 270 members from nearly 40 countries, who are dedicated to the establishment of a technical system for digital broadcasting systems. The DVB project provides a series of standard frameworks (DVB-C, DVB-S, and DVB-T) for digital video broadcasting systems using different transmission media (e.g., coaxial cable, satellite, and terrestrial) and has announced over 60 DTV broadcasting standards which have been accepted worldwide. The DVB-S is the transmission standard for satellite digital broadcasting in which one analog TV channel which previously delivered one PAL program can now support four DTV programs, and this greatly increases the efficiency of the satellite broadcasting system. The DVB-C is the transmission standard for DTV within the cable TV network in which one analog TV channel that previously delivered one PAL program can now provide four to six DTV programs. The DVB-T is the transmission standard for terrestrial digital broadcasting in which one analog TV channel that previously delivered one PAL program can now provide four to six DTV programs. DVB-T was first published in 1997, and the first broadcasting took place in the United Kingdom in 1998. These standards were all adopted by both the European Telecommunications Standards Institute (ETSI) and ITU. Like the ATSC, the DVB also initially selects MPEG-2 as the standard for audio and video source coding, system information, and multiplexing. Unlike ATSC, DVB-T is a multicarrier system which uses the coded orthogonal frequency division multiplexing (C-OFDM) technology for transmission. Compared to the ATSC, the DVB-T can effectively support both fixed and mobile reception under a complicated environment at very little expense of both spectral and power efficiencies and can support the single-frequency network application well. The extended application, the mobile TV standard DVB-H, has also been introduced. So far, over 60 countries have officially chosen DVB-T as the terrestrial DTV transmission scheme and more than 30 countries are now covered by DVB-T signals, among which some have finished the analog switch-off.

DVB decided to study options for an upgraded DVB-T standard in March 2006 and a formal study group named Technical Module on Next Generation DVB-T was established to develop an advanced modulation scheme as the second-generation digital terrestrial television standard in June 2006. In June 2008, DVB announced its second-generation DTTB standard, known as DVB-T2, and some countries and regions have shown strong interest in adopting it as it can provide more than 30% throughput than the first-generation DTTB standards. More details regarding DVB-T2 will be given in the following chapters.

The Japanese authority started the development of DTV broadcasting standards in 1994. They have also decided to use MPEG-2 as the standard for source coding and system information. The core standards of ISDB, the Japanese standard, are ISDB-S (satellite), ISDB-T (terrestrial), and ISDB-C (cable). Similar to DVB-T, the developers of the ISDB-T standard also chose OFDM as the modulation scheme, while using frequency segmentation to deliver both terrestrial and hand-held TV programs within the same 6-MHz frequency band. In other words, broadband and narrow-band information is transmitted using the same facility and within the same channel for the same coverage area, which greatly facilitates mobile reception by portable devices. This mixed transmission scheme turns out to be a big success to support mobile TV users. Japan finished its analog switch-off in 2012 and ISDB-T has also been adopted in several countries and regions.

The effort on developing the Chinese DTTB standard was officially started in 1999 through the call for proposals from the Chinese government. With several individual proposals being successfully merged in 2005 and an independent test by a third party, the Chinese national DTTB standard was approved by the Standardization Administration of the People's Republic of China and announced on August 18, 2006 [4]. The standard is called "Framing Structure, Channel Coding and Modulation for the Digital TV Broadcasting System," with an official label of GB20600-2006. The English translation is "Digital Television Terrestrial Multimedia Broadcasting (DTMB)." DTMB can satisfy various requirements of broadcasting services, such as HDTV, SDTV, and multimedia data broadcasting. It provides large-area coverage and supports both fixed and as mobile reception. DTMB adopts both single- and multicarrier modulation with a unique frame structure called time-domain synchronous OFDM (TDS-OFDM) and uses the low-density parity code (LDPC). It can therefore provide fast system synchronization, better receiving sensitivity, and excellent system performance against the multipath effect plus the advantage of high spectrum efficiency and flexibility for future extension. The massive deployment of DTMB in China started in 2008 [5] and DTMB became the ITU standard in 2011.

1.2.2 Related International and Regional Organizations

To overcome the engineering problems that arose from the development and deployment of DTV networks and ensure smooth analog-to-digital migration, many international organizations have been working closely and developed a series of DTV-related frameworks and supporting standards. These standards cover all fields related to DTV broadcasting implementation, e.g., compression/decompression, coding/decoding, modulation, framing, frequency allocation, content encryption, conditional access, and signal distribution for the DTV signal. These organizations that have contributed significantly are as follows:

1. The Moving Image Experts Group (MPEG), a working group of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), has the responsibility of developing the standards for compression, decompression, and processing on video, audio,

and a combination of both. The MPEG is a subsidiary organization of the ISO/IEC technical committees dedicated to standardizing the information technology related equipment.

2. The Multimedia and Hypermedia Information Coding Expert Group (MHEG) is another working group under the same subcommittee to which the MPEG belongs. MHEG is dedicated to the coding of both multimedia and hypermedia information by defining the encapsulation format for the multimedia documents such that communication can be performed by a special data format.
3. The Digital Audio Video Council (DAVIC) was founded in Switzerland in 1994 as an international, nonprofit organization with a membership of 220 corporations from 25 countries. The DAVIC is dedicated to providing end-to-end interoperation standards for both digital video and audio between different countries and different applications and delivers open interface and protocols for digital services and applications.
4. The European Broadcasting Union (EBU) is a nongovernmental and nonprofit organization. Any non-European broadcasting company can also become a member of EBU. It supports both DVB projects and the Digital Terrestrial Television Action Group (DigiTAG) as well as work by other standard groups, e.g., European Committee for Electrotechnical Standardization (CENELEC), ETSI, ITU, and IEC.
5. ITU, a subsidiary organization under the United Nations, is perhaps the most important international standardization organization in both the telecommunication and radio communication fields in the world. It is a major publisher for telecommunication technologies, rules, and standards and is dedicated to spectrum management. The ITU Radiocommunication Sector (ITU-R) formulates the DTV broadcasting standards.
6. ETSI and the American National Standards Institute (ANSI) have made a joint effort for the interconnection between video transmission circuits and telecommunication devices, and formulated two major standards: ETS 300 174 (equivalent to ITU-T Rec. J. 81) and ANSI TI. 802.01. These two standards distribute a video channel to each bit stream and describe coding, multiplexing, encryption, and network matching for the video channel so that devices are able to connect to the telecommunication devices directly. ETSI was founded in 1988 aiming to help establish the unified telecommunication market in Europe by formulating the related telecommunication standards. The ETSI technical committee formulated standards for interconnection between public networks and private networks. ETSI's multimedia Codec is used for the interconnection between the broadcasting networks and the telecommunication networks. ANSI's Codec is similar to ETSI's Codec except for the audio interface and the SMPTE control function and has good connection to the telecommunication networks in the United States with a transmission rate of 45 Mbps.
7. IEC is responsible for standardization of electrical equipment. ISO is a nongovernmental international alliance for standardization responsible for

formulating industrial standards. Both ISO and IEC are dedicated to the standardization of global personal and industrial equipment. They have established many joint technical committees in these fields.

8. The JTC 1 (Joint Technical Committee formed by the ISO and IEC) aims at formulating standards for information technology related equipment. JTC 1 establishes a subsidiary organization with the acronym of MPEG to formulate standards for digital video coding and audio compression equipment as described above.
9. The DigiTAG was founded in 1996 and is dedicated to creating a framework for digital terrestrial television applications in accordance with DVB-T specifications. The DigiTAG has around 40 members from 14 countries and is managed through EBU.
10. CENELEC was founded in 1973 and is a nonprofit European organization for electrotechnical standardization. CENELEC members are the national electrotechnical standardization bodies of most European countries. They are dedicated to solving the integration issues between the member states of the European Commission (EC). CENELEC cooperates with technical experts from 19 EC and European Free Trade Association (EFTA) member states to prepare voluntary standards which help facilitate trade between countries, create new markets, cut compliance costs, and support the development of a single European market. CENELEC also works closely with other technical committees in fields such as television and cable classification.

1.3 COMPOSITION OF DTV SYSTEM

1.3.1 Constitution of DTV System

A complete DTV broadcasting system consists of three key components; the transmitting head-end system, transmission system/distribution network, and user terminal system.

1.3.1.1 Transmitting Head-End System for DTV Broadcasting A transmitting head-end system for DTV broadcasting refers to the professional equipment for the TV station, and it mainly comprises the video cameras, video recorders, storage devices, special effect machines, editing machines, subtitling machines, audio and video encoders. Considering MPEG-2 has been used and is still used for video compression by most of DTV standards currently, MPEG-2 will be used as an example for the following discussion. The equipment is mainly used for source processing, information processing, storage, and play as well as other functionalities.

The source processing unit usually includes audio and video encoders, an adaptor, a data encapsulation device, a VOD (video on demand) system, and an editing processor. The MPEG encoder compresses and encodes the recorded audio and video signals into MPEG-2 format; the adaptor adaptively receives MPEG-2 signals from other networks such as synchronous digital hierarchy (SDH) and satellite and then sends them to the multiplexers for multiplexing purposes or to the program libraries for storage as well as further editing; the data encapsulation device helps packetize the Internet Protocol (IP) data and data in other formats used for data broadcasting as well as interactive services into signal format for DTV broadcasting and transmits these signals together with other signals to the users; the VOD system sends the programs and information requested by users; the editing processor edits and helps manage the stored digital programs.

The information processing unit usually comprises the program scheduling system, the user management system, the multiplexer, and the conditional access (CA) system. The program scheduling system is a platform for the service management and system applications. The user management system is responsible for handling users' account information. The multiplexer is the core part of the unit and is responsible for content scheduling, including reselection, allocation, multiplexing, and distribution of the contents gathered from different places to different channels with control of the program scheduling system. CA applies the encryption mechanism to the different program contents via a scrambler and multiplexer so that the program contents are encrypted according to different time periods and user groups according to service modes and user demands. As a new and attractive service of DTV broadcasting, an electric program guide (EPG) helps provide more program information to the end users by inserting the corresponding information into a real-time bit stream at the head end.

1.3.1.2 Transmission System/Distribution Network for DTV Broadcasting The typical networks for transmitting and distributing the DTV signals include terrestrial broadcasting, cable, and satellite.

Statistics show that terrestrial broadcasting is still the most important and popular TV broadcasting scheme. To accommodate the most complicated transmission environment for terrestrial broadcasting, the technologies and functional blocks in the DTTB system are different not only from that of the analog television but also possibly from that of satellite or cable DTV broadcasting. The terrestrial broadcasting transmission network mainly comprises the SFN adapters, exciters, and transmitters.

Cable TV is the major TV transmission method in densely populated regions such as metropolitan areas. Because the signal is sent through a coaxial cable, a very stable quality of signal transmission with a large number of programs can be supported. Cable DTV is also convenient to offer pay-per-view (PPV), VOD, and other bidirectional as well as value-added services.

Satellite TV provides large coverage and its signals can be received in urban, suburban, and rural areas if there exists a line-of-sight (LOS) path between the satellite and the receiving antenna. The equipment in a satellite TV transmission network mainly comprises the satellite modulators, RF power amplifiers, and satellite transponders.

1.3.1.3 User Terminal System for DTV Broadcasting In the DTV era, either a digital TV set or a set-top box (STB) matching the analog TV set is needed to watch DTV programs, and STB is very popular due to its low cost and user convenience

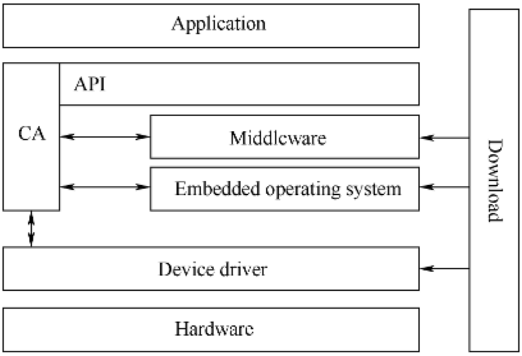

FIGURE 1-2 Layered structure of STB for DTV broadcasting.

during the switch-over period. Generally, each DTV STB consists of the hardware platform and the associated software. The structure of STB can be typically divided into four layers: hardware, device driver, middleware, and application software from the bottom to the top. In addition, there is also a CA module, as shown in Figure 1-2.

1. *Hardware Layer.* This layer provides the hardware platform for STB, which mainly comprises a receiving front end for the DTV broadcasting signal, MPEG-2 decoder, video/audio and graphic processing unit, CPU, memory, and various interface circuitries. The receiving front end for DTV broadcasting includes a tuner and a digital demodulator; the demodulator receives, demodulates, and decodes the RF signal to obtain the MPEG-2 transport streams. The MPEG-2 decoding part includes the demultiplexer, a descrambling engine, and the MPEG-2 decompression module and outputs audio and video data as well as data of other services. The video, audio, and graphic processing part provides digital and analog output of video/audio and graphic processing functions. The CPU and memory module are used to store and run the software and control all other modules. The interface circuitry supports various peripheral interfaces, including the universal serial interface (USB), Ethernet interface, RS232, and the video/audio interface.
2. *Device Driver.* The device driver provides the operating system (usually an embedded real-time operating system) kernel and various hardware drivers for STB.
3. *Middleware Layer.* The middleware layer separates the application software from underlying software which relies on the hardware, and this provides a unified functional interface for applications independent of specific hardware platforms. This layer is typically composed of various virtual machines.
4. *Application Software Layer.* The application software layer performs the functions required by the end user. It can be stored locally or downloaded through the broadcasting network.

5. *CA Module.* A CA module encrypts DTV contents by scrambling the service data based on certain algorithms and sending the encryption keys so that all authorized users can receive and use the service legally while those unauthorized cannot. This function provides the necessary technical means for DTV commercial operation.

1.3.2 Functional Layers of DTV

The DTV system can be divided into three layers, the compression layer, multiplexing layer, and transport layer, as shown in Figure 1-3.

These three functional layers can fully reflect the major differences between digital TV and analog TV broadcasting and can explain why DTV is superior to its analog counterpart from a technical point of view, as given in Table 1-1.

1.3.2.1 Compression Layer Source coding and decoding usually refer to video and audio compression and decompression. One of the most important tasks for the compression, especially for high-definition DTV, is to compress the video signals. Uncompressed SDTV (4:2:2) video has data throughput of 216 Mbps while for HDTV it is about 1.2 Gbps. Therefore, the DTV signal cannot be directly transmitted like the analog TV signal and compression (video encoding) is required to reduce the data rate.

The main function of video encoding technology is to compress the images to reduce the data rate from 1.2 Gbps down to ~20 Mbps for HDTV signals and from

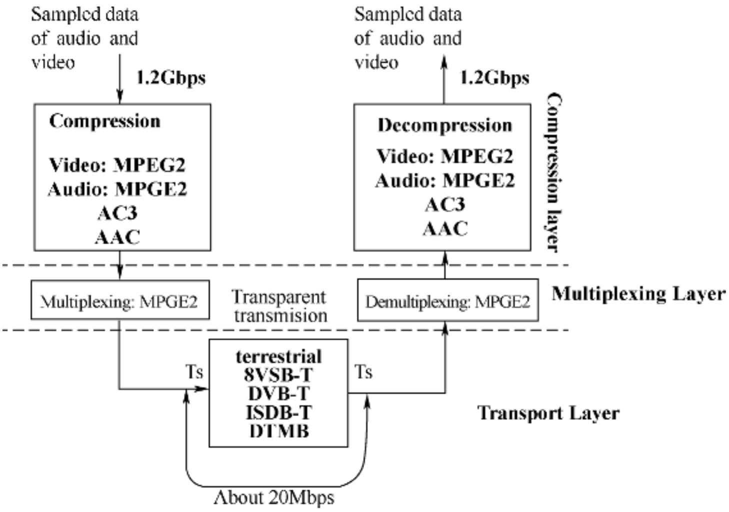

FIGURE 1-3 Functional layers of DTV broadcasting system.

TABLE 1-1 Major Technical Differences between Digital TV and Analog TV Broadcasting

	Digital TV Broadcasting	Analog TV Broadcasting
Source coding and decoding (compression layer)	The data transmission rate for DTV signals without compression is very high and a high-quality video/audio compression scheme must be applied.	Analog TV signal needs no compression.
Multiplexing (multiplexing layer)	The DTV system needs to packetize and multiplex encoded video/audio signals as well as auxiliary data into a single stream to ensure scalability, interactivity, and network interconnectivity.	Analog TV does not need multiplexing.
Channel coding and decoding and modulation and demodulation (transport layer)	The DTV signal no longer has vertical and horizontal flags after both compression and multiplexing. A DTV system uses error correction and equalization to improve the anti-interference capability and more DTV programs can be supported by one analog channel with the use of high-order constellation, and therefore, system transmission efficiency is highly improved.	Analog TV signals are arranged by line and field, and compensation is done with the help of both horizontal and vertical synchronization signals; pre- and postequalization pulse frequency or amplitude modulation is used as the modulation scheme.

216 Mbps to ~4 Mbps for SDTV signals. Video compression can be achieved mainly based on the following:

1. *Time Correlation between Consecutive Images.* Usually, the adjacent images of the video signal are highly correlated, and this helps reduce the information to be transmitted.
2. *Space Correlation in Image.* For example, it will be unnecessary to store all the pixels if the large portion of the image has a single color.
3. *The Visual Characteristics of Human Eye.* The degree of sensitivity of the human eye to the distortion in different portions of an original image is quite

different. For example, the human eye is usually insensitive to the distortions (even the total loss) on the insignificant information of the image. However, the distortion of information to which the human eye is quite sensitive should be minimized if not fully eliminated.

4. *Statistical Characteristics of Input.* The smaller the occurrence probability of the data pattern, the greater the entropy it will be, and this means that a longer code word is required. On the other hand, the larger the occurrence probability of the data pattern, the smaller the entropy, and this means a shorter code word should be assigned.

Similar to video coding and decoding, the main function of audio coding and decoding is to compress the sound information after digitization. Compression of the audio signals is mainly based on the following auditory features of the human ear:

1. *The Auditory Masking Effect.* As to the auditory sense of human beings, the presence of one sound masks the presence of another, and this masking effect is a relatively complex psychological and physiological phenomenon, including both the frequency-domain and time-domain masking effects of the human ear.
2. *Directional Characteristics of Human Ear to Sound.* The ear can barely figure out the direction of acoustic signals with frequency over 2 kHz, and therefore it is unnecessary to repeatedly store the high-frequency components of stereo broadcasting.

There are different international standards for digital image compression, and several examples of them are H.261, mainly used for TV conference; the JPEG standard, mainly used for still images; and the MPEG standard, mainly used for sequential images. As for the HDTV video compression coding and decoding standard, the MPEG-2 standard has been and is still widely used around the world. As for the audio coding, the MPEG-2 standard is used in Europe and Japan. The United States has adopted the Dolby AC-3 scheme with MPEG-2 as an alternate. With the progress in compression technologies, other excellent video compression standards, such as H.264, MPEG-4, AVS, and H.265, have been announced with higher compression ratios for the same image quality. Therefore, the bandwidth needed for video transmission can be further reduced.

1.3.2.2 Multiplexing Layer A multiplexing layer multiplexes several compressed information streams into one single stream, which makes it possible to transport all these data through one analog TV channel. For data flow from the transmitter side, the multiplexing layer packet processes and multiplexes all the output information streams from the encoders of video, audio, auxiliary data, etc., into one stream based on a certain rule and then sends this stream for the channel coding and modulation module before the frequency upconversion. The multiplexing layer is the basis to ensure the extensibility, scalability, and interactivity of the DTV system. There is no multiplexing needed in the analog TV system as video and audio signals are separately modulated and transmitted. Using the widely used MPEG-2 as an example for the DTV multiplex transport standards, the data format after the multiplexing is in transport stream (TS) format with a fixed data packet length of 188 bytes. The TS stream is convenient for the channel transmission, and various time tags used for indication and synchronization can be easily inserted into the TS streams.

Pay TV is very popular now and also widely believed to be an important feature for the future TV. The multiplexing layer helps to support this functionality by CA: The packetized program data are scrambled so that unauthorized receivers are unable to descramble the data and retrieve the original stream.

1.3.2.3 Transport Layer In the DTTB system, the transport layer mainly consists of the channel coding and signal modulation functional blocks, which are the major deterministic factors for DTV transmission system performance. Different DTTB systems adopt different forward error correction coding and modulation schemes with the general schematic diagram shown in Figure 1-4. The cascade correcting codes, including outer error correction code, time-domain interleaving, inner error correction code, and time- and/or frequency-domain interleaving, are basically applied to the error correction coding module. For the existing DTTB systems, there are two modulation technologies: single-carrier and multicarrier modulations. American ATSC [6] and the DTMB system (with parameter $C = 1$) [4] are examples of systems using single-carrier modulation, while the European DVB-T system (using coded-OFDM [7]), Japanese ISDB-T BST system (using segmented OFDM technology [8]), and the DTMB system (with $C = 3780$) (using TDS-OFDM) are examples of systems using multicarrier modulation.

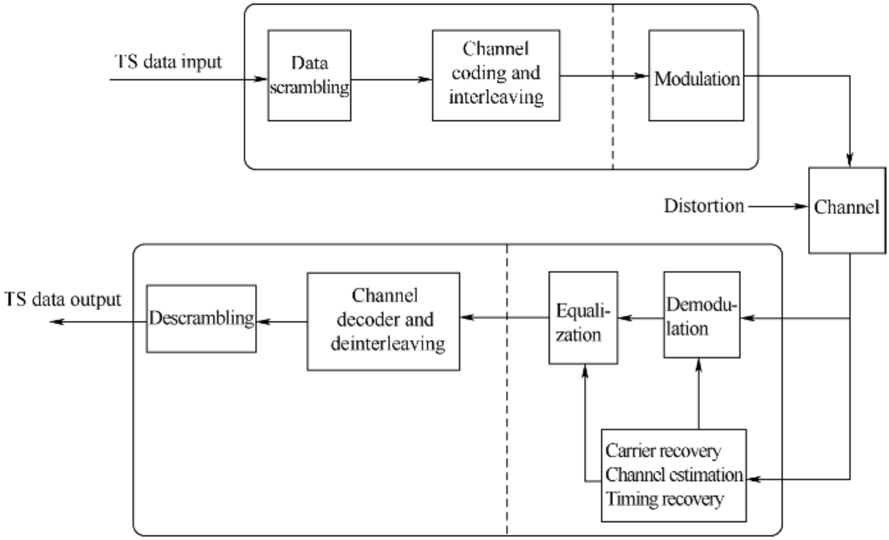

FIGURE 1-4 Transport layer of DTV.

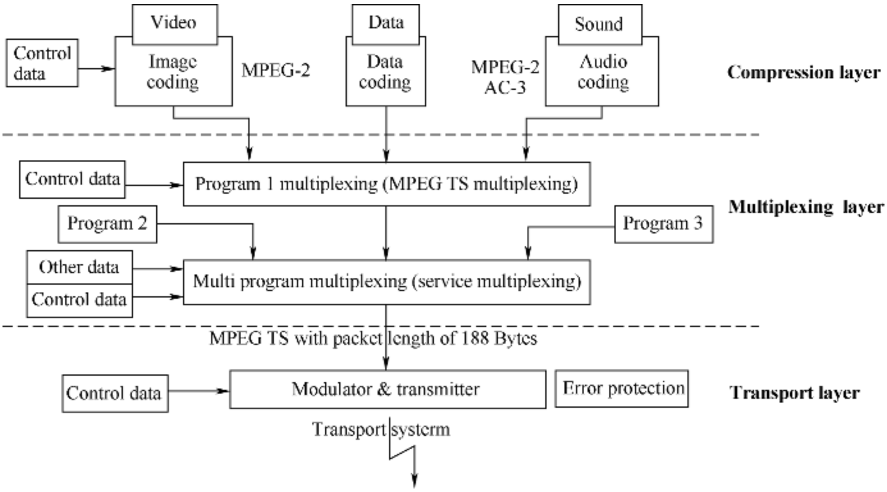

FIGURE 1-5 Layered structure of head-end transmitting system for DTV broadcasting.

This book focuses on the transport layer, with the transmission technologies involved in various DTTB standards described one by one in the following chapters. The compression and multiplexing layers are only introduced in this chapter to give readers an idea of the general principles so they have a complete understanding of the DTV system as well as the relationship between each of these two layers and the transport layer, as shown in Figures 1-5 and 1-6.

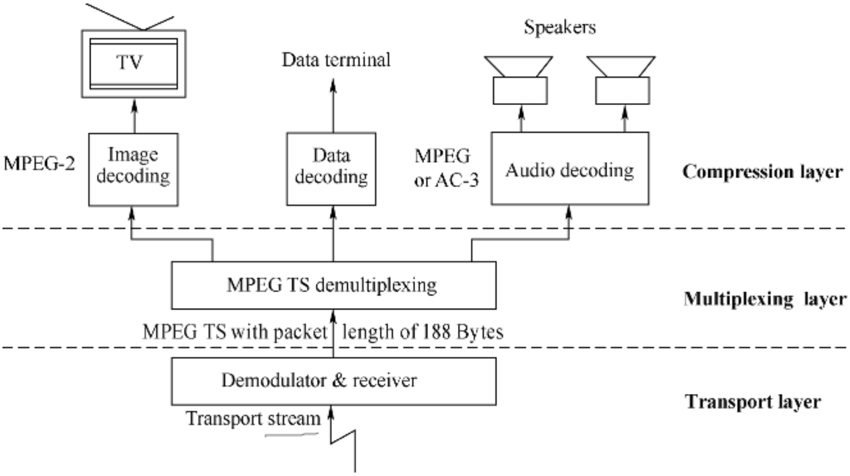

FIGURE 1-6 Layered structure of user terminal system for DTV broadcasting.

TABLE 1-2 Parameters of Video Formats of SDTV and HDTV

Category	Image Resolution	Scanning Mode	Display Mode (Aspect Ratio)
HDTV	1920 × 1080	P; I	16:9
	1920 × 1035; 1440 × 1152	I	16:9; 4:3
	1280 × 720	P	16:9
SDTV	576 or 480 × (720, 640, 544, 480, 352)	I; P	16:9; 4:3
	576 or 480 × (720, 640, 544, 480, 352)		

1.4 COMPRESSION LAYER AND MULTIPLEXING LAYER

1.4.1 Image Format

The major difference between HDTV and SDTV lies in the image quality (in terms of image resolution or definition), and therefore the bandwidth needed for the transmission is different. From the perspective of visual effects, the image quality of HDTV (over 1000 lines) reaches or comes close to the level of the 35-mm wide-screen film. The image quality of SDTV roughly corresponds to images with resolution of about 500 lines and is equivalent to that of DVD. If the MPEG-2 compression encoding standard is used for SDTV, the video code rate will be ~4 Mbps while that for HDTV will be around 20 Mbps. The parameters of SDTV and HDTV video formats are listed in Table 1-2, where I represents interlaced scanning and P represents progressive scanning.

Digital TV has various display modes (e.g., 4:3 and 16:9), among which the 16:9 wide-screen mode is the most common in HDTV. According to different display modes, there are different MPEG image formats. The basic formats are classified into four levels: low level, main level, high-level narrow screen (4:3), and high-level wide screen (16:9). For example, the parameters of the image format of the high-level wide screen are shown in Table 1-3.

1.4.2 Compression Modes for DTV Signal

The ITU BT.601 standard is believed to be the first formal step for the parameter standardization of DTV broadcasting systems. It specifies the basic parameters of signal coding for the TV studio using the 625-line (PAL) or 525-line (NTSC) system.

TABLE 1-3 Parameters of Image Format for Wide Screen (16:9)

Corresponding TV system	625 lines/50 fields/4:3
Wide-screen TV system	1250 lines/50 fields/16:9
Effective number of pixels	1920 × 1080
Sampling frequency	Luminance: 72 MHz; chrominance: 36 MHz
Line frequency	31250 Hz
Image bandwidth	27 MHz

The BT.601 standard specifies video formats for TV studios as well as the coding mode, the sampling rate, and the sampling structure for the color TV signal as follows:

1. Component coding should be used for color DTV signals, which means that composite color TV signals are first separated into luminance signal (denoted as Y) and chrominance signals (denoted as B–Y and R–Y, respectively) before they are quantized, encoded separately, and then combined into one DTV signal.
2. Using 4:2:2 coding as an example, the sampling frequency of the luminance signals and color difference signals are specified as 13.5 and 6.75 MHz, respectively, and in a quadrature structure. That is, the R–Y and B–Y are sampled on each line (and repeated by line, field, and frame) at the same sampling position as the Y signal having the odd index. With this arrangement, the sampling structure for the image is fixed, and the relative position of each sample point will be unchanged on the TV screen.
3. Linear PCM coding is to be performed on both luminance signal Y and two color difference signals (R–Y, B–Y), and the value of each sampling point is quantized by 8 bits. It also specifies that the digital coding not use the entire dynamic range of analog-to-digital (A/D) conversion; only 220 quantized levels are allocated to the luminance signal with the black level corresponding to the quantized level 16 and white level corresponding to the quantized level 235. There are 224 quantized levels allocated to each color difference signal with the zero level of the color difference signal corresponding to the quantized level 128.

In summary, the data throughput in component signal coding is very high. Taking the 4:2:2 coding standard as an example, the data rate of the bit stream is $13.5 \times 8 + 6.75 \times 8 \times 2 = 216$ Mbps, and this is only the sampling frequency required for the SDTV definition, as shown in Table 1-3. The sampling frequency for HDTV is 72 MHz for the luminance signal and 36 MHz for the chrominance signal, and the corresponding data rate is around 1.2 Gbps. Therefore, the challenge for DTV is how to adopt an efficient compression method to eliminate the redundant information (redundancy) from the DTV signal so as to reduce the required transmission rate by orders of magnitude.

The 4:2:2 encoding mode also has a variant mode of 4:2:0, and this format is widely applied to DTV transmission systems when the bandwidth is limited. In this mode, the chrominance signal is sampled on every other line to drop the vertical sampling frequency to one-half of the horizontal sampling frequency, and it helps to decrease 25% of the data.

1.4.3 MPEG-2 for Video Compression

MPEG-2 is a frame-based video compression standard and supports both interlaced scanning video and different aspect ratios. MPEG-2 is a hierarchical compression scheme to adapt the different channel transmission conditions. This standard

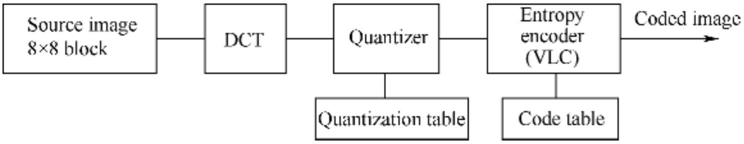

FIGURE 1-7 Intraframe coding scheme based on DCT.

defines the syntax of the data streams and the decoding process, not the encoding process.

The MPEG-2 compression scheme includes intraframe and interframe coding. During the compression, intraframe coding is performed by utilizing the spatial correlation within a frame while interframe coding uses time as a parameter and utilizes the adjacent image frames as a reference for the prediction and estimation to eliminate the temporal redundancy of video signals, and this can reduce the data rate significantly.

1.4.4 Intraframe Coding

Intraframe coding mainly comprises the discrete cosine transform (DCT) and quantizer and entropy coding, as shown in Figure 1-7.

1.4.4.1 Discrete Cosine Transform DCT is used for spatial transform in MPEG-2, which is performed in an 8×8 image block to generate one 8×8 DCT coefficient block. In general, the energy of the image will concentrate on the a few low-frequency DCT components after DCT, i.e., only values for a few lower-frequency components on the left upper corner of the 8×8 DCT coefficient block are greater, while the rest are very small. This makes it possible to transmit only those large values in the DCT coefficient block without significantly degrading the image quality.

DCT does not directly compress the images but helps concentrate the energy of the image, which is the foundation of video compression.

1.4.4.2 Quantizer In MPEG-2, quantization is performed on the DCT coefficients of the image by dividing the DCT coefficient by the quantization step (also known as quantization precision). The smaller the quantization step, the more accurate the quantization precision will be. As more detailed information of the image is preserved, the required transmission bandwidth is higher. According to the visual reaction principle, different DCT coefficients have different significance to the human eye; hence, an encoder will apply the different quantization precisions to the 64 DCT coefficients to ensure enough specific frequency information is contained in DCT while the quantization precision does not exceed the required limit. Among the DCT coefficients, the lower frequency coefficients have more significance to the human eye; therefore, a simple quantization step should be used. On the other hand, as high-frequency coefficients have much less significance to the human eye, a more complex quantization step is appropriate. In general, most high-frequency coefficients in the DCT block will become zero after quantization, which means the information loss caused by quantization cannot be recovered or the process is irreversible.

1.4.4.3 Zig-Zag Scanning In MPEG-2, the two-dimensional 8 × 8 array generated by DCT has to be converted into a one-dimensional array before transmission, and there are two conversion methods or so-called scanning modes: zig-zag scanning and interlaced scanning. Zig-zag scanning is commonly used. After quantization, most nonzero DCT coefficients will be within the upper left corner of the 8 × 8 matrix (i.e., low-frequency component area). These nonzero DCT coefficients will be at the beginning of the one-dimensional array after zig-zag scanning, followed by a long string of zeros (due to the quantization). This creates a favorable condition for run length coding.

1.4.4.4 Entropy Coding Coding on the bit stream generated by the quantization must be performed before transmission. A simple coding method uses a fixed-length code, i.e., every quantized coefficient value is expressed by a fixed number of bits, and this method has very low efficiency. Adoption of entropy coding can improve coding efficiency as it has the advantages of the statistical characteristics of the signals and therefore can reduce the averaged bit rate of the coded signal. Huffman coding is one of the most commonly used entropy coding and is adopted by MPEG-2 video compression systems. In Huffman coding, a code table is created after determining the probability of all the coded signals so that fewer bits are assigned to represent signals with high probability while more bits are assigned to represent signals with low probability, which makes the average length of the overall code streams as short as possible.

1.4.4.5 Channel Buffer The data rate of the bit streams generated by entropy coding generally varies with the statistical characteristics of the video images while the data throughput assigned for transmission is usually constant in practice. It is therefore required to introduce the channel buffer before the coded bit stream is sent to the transmitter. The bit stream is written into the channel buffer from the entropy encoder at the variable bit rate and read out at the nominal constant data throughput of the transmission system. The size of the buffer (or the so-called capacity) is preset but the instantaneous output bit rate of the encoder is often significantly above or below the data throughput of the transmission system, and this may cause overflow or underflow of the buffer. Therefore the control mechanism for the buffer is required to adjust the bit rate of the encoder by controlling the compression algorithm through feedback so that the written-in data rate and read-out data rate of the buffer eventually become balanced. Buffer control to the compression algorithm is achieved by changing the quantization step of the quantizer. When the instantaneous output rate of the encoder is too high and overflow of the buffer immediately occurs, the quantization step should be increased to lower the coded bit rate at the cost of the image quality. If the instantaneous output rate of the encoder is too low and underflow of the buffer is about to happen, the quantization step is decreased to increase the coded bit rate.

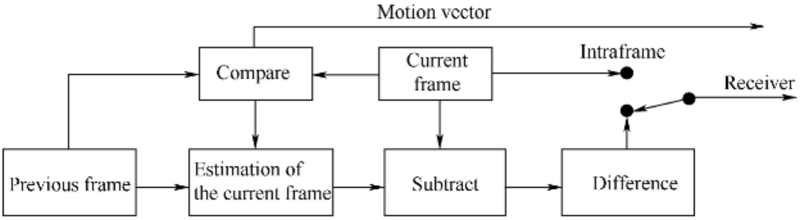

FIGURE 1-8 Motion estimation and compensation.

1.4.5 Interframe Coding Method

MPEG-2 is a frame-based compression scheme and is able to reduce interframe redundancy. In general, there is not too much difference between adjacent frames, and the MPEG-2 scheme tries to predict the current frame by the previous frame (as the reference frame), called interframe prediction. Popular methods of interframe coding are motion estimation and compensation, as shown in Figure 1-8.

When motion estimation is used for interframe coding, the compressed image is estimated by referring to the image of the reference frame. The accuracy of motion estimation is very important to the compression effects. For good motion estimation, only a very few bits are left after subtracting the estimated image from the current image for the compression. Motion estimation is performed on each macroblock to compute the position displacement at the corresponding positions between the current and reference images. While the basic coding unit used to eliminate the spatial redundancy in DCT an is 8×8 block, motion compensation is usually based on 16×16 blocks denoted as macroblocks. Position displacement is described by a motion vector characterizing this displacement along both horizontal and vertical directions. As mentioned before, the MPEG-2 standard only defines the decoding process and motion estimation can be realized in many ways, and hence the performance of different processing methods are also different. The most important parameter is the searching range for interframe motion estimation, and there are many modes to achieve motion estimation and prediction. Those modes include forward estimation, which predicts the macroblocks in the current frame by the corresponding macroblocks in the previous frame; backward estimation, which predicts the macroblocks in the current frame by the corresponding macroblocks in the future frame; and internal coding, which does not make the macroblock prediction. These prediction modes are chosen based on the picture type.

There are three common types of pictures in the MPEG-2 standard: I-, P-, and B-frames. The I-frame, the intraframe, should be coded without referring to any other pictures. Since its compression cannot eliminate the temporal redundancy, the compression ratio is quite limited. The P-frame is the predictive frame. The compression of the P-frame utilizes the previous I- or P-frame picture for the motion estimation and prediction on the current picture and uses the previous picture as the reference for the sequential prediction. This type of picture can eliminate both temporal and spatial redundancies at the same time, and the compression ratio is

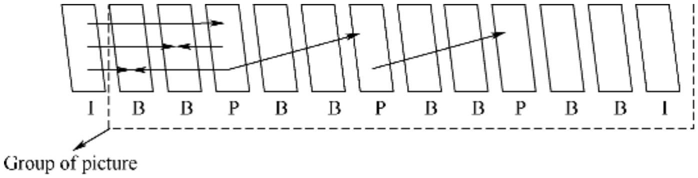

FIGURE 1-9 Structure of GOP.

higher than that of the I-frame picture. The B-frame is the bidirectional predicted picture, and its compression utilizes both previous and future I- or P-frame pictures at the same time to perform motion estimation. To support the backward prediction, which needs future frames, the encoder must buffer and readjust the input order of the image frames so that the B-frame can refer to the future frame picture for prediction. Continuous B-frame pictures would cause certain delay; however, this type of picture has the highest compression ratio.

A group of pictures (GOP) consists of all three types of pictures mentioned above and is shown in Figure 1-9. Two parameters are used for GOP description and they are N (the number of pictures in the group) and M (the spacing of the predictive pictures). Each GOP represents the integrity of a series of pictures for coding, and any editing and division of the coded bit stream must be performed between GOPs.

1.4.6 Audio Compression

The sampling frequency of audio signals is relatively low compared to that of video signals. Part 3 of the MPEG-1 standard is the digital audio coding standard, which is divided into three layers (1, 2, and 3 in ascending order) according to their performance and complexity; a higher layer is backward compatible with a lower layer. The three sampling frequencies are 32, 44.1, and 48 kHz and consist of a monochannel, a dual channel, and other sound modes. A cyclic redundancy check (CRC) code is applied to the code stream to improve the error correction ability at the receiver. An example of an MPEG audio signal encoder is shown in Figure 1-10. A digital audio signal is split into a number of subband signals by the analysis filter

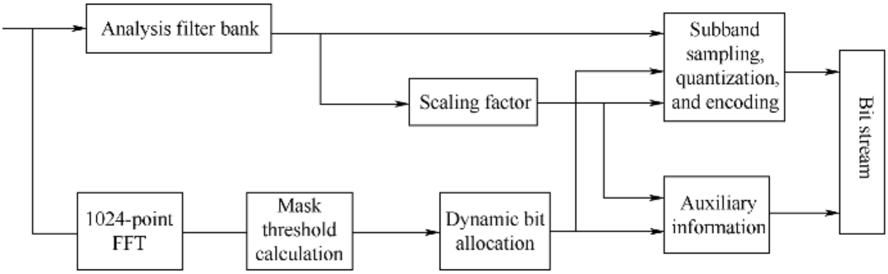

FIGURE 1-10 MPEG audio encoder.

bank, and each subband signal is then sampled, quantized, and coded separately. The quantization steps and the number of bits for quantization are dynamically allocated based on the psychoacoustic model. More accurate spectral analysis is performed on a group of sample points after fast Fourier transform (FFT) to compute the masking threshold. The allocation of the sampling points to each subband signal is different, and the quantization levels of each subband signal are also provided to the decoder as the auxiliary information.

Part 3 of the MPEG-2 standard introduces new digital audio coding methods. It is compatible with Part 3 of the MPEG-1 standard and supports multichannel coding (front center C, front left L, front right R, surround left Ls, surround right Rs, and low-frequency enhancement LFE). The MPEG-2 Advanced Audio Coding (AAC) as the high-quality digital audio coding standard was added to the Part 7 of the MPEG-2 standard.

1.4.7 MPEG-2 Coding

The MPEG-2 coding process is shown in Figure 1-11. The left is the compression layer and the right is the multiplexing layer. The compression layer encoding consists of both video and audio encodings in compliance with ISO/IEC13818-2 and ISO/IEC 13818-3, respectively, and both video and audio elementary streams (ESs) are generated after encoding. In the MPEG-2 multiplexing layer, each ES is packed into the packetized ES (PES) after a packet header is added. Each PES packet and finally video and audio PESs are multiplexed into one TS or program stream (PS). The multiplexing layer complies with the ISO/IEC 13818-1 standard. PES is a logical structure for the multiplexing process and is not used for either storage or transmission. PS has a flexible packet length that is suitable for video storage and editing and is applicable to DVD, interactive multimedia services, etc., with either fixed or variable code rates. TS is generally suitable for channel transmission such as DTV broadcasting.

Based on the above introduction and Figure 1-11, MPEG-2 encoding can be divided into three steps and each generates the ES, PES, and TS, respectively. Each

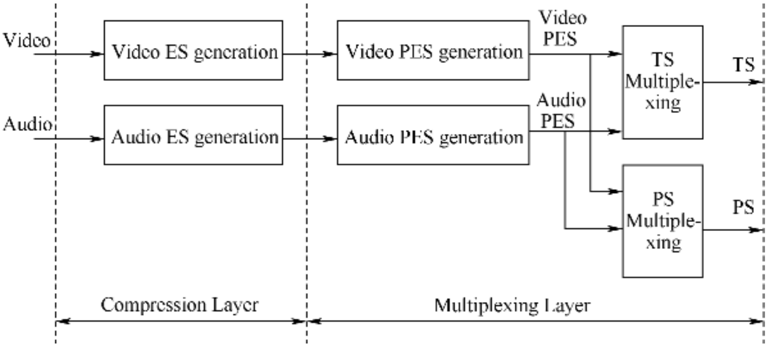

FIGURE 1-11 Generation process of MPEG-2 transport stream.

ES contains the compressed video, audio, and auxiliary data. A packet header is added to the whole or part of the ES to form the PES packet with fixed or variable packet length. A packet header is added to the whole or part of the PES packet to create the TS packet with fixed packet length of 188 bytes. A series of TS packets of audio, video, and auxiliary information are multiplexed together based on certain rules to generate the transport stream.

1.4.8 MPEG-2 Multiplexing

For DTV, MPEG-2 TS multiplexing includes two steps. In the first step, various transport streams of the audio, video, and data PES packets of the same program are multiplexed by a certain ratio to generate a single transport stream for the program [program-specific information (PSI) should be inserted during multiplexing for program identification purposes], so that one complete program transport stream is generated (this process is performed by the MPEG-2 encoder). In the second step, TSs of the different programs are multiplexed into one TS containing multiple programs, and this process is generally performed by a special multiplexer. Multiple DTV programs can be transported using one analog TV channel with bandwidth of 6, 7 or 8 MHz after video–audio compression and digital modulation. To fully utilize the most valuable spectrum resources, TSs of multiple programs are multiplexed again, and this is the second step of the multiplexing. The multiplexer is one of the core units in the DTV video compression system, which packetizes multiple DTV programs based on the protocols specified by MPEG-2 multiplexing layer and provides the interface for the channel transmission. In the TS, the program association table (PAT) and program map table (PMT) are necessary for the multiplexing, and all multiplexed programs are decoded based on the indications of the PAT and the packet identifier (PID) in the PMT.

The multiplexing layer multiplexes the synchronized audio and video information of multiple programs into a single serial bit stream, and synchronization of both the audio and video streams is crucial to the multiplexing layer. The key point of the first step is to introduce an adjustment field by the program clock reference (PCR) to restore the system clock. The key operations for the second step are the readjustment of the PCR field and collection and reconstruction of the PSI. The modifications on the TS within the multiplexer can be performed based on the new PSI.

1.4.9 Transport Stream

Every TS packet as shown in Figure 1-12 starts with 0 × 47 for the synchronization and its payload content is distinguished by the PID. As the option of the adaptation field in the TS packet header, the program clock reference (PCR) provides the information of time synchronization to the decoder. The synchronization for audio signals is relatively easy as they are sampled in order. However, a mechanism for retrieving each video frame sequence is required due to the frame rearrangement of video signals. Both the audio and video encoders use the same system clock of 27 MHz as the synchronization reference for the programs, and this system clock

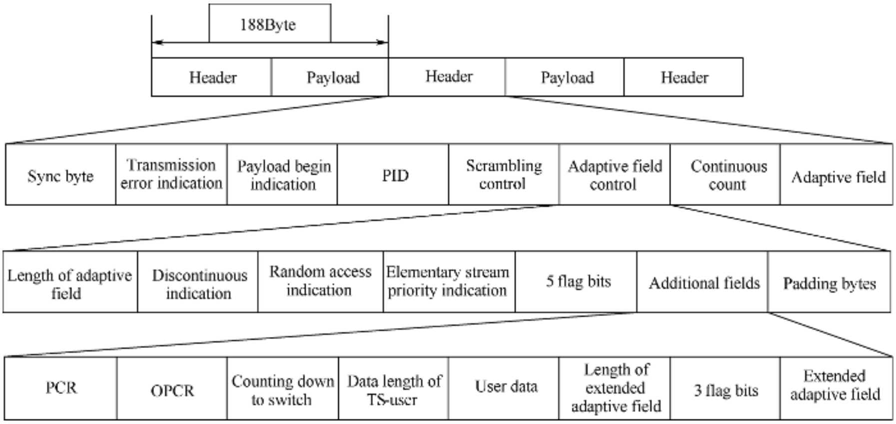

FIGURE 1-12 Syntax structure of transport layer for MPEG-2 TS.

reference information is carried by the PCR field within the TS (for the TS containing multiple programs, each program has its own system synchronization information). The fields indicating audio/video signal decoding and display time are called the decoding time stamp (DTS) and the presentation time stamp (PTS), respectively. At the transmitter side, the PCR of all programs are introduced to the TS while the PTS and DTS based on the PCR are introduced to the PES. At the receiver, the decoder restores the STC (system time clock) according to the PCR value of the program to be received from the TS and adjusts the time delay for the data in the buffer according to the PTS and DTS values to synchronize the time with the transmitter. After time synchronization is achieved, both audio and video data are decoded and displayed according to the DTS and PTS in the PES so as to realize the synchronization of the system clock, audio and video, and also the synchronization between audio and video signals. However, the "synchronization" used here does not necessarily mean the synchronization of the reception and reproduction with the pictures and the sound from the studio in real time. In fact, it is always necessary to have buffers at both transmitter and receiver and the synchronization for the broadcasting services is considered to be achieved if the system only has a constant delay between the transmitter and receiver.

To extract management and synchronization information from programs, the information related to decoding at the receiver, such as PSI and SI (service information), needs to be inserted into the TS to make sure that the receiver can identify the program to be received. PSI is equivalent to the PES packet from the syntax level, which belongs to the lower level TS packet structure. PSI is classified into four different tables as listed in Table 1-4, which become the payload in TS packets after segmentation. The PIDs of these TS packets are specified or given from the PAT. Each transport stream requires at least one complete and effective PAT, which provides the program number and the PID of the TS packet containing the program map table (PMT PID) to make sure that the program can be received well.

TABLE 1-4 Four Different Tables Defined in PSI

Table Name	Stream Type	PID	Description
Program association table (PAT)	ITU-T Res. H.222.0, ISO/IEC 13818-1	0 × 00	It is the root directory of PSI information and information of all programs will be searched from PAT.
Program map table (PMT)	ITU-T Res. H.222.0, ISO/IEC 13818-1	Specified by PAT	The PID of all programs in the TS points to this table. The corresponding PMT can be found by the program PID, and the PID of all the video, audio, data, and related information of the program can be found in the PMT table.
Network information table (NIT)	Private	Specified by PAT	Physical network parameters: FDM frequency, transmitter ID, etc.
Conditional access table (CAT)	ITU-T Res. H.222.0, ISO/IEC 13818-1	0 × 01	All the entitlement management messages (EMMs) for the encrypted/scrambled network are provided.

PMT provides the elementary PID of the TS packet belonging to the PES, and the corresponding TS packet can therefore be identified within the stream. PCR is generally included in the TS packet with the same PID within the video PES or is contained in a separate TS packet. The conditional access table (CAT) describes the ES encryption mode for a program and only the authorized decoder can receive the key from CAT for decoding the corresponding data stream. The content in the network information table (NIT) belongs to the service provider for private use, is not defined by the MPEG-2 standard, and is typically contained in the user-selected services. Since PSI is very important, and CRC is utilized.

1. The decoder first extracts the effective PAT, then finds the PID from the TS packet containing the PMT of the desired programs, and finally restores the PMT from the payload in the corresponding TS packet. After that, it extracts PCR and the corresponding audio and video PES of the desired program from the payload of the corresponding TS packets based on the PID in PMT. Eventually, the audio and video ESs are restored from the PES load.
2. The MPEG-2 standard specifies that all program information tables must be sent at a certain frequency of not less than 20 times per second so that the decoder can obtain the PSI in a timely fashion and perform the decoding correctly. However, if there is only PSI in MPEG-2, the receiving decoder still cannot provide the corresponding service information of the program. Therefore, the standard also defines the auxiliary SI to complement the PSI. SI mainly

provides the necessary information for the reception and decoding, such as program type, program time, program source, etc.

Additional tables such as the running status table (RST) and EPG are also multiplexed into the data stream to assist in successful reception. In this way, multiple programs can be carried by one physical channel using MPEG-2 transport stream multiplexing technology.

1.5 CURRENT DEPLOYMENT OF DTTB SYSTEMS

Currently, many countries are experiencing the migration from analog TV to the DTV [9]. Considering to the previous evolution from all-analog technologies to digital technologies in the telecommunication area, driven primarily by both customer demand and the progress of science and technology, DTV technology is more mature and advanced. While providing higher quality, more functional, and personalized audio and video programs, both DTV services and the method of reception have become much more diversified; the image resolution can be HDTV, SDTV, and mobile low-definition TV (LDTV). LDTV has horizontal scan lines (also known as pixels of vertical resolution) of no less than 250 with typical resolution of 340×255, and this corresponds to the resolution level of VCD. Users can receive DTV services over the air or by cable, satellite dish, Internet protocol television (IPTV), and mobile DTV receiver.

Direct-to-home (DTH) TV signals generally refer to direct broadcasting services provided by either telecommunication or broadcasting satellites, while DBS specifically refers to direct broadcasting services provided by broadcasting satellite. The DBS service is generally used for nationwide coverage, and the coverage area of the DTH service could easily be across several countries. In urban areas, DTV terrestrial broadcasting equipment can also be used (other than its own over-the-air DTV programs) to relay direct satellite broadcasting TV programs, which allows use of in-home equipment (fixed or mobile, all are capable of receiving terrestrial DTV programs) to receive high-quality direct broadcasting TV programs with a very simple antenna.

IPTV provides either service in one direction or interactive service, including the direct broadcast program, relaying program, VOD program, time-shifted program, and other services using the Internet as the transmission medium and the STB together with TV or PC as the terminal equipment. One important advantage that the Internet can provide is bidirectional channels to support interactive services, especially games. The unique interactive capability and various program sources of IPTV have made and will continue to have significant impact on cable DTV as well as other DTV networks. Moreover, with continuous advances in the technology, the TV industry is reshaping itself. More and more TVs are providing Internet connectivity while the computer monitor has been used to watch TV programs for a long time.

Another interesting observation on DTV deployment and application refers to two extremes for DTV reception: “big” and “small.” Big usually means a large screen and high definition for not only in-home use but also big squares and large offices (screen wall). Small means the DTV receiver for mobile devices. Of course, the video resolution for a small TV is not as good as that of big TV, and much efforts has been made to minimize this difference. Considering the strong demand for mobile TV reception, many countries around the world are seriously considering creating or adopting the DTTB standard, which could potentially support portable mobile terminals. Portable mobile terminals include but are not limited to mobile phones which can receive the TV signal and other portable equipment such as DTV receivers on automobiles, laptop computers, PDAs, and MP4. The broadcast network can support music, text, image, data, and other multimedia services in addition to conventional DTV programs.

DTV has greatly shaped the industry and changed people's lives forever, not only the way people watch TV but also their daily life style.

1.5.1 Developments of ATSC, DVB-T, and ISDB-T

The United States is one of the countries that initiated the development of DTV and has successfully and smoothly completed the analog-to-digital switchover. As early as 1996, the U.S. Congress passed the Telecommunications Act of 1996, requiring that the transition from analog TV to DTV in terrestrial networks be completed by the end of 2006, which was a very ambitious plan. Due to problems in development, this deadline was postponed several times, and analog TV broadcast shut-down was eventually accomplished nationwide on June 12, 2009. Thereafter, there were no more full-power analog TV transmitters carrying analog TV signals. However, some low-power analog transmitters still provide analog TV service to people in rural areas, although both the areas and the number of households using analog TV services is very small [10]. The U.S. government has made it clear that all analog TV transmitters must shut down by September 1, 2015. Currently, ATSC has nearly achieved 100% coverage, and around 90% of households can receive at least eight ATSC programs. Over the whole country, more than 1600 TV stations broadcast the ATSC signals, which are mainly HDTV programs, and more than 600 TV stations are broadcasting SDTV programs.

During the transitional period, the U.S. government provided more than 30 million households with gift certificates to purchase the ATSC STB with a total cost of about $1.34 billion. This effort has greatly promoted DTV in the United States and ensured the postponed deadline will be met. In addition, the U.S. Congress also passed legislation in 2006 requiring that large-screen TV sets have built-in demodulators for the terrestrial DTV signal. Meanwhile the FCC established a timeline for all local TV broadcasters to finish the switchover and the copyright protection rules for the DTV programs, which paved the road for the DTV promotion in the country.

Several other countries, including Canada, Mexico, South Korea, and Honduras, have adopted the ATSC standard. As the ATSC M/H standard supporting mobile and portable equipment reception based on ATSC has been published, mobile and portable ATSC receivers are now sold in large quantities in many countries after more local broadcasters started carrying ATSC M/H signals.

ATSC 2.0 is a major new revision of the standard backward compatible with ATSC 1.0 announced in 2013 as a candidate standard and supports interactive and hybrid television technologies when the TV connects to the Internet [11]. The new features include the content delivered to the home either over the air or via the Internet; the ability to store and watch (pushed) video on demand in non–real time (NRT); broadcast of interactive content or Hypertext Markup Language (HTML) applications; advanced audio and video compression such as H.264 and high-efficiency AAC; and audience measurement, enhanced programming guides, the ability for the receiver to forward content to other devices; etc.

ATSC is now developing a new system/standard, ATSC 3.0, which is non–backward compatible with the existing ATSC 1.0. ATSC 3.0 will adopt new physical layer transmission technologies which fully reflect the latest technical breakthroughs to satisfy the ever-increasing demand of users for multimedia service from the broadcasting networks. A call for proposals for the ATSC 3.0 physical layer supporting video with a resolution of 3840×2160 at 60 fps was announced on March 26, 2013. The ATSC 3.0 Technology Standards Group (called TG3) has since then been established with the objective of developing standard(s) for a future broadcast television system, including, but not limited to, standard(s) for the physical, transport, and presentation layers. There are two subgroups in TG3: TG3-1, which aims to develop system requirements and implementation scenarios and conduct research on potential future scenarios and use cases, which are expected to generate further potential system requirements, and TG3-2, with the objective of evaluating the physical layer and conducting research on physical layers starting with relevant attributes, evaluation criteria, and candidate solutions.

Even though not all technical details of the proposals are available to the public and the deliberation process is still ongoing, TG3 is expected to establish requirements for high spectrum efficiency and support of multiple services. The following features and technologies for the physical layer transmission have been proposed and seriously considered: OFDM, bit-interleaved coding and modulation (BICM, with or without iterative decoding/demodulation) for capacity-approaching performance, including LDPC with code rate from very low to high, nonuniform quadrature amlitude modulation (QAM) or amplitude-phase shift keying (APSK), bit-to-cell word demultiplexing, etc.; multi-input–multioutput (MIMO) technology for either diversity or multiplexing gain; layered transmission called cloud transmission (Cloud Txn) [12]; enhanced SFN (eSFN) and SFN planning considering both large-area coverage and local services; support of nontraditional TV services such as non-real-time and emergency alert services, etc.

There is no clear deadline on when ATSC 3.0 will be finalized, but it is been widely expected to be done around 2016–2017.

Europe promoted DTV very quickly and successfully. By the middle of 2013, nearly 20 countries, including Germany, Spain, Norway, The Netherlands, Belgium, Finland, and the United Kingdom (UK), have completed their transition from analog to digital TV. Similar to the United States, these countries have also used legislation and government funding to ensure the smooth transition from analog to DTV [13].

The U.K. is among the countries to initiate efforts in promoting DTV. It has the most influential satellite pay-TV operator, British Sky Broadcasting Group PLC (BSkyB), and public TV broadcaster, British Broadcast Corporation (BBC). The pay mode for commercial operation, however, failed completely in the early stages of promotion. Later on, it promoted the free DTV broadcasting plan, Freeview, making most of the channels free while providing some pay services in 2002. The plan has successfully sped up the deployment process of DTV in the U.K. and made DTV service very popular. Thereafter, the number of DTV users increased steadily and switchover in the U.K. from analog to digital TV was completed by the end of 2012. Germany completed its switchover to DTV by regions and in stages. In April 2003, the transition was first completed in Berlin and then gradually to other areas in the country. By June 2009, the transition in the whole country was accomplished. The analog signal of both cable and satellite TVs was also completely shut down. The Netherlands was the first country in the world to transition from analog to digital TV with the switchover completed by the end of 2006.

Currently, the framework and standards for the second generation of digital video broadcasting (namely DVB-S2, DVB-T2, and DVB-C2) in Europe have been fully implemented. The major consideration for this framework and these standards was to improve overall system performance and reduce the research and development risk, cost, and time by sharing the newly developed technologies. For example, the forward error-correcting code in the second generation of DTV terrestrial transmission standards adopts the high-performance LDPC code which has already been used in the second generation of the satellite DTV transmission standard DVB-S2, and DVB-C2 not only chooses this LDPC code but also adopts the C-OFDM modulation technology used in terrestrial standard DVB-T2. The DVB T2-lite profile was added in June 2011 to the DVB-T2 standard to support mobile and portable TVs and to reduce implementation costs. The T2-Lite profile is mostly a subset of the DVB-T2 standard, and two additional code rates were added for improvement of mobile performance. T2-Lite is the first additional transmission profile type that makes use of the future extended frame (FEF) of DVB-T2. The FEF mechanism allows T2-Lite and T2 to be transmitted in one RF channel, even when the two profiles use different FFT sizes or guard intervals. The DVB next-generation broadcasting system to hand held (NGH) is a draft ETSI EN 303 105 standard [14,15]. This standard defines the next-generation transmission system for digital terrestrial and hybrid (combination of terrestrial with satellite transmissions) broadcasting to hand-held terminals. The NGH standard is based on the DVB-T2 standard and reuses or expands many concepts introduced in the DVB-T2 specification, such as nonuniform constellation, 4D rotated constellations, and the hierarchical modulation for local service insertion.

Japan has also progressed very rapidly in the research and development of DTV using its own home-grown ISDB-T standard [16,17]. In 2003, Japan started the DTV terrestrial broadcasting test in Tokyo, Osaka, Nagoya, and several other cities carrying digital HDTV programs. On April 21, 2006, Japan launched the so-called One-Seg mobile DTV service. By using one of the 13 segmented spectra for each analog TV channel, both terrestrial and mobile DTV services are carried by the same network. With this arrangement, the cellular phone allows viewers to watch a TV program for free other than for telecommunication purpose. One-Seg was originally launched by 29 TV stations and was popularized nationwide by December 2006. By the end of 2009, a system combining terrestrial and mobile DTV programs has been very successful in the commercial promotion, leading to the growth of mobile customers of One-Seg to over 30 million. At the same time, the broadcast operators (NHK and the private broadcast industry) still carried out the transmission of digital broadcasts. By the end of 2008, NHK had established 1444 relay stations, covering 96% of users. By January 2009, the number of DTTB receivers had grown to 46 million. Japan succeeded in the complete digitalization of terrestrial TV broadcasting by terminating analog broadcasting on July, 24, 2011 (except in some regions afflicted by the earthquake/tsunami damage). Several other countries in Asia and South America have decided to implement the ISDB-T standard [17].

1.5.2 Development and Deployment of DTMB System

China ranks number one in both the production and consumption of TVs worldwide: The total shipment is around 100 million sets (export and domestic sales account for about 50% each) in the past year and altogether there are around half billion TV sets in Chinese households. The research and development efforts on DTMB started in the late 1990s. After careful and thorough investigation, it was decided that the main design objective for the DTMB system should focus on high-spectrum efficiency and stable fixed as well as mobile reception capability. Specifically, the following technical features and requirements should be met:

1. The system should at least have the same reception performance as that of existing DTV systems. Users should easily receive stable DTV signals through existing facilities for analog TV, especially through the very simple, low-gain small antennas. The DTV signal should also be received successfully using directional, high-gain outdoor antennas at the edge of the service area or other places with weak signal strength. In other words, it should support stable operation whether it is under a strong static or a dynamic multipath reception environment.
2. The system transmission capacity for its typical working modes should be more than 20 Mbps. It is required that the DTTB system provide such services as HDTV programs or multiple SDTV programs plus multiple audio signals, auxiliary data, system service/control information, and program guides in one analog TV channel (i.e., 8 MHz bandwidth). This means the system should have a high enough payload bit rate to support these services simultaneously. System data capacity is one of the most important metrics to evaluate the design of the DTV system, especially for terrestrial broadcasting with total transmission capacity limited by a very harsh transmission environment. Improvement of other metrics of the DTTB system should not be at the expense of the data transmission capacity.
3. The system must support mobile reception. Portable (mobile) reception is one of the most fundamental requirements for DTTB service, and this helps provide

the satisfactory experience for the seamless reception at any time and place. This requires integration between the DTV receiver and mobile devices such as a mobile phone, PDA, digital camera, and portable computer. The integration also needs to address the design issues of the low power consumption and low implementation complexity of the system.

4. The system should support single-frequency network application for higher spectrum efficiency. The DTTB system should provide excellent anti-interference capability regardless of both cochannel and adjacent-channel interference, support the use of “taboo” channels of the analog TV system, and use either multifrequency or single-frequency networks to increase coverage and fill up the “shadow” area.

The DTMB system successfully integrates the unique contributions from different proposals and harmonizes them to form a uniform standard. It adopts the frame structure and multicarrier modulation technique of the TDS-OFDM proposed by the proposal from the consortium led by Tsinghua University, adopts the single-carrier modulation technique as well as the system information definition proposed by the consortium led by Shanghai Jiaotong University, and accepts the proposal of using LDPC code as the forward error correction code proposed by the Academy of Broadcasting Science of the State Administration of Radio, Film and Television (SARFT). One important feature of this standard is that it combines both single- and multicarrier modulation schemes under the same system structure with the same system frame structure, scrambling method, forward error correction code, system clock, signal bandwidth, and time interleaving so that both the transmitter and receiver can be automatically supported by the same hardware platform with very little increase of complexity.

The whole industry chain for DTMB is now pretty mature and the related standards for terrestrial DTV broadcasting have been issued. There are 17 standards on the transmit side as well as network planning that include the standards of implementation guidance, frequency, and service planning with the corresponding data interface, system assessment and measurement, equipment requirements and measurement, single-frequency network planning, and service information and monitoring. They are drafted and published by the Digital TV Terrestrial Technique Standard Group, which is led by SARFT. In addition, the DTV standard work group led by the Ministry of Industry and Information Technology has drafted 16 supporting standards, focusing on equipment and terminals, including transmitting equipment, receiving terminal equipment, data interface, display devices, system software, measuring instrument, and assessment methods for the video reception quality.

Hong Kong was the first city in the world to launch commercial DTMB broadcasting, after confirming that DTMB meets all the performance requirements for both fixed and mobile reception under different conditions such as LOS, non–line of sight (NLOS), single-frequency network, and tidal fading. In June 2007, the Office of the Telecommunications Authority (OFTA) in Hong Kong issued an official statement adopting the DTMB as the digital terrestrial TV broadcasting system for Hong Kong.

On December 31 of the same year, commercial broadcasting was formally launched in Hong Kong. In 2008, Macau also adopted the DTMB standard for broadcasting. By the end of 2010, a single-frequency network consisting of 7 transmitting stations had been successfully established in Hong Kong. The network can broadcast 14 programs, including HDTV and SDTV simultaneously, and both coverage and reception quality are far superior to that of analog broadcasting. The statistics data show that by the end of 2011, the DTMB system covered nearly 99% of the area in Hong Kong, with around 70% of the population using DTMB, and there are now more than 200 different models of DTMB receivers available in the Hong Kong market.

In Mainland China, the massive deployment of DTMB was planned and executed step by step. Announcements by SARFT indicated that, by 2009, DTMB signal broadcasting was accomplished in 37 cities, including the provincial capitals, municipalities directly under the central government, separate planning cities, and the cities hosting the 2008 Beijing Olympic Games. DTMB signal broadcasting over 300 large cities was also completed in 2010. Over 50% of the population in China is now covered by the DTMB signal. The next step is to launch DTMB signal broadcasting in close to 3000 county-level cities.

In the meantime, MIIT announced its plan to promote DTMB user terminals. MIIT required that all newly produced TV sets with a size of over 46 inches should have a built-in DTMB demodulator starting January 1, 2014, and all newly produced TV sets should have a built-in DTMB demodulator starting January 1, of 2015.

1.5.3 Network Convergence with DTTB Systems

Network convergence, recently a hot topic, is not the integration of different physical networks or infrastructures but the integration of different services. That is, the interactive multimedia services, including video/audio, data, and voice, should be supported at the same time within the same network, such as the triple play in telecommunications. The vision for network convergence is to fully utilize the resources of the existing network to generate the highest possible revenue and profit by providing comprehensive services to subscribers and users.

For the existing TV network infrastructure, which was originally designed for one-way broadcasting, especially for both terrestrial and satellite systems, network convergence presents a huge challenge to support bidirectional services based on the existing network architecture to tens of thousands of users within the coverage. If successful, it could potentially provide a huge return as it will help retain those subscribers seeking triple-play-like service. DVB-RCT (DVB-return channel terrestrial) and DVB-RCS (DVB-return channel by satellite) were proposed by the DVB organization to support the bidirectional functionality within the broadcasting network, yet both failed to make a case for the successful commercial application due to frequency requirement, costs, and other issues. Another way to support two-way services is the concept of the Integrated Communication and Broadcasting Network (ICBN). In this case, all services are carried not only by a single network but also by either broadcast or telecommunication networks depending on the nature of the requested service. For example, due to the capability of high-speed and broad

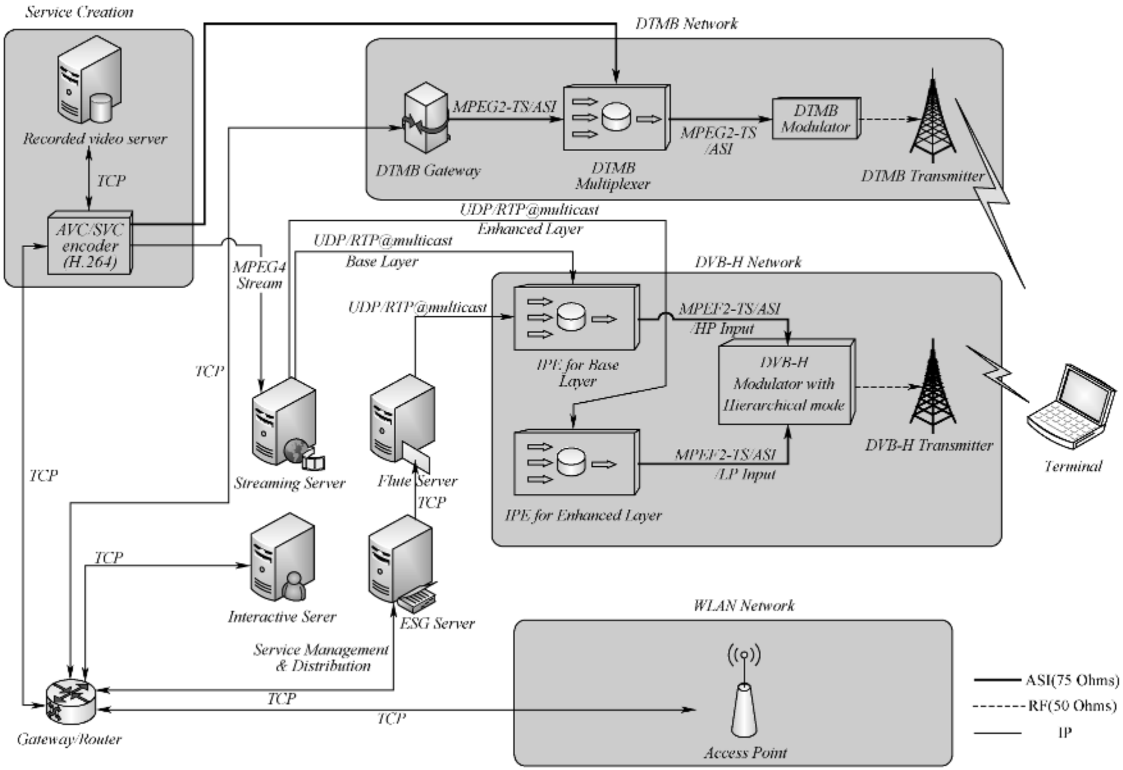

FIGURE 1-13 Schematic diagram of application scenario of MING-T project.

coverage (usually means more users to be supported) of the broadcasting network, commonly or repeatedly requested information or content-pushing services can be supported by the broadcasting network, which is good at delivering the information to lots of users simultaneously and efficiently. The individualized and interactive services, authentication, authorization, and accounting can be effectively supported by telecommunication or data networks. In this way, two-way services can be supported at very low cost without significantly modifying the existing network or requiring additional spectrum. One example of this ICBN concept is the MING-T (the acronym of Multistandard Integrated Network convergence for Global Mobile and Broadcast Technologies) project, a joint European and Chinese project funded by the European Commission within the framework of the FP6-IST program. The basic idea of the project is to use the broadcasting network as the downstream channel for bulk information which mainly provides multimedia information commonly required by a great many users and to use the telecommunication or data network (Internet) to offer the personalized interactive services (both downlink and uplink) or serve as the upstream service request channel. The schematic diagram for the application scenario of the MING-T project is shown in Figure 1-13. The research emphases include interoperability between different broadcasting systems with different standards and a combination of broadcasting and telecommunication systems, real-time handoff, and how to apply scalable video coding to the network SVC to ensure graceful degradation under different reception conditions and other core technologies. The project team has developed hardware and software architecture meeting application requirements for network integration and has carried out related laboratory demonstration and on-site tests [18,19] which could be referenced in the future as a potential way to support the implementation of the network convergence.

1.6 SUMMARY

This chapter has presented the history and evolution of analog and digital TV over the past century. The evolution of DTV has had significant impact on the broadcasting industry above and beyond the analog TV (including both black-and-white and color TV) age. DTV can efficiently use the spectrum and provide more capacity than analog TV broadcast (hence, more programs), better quality images, and lower operating costs.

However, the digital terrestrial TV broadcasting system uses over-the-air broadcast to users instead of a satellite dish or cable TV connection. These broadcasting systems would present the toughest propagation environment, which requires a very robust system design.

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