MULTI-MEDIA TERMINAL ARCHITECTURE

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Abstract

This paper presents the basic hardware and software architecture of a class of multi-media terminals that are connected to networks which deliver entertainment and home shopping services to consumers. Some important attributes of the multi-media terminal are: simple user input devices (e.g. infrared remote control), real-time interactivity, adherence to international standards for information representation and communication, and support for downloaded applications from service providers. The terminal discussed in this paper is representative of the current offering of the Digital Video Communication Systems (DVS) business unit of Philips. These terminals are the result of close cooperation between research and product divisions of Philips world-wide in the race to compete in the rapidly growing multi-media and communications markets. The current architecture of the terminal reflects the urgency to get to market with a viable solution; therefore the paper gives some indication of future trends for the hardware and software architecture for this class of multi-media terminals.

Keywords: Set top box, multi-media terminal, media access terminal, digital entertainment terminals, DET, interactive terminals, MPEG-2, DAVID, OS-9, video-on-demand, video dial tone service, VDT, home shopping network service.

1. Introduction

Currently, consumers watch television via set-top boxes (STB) which are connected to cable, or are connected to an antenna that receives direct-to-the-home (DTH) satellite transmission. In the future, the STB (i.e. terminals) will incorporate new capabilities that will make them behave like multi-media computers. Also, the cable will become a communication network that will enable real-time interaction between set-top-boxes. Ultimately, the act of watching television will become one of real-time interaction with services created out of multi-media (i.e. video, audio, text, and graphical) objects.

This paper presents the hardware and software architecture of a terminal located in a consumer's home. The terminal connects to a communication network that primarily provides entertainment and shopping services to the home. These services present information in the form of video, audio, text, and graphics. In this regard these terminals are multi-media terminals.
The terminal discussed in this paper is representative of the current product offering by the Digital Video Communication Systems (DVS) business unit of Philips. In order to compete in the rapidly growing multi-media and communications markets, Research and Product divisions of Philips, world-wide, have closely collaborated to create multi-media terminal products.

This paper is organized into five major sections. Section 2 provides an overview of terminals and multi-media communication systems, and summarizes the state of the multi-media terminal market. The hardware and software architectural aspects of a representative Philips multi-media terminal are discussed in Sections 3 and 4, respectively. Section 5 presents additional features of the terminal discussed in Sections 3 and 4 that are specific to multi-media applications. Section 6 discusses future development trends for the multi-media terminal. We conclude the paper in Section 7.

2. Multi-media communication systems and markets

2.1. General characteristics of terminals

A terminal is a key component in any communication system. It provides the means for accessing resources and services on the communication system. Basically, there are two types of terminals on a communication system: consumers of data, also known as 'client terminals', or simply 'terminals'; service providers, also known as 'server terminals', or simply 'servers.' Figure 1 shows a typical communication system with 'servers' and 'terminals.' Although servers and terminals primarily produce and consume data, respectively, they need to have some capacity to consume and produce, respectively, commands. This is necessary for terminals to request services from servers and to regulate the flow of information from the server to the terminal. To support this, a typical communication network allocates more capacity for carrying data to the terminal than from the terminal. Other types of terminals are capable of producing data that exceed the level necessary for basic command and flow control. Such a terminal is capable of maintaining an 'interactive' dialogue with a server. Interactive dialogue can also be maintained between two terminals of similar capabilities. Figure 1 illustrates server-to-terminal interaction between server A and terminal C, and terminal-to-terminal interaction between terminals D and E.

A multi-media terminal presents commands and data to its user in the form of video, audio, text and graphics. A multi-media terminal should provide several means of receiving data and commands from the user. For the consumer electronics
market the preferred input devices are infrared remote control units, magnetic card readers, and keyboards with few keys.

![Diagram of communication system with two types of terminals - servers and consumers. Terminals A and C depict pairwise interaction, while terminals B, D, and E depict multiple terminal interaction.](image)

The multi-media terminal is similar in capabilities to a multi-media computer. However, there are significant differences. Whereas a multi-media computer is an expensive and versatile device, the multi-media terminal is an inexpensive limited-functionality device primarily targeted at entertainment and home shopping services. A computer might be equipped with a floppy or a hard disk drive, but the multi-media terminal will likely not be so equipped. The computer can execute a large variety of application programs such as word processing, number crunching, desktop publishing, etc. However, there is a limited scope of applications that can
be executed on a multi-media terminal because it is not intended to be the principal computing device for the home environment.

The technology embodied in a multi-media terminal spans several engineering disciplines, i.e. systems, software, digital and analog hardware. Although each discipline is mature, their application in multi-media terminals has been plagued with problems—because of factors such as standards that are still evolving (e.g. MPEG-2 [1]), or standards that are not international (e.g. DAVID [2]), uncertainty regarding the size of the multi-media terminal market, and uncertainty as to the most economical network configuration for the delivery of Video Dial Tone (VDT), Video-On-Demand (VOD) and home shopping services. The fact that the multi-media terminal, a complex computing system, targets the mass consumer market makes its cost an important issue. The customers have in mind a price range of $200–$350 for a terminal, i.e. roughly the price span for various sizes of TV sets. This price range is achievable if production quantities are large, i.e. in the tens of millions. So far, only trial deployments involving a few thousand homes are planned by the telephone and cable industry proponents, so it may take a couple of years before the market reaches ‘mass market’ levels. So the cost of the multi-media terminal will continue to be an issue until large quantities are produced or more cost-effective technology is developed by the manufacturers.

2.2. Types of communication systems and services

Multi-media implies that a system is capable of simultaneously handling information in many formats, i.e. video, audio, text and graphics. On the basis of this definition there are many types of multi-media communication systems. For example, the Internet and the Arpanet are networks that qualify as multi-media in nature. However, they exist primarily to serve the computation and communication needs of the engineering and scientific community. Telephone and cable networks are being upgraded to provide multi-media services to consumers, primarily in the form of entertainment and database access. These services will be interactive as well as non-interactive [3–5]. Telephone and cable multi-media communication systems are the environment applicable to the multi-media terminal discussed in this paper.

An example of a minimally interactive service in such a communication system is that of VOD or a television program—typically the service session consists of a brief interactive set-up phase followed by a long duration non-interactive phase in which the terminal is a recipient of data and commands. Examples of interactive services are home shopping, games, education, public information accessing, and financial transactions. A characteristic of these services is that the entire session consists of a significant volume of traffic flow, in both directions, between the
server and the terminal. In the case of games, there could be interaction between multiple terminals and a server.

In a typical system, the inputs to and outputs from the terminal are digitized, packed into cells and transmitted across the network over a variety of media consisting of combinations of twisted copper wires, coax cable, fiber optic cable, RF or microwave links. The signalling and messaging protocols for establishing, maintaining, and concluding communication between equipment are specific to a given network. They conform to established international standards for digital packet switched networks [6]. The formats for encoding, decoding and transporting the video, audio and text information also conform to international standards. Similarly, the applications that run on the terminal adhere to standards that define the interfaces and behaviour of the constituent modules. Standardization of the interfaces and modules makes it easy for different manufacturers to provide terminals for the network and ensures that applications do not have to know the specific details of a given terminal to produce a desired effect [2,7,8]. This is essential for business success.

2.3. Philips in the multi-media communication market

Although Philips is creating end-to-end products for the multi-media market, the immediate emphasis is on the multi-media terminal market. Philips' experience in the consumer electronics market coupled with its vast manufacturing capability can be leveraged to address new opportunities in the multi-media terminal market.

The terminal market comprises three product types normally called STB. The first type is the traditional analog STB provided by cable operators. They use standard analog television transmission standards and channels to deliver movies to the home, and the telephone system as the return path. The big players in this market segment are General Instrument, Scientific Atlanta, Pioneer, and Zenith. The second type is the digital STB, and comes in two flavours—the interactive and the non-interactive. RCA/Thomson and PrimeStar dominate the non-interactive digital terminal market segment. RCA/Thomson is clearly the leader in this market with its Digital Satellite System (DSS) terminal which uses a DTH satellite delivery network and is based on MPEG compression technology. PrimeStar, the second in this market segment, provides a DTH satellite delivery system based on General Instrument's DigiCipher compression technology. The above terminals are all real products that have been deployed.

The interactive digital terminal market is the segment that the telephone companies, with their broadband fiber based network, are betting on. This is the market segment at which the terminal discussed in this paper is targeted. The third
STB terminates hybrid analog/digital networks. This type of network attempts to capitalize on existing cable plants as the final leg of the distribution chain. This type of STB is the most flexible, but also the most expensive. This last type of terminal has yet to be deployed as a 'product'.

Although digital and hybrid markets are uncertain at this point, nonetheless Philips intends to be a key player when they take off. The Bell Atlantic trial deployment, the largest in the United States, is based on the Philips terminal described in this paper. Philips is also actively pursuing opportunities with other US telephone companies for both digital and hybrid terminals. In Europe and Asia, Philips is aggressively going after opportunities for deployment of terminals for both the cable and satellite forms of delivery defined in the European Digital Video Broadcast (DVB) standards. Philips is also active in trials involving telephone companies in Europe.

3. Hardware architecture of the Philips multi-media terminal

Figure 2 shows the block diagram of one of the Philips multi-media terminals. This terminal is similar in architecture and functionality to the terminals in the Philips product family that are in use for any one of the purely digital delivery networks, such as the fiber-to-the-curb (FTTC) network architecture. This hardware architecture is the basis for the multi-media terminal used in the Bell Atlantic (BA) VDT network, comprising switched broadband networks, and public switched telephone network/integrated services digital networks. For a hybrid digital/analog delivery network the hardware architecture in Fig. 2 needs to be supplemented with an analog processing sub-unit similar to those already in existence in a normal television set. In this section we describe the architecture of the BA terminal as a specific example of a multi-media terminal.

The hardware for the multi-media terminal consists of a communication network interface module, a host microprocessor subsystem, user input and output subsystem, an MPEG-2 decoding subsystem, a graphics subsystem, and an NTSC encoding subsystem. The important subsystems that are key to the multi-media terminal will be discussed below.

3.1. Network Interface Module

The Network Interface Module (NIM) provides access to the network. It is a network specific unit and therefore is designed to be easily replaceable. However, the NIM's interface to the rest of the terminal, i.e. the Digital Entertainment
Terminal (DET), is standardized. The architecture shows two physical interfaces connecting the DET to the NIM. A dedicated physical bit-serial interface delivers MPEG-2 transport streams into the DET, i.e. into the MPEG-2 port, in bursts at a rate of 45 Mbps. This interface maintains compatibility with the inherent bit-serial data delivery of the network, and minimizes necessary I/O pins. A benefit of this choice is that latency through the NIM is kept to a minimum, thereby preserving the time of arrival of the MPEG-2 transport packets. The other physical interface is part of the host microprocessor bus system, i.e. is memory-mapped. This interface supports two logical ports. One logical port provides unidirectional delivery of data through direct memory access (DMA) via the bus, the other is a bi-directional port.
for control messages between the DET and the network. Information crossing this interface does not have stringent arrival time constraints; therefore, the byte-serial format is acceptable. The byte-serial format improves the data throughput rate across the interface compared to a bit-serial format.

On the network side of the NIM there are two physical channels frequency-division multiplexed on the coax cable—a 180 Mbps downstream channel and a 10 kbps upstream channel. The downstream channel is a digital baseband signal containing four DS3 streams (45 Mbps). Each DS3 stream contains a multiplex of several ATM streams [6]. To facilitate transport of ATM cells on DS3 a Physical Layer Convergence Protocol (PLCP) helps to create a periodic 12-cell structure. Specific ATM cell streams are transported over ATM networks according to the ATM Adaptation Layer 5 (AAL5) protocol. The upstream channel is QPSK modulated well above baseband, and it carries messages according to the X.25 protocol. The NIM's principal functions include data framing, data packet demultiplexing and channel error correction or detection and reporting.

3.2. Host microprocessor subsystem

The host microprocessor CPU is a Motorola MC68341 Integrated Processor with a 32-bit address bus and a 16-bit data bus. The choice of processors is limited to those supported by Microware Inc. for the Digital Audio Video Interactive Decoder (DAVID) environment [2]. The MC68341 integrates the following on one chip: a 68020 based CPU, a two-channel DMA controller, two serial channels, a timer/counter, and a queued serial peripheral interface. The 68341 also integrates system-specific support functions such as a clock synthesizer, system lockup or failure protection, external bus interface, real time clock, and programmable chip select outputs. The MC68341 runs on a system clock of up to 16 or 25 MHz.

The host CPU is equipped with 1M×16 DRAM, 512K×16 FLASH memory, and expansion via a PCMCIA (type II) slot. The FLASH memory contains read only programs that define the software capabilities of the DET (e.g., diagnostics, boot, OS-9 kernel, device drivers, and default DAVID application). When required, sections of the FLASH memory can be updated through the network or the PCMCIA ports. DAVID application programs execute out of DRAM. Thus before executing an application the server must first download the necessary program. Consequently the DRAM contents change from one application to the next.

Also located on the host processor bus is a CD-i Graphics processor, and an MPEG-2 transport stream demultiplexer device. The CD-i graphics processor requires a private 512K×16 memory (DRAM) for CD-i graphics instructions and objects. Even though this memory is local to the CD-i graphics processor it is
mapped into the address space of the host processor and therefore augments the main host DRAM. The MPEG-2 transport demultiplexer is a Philips ASIC design. This ASIC also doubles as a gateway to an 'MPEG-2 application bus.' A 32K×8 SRAM provides a rate buffer FIFO between the incoming 45 Mbps serial stream and the slower rates at which the audio and video decoders consume bits. The SRAM also provides temporary storage for data stripped from the MPEG-2 stream for use by the host processor (e.g. program specific information, time stamps) or events and status conditions queued during stream processing. The host CPU, through the MPEG-2 transport demultiplexer device, has access to the audio and video decoders and their local memories. Real time events occurring within the NIM, MPEG-2 transport demultiplexer, CD-i graphics processor, the audio decoder, and the video decoder are made known to the host CPU by interrupt request signals, shown as dashed inputs in Fig. 2.

3.3. I/O subsystem

The I/O subsystem manages the human interface to the terminal through the IR, DET front panel keyboard, and magnetic card. These interactions are slow and asynchronous relative to the application that executes on the host processor. The auxiliary processor, an 80C51 derivative, oversees these low-level tasks. The auxiliary processor is connected to the MC68341 through one of the two serial channels. The second serial channel provides an RS232-C port to the terminal.

3.4. MPEG-2 decoding subsystem

The MPEG-2 application bus provides the interface for the delivery of compressed audio and video bit streams through the network as well as the flow of command and status between processes executing on the host processor and the hardwired audio and video decoding processes. Compressed bits can come from the channel directly through the MPEG-2 port, or indirectly through the host DRAM. This second mode sustains bit rates of up to 1.5 Mbps, i.e. MPEG-1 program streams. The bit rates are limited to 1.5 Mbps due to the host–bus transfer-rate limit and expected activity on the bus.

In the Bell Atlantic version of the terminal the audio and video decoders are independent devices, each with its own DRAM to support BA's specifications. The audio decoder is equipped with 256K×4 DRAM, while the video decoder is equipped with 256K×64 DRAM. Each of these DRAMs contains both the compressed bits as well as decoded audio and video frames. The host processor has access to the command and status registers of the decoders through the MPEG-2
transport device. Host processor access to the DRAMs is through the decoders.

The video decoder output is combined with the graphics decoder output in the video encoder device to create an NTSC color video baseband signal (CVBS) output. By combining these two outputs the DET is able to display video with graphics and/or text overlays. The audio decoder output is converted to analog to create a baseband stereo audio output. The video and audio baseband signals combine in an RF modulator to provide a signal that can be received by a normal TV tuner.

4. Software architecture of the Philips multi-media terminal

It is evident from the description in the previous section that the terminal is a micro-computer with specialized hardware elements. In this section we present the software perspective of the terminal.

4.1. Software hierarchy

In Fig. 3 we depict a software-centric view of the terminal. The important point to note is that there is hierarchy in the terminal's software. At the top sit applications, resident and downloaded, that conform to the DAVID application programming interface (API) protocol [2]. Below the application layer is the operating system software layer—composed of DAVID I/O managers, the device drivers, and the OS-9 kernel. This completes the software hierarchy. Below the operating system software layer is the hardware layer—the Philips' DET specific devices. Below the hardware layer is the physical layer interface to the network. Note that the MC68341 control environment encompasses everything except the NIM and the auxiliary processor.

The auxiliary processor environment is shown here to comprise only two layers—at the top is a system software-like entity (different from OS-9); below that is the auxiliary hardware processor. There is no DAVID application. However, through an I/O manager (i.e. the UCM—see Table I), its associated device drivers (in the MC68341 environment), and companion device drivers located in the auxiliary processor, the DAVID application is able to receive commands from the IR detector, card reader and the keyboard.

A stand-alone boot and monitor program exists within the MC68341 environment. This software has access to all the devices located on the host bus and the I/O subsystem bus. It does not conform to DAVID or OS-9 conventions. This software is the first to execute when the DET turns on. It performs diagnostic checks and DET specific hardware initialization tasks before releasing the MC68341 to the
control of the OS-9 kernel. Once OS-9 initialization is completed the default DAVID application is executed.

4.2. Concurrently executing processes

Once OS-9 and a DAVID application are executing, the MC68341 environment is made up of several concurrently executing processes. The set of processes defines the characteristic of the application. Some of these processes are hardware based (e.g. audio decoding, video decoding), others are software based. The software processes time-share the MC68341 processor. Figure 3 depicts explicitly the communications (shown as broken lines) between the DAVID application and the I/O managers (and device drivers), and between the hardware processors and their associated device drivers. There are also communications between I/O manager processes (not shown in this figure). The inputs and outputs of most of the processes are the communication signals amongst themselves that provide the means to control and monitor the state of the application. For some processes there are data

Fig. 3. Organization of the software within the Philips multi-media terminal, showing how various software modules map onto layers and processors.
inputs and outputs (shown as solid lines in the figure). Data may be consumed by a process or passed on to the next process with or without modification. For example, the NIM feeds the MPEG-2 transport demultiplexer with channel data that ends up in the audio and video decoders. Also, the NIM feeds data to a device driver (and I/O manager) process that may end up as the downloaded application code, or new code to upgrade the operating system, or as audio and video bit streams for the decoders.

4.3. I/O managers

The DAVlD API provides a fixed set of I/O manager processes with defined functions, states, inputs and outputs. Thus a DAVlD application needs to invoke combinations of these managers, as a function of time, with the appropriate control and data signal configuration in order to provide the desired multi-media service to the terminal user. Table I summarizes key DAVID I/O managers supported in this terminal.

5. Capabilities of the multi-media components

In this section we describe in detail the characteristics of the multi-media components in the terminal.

5.1. MPEG-2 transport, video and audio

The terminal's MPEG-2 demultiplexer decodes bit streams of up to 45 Mbps. MPEG-2 video decoding includes the capability for Main Profile at Main Level with B-frames and supports resolutions up to CCIR-601. The video decoder supports bit rates of up to 15 Mbps. Film mode support includes 3:2 pull down decoding for frames transmitted at 24 Hz. The video decoder provides support for 16:9 as well as 4:3 aspect ratio display. Error concealment is provided to combat errors in transmission. Freeze frame feature is supported, and is controllable either by the service provider or the user. The audio decoder supports MPEG/MUSICAM Levels 1 and 2. The terminal is also capable of decoding PCM coded audio.

5.2. Graphics

Two levels of graphics are possible. The MPEG-2 video decoding device provides for simple bit-mapped on screen display (OSD) of text. The CD-i [9] device provides the possibility to create and display complicated graphics with
animation and special effects. This is used by applications to display menus, text overlays, and channel captions. For home shopping, games, and demanding graphical applications, the full capability of CD-i compatible graphics may be required. The CD-i features include support for up to $720 \times 480$ pixel resolution display, four colors per line from a palette of 4096, and two pages of display storage. Other attributes include manipulation of four graphics planes (in addition to two video planes) consisting of one hardware cursor plane, two graphics image planes, and one solid backdrop plane. Special effects include mixes and dissolves, vertical and horizontal wipes and scrolling, and control of visual effect transition speed.

**TABLE I**
A partial list of some of the key DAVID I/O managers used in the Philips multi-media terminal

<table>
<thead>
<tr>
<th>I/O manager</th>
<th>Function</th>
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<tbody>
<tr>
<td>SPF (Sequential Packet File manager)</td>
<td>User 2-way command/control channel. Handles many protocols (ATM, X.25, TCP/IP, etc.). Network specific.</td>
</tr>
<tr>
<td>SCF (Serial Character File manager)</td>
<td>RS-232 link.</td>
</tr>
<tr>
<td>UCM (User Communication Manager)</td>
<td>Graphics display and IR control. Displays images, draws shapes, writes text and controls hot regions. Cursor support.</td>
</tr>
<tr>
<td>RTNFM (Real-Time Network File Manager)</td>
<td>High speed data channel of real-time streams. Independent of network characteristic.</td>
</tr>
<tr>
<td>MPFM (Motion Picture File Manager)</td>
<td>MPEG-1 and -2 real-time stream support. Video and audio control (e.g. play, pause, etc.).</td>
</tr>
<tr>
<td>PCFM (PCMCIA File Manager)</td>
<td>Access to data files on PCMCIA card.</td>
</tr>
</tbody>
</table>
5.3. Miscellaneous features

Closed captioned data is demultiplexed from the stream, decoded, and then passed via the IIC bus to an NTSC DENC device. It is re-encoded onto line 21 of the analog video. The terminal supports display of emergency broadcast service (EBS) text messages. Copy protection is supported, via software switches, based on the Macrovision™ anti-copy system. This system enables or disables a VCR's ability to record and play back the protected program. Macrovision™ invocation is under the control of the service provider.

6. Future developments

The present terminal architecture clearly is a synthesis of existing technologies and some specific developments for transmission and digital audio/video decompression. It is to be expected that in the future the terminal architecture will rationalize: the system will probably get a more unified, flexible architecture, allowing its resources to be used in an optimal way for different applications.

For the hardware there will be a strong trend towards very flexible decoders in the form of signal processors and fast CPUs possibly even combined in one large digital signal processing CPU, allowing for fast time-to-market for new formats and signal processing applications. The different memory subsystems are likely to merge for reasons of scale (many small memories are more expensive than one large one). This will also make allocation of memory for different purposes easy. Similarly this will hold for various busses present in the system now. Connections to external equipment will allow digital transfer up to several 100 Mbits/s. It is not unreasonable to assume that the arrangements for sending information from the terminal into the network will improve both in latency and in throughput. The graphics subsystem is likely to grow towards 3D applications (mainly for games) in the very near future.

For software the most critical issue will be to standardize the interface between applications and system software in a way that will allow applications to run on different terminals (and PCs) of various brands and models, in order to leverage application tool development and application development itself. Also a more transparent division between data (objects) residing on the server and those residing on the terminal will be an issue, as this will improve flexibility for application developers dramatically. Future generations of platform terminal software (operating systems) will allow execution of multiple applications simultaneously. Security, encryption and decryption technology will require substantial attention in the future.
7. Conclusions

In this paper we have described a multi-media communication system and the terminals used for gaining access to the services and products on such a system. The specific terminal discussed here is an all-digital interactive terminal representative of a variety of terminals that Philips produces for applications in telephone, cable, and satellite networks that provide multi-media services to a consumer's home. We presented the hardware and software architecture of such a terminal. We stressed the notion that the success of such a terminal is dependent on technologies that conform to standards. In fact, this is necessary for business success. The realization of this product is due to a unique collaboration between Philips Research and Product divisions world-wide.

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Authors

Olu Akiwumi-Assani is a principal member of the research staff at Philips. He has a BS in Physics from the University of Science and Technology (Ghana), and a Master's degree in Electrical Engineering from Lehigh University (PA). He joined Philips in 1980 and has worked in the areas of computer architecture, medical image compression and VLSI design. He was project leader for the design and implementation of the ATRC video decoder submitted for the FCC HDTV testing in 1992. Before being assigned to his current responsibilities he was one of the project leaders responsible for the Grand Alliance video decoder design and implementation, and also represented Philips on the GA Transport Specialist and GA Systems groups. He is currently project leader for the hardware development of the set top boxes for the Bell Atlantic Video Dial Tone (VDT) service.
Marnix Vlot graduated from the University of Twente in 1986 on a subject in the area of control theory. He joined Philips Research that year. During 1986–1990 he worked on the architecture of a large parallel data-base machine POOMA, leading the hardware subteam during 1989 and 1990. During 1990–1992 he worked on the areas of Home Systems (domestic automation networks), defining the overall architecture and technically coordinating the Esprit Home Systems standard in this area. During 1993 he worked on a research project to improve the architecture of a GSM handset. Since 1993 he has led a team in Philips Research active in the area of CPU core and system design for embedded systems, focusing in particular on the mix of signal/data processing in both video and PDA-type applications.