by the DVB-T standard. As it appears in Figure 8.6, the DVB-T front-end is much more complex than those of cable or satellite due to the COFDM modulation used. We will limit ourselves to the description of the blocks.

Tuner

The tuner and IF part are functionally similar to the cable parts, but they have to satisfy more stringent requirements regarding the phase noise of the tuner's PLL and also the selectivity (because of the coexistence with adjacent analog channels, which can be more powerful than the desired channel). The tuner selects the desired channel in the VHF/UHF bands (47 to 230 and 470 to 860 MHz), transposes it into an intermediate frequency F_{IF} centered on 36.15 MHz and realizes the required selectivity by means of two SAW filters (only one is required by some very recent COFDM demodulators); the AGC amplified IF signal is either transposed at a frequency F_S in the order of 4.5 MHz by means of a "supradyne" mixer-oscillator ($F_{OSC} = F_{IF} + F_S \cong 40.65$ MHz), or directly applied to a recent COFDM demodulator (since 2001 products only) which accepts IF signals at 36.15 MHz at their input, thus avoiding an additional conversion stage.

ADC

The COFDM signal, transposed or not, is applied to an analog-to-digital converter with a resolution of 9 or 10 bits, and digitized with a sampling frequency in the order of 20 MHz (undersampling when it is the IF signal at 36.15 MHz).

COFDM demodulation

This block is the main element of the demodulation process. I and Q signals are reconstituted from the digitized IF signal, and the OFDM signal is demodulated by means of a fast Fourier transform (**FFT**) on 2K or 8K points, depending on the mode (number of carriers) of the received signal.

Channel correction

This block performs the estimation of the transmission channel and its correction, and participates in the time and frequency synchronization.

Synchronization

From the information it gets from the channel correction block, this block performs time and frequency correction of the COFDM demodulation.

Channel decoding

This block performs frequency de-interleaving and demapping of the COFDM symbols. It is followed by a similar error correction to a satellite receiver (Viterbi decoding, Forney de-interleaving, RS decoding and energy dispersal removal).

The transport stream data at the output (188 bytes transport packets) are generally delivered in parallel format (8 bits data + control signals, one of which signals non-correctible packets). Recent circuits generally deliver the transport stream in a serial format.

All the functional blocks contained in the large gray rectangle in Figure 8.6 are now included in a single integrated circuit. The processor, conditional access, descrambling, demultiplexing, MPEG-2 audio/video decoding, and all secondary functions (OSD, interfaces, modem, etc.) are, in principle, identical to those described above for the satellite for the same level of functionality.

9 Middleware and interoperability aspects

The size of investments required for setting up and running digital television transmissions as well as the bewildering increase in transmission rights of attractive contents (sports, recent movies) are such that the vast majority of digital TV programs are not free-to-air in countries where they have a significant penetration (the United States, United Kingdom, France, Italy, Spain). Even if the DVB consortium, like the GSM in the field of mobile telephony, played the role of a powerful unifier in Europe, it could not impose a common conditional access system or a unique user interface specification.

We saw in Chapter 5 that there were numerous conditional access systems using the DVB-CSA scrambling algorithm. These systems differ from one another due to the protocols used to manage and transmit access rights and keys, mainly by software embedded in the set-top box and the subscriber's smart card. Besides the conditional access system, the most important part of the software for ensuring complete interoperability between different operators of digital TV bouquets (beyond the simple passive reception of TV programs compliant with the DVB standard) is what is generally referred to as "middleware" or sometimes "interactivity engine" or, less often, just **API** (application programming interface). In fact, the term "middleware" is rather vague and does not mean anything more than that it is situated somewhere between the hardware and (application) software. The term API *stricto sensu* points only at the interface between an application and the software layer immediately below it. It is essentially made of a predefined set of function calls of the middleware.

The middleware can be functionally compared to a high-level operating system with graphical user interface (GUI) such as Windows, which is very different from a low-level real-time operating system (**RTOS**, such as pSOS, vxWorks, Nucleus to cite just a few), on which the middleware is based.

One of the crucial functions of most middlewares is to make the application independent of the hardware platform on which it is run, assuming it has sufficient resources (processing power and device functionality).

In order for the same hardware platform to relatively easily support many middlewares, which not only differ from one another by their upper API (to the applications), but also by their interface to the lower layers of the software (which we will name "middleware API"), the set-top box manufacturers most often interface the middleware to their own API (which we will name "platform API") through an adaptation layer. Figure 9.1 illustrates the different software layers of a set-top box using a middleware in comparison to the layers of a personal computer (PC).

It is the middleware that defines the look and feel of the user interface, the aspect and the possibilities of the Electronic Program Guide

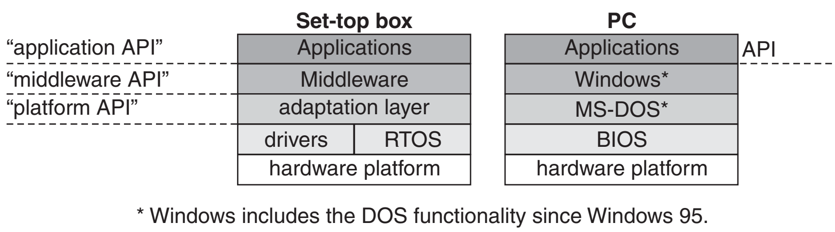

Figure 9.1 Comparison of the software layers of a set-top box and a PC.

(**EPG**), the interactivity level of the applications which are offered to the user (pay-per-view programs, games, specific services requiring a return channel to the service provider, special functions such as hard disk recording, etc.). All middlewares generally offer two levels of interactivity:

- A local or off-line interactivity of the carousel type, which means that the user can only access data which are broadcast cyclically, in a manner similar to the Teletext information of analog TV transmissions (this is particularly the case with the Electronic Program Guide).
- An on-line interactivity, where the user is connected to a server by means of a return channel (telephone modem or cable return). The user can thus access remote data, either in a manner comparable to Videotex (e.g., Prestel or Minitel), the Internet, within the limits allowed by both the service provider, and/or from a terminal connected to a TV screen.

All middlewares allow downloading of data and software into the FLASH memory of the set-top box by means of the broadcast channel, which allows updating and upgrading (bug corrections, new functionalities) as well as downloading of applications.

Table 9.1 lists some proprietary middlewares in use today in the world of digital television.

Table 9.1 Some popular middlewares used for digital TV

Middleware	Type	Origin	Service providers (examples)
Betanova	V	Betaresearch (D) (obsolete)	Premiere World, Deutsche Telekom
Liberate	P	Liberate	CWC, Telewest...
MediaHighway	V/P	Canal+ Technologies (now NDS)	Canal+, Canal Satellite, DirecTV
Microsoft TV	P	Microsoft	TV Cabo, cable operators (U.S.)
OpenTV	P	OpenTV	BSkyB, Sky Italia, TPS

Middlewares are classified as *proprietary* (P) when they belong to a company which is not linked to a pay TV operator, or as *vertical* (V) when a specific middleware has been developed by an operator or an affiliate company for its own use. They are noted P/V if they are both vertical and proposed to other service providers. However, independently of the middleware core, pay TV service providers (whose terminals are rented or subsidized most of the time) can personalize their own version of the middleware or restrain it in order that it cannot execute non-approved applications (for instance coming from a competitor), even if they are compliant to the middleware's API. Likewise, rented receivers are sometimes deliberately limited in order not to be able to receive transmissions (even free-to-air) from competitors who did not conclude an agreement with the service provider.

If this situation can be accepted in the context of pure pay TV (even if it is leading the customer to rent or buy one specific terminal for each service provider if he or she wants to access all the services), it is at least not desirable in view of "digital TV for everybody." In many countries, this should happen with digital terrestrial TV when it replaces analog TV at the end of the decade and include a large proportion of free-to-air transmissions. This is why alternative solutions are being developed to cover the needs of any service provider of pay or free-to-air TV, with different levels of functionality. These solutions are said to be horizontal, as opposed to vertical, integrated solutions of pay TV service providers (which range from the delivery of programs to specific set-top boxes).

Until boxes with such a standard middleware become available, it is possible to find on the market DVB-compliant receivers that do not use any middleware, commonly called "zapper boxes." These receivers have a proprietary control software, built directly on the RTOS and drivers of the hardware platform; most of the time they do not have a modem because its use would imply that it could run the application of a service provider requiring its middleware. So this proprietary software does not incorporate real interactive (on-line) functionalities, but it can usually be updated by downloading from satellite or from a PC connected to its serial port.

This software ensures the basic functions required for reception of TV programs, often with a mini-EPG limited to the information on the current program and the following one (sometimes called "*now and next*" function), assuming this information is transmitted in the EIT table of DVB-SI.

In addition to the free-to-air (**FTA**) transmissions some receivers are able to receive encrypted pay TV transmissions either by means of an embedded conditional access (Viaccess is one of the most common) or by means of an appropriate DVB-CI module. In both cases, of course, the appropriate smart card containing valid rights for the programs to be received is required. We will first have a brief look at three of the most common proprietary middlewares in use in Europe, then we will examine two open and standardized solutions.

9.1 Main proprietary middlewares used in Europe

9.1.1 MediaHighway: the middleware of the Canal+ "galaxy"

MediaHighway was developed in 1993 by the R&D department of Canal+ (which subsequently became Canal+ Technologies) initially for the launch of the first French digital TV service in April 1996: Canal Satellite Numérique (CSN).

MediaHighway is used by all the national variations of Canal Satellite which were launched shortly afterward (Spain, Italy, Poland, etc.). More recently it was proposed to service providers not belonging to the Canal+ group such as OnDigital (UK) in 1998, which later became ITV Digital, and some other satellite and cable operators in Europe, Asia, and the United States. Canal+ Technologies requires a tough certification process, which includes an important suite of unitary tests before allowing the marketing of products with the MediaHighway label.

Many versions of MediaHighway exist, which correspond to a **DLI** (device layer interface) number. The DLI is in fact the interface of the middleware to the lower layers of the software. The hardware platform together with its operating system and its drivers must comply with the DLI specification, generally via an adaptation layer. The DLI defines the functionalities supported by the middleware and ensures an independence (or abstraction) from the hardware platform and RTOS used.

MediaHighway supports near video-on-demand (NVoD) applications and impulse pay-per-view (IPPV) and allows downloading of data or applications. MediaHighway is usually used with MediaGuard, the in-house conditional access system, but can, in principle, be used with any embedded CA system; it also supports the DVB-CI interface standard for detachable conditional access modules. The DLI versions currently in use are

- **3.xx:** used by most satellite service providers of the Canal+ group, because of their early starting date. They have been enhanced by satellite downloads.
- **4.xx:** DLI version 4.1 was introduced at the beginning of the UK's DTT service (On Digital pay TV) in order to support the MHEG-5 API mandatory by law in the UK for digital terrestrial services. Other variants of the 4.xx DLI now include an Internet browser and management of a hard disk drive for recording TV programs and other data.

Recent versions of MediaHighway are based on "MediaHighway virtual machine" which can execute applications developed under many different standard languages (Java, etc., HTML, MHEG-5, etc.) by loading the appropriate interpreter.

This feature has allowed MediaHighway to be one of the first proprietary middlewares to be able to support applications compliant with the new DVB-MHP open standard, which is based on the Java language of Sun Microsystems. (See the website: www.canalplus-technologies.com.)

9.1.2 OpenTV: the most widely used middleware

OpenTV is a middleware proposed by a company (now independent) bearing the same name. It was originally a joint venture between Thomson MultiMedia and Sun Microsystems (Sun Interactive Alliance formed in 1994). The first digital TV service provider to use OpenTV was the French satellite bouquet TPS in 1996. OpenTV is now used by more than 30 digital TV service providers worldwide and is installed in more than 10 million set-top boxes produced by approximately 30 suppliers. Consequently, OpenTV has to support many different embedded conditional access systems as well as the DVB-CI interface standard for detachable conditional access modules.

OpenTV supports near video-on-demand (NVoD) applications, impulse pay-per-view (IPPV) and allows downloading of data or applications. Many OpenTV versions exist. Their numbers reflect their date of introduction:

- **OpenTV 1.O.x** is the version still used by the pioneers, mainly French cable and satellite service providers. It has no longer been proposed to new customers since early 2000. It has nevertheless been enhanced by many downloads over time.
- **OpenTV 1.2** is a specific derivative for the British satellite service provider BSkyB.
- **OpenTV EN** is the second generation of OpenTV.
- **OpenTV EN2** is the third generation, inheriting from both OpenTV EN and OpenTV 1.2.

OpenTV EN2 is based on two libraries:

- Basic functions are included in the core library, which is the heart of the middleware and is compatible with many real-time operating systems (RTOS).
- Optional functions are located in the extensions library, which allows service providers to personalize the middleware and extend its functionality by downloading.

OpenTV EN2 executes OpenTV applications written in O code (conceptually comparable to the byte code of Java) by means of a virtual machine (interpreter). This is why the architecture allows a relatively easy porting of MHP by means of adjunction of a second virtual machine (Java), which will enable the middleware to be compliant with both OpenTV and MHP applications. OpenTV functionalities extend now to the management of a hard disk and Internet browsing, notably thanks to the acquisition in 2000 of the company Spyglass. (See the website: www.opentv.com.)

9.1.3 Betanova: a very vertical middleware

Developed by Betaresearch, the technology branch of the big German media group Kirch, Betanova, in contrast to most other middlewares, does not pretend to be independent of the hardware platform or the RTOS upon which it runs. It is intimately linked to the “d-box,” the set-top box developed for the satellite pay TV bouquet Premiere World. A cable variant of this platform has been adopted by Deutsche Telekom for its cable networks. Two generations of Betanova exist:

- **Betanova 1.xx:** this is the historical version, which runs on more than one million d-boxes. It supports NVoD applications, impulse pay-per-view (IPPV), and allows downloading of additional applications to the Electronic Program Guide (**EPG**). On the satellite d-box, Betanova also supports the DiSEqC antenna control system.
- **Betanova 2.xx:** this new version supports all the functionalities of the 1.xx version. It is written in Java, which simplifies adaptation and accelerates the writing of new applications. In addition, this new architecture is more flexible and foresees the support of the API of DVB-MHP (also based on Java), but it is still dedicated to the d-box. This new version of Betanova is also intended to support access to the Internet as well as home banking and home shopping applications.

Mainly due to the strict interdependence between Betanova and the d-box, both have found themselves limited to the German market, on which their monopoly and lack of openness have been bitterly criticized by their competitors. However, things in favor of MHP and open platforms on the German market, among others, are changing due to the end of the *de facto* monopoly of Deutsche Telekom on the cable networks. Betaresearch is being dissolved after going bankrupt; this middleware does not evolve anymore.

9.2 The open European middlewares

9.2.1 MHEG-5: the first standardized middleware for digital TV

The **MHEG** (Multimedia and Hypermedia Expert Group) is a descriptive language of multimedia presentations, comparable to **HTML** (HyperText Markup Language) for hypertext pages. It is based on an object-oriented multimedia exchange format independent of the hardware and software (OS) platform on which it is executed. It is a declarative, as opposed to a procedural, language (such as Java).

The **MHEG-5** version, standardized under the ISO/IEC 13522-5 reference, is a subset of MHEG-1 particularly dedicated to digital TV receivers (set-top box or integrated digital TV receiver, iDTV) with limited processing power and memory size. It is practically the only MHEG version in real volume usage.

In the MHEG vocabulary, a multimedia presentation is an MHEG application or an MHEG scene. An MHEG application is a grouping of MHEG scenes. An MHEG scene is made up of three main groups of objects or ingredients:

- the interactive objects such as buttons, cursor, or other similar objects;
- the link objects (links) which define processes triggered by user actions on interactive objects;
- the presentation objects (objects) controlled by the above-mentioned link objects.

A certain number of other objects exist, which regroup many presentation objects. When an MHEG application is started, it generally expects an action from the user. If the user presses a button, the application generates the event “button selected.” A link can be defined on this (interactive) object, for example in order to start a video sequence (presentation object). Objects themselves can in turn generate events which can trigger links. Relatively complex applications (video games, catalog sales, etc.) can be realized in this way.

An application is normally made up of scenes and some common objects and links. A scene is only made up of objects and links. Other versions of MHEG exist:

- MHEG-1 to 4: (for the record) the ancestors of MHEG-5—little used.
- MHEG-5: the most important, used by the digital TV services in the UK.
- MHEG-6: an extension of MHEG-5 by a virtual machine allowing the inclusion of applications based on a procedural language.
- MHEG-7: defines test and conformance procedures of MHEG-5 applications.
- MHEG-8: a project aimed at combining XML and MHEG.

The small amount of resources required to run MHEG-5 makes it a good candidate for the basic digital terrestrial receivers in countries starting transmissions.

9.2.2 DVB-MHP: the universal middleware for digital TV of the future?

From 1997 onward, since the standardization of coding of digital television signals was achieved, the DVB consortium decided to tackle the problem of software and hardware interoperability between digital TV services compliant with the DVB standard for broadcasting their signals. In addition to the initial assumption of interoperability, the main objectives of the development of **MHP** (Multimedia Home Platform) have been evolution (with the possibility of extending the functionality by downloading), backward compatibility, modularity, and stability.

The Internet has also been taken into account, as well as the integration to a local home network made up of various terminals (PC, telephones, domestic appliances, etc.). One of the prerequisites was that this new standard would be based on open standards in order to guarantee a non-discriminatory access to anybody desiring to use it. Another concern was to use an efficient format in terms of bandwidth requirements but still ensuring a complete separation between data and applications. A total neutrality versus the different optional conditional access systems, embedded or based on the DVB-CI interface, was another prerequisite.

MHP defines a generic software interface (API) between the interactive applications coming from different service providers and the terminals on which they should be run, independently of their hardware and software implementation. The performance level of these terminals can vary greatly. MHP can support various applications (in increasing order of interactivity):

- Electronic Program Guide (**EPG**);
- information services comparable to a super teletext;
- applications linked to the current TV program (betting on matches, games, etc.);
- electronic commerce (e-commerce) with secure banking transactions.

The MHP architecture has three levels: resources, system software, and applications (Fig. 9.2). Resources include all the essential parts of the set-top box: MPEG decoding, input/output devices, host processor, graphics subsystem, etc.

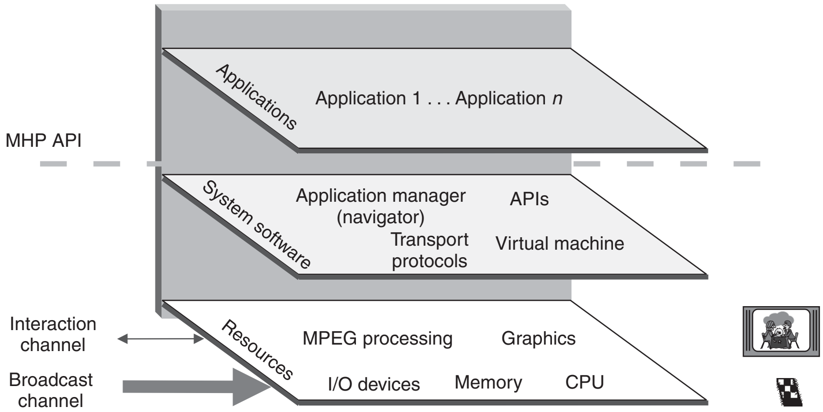

Figure 9.2 The three levels of the MHP architecture (Source: © DVB 2000).

- System software enables presentation of an abstract view of the platform to the applications. It includes a navigator (or *application manager*) which takes control of the platform and applications which are run on it. The software kernel of MHP is called DVB-J (DVB-Java), based on the *Java Virtual Machine* defined by Sun Microsystems.
- MHP applications access the platform through the MHP API. A number of software interfaces required to make use of specific resources of the hardware platform are implemented by means of extensions. The task of any practical implementation of MHP is to ensure correspondence between the API and the hardware resources of the platform.

Three profiles have been defined for the MHP platform, by order of increasing functionality, which imply an increasing need for processing power and hardware complexity:

- enhanced broadcast profile—makes use of unidirectional broadcast services only;
- interactive broadcast profile—adds support for interactive services requiring only a low speed return channel (V22 modem for instance) via the telephone network;

- Internet access profile—adds the supplementary functionalities brought by Internet access within the limits of TV screen display. It requires a higher speed connection (e.g., V90 modem).

Other profiles or elements of profiles will be added in the future, for instance for the support of hard disk recording. Figure 9.3 illustrates the functionalities and the ascending compatibility between the three different profiles of MHP.

MHP version 1.0 includes the first two profiles, and is now standardized by ETSI under the reference TS 101 812. **MHP version 1.1** covers the Internet access profile and thus adds the HTML functionality. It is specified in the ETSI document TS 102 812. DVB-MHP seems to be the only open standard which can deliver, at the same time, a unified user interface with different levels of functionality and a satisfactory evolution. These features can be seen as prerequisite conditions to a full switchover from analog to digital TV.

This is why MHP has obtained the support of many actors in the world of European television and beyond, especially in view of the generalization of digital terrestrial TV. However, MHP has not been

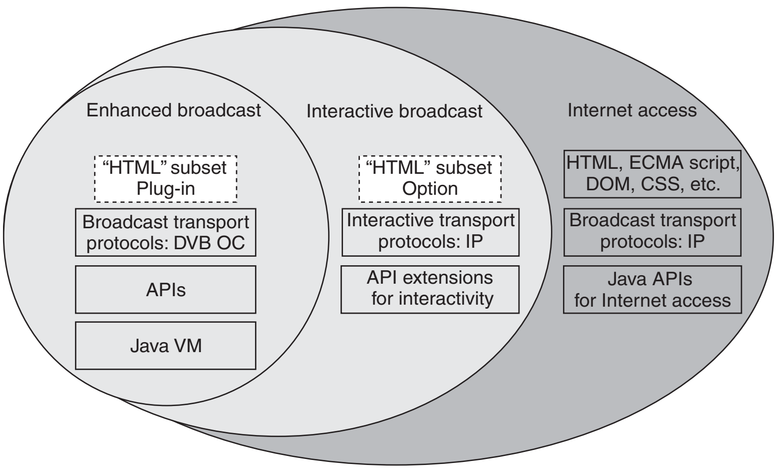

Figure 9.3 Ascending functionality of the three profiles of MHP (Source: © DVB 2000).

made mandatory in the terminals because of a significant cost increase which is criticized by its detractors, due to the hardware resources (higher processing power and memory size) required by the Java virtual machine.

At time of writing (early 2006), MHP had not met the expected success in most countries where DTT has been launched, except in Italy where MHP interactive receivers have been strongly subsidized. But even there the interest has decreased after reduction of the subsidy after one year. MHP's relatively steep licensing fee also limits its general adoption. (See the website: www.dvb-mhp.org.)