Broadband consumer electronics networking and automation

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SUMMARY

Although a critical mass of households worldwide have access to the information superhighway, the broadband consumer networking and automation market is still evolving very slowly. Two reasons may be identified for this delay. The first one is related to the lack of broadband home data networks. Consumer electronics networks either do not exist at all or they are not able to support multimedia communications. The second reason is the large variety of ad hoc consortia or (un-)authorized standardization bodies that have been defining independent, in many cases non-interoperable specifications for residential networks. In this paper, we analyse and compare some of the most widely accepted, foreseen or advanced current and future broadband consumer electronics networking technologies able to support home automation and multimedia in-home appliances. Technologies and standards are categorized in three groups based on their physical medium requirements. Moreover, we discuss technologies that are independent of the lower layers, and aim to provide convergence between multiple in-home and access networks. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS: consumer electronics networks; home automation; digital home; standardization activities; network architecture; wireline/wireless technologies; power-line; phone-line; coaxial; residential gateway

1. INTRODUCTION

Residential Networking represents a unique opportunity for extending the saturated, corporate telecommunications segment to a huge, new market. Connecting each house to broadband access networks will enable the network operators and service providers to offer added value services and broadband Internet access to residential users, exponentially increasing their customer base and revenues.

The major barrier to ‘digital networked house’ has been the access network. The inadequate network infrastructure and the huge cost of new installations have formed the well-known ‘last mile problem’, which has hindered the broadband access at home. The last couple of years, however, innovations in broadband access technology and investments in access infrastructure have brought the information superhighway just outside of a critical percentage of houses worldwide. A number of competing access network technologies, ranging from copper...
enhancements/Digital Subscriber Line variations (e.g. ADSL, HDSL, VDSL), Cable TV/Modem (e.g. DOCSIS), wireless solutions (e.g. Wireless Local Loop- WLL, Multi-channel Multipoint Distribution System-MMDS, Local Multipoint Distribution System-LMDS) and satellite communications to Fibre To The Curb (FTTC), Fibre to the Home (FTTH), and various combinations between fibre/twisted pair (e.g. FTTC combined with VDSL) or coaxial (Hybrid Fibre Coaxial—HFC) have been tested and evaluated [1,2]. A non-exhaustive comparison of access technologies is provided in Table I. In parallel, advances in microelectronics and networking technologies have turned Consumer Electronic devices from dumb terminals to intelligent, network enabled devices.

Despite this promising prospect, the home networking market is still evolving very slowly. Two reasons may be identified for this delay. The first one is related to the lack of home data networks. Consumer electronics networks either do not exist at all or they are not able to support multimedia communications. Today, especially in U.S.A., a large percentage of houses have PCs, modems or multimedia network-enable appliances; however, in most cases they are not prepared to support their interconnection. Of course the most daunting cost of home networking is the cabling installation. Pulling wires in an existing home is difficult, while it is not a solution amenable to the mass market. Most consumers are unwilling or cannot afford a large-scale home rewiring, especially in the brick/concrete buildings of Europe. Thus apart from some exceptions, many vendors and service providers have put great focus on the so-called ‘no-new-wires’ solutions that eliminate the need for wires pulling. These solutions are based on existing in-home cables and wireless technologies.

The second reason is the large variety of ad hoc consortia or (un-)authorized standardization bodies that have been defining independent, in many cases non-interoperable specifications for residential networks [3]. Since the mid-1980s the lack of a general accepted standard, has given space to important consortia, organizations and projects to design, build and promote independent technologies, protocols and products (Figure 1). Today, more than 50 candidate technologies, working groups and standard specifications for home networking already exist, providing communication between access and in-home networks, while increasing the entropy in the home network industry [4].

In this paper, we analyse and compare some of the most widely accepted, foreseen or advanced current and future broadband consumer electronics networking technologies able to support home automation and multimedia in-home appliances. Technologies and standards are categorized in three groups based on their physical medium requirements. In Section 3, we present technologies that do not need rewiring and are based on enhancements of the existing in-home consumer electronics networks. In Section 4, wireless technologies are presented, while in Section 5 we present technologies that mainly target new houses. Moreover, in Section 6 we discuss technologies that are independent of the lower layers, and aim to provide convergence between multiple in-home and access networks. Conclusions are recapitulated in Section 7.

2. UTILIZING EXISTING HOME WIRING

Structured wiring for power and telephone distribution represent the major in-home existing network. Most houses worldwide have them, while a large percentage of new buildings have also coaxial cabling for TV delivery. In this section, we survey the major technologies that reutilize these networks for data distribution.
<table>
<thead>
<tr>
<th>Access technology</th>
<th>Physical medium</th>
<th>Applications</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Old Telephone Service (POTS)</td>
<td>Twisted pair</td>
<td>Telephony, low-rate data</td>
<td>Uses standard telephone lines, wide availability and low cost</td>
</tr>
<tr>
<td>Integrated Services Digital Network (ISDN)</td>
<td>Twisted pair</td>
<td>Telephony, medium bandwidth data</td>
<td>Widely available. Telcos and ISPs are investing and building out the infrastructure to further develop it</td>
</tr>
<tr>
<td>Digital Subscriber Line (DSL) technologies (HDSL, HDSL2, SDSL)</td>
<td>Twisted pair</td>
<td>Telephony, broadband data</td>
<td>Use existing twisted pair, service coverage is improving. Use like fast communication links</td>
</tr>
<tr>
<td>Asymmetric Digital Subscriber Line (ADSL)</td>
<td>Twisted pair</td>
<td>Telephony, video on demand, broadband data</td>
<td>Provides asymmetric bandwidth in downstream/upstream directions. SDSL might get the highest market share short-term, full-rate ADSL and VDSL long-term</td>
</tr>
<tr>
<td>Cable TV/Modem</td>
<td>Coax</td>
<td>Telephony, video, broadband data</td>
<td>Good for new builds and rebuilds. It is based on the existence of Cable Network</td>
</tr>
<tr>
<td>Hybrid Fibre Coaxial (HFC)</td>
<td>Fibre, coax</td>
<td>Telephony, video, broadband data</td>
<td>Good for new builds and rebuilds. It extends the existing Cable Network with Fibre</td>
</tr>
<tr>
<td>Fibre to the Home (FTTH)</td>
<td>Fibre</td>
<td>Telephony, broadcast video, video on demand, broadband applications</td>
<td>Long-term solution for broadband. Cost is the obstacle, telcos have been unwilling to take the risk of upgrading their local loops to Fibre</td>
</tr>
<tr>
<td>Fibre to the Curb (FTTC) + very High Rate DSL (VDSL)</td>
<td>Fibre + twisted pair</td>
<td>Telephony, video broadcast/on demand, broadband applications, cost savings.</td>
<td>Cost/technology/standardization are the obstacles, deployment is still in the first phase. Less investment is required as compared to FTTH</td>
</tr>
<tr>
<td>Fixed Wireless (MMDS/LMDS)</td>
<td>Air 2–3 GHz/28–38 GHz</td>
<td>Broadcast video, Telephony, broadband data</td>
<td>Good for rapid deployment of video overlays. Combined with other technologies, such as ADSL, for point-to-point applications</td>
</tr>
<tr>
<td>DBS</td>
<td>Satellite</td>
<td>Broadcast video</td>
<td>Provides broad geographic coverage; difficult to support local programming</td>
</tr>
</tbody>
</table>
2.1. Consumer Electronic Bus (CEBus)

Consumer Electronic Bus (CEBus) [5] powerline technology was the one of the first attempts to transport messages between household devices, using the 110–120 V AC electrical wiring in U.S.A. households. The CEBus protocol is an American National Standards ANSI/EIA-600 developed by the Consumer Electronics Association (CEA), a sector of the Electronics Industries Alliance (EIA). Back in 1984, CEBus specification was released, defining an open architecture and protocols that enabled products communication through powerline wires, low-voltage twisted pairs, coax, infrared, RF and fibre optics. More than 400 companies have attended the CEBus committee meetings, providing a comprehensive standard, intended for the consumer electronics industry. The main objectives of CEBus has been: Low-Cost implementation, Home automation for retrofit into existing cabling networks, Define minimum subsets per appliance intelligence and functional requirements, Distributed communication and control strategy, Basic Plug-n-play functionality allowing devices to be added or removed from the network without interrupting the communication of other subsystems, accommodate a variety of physical media.

However CEBus faced only the home automation area, and never offered really multimedia capabilities. In late 1995, CEBus became part of an umbrella standard known as Home Plug ‘n’ Play (HPnP) and a universally understood translation called Common Applications Language (CAL). CAL aims to promote interoperability among various other consumer electronics home-control technologies.
2.2. X10

X10 [6] is a rather low bandwidth protocol that basically targets control and automation applications. However, some entertainment products are already available. X10 provides up to 100 kbps over the existing home powerline wiring tree, by exchanging coded low-voltage signals superimposed over the 110–120 V AC current. X10 does not operate over 220–240 V AC, thus it is mainly restricted in U.S.A. Recently, wireless plug-in bridges that extend the X10 operation became available. The bridges receive the radio signals and put the X10 signal onto the powerline, enabling the reception of X10 signals over the air.

Like CEBus, X10 specification defines a communication ‘language’ that allows compatible home appliances to talk to each other based on assigned addresses. X10 is a broadcasting protocol. When an X10 transmitter sends a message, any X10 receiver plugged into the household powerline tree receives and processes the signal, and responds only if the message carries its address. X10 enables up to 256 devices to be uniquely addressed, while more than one device can be addressed simultaneously if they are assigned the same address.

2.3. PowerLine Carrier (PLC)

At the end of 1999, the CEA formed the Data Networking Subcommittee R7.3, and began work on a high-speed PowerLine Carrier (PLC) standard. PLC technology aims to deliver burst data rates up to 20 Mbps over powerline cables. However, just like CEBus and X10, PLC shares the same power network with motors, switch-mode power supplies, fluorescent ballasts and other impairments, which generate substantial impulse and wideband noise. Electrical loads generate a time-varying environment, altering both the impedance of the line as well as the noise environment [7]. To face this mesh environment, different technologies take widely differing approaches depending on the applications they are pursuing. Technologies and algorithms including orthogonal frequency-division multiplexing (OFDM), rapid adaptive equalization, wideband signaling, Forward Error Correction (FEC), segmentation and reassembly (SAR), token passing MAC layer are employed over the powerline physical layer technologies in order to enhance transmission robustness, increase the required bandwidth, guarantee the quality and provide both asynchronous and isochronous transmission.

2.4. HomePlug

The HomePlug [8] Powerline Alliance is a rather new founded, non-profit industry association established to provide a forum for the creation of an open specification for home powerline networking products and services. HomePlug mission is to promote rapid availability, adoption and implementation of cost-effective, interoperable and specifications-based home powerline networks and products enabling the connected home. Moreover, HomePlug aims to build a worldwide standard, pursuing Frequency Division for coexistence with access technologies in North American, Europe and Asia.

The alliance consists of 12 founding members (3Com, Cisco Systems, Compaq, Conexant, Enikia, Intel, Intellon, Motorola, Panasonic, RadioShack, SONICblue and Texas Instruments), while more than 80 member companies participate in the development of the specification and the promotion of the technology.

HomePlug Alliance keeps proprietary the methods of scaling HomePlug technology to higher speeds. However, their areas of focus are modulation techniques, protocol enhancements and
circuit design optimization. The objective of the final specification is a simple-to-use, Ethernet-class powerline networking standard that will support a range of products for the gaming, consumer electronics, voice telephony and PC markets. As a starting point, HomePlug evaluated various powerline networking technologies through an industrywide, open evaluation process that incorporated theoretical analysis, lab testing and field testing. The evaluation criteria included Ethernet-class speed, clear compatibility, robustness and ease of implementation. Among the evaluated technologies, HomePlug selected the technology provided by Intellon as the baseline upon which to build HomePlug 1.0 specification. In early 2001, HomePlug began field-testing its baseline technology specification in more than 500 households and nearly 10,000 wiring paths in the United States, Canada, Japan, Korea and several European countries. Upon the completion of the field trials, HomePlug will finalize its initial technology specification and establish a certification lab to guarantee product compliance.

2.5. HomePNA

HomePNA [9] is defined by the Home Phoneline Networking Association [10], in order to promote and standardize technologies for home phone line networking, and ensure compatibility between home-networking products.

As it is shown in Figure 2, HomePNA takes advantage of existing home phone wiring and enables an immediate market for products with ‘Networking Inside’. Based on 802.3 framing and Ethernet CSMA/CD media access control (MAC), HomePNA v1.0 is able to provide 1 Mbps mainly for control and home automation applications, while HomePNA v2.0 provides up to 10 Mbps. Future versions promise bandwidth up to 100 Mb/s. Moreover, in order to meet latency requirements and guarantee Quality of Service (QoS), HomePNA 2.0 provides 8 priority levels and an improved collision resolution technique.

2.6. Home Cable Network Alliance (HomeCNA)

Home Cable Network Alliance (HomeCNA) is an alliance, aiming to standardize the physical aspects of the home coax network, wherever it is available. The HomeCNA mission is to

![Figure 2. HomePNA network architecture.](image-url)
‘develop, promote and proliferate a spectral application allocation standard for home coaxial wire and facilitate widespread adoption of the standard by the Cable, Telecom, Entertainment and Consumer Electronic Industries’ [11]. HomeCNA has gained broader acceptance by proposing a multi-industry standard, and collaborative cross-endorsement of other key standards, such as VHN, UPnP, HAVi, HomeRF, CableHome, etc.

Apart from the cable operators’ signals, HomeCNA specification also proposes a frequency allocation scheme, which enables the home coaxial network to be reused as the physical medium for higher layer technologies by utilizing unused frequency bands. Figure 3 shows the proposed schema that mixes the analog and digital video signals as well as the cable modem, the IEEE 1394 and the Ethernet signals over the same coax. In this way the coax network may play the role of home network backbone, and IEEE 1394 or Ethernet signals may be modulated and carried beyond the local audio/video (A/V) or date clusters.

3. WIRELESS TECHNOLOGIES

The wireless technologies are expected to play a key role in pushing forward the wide acceptance of the digital house. Among the RF technologies, IEEE 802.11 variations as established, proved and mature technologies and Bluetooth as simple and cheap solution for short distances are expected to capture the maximum share of the market for different applications.

3.1. HomeRF

HomeRF is an effort that aims to face the interoperability limitations of many wireless networking products. It is supported by the HomeRF Working Group (HRFWG), which was formed to establish the mass deployment of interoperable wireless networking access devices to carry both local content and the Internet for voice, data and streaming media in consumer environments [12,13]. HomeRF specification defines a new common interface that supports wireless voice and data networking in the home. The standard is based on the LAN RF technology by Proxim, which permits transmission speeds of up to 1.6 Mbps.

Meanwhile, companies like Compaq, HP, Intel, Microsoft, Motorola, Proxim and Sony are working with the HRFWG to develop the Shared Wireless Access Protocol (SWAP) [14] for radio-based home networks. The SWAP specification aims to define a new, common air interface that supports both wireless voice and data services in the home environment, provide data rates up to 10 Mbps and ensure interoperability among multivendor consumer electronics wireless products. SWAP operates in the 2.4 GHz band and combines elements of the Digital...
Enhanced Cordless Telecommunications (DECT) and the IEEE 802.11 standards. It supports both a Time Division Multiple Access (TDMA) service to provide delivery of interactive voice and other time-critical services, and a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) service for delivery of high-speed packet data. The protocol architecture closely resembles the IEEE 802.11 wireless LAN standards in Physical layer and extends the Medium Access Control (MAC) layer with the addition of a subset of DECT standards to provide isochronous services such as voice. As a result, the SWAP MAC layer can support both data oriented services, such as TCP/IP, and the DECT/GAP protocols for voice.

The SWAP system can operate either as an ad hoc network for data only communications or as a managed network under the control of a Connection or Access Point for voice and data communications. The Connection Point provides the gateway to the telephone network and can be connected to a PC via a standard interface such as USB.

The HomeRF network can accommodate up to 127 nodes of four basic types: the Connection Point, which supports voice and data services, the Voice Terminal, which uses the TDMA service only to communicate with a Connection Point, the Data Node, which uses the CSMA/CA service to communicate with the Connection Point and other data nodes and the Voice/Data Node, which can use both types of services.

3.2. Bluetooth

Bluetooth [15] intends to serve as a universal low cost, user friendly, air interface that will replace the plethora of proprietary interconnect cables between a variety of personal devices and peripherals. Bluetooth is a short-range (10 cm–10 m) frequency-hopping wireless system providing up to 1 Mbps in the unlicensed 2.4 GHz band. To add more flexibility, there are efforts to extend the range of Bluetooth with higher-power devices [16], though it remains a last meters technology.

Bluetooth supports both point-to-point and point-to-multipoint connections. Currently up to seven slave devices can communicate with a master radio in one device. It also provides for several piconets to be linked together in ad hoc networking mode, which allow for extremely flexible configurations such as might be required for meetings and conferences [17,18].

The Bluetooth protocol stack architecture is shown in Figure 4. It is a layered stack that supports physical separation between the Link Manager and the higher layers at the Host Interface, which is common in most Bluetooth implementations. The Baseband RF layer provides the functionality required for air interface packet framing, establishment and maintenance of piconets and link control. The Link Manager is responsible for link set-up and control including authentication, encryption control, physical parameters control, etc. [19,20]. The Logical Link Control Adaptation Layer Protocol (L2CAP) provides connection-oriented and connectionless data services to higher layer protocols. Finally Service Discovery Protocol (SDP) allows Bluetooth devices to discover what services are available on a device, RFCOMM provides an emulation of serial ports, and Telephony Control Specification (TCS) provides an adaptation layer that enables Q.931 call control services. Bluetooth is ideal for both mobile office workers and small office/home office (SOHO) environment as a flexible cable replacement that covers the last meters [21–23]. For example, once a VoIP call is established, a Bluetooth earphone may automatically switch between cellular and fixed telephone networks, when one enters his home or office. Of course the low bandwidth capability permits only limited and dedicated usage, and inhibits Bluetooth from in-house multimedia networking.
3.3. **IEEE 802.11**

IEEE 802.11 [24] is the most mature wireless protocol for wireless LAN communications, deployed for years in corporate, enterprise, private and public environments (e.g. hot-spot areas). The IEEE 802.11 standards [25] support several wireless LAN technologies in the unlicensed bands of 2.4 and 5 GHz, and share use direct-sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS) physical layer RF technologies. Infrared technology is also supported, but it is not really adopted by any manufacturer.

Initially the IEEE 802.11 standard provided up to 2 Mbps at the 2.4 GHz band, without any inherent QoS [26]. The wide acceptance, however, initiated new versions and enhancements of the specification. The first and most important is the IEEE 802.11b specification, which achieves data rates of 5.5 and 11 Mbps by using complementary code keying (CCK) modulation [27–29]. Recently, the IEEE 802.11g task group has formed a draft standard that achieves data rates higher than 22 Mbps; adopting either single-carrier trellis-coded 8-phase shift keying (PSK) modulation or OFDM schemes, while in the 5 GHz band, the IEEE 802.11a technology supports data rates up to 54 Mbps using OFDM schemes. OFDM is very efficient in time-varying environments, where the transmitted radio signals are reflected from many points, leading to different propagation times before they eventually reach the receiver. Other 802.11 task groups targeting specific areas of the protocol are [30]:

- **802.11d** task group works towards 802.11b versions at other frequencies, for countries where the 2.4 GHz band is not available.
- **802.11e** task group works towards the specification of a new 802.11 MAC protocol in order to accommodate additional QoS provision and security requirements over legacy 802.11 PHY layers.
- **802.11f** task group aims to improve the handover mechanism in 802.11 so that users can maintain a connection while roaming between access points attached to different networks.
- **802.11h** aims to enhance the control over transmission power and radio channel selection to 802.11a, in order to be acceptable by the European regulators.
- **802.11i** aims to enhance the security mechanism. Instead of the Wired Equivalent Privacy (WEP), a new authentication/encryption algorithm based on the Advanced Encryption Standard (AES) will be proposed.
- **802.11j** aims to propose the IEEE 802.11a and HiperLAN2 interworking.

In order to ensure interoperability and compatibility across all market segments [31], a Wireless Ethernet Compatibility Alliance (WECA) has been formed in order to certify a compliance procedure called Wi-Fi (Wireless Fidelity) of new products [32].

### 3.4. IEEE 802.15.3

The IEEE 802.15.3 is a new specification designed from scratch in order to support *ad hoc* networking and multimedia QoS guarantees. In *ad hoc* networking mode, based on existing network conditions, a device may join or leave a group or sub-network, and play the role of a master or a slave node [33].

The IEEE 802.15.13 PHY has some similarities with IEEE 802.11b. Both operate in the unlicensed frequency band of 2.4 GHz and employ the same symbol rate, 11 Mbaud. However, 802.15.3 is designed to achieve data rates from 11 to 55 Mb/s targeting distribution of high-definition video and high-fidelity audio. IEEE 802.15.3 uses five types of modulation formats: trellis coded QPSK at 11 Mbps, uncoded QPSK at 22 Mb/s, and 16/32/64-quadrature amplitude modulation (QAM) at 33, 44 and 55 Mb/s, respectively (TCM) [34]. The base modulation format is QPSK (differentially encoded). Depending on the capabilities of devices at both ends, the higher data rates of 33–55 Mb/s are achieved by using 16, 32, 64-QAM schemes with 8-state 2D trellis coding. The 802.15.3 signals occupy a bandwidth of 15 MHz, which allows for up to four fixed channels in the unlicensed 2.4 GHz band.

The IEEE 802.15.3 superframe is shown in Figure 5 [35–37]. Initially a network beacon is transmitted carrying network specific parameters (e.g. information for new devices to join the network, power management). Then a Contention Access Period (CAP) follows utilizing a CSMA/CD medium access control mechanism for transmission of frames that do not require QoS guarantee (e.g. short bursty data or channel access requests). Finally a Guaranteed Time Slot (GTS) period follows allocated for image files, standard and high-definition video (MPEG-1, MPEG-2) and high quality audio.

IEEE 802.15.3 can be considered as a Bluetooth evolution as it is optimized for short-range transmission limited to 10 m, enabling low-cost and integration into small consumer devices e.g.
a flash card or a PC Card. The PHY layer also requires low current drain (less than 80 mA) while actively transmitting or receiving data and minimal current drain in the power save mode.

3.5. HIPERLAN/2

HIPERLAN/2 is the European proposition for a broadband wireless LAN operating with data rates up to 54 Mbps at PHY on the 5GHz frequency band. The HIPERLAN/2 is supported by the European Telecommunications Standards Institute (ETSI), and developed from the Broadband Radio Access Networks (BRAN) group [38–40].

HIPERLAN/2 is a flexible Radio LAN standard designed to provide high-speed access to a variety of networks including 3G mobile core networks, ATM networks and IP-based networks, and also for private use as a wireless LAN system. HiperLAN/2 is a connection-oriented Time Division Multiplexed (TDM) protocol. Data is transmitted on connections that have been established prior to the transmission using signaling functions of the HiperLAN/2 control plane. This makes it straightforward to implement support for QoS. Each connection can be assigned a specific QoS, for instance in terms of bandwidth, delay, jitter, bit error rate, etc. It is also possible to use a more simplistic approach, where each connection can be assigned a priority level relative to other connections. This QoS support in combination with the high transmission rate facilitates the simultaneous transmission of many different types of data streams, e.g. video, voice and data [41,42].

The HiperLAN/2 protocol stack is shown in Figure 6 [43]. At the physical layer, like IEEE 802.11a, HiperLAN/2 uses OFDM to transmit the analogue signals. Above the physical layer, the MAC protocol is built from scratch implementing a type of dynamic TDMA/TDD scheme with centralized control. The Error Control is responsible for detection and recovery from transmission errors on the radio link. Moreover, it ensures in-sequence delivery of data packets. In the Control Plane, the Radio Link Control Sublayer (RLC) provides a transport service to the DLC User Connection Control, the Radio Resource Control and the Association Control Function. Finally a convergence sublayer is provided for each supported network.

3.6. 5 GHz Unified Protocol (5-UP)

IEEE 802.11a technology is one of the most powerful, however, it does not provide any inherent QoS support; thus European regulators prefer and promote the ETSI HiperLAN/2. In order to overcome this issue, ETSI and IEEE have formed a joint venture called the 5 GHz Partnership Project (5GPP), which aims to merge 802.11a and HiperLAN2 into a single standard, tentatively known as the 5 GHz Unified Protocol (5-UP). By tying two or even three channels together, this standard would offer even higher data rates than the existing systems, while guarantee approval within Europe [30].

The 5-UP [44,45] proposal extends the OFDM system to support multiple data rates and usage models. 5-UP is expected as an enhancement to the existing IEEE 802.11a standard that would permit cost-effective designs in which every consumer electronic device, from cordless phones to high-definition televisions and personal computers, could communicate in a single wireless multimedia network. 5-UP achieves this by allocating the carriers within the OFDM signal on an individualized basis. As shown in Figure 7, multiple devices simultaneously transmit to an access point utilizing different OFDM carriers.
4. NEW WIRING REQUIREMENTS

Technologies that require new structured wiring provide a secure way to deploy new services, as technologies that have been tested in enterprises and business sectors are now brought to the
home environment. Among various interfaces/technologies that fall into this category, we underline the Ethernet, the USB and the FireWire (IEEE 1394).

4.1. Ethernet

Ethernet is the default LAN technology for the PCs and maybe the most widespread and well-known LAN technology used in corporate and enterprise networks. It is formally defined as IEEE 802.3 and uses either BNC or UTP wiring, in bus and star topologies, respectively.

Ethernet is going to be one of the major alternatives for the in-home networks. It is a mature technology, with proven speeds up to 100 Mbps over Unshielded Twisted Pair (UTP) CAT-5 (UTP-5) or better wiring. Moreover, it is supported by a plethora of vendors, which have driven the cost of the Ethernet enable devices, the Network Interface Cards (NICs) and the wiring to very low prices. It is not a coincidence that the majority of Set-Top Boxes, Cable or DSL modems have an Ethernet interface.

Of course, Ethernet has also several drawbacks starting from the requirement for re-wiring of the home, with UTP CAT-5 cable and the need for an NIC for each PC. Moreover, consumer electronics’ networks will require carrying both asynchronous/data traffic (e.g. generated from PCs) and isochronous traffic (e.g. from multimedia applications such as video, audio and voice telephony), which require QoS. Ethernet does not support inherently QoS. In order to solve this problem two approaches can be followed: (i) use QoS techniques like DiffServ, IntServ and MPLS for controlling the available bandwidth resources or (ii) utilize switched Ethernet network devices that isolate the traffic between different sub-networks. In this way, large files may be downloaded or transferred in one segment, without harming the quality of a video stream in a different segment. Last but not least, as Ethernet is a broadcasting medium network that does not control traffic distribution. Thus, content providers have formed a Copy Protection Technical Working Group (CPTWG) [46], who tries to endorse the movies via content encryption. Regardless of these drawbacks, the Ethernet is foreseen to play an important role in home networking, especially for the new homes.

4.2. Universal Serial Bus (USB)

USB is a wireline technology, which like Bluetooth, aims to replace all the different kinds of serial and parallel port connectors with one standardized interface. The main advantage of USB in the Consumer Electronics’ Networks is its ability for ‘hot-swapping’ of multiple peripherals in daisy-chain architecture. As most PCs today have at least 2 USB ports on-board, accessible from outside the case, connecting new USB devices is a very simple plug’n’play process. Moreover, USB is able to cover limited power requirements of the devices, eliminating in many cases the need for additional power cables.

USB v1.1 [47] provides both asynchronous data transfer and isochronous streaming channels for audio/video streams, voice-telephony and multimedia applications, and bandwidth up to 12 Mbps adequate even for compressed video distribution. USB v2.0 transfers rates up to 460–480 Mbps, about 40 times faster than v1.1, covering more demanding consumer electronic devices such as digital cameras and DVD drives.

The USB standard is supported and promoted by many very large PC hardware/software manufacturers. Moreover, the USB Implementers forum [48] aims to set USB as the de-facto standard for all peripheral devices. However, USB may not dominate in the Consumer Electronics Networks in the short term, though it will be among the major players. Apart from

the new wiring requirements, USB has found rather limited acceptance until now in the business environment, due to installed equipment with different interfaces (PS/2, serial, parallel, Ethernet). This may also be reflected in Consumer Electronics Networks, limiting USB to short distance connections between peripherals.

4.3. **IEEE 1394**

IEEE 1394 [49] (i.Link or Firewire) was initially proposed for entertainment appliances, but soon turned into an emerging standard that targets all consumer multimedia networks. Although IEEE 1394 does not specify a physical medium, in most cases it utilizes twisted pair (UTP CAT-5) or Plastic Optical Fibre (POF) [49]. POF provides the advantages of glass optical fibre (GOF), but at lower cost, much shorter distances and easier use. Initially, GOF received more attention, due to its rapid acceptance in the telephone industry, but recent developments have made POF a contender for a large number of data and audio applications [50].

IEEE 1394 implements an easy to set-up, hot plugging, scalable, bus architecture, which does not require any terminators or device addresses. It is able to provide speeds of 100–200 Mbps over CAT-5, or 400, 800 or 1600 Mb/s over POF for peer-to-peer communications and allows a mix of transfer speeds on the bus, enabling the interconnection of devices with different speed capabilities and cost. Furthermore, IEEE 1394 supports both asynchronous and isochronous types of data transfer, and guarantees data transport at a predetermined rate utilizing isochronous data channels [51].

Figure 8 shows the IEEE 1394 protocol stack [52]. As it is shown there are three layers: a Physical Layer, responsible for physical layer functions, a Link Layer responsible for packet transmission/reception and error control, and a Transaction Layer responsible for packets read, write and lock.
write and lock functions. In parallel, the Serial Bus Management plane controls and manages
the Bus functions and the isochronous resources. It is important to note that the protocol stack
is independent of the IEEE 1394 Physical Interface.

Currently, many standardization bodies and committees, including the Digital Video
Broadcasters (DVB), the Digital VCR Conference (DVC) and the CEA R4.1 and R7.4 VHN
Subcommittees, have adopted IEEE 1394 as their default interface for broadband, low-cost,
digital communications [53,54].

5. HIGHER-LAYER TECHNOLOGIES

Apart from the physical medium, interoperability can be provided at higher layers. In this
paragraph we describe such technologies, which, to our belief, are among the major players in
the area.

5.1. Home Electronic System (HES)

HES [55–58] standards aims to specify rules to guarantee, in a multivendor/multiapplication
context, free implementation and configuration of the system and interoperations between the
devices in the system. The basic principle is to separate the devices and the network, and define
stable interfaces between them. The HES standards do not cover the medium and the associated
access units. Instead it gives the specifications for the services delivered through these interfaces
and for the local implementations of them. A home network may be based on one or more
different physical media (e.g. powerline, twisted pair, infrared or RF) and may also be connected
to access networks (e.g. telephone, CATV, power network). An implementation of the Home
Electronic System may be assembled by one application at a time, starting from single
applications like lighting control, security control or audio and video control, to grow
eventually into an integrated multiapplication system.

HES standard principle is plug-compatibility, which is defined as the ability to provide for
interoperability and interconnectivity between devices [59,60]. Moreover, devices’ interoper-
ability is defined as the ability of the higher communication layers to exchange commands and
result in meaningful actions, while devices’ interconnectivity is defined as the ability of the
devices to be hooked together on a shared transmission medium. The goal of plug-compatibility
is to specify hardware and software that enable a manufacturer to offer one version of a product
for connection to a variety of home networks. To make this possible the HES separates the
appliances from the Network medium.

As shown in Figure 9, HES specifies a Universal Interface to be incorporated into an
appliance for communication over a variety of home networks, Application Service Elements
(ASE) and a communication language for ASE-to-ASE communication in the same appliance
or appliance-to-appliance communication. Moreover, in the HES Reference Model [61] a
distinction is made between information channels, which use circuit-switched transmission and
control channels, which use packet-switched transmission. Although circuit-switch transmission
may be optional in case of simple automation applications, control channels are mandatory for
all consumer electronic systems; thus, all HES implementations shall provide a control channel.
Finally in order to allow manufacturers to implement cheaper devices/network combinations, a
simpler HES conformance type is also defined. In this case, a device connects directly to the
medium (without the UI). These devices will however be medium dependent and do not have the advantages of devices with full HES conformance.

5.2. Home Audio/Video Interoperability (HAVi)

HAVi [62,63] aims to allow all manner of digital consumer electronics and home appliances to communicate with each other. HAVi was defined by Grunding, Hitachi, Panasonic, Philips, Sharp, Sony, Thomson and Toshiba, who have been committed to develop products following the HAVi protocol. HAVi has selected the IEEE 1394 as physical medium to interconnect the devices, while it does not exclude other physical media.

HAVi is a digital AV networking initiative that provides a home networking software specification for seamless interoperability among home entertainment products. Equally important, the HAVi specification is AV-device-centric, so it has been designed to meet the particular demands of digital audio and video. It defines an operating-system-neutral middleware that manages multidirectional AV streams, event schedules and registries, while providing APIs for the creation of a new generation of software applications. The main characteristics of HAVi are:

- **Distributed Control**: Functions on any device may be controlled from another device.
- **Interoperability**: Entertainment products from different manufacturers will communicate with each other.
- **Hot “Plug and Play”**: HAVi compliant devices automatically announce their presence and capabilities, greatly simplifying installation and setup.
- **Upgrade capability**: New functionality and capabilities may be downloaded/uploading via the Internet.

Figure 10 shows the HAVi protocol stack [63,64]. As it is shown, HAVi is independent from the physical medium and lower layer protocol and operates over Vendor’s specific Real Time Operating Systems. Its Device Control Modules (DCMs) define four devices profiles: (a) full audio-video devices, which can download and execute HAVi applications, (b) intermediate HAVi devices that can execute limited applications, (c) base audio–video devices, which offer...
read-only information about themselves and (d) legacy devices, which do not support HAVi, but can be controlled by other devices. It is important to note that apart from the HAVi specific layers, JAVA Virtual Machine is also supported, and Java applications (Havlets) that can be extracted from a DCM or an Application on request.

HAVi will make it easier for companies to build and market new application programs by using HAVis APIs or programming in Java. Bridges will also be available to home control systems, security systems, communication systems and PC-based applications.

5.3. Universal Plug’n’Play (UPnP)

UPnP [65,66] aims to extend the simplicity and auto-configuration features from device Plug and Play (PnP) to the entire network, enabling discovery and control of networked devices and services. UPnP is supported and promoted by the UPnP forum. UPnP is led by Microsoft, while some of the major UPnP forum members are HP, Honeywell, Intel, Mitsubishi and Philips. The scope of UPnP is large enough to encompass many existing, as well as new and exciting consumer electronics networking and automation scenarios including home automation/security, printing and imaging, audio/video entertainment, kitchen appliances and automobile networks.

In order to ensure interoperability between vendor implementations and gain maximum acceptance in existing networked environment, UPnP leverages many existing, mature, standard protocols used on the Internet and on local area networks like IP, HTTP and XML.

UPnP enables a device to dynamically join a network, obtain an IP address, convey its capabilities and learn about the presence and capabilities of other devices. Devices can automatically communicate with each other directly without any additional configuration. UPnP can be utilized over most physical media including Radio Frequency (RF, wireless), phoneline, powerline, IrDA, Ethernet and IEEE 1394. In other words, any medium that can be
used to network devices together can enable UPnP. Moreover, other technologies (e.g. HAVi, CeBus or X10) could be accessed via a UPnP bridge or proxy, providing for complete coverage (Figure 11).

The basic protocols used to implement UPnP [67] are summarized (Figure 12):

- **IP**: UPnP is based on the IP protocol. Thus, leverages the protocol’s ability to span different physical media and enable the direct usage of protocols like TCP, UDP, IGMP and ARP as well as core services such as DHCP and DNS.
• **HTTP/HTTPU/HTTPMU:** HTTP over TCP is also a core part of the UPnP protocol, while its variants, HTTP over UDP (HTTPU) and HTTP Multicast over UDP (HTTPMU) are used when message delivery does not require the overhead associated with reliability.

• **Simple Service Discovery Protocol (SSDP):** defines methods both for devices to announce their availability and control points to locate the resources on the network. As a result, every control point has a complete view the network state. Moreover, SSDP enables devices and associated services to gracefully leave the network and includes cache timeouts to purge stale information.

• **Generic Event Notification Architecture (GENA):** provides the ability to send and receive notifications to subscriber entities using HTTP over TCP/IP and multicast UDP. A control point interested in receiving event notifications will subscribe to an event source, and GENA will create the presence announcements to be sent using SSDP and to provide the ability to signal changes in service state for UPnP eventing.

• **Simple Object Access Protocol (SOAP):** defines the use of XML and HTTP to execute remote procedure calls (RPC). By making use of the Internet’s existing infrastructure, it can work effectively with firewalls and proxies. SOAP can also make use of Secure Sockets Layer (SSL) for security and use HTTP’s connection management facilities, thereby making distributed communication over the Internet as easy as accessing web pages.

• **UPnP Specific Protocols:** UPnP vendors, UPnP Forum Working Committees and the UPnP Device Architecture layers define the highest layer protocols used to implement UPnP. Based on the device architecture specification, the working committees define information global to specific device types such as VCRs, HVAC systems, dishwashers and other appliances. Subsequently, UPnP Device Vendors define the data specific to their devices such as the model name, URL, etc.

5.4. **European Home System (EHS)**

The European Home Systems Association (EHSA) [68] may be considered as a major European proposition in Home Systems standardization. EHSA is an open organization supported by major European electronic and electric companies, aiming to support and promote European industry in the field of Home Systems. In order to let electronic and electric devices from different manufacturers communicate with each other, EHSA developed the EHS specification based on the OSI reference model. EHS defines a complete network system, which supports all domestic functions, in a modular, extendible and automatically configurable way. EHS is an open system with distributed management and control functions, suitable for all commonly available media. The EHS specification, release 1.2 (Table II) covers six medium types to transport control data (Twisted pair TP1/TP2, Coaxial, PowerLine, RF and Infrared) sharing the same Logical Link Control (LLC) sub-layer. Conformance and inter-operability testing, ensure that products from different manufacturers are inter-operable.

5.5. **KONNEX**

KONNEX Association [69,70] is the name of the merging between the Batibus Club International (BCI), the European Installation Bus Association (EIBA) and the European Home Systems Association (EHSA). The Baltibus, EIB and EHS technologies, respectively,
suited to certain application areas, have been merged, in order to provide the technical basis for the convergence into a single common system supported by relevant industrial companies.

KONNEX is based on the fact that different system specifications from different industrial areas have confused planning engineers, contractors, installers, resellers, end-users, building owners and investors. This situation is hindering market acceptance and growth, while each system lacks the necessary volume success. The newly established KONNEX technology aims to provide for the first time a common field bus platform, suitable for all applications in the residential and building market.

5.6. Open Services Gateway Initiative (OSGi)

OSGI [71] is an organization largely comprised of equipment OEMs and a handful of service providers looking to develop a standard set of APIs that together make up a service gateway specification. OSGI mission is to create an end-to-end solution that enables the delivery of services in different media environments. OSGi is developing a set of Java-based APIs that will enable service providers to offer just-in-time value added services. Moreover, it promotes a new consumer networking device, called Residential Gateway (RG). The RG will be capable of interfacing multiple access and indoor media and terminals and will become a service distribution, integration and management point in an SOHO or residence.

OSGi is led by Sun, Oracle and Sybase, while other members of OSGi are Ericsson, IBM, NCI, Nortel, Philips, Alcatel, Motorola, Lucent, Enron, Cable and Wireless, EDF and Toshiba, Electricité de France, while OSGi states that it is currently working with a number of service providers to get service requirements for the first draft of the specification.

The first OSGi specification will concentrate on Java-based APIs for the RG. Then, OSGI will create some reference specifications for tying in all Home LAN protocols and define some service protocols for service providers. The group has not laid out a timetable for these activities. OSGI is based on a three tier-computing model incorporating device, RG and the backend systems. The RG acts as the middle of the services sandwich infrastructure. The backend systems include database servers of various vertical service providers (e.g. Oracle, Sybase). Figure 13 shows the OSGI’s protocol stack [72,73]. OSGI is based on a Sun’s Java

Table II. European Home System Specification Network Characteristics.

<table>
<thead>
<tr>
<th>Medium type</th>
<th>Twisted pair type 1 (TP1)</th>
<th>Twisted pair type 2 (TP2)</th>
<th>Coaxial cable</th>
<th>PowerLine</th>
<th>Radio</th>
<th>Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target application</td>
<td>General purpose control</td>
<td>Telephony, ISDN, Data, Control</td>
<td>AV, TV, Data, Control</td>
<td>Control</td>
<td>Telephone, CT2</td>
<td>Remote control</td>
</tr>
<tr>
<td>Bit rate</td>
<td>9.6 kbps</td>
<td>64 kbps</td>
<td>9.6 kbps</td>
<td>2.4 kbps</td>
<td>1.2 kbps</td>
<td>1.1 kbps</td>
</tr>
<tr>
<td>Access</td>
<td>CSMA/CA</td>
<td>CSMA/CD</td>
<td>CSMA/CA</td>
<td>CSMA/ACK</td>
<td>CT2</td>
<td>—</td>
</tr>
<tr>
<td>Power feed</td>
<td>35 V</td>
<td>35 V</td>
<td>15 V</td>
<td>230 V AC</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Channels</td>
<td>—</td>
<td>14</td>
<td>Many</td>
<td>—</td>
<td>40</td>
<td>—</td>
</tr>
<tr>
<td>Bit rate</td>
<td>—</td>
<td>64 kbps</td>
<td>Analog</td>
<td>—</td>
<td>32 kbps</td>
<td>—</td>
</tr>
<tr>
<td>Coding</td>
<td>—</td>
<td>TDM</td>
<td>FDM</td>
<td>—</td>
<td>FDM</td>
<td>—</td>
</tr>
<tr>
<td>Topology</td>
<td>Free</td>
<td>Bus</td>
<td>Bus</td>
<td>Free</td>
<td>Free</td>
<td>Free</td>
</tr>
<tr>
<td>Units/network</td>
<td>128</td>
<td>40</td>
<td>128</td>
<td>256</td>
<td>256</td>
<td>256</td>
</tr>
<tr>
<td>Range</td>
<td>500 m</td>
<td>300 m</td>
<td>150/50 m</td>
<td>House</td>
<td>50–200 m</td>
<td>Room</td>
</tr>
</tbody>
</table>
Virtual Machine. Over OSGi provides a general purpose, secure, managed JAVA framework that supports the deployment of downloadable applications, known as bundles.

Since the group’s focus is on the application layer, OSGI claims to be media agnostic. The group states that its APIs will work with different underlying transport protocols, including SWAP, HPNA, Ethernet, 802.11 and other various networking protocols. However, because OSGI is primarily Java based, its naturally predisposed to best interoperate with Jini for internetworking connectivity within the consumer electronics devices.

6. TECHNOLOGIES COMPARISON

The selection among all these wireline/wireless current/future technologies is quite difficult. Among the technologies that require rewiring, Ethernet is going to be one of the major alternatives. It is a mature and reliable technology, with simple and low-cost installation and configuration. Another indication towards potential broad acceptance of Ethernet is the fact that the most Set-Top Boxes, Cable or DSL modems have an Ethernet interface and many Telecom Operator request for home networking products with multiple switched 10/100 BaseT Ethernet interfaces. On the other hand, due to Ethernet’s lack of QoS and isochronous transmission, IEEE 1394 will also dominate. IEEE 1394 has more than enough capacity for carrying simultaneously multiple digital audio and video streams around the house, and can be utilized over multiple physical media (POF, UTP, wireless). Finally, USB has the features and the political support, thus it may play an important role in the home-network domain especially for short distances connections.

Owing to simplicity and economical reasons, however, it is rather obvious that the ‘no rewiring’ technologies, will get the major part of the existing houses market. Among the technologies that reuse existing house wiring, home coax network is a very good candidate solution. Especially in new buildings and in some developed countries there is a large penetration of houses that are already wired with coax mainly for analogue TV distribution. In that cases, coax may play an important role as the consumer electronics backbone network.
However, there is not critical mass of wired houses worldwide, so coax may not be a broadly accepted solution.

On the other hand, the powerline and the phoneline technologies are expected to play an important role, but may not dominate. In case of powerline, higher layer standards (e.g. HomePlug and UPnP) aim to overcome the problems inherited from the inferior, yet wide available physical medium. However, powerline technologies are still not mature enough for a large Consumer Electronics market share. It is also important to note that the powerline network can also be used as access network. However, the different characteristics, devices and architecture of the network worldwide, along with the highly noisy environment limit the short-term expectations. In case of phoneline, HomePNA may be just complementary to other technologies, due to the telephone wiring network architecture, the limited number of telephone jacks in each room and the inconvenient places where they are located.

The wireless technologies are expected to push forward the wide acceptance of the digital house and be the eventual dominant player. Among them, IEEE 802.11b as an established, proven and mature technology and Bluetooth as a simple and cheap cable replacement for short distances are expected to capture in short- to mid-term the maximum share of the market. Until recently, IEEE 802.11b technology was too expensive for use in the home. However, as with most technologies, advances in VLSI and volume production have reduced the cost of the implementation. Moreover, corporate users are already familiar with 802.11b, while many laptops are already 802.11b-enabled eliminating the need for an extra interface card. The major limitation of IEEE 802.11 is the lack of QoS and isochronous transmission slots, which will be provided by IEEE 802.11e. Apart from IEEE 802.11 variations, IEEE 802.15.3, HIPERLAN/2 and 5-UP technologies are foreseen as very good candidates for the home network, whenever compatible products are available. Table III provides a comparison of Home RF Technologies, underling the major differences and competitive advantages.

Besides the features and drawbacks of the candidate individual network protocols and physical mediums, it is obvious that multiple technologies will be involved in the digital home network. Thus, interoperation between the in-home technologies along with interconnection with the access network technologies will be a very crucial. In this paper, we reviewed propositions and standards that aim to provide interoperability and interconnectivity. Among the alternative solution HAVi and UPnP are expected to play the most important role, giving UPnP a small advance. Both are based on higher layer, standardized and wide accepted protocols (TCP, UDP, IP, JAVA). However, UPnP may utilize any physical medium, while HAVi utilizes only IEEE 1394, and UPnP incorporates and utilizes standard, wide accepted protocols, while HAVi only supports the Java Virtual Machine.

Last but not least, both the OSGi and the UPnP standards support the RG concept. As shown in Figure 14, the RG is expected to be the demarcation and interconnection device between the access and the in-home networks. It will provide not only the Network Terminator (NT) and the modem functionality, but also interface/Interconnect all in-home networks and carry out the switching functions for telecommunication, computing and entertainment service deliveries to the end-users. At the same time, the RG will provide overall control and management over a variety of electrical and consumer electronic appliances. Its role within the end-to-end network architecture will be to offer transparent access to a diversity of services offered by network operators and service providers while at the same time allow for the introduction of new, added value services. Finally, the RG or the user via the RG may control...
### Table III. Comparison of home RF technologies.

<table>
<thead>
<tr>
<th></th>
<th>Bluetooth 2</th>
<th>HomeRF2</th>
<th>802.11</th>
<th>802.11b</th>
<th>802.11a</th>
<th>802.11g</th>
<th>802.15.3</th>
<th>HiperLAN2</th>
<th>5-UP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band Technology</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>5 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>5 GHz</td>
<td>5 GHz</td>
</tr>
<tr>
<td>Technology</td>
<td>FHSS</td>
<td>FHSS</td>
<td>FHSS/DSSS</td>
<td>DSSS</td>
<td>OFDM</td>
<td>DSSS/OFDM</td>
<td>OFDM</td>
<td>OFDM</td>
<td>OFDM</td>
</tr>
<tr>
<td>Range</td>
<td>10 cm–10 m</td>
<td>50 m</td>
<td>150 m</td>
<td>150 m</td>
<td>50 m</td>
<td>150 m</td>
<td>10 m</td>
<td>80 m</td>
<td>80 m</td>
</tr>
<tr>
<td>Complexity</td>
<td>1x</td>
<td>1.5x</td>
<td>1x</td>
<td>1.2x</td>
<td>4x</td>
<td>~3.5x</td>
<td>1.5x</td>
<td>2.5x</td>
<td>2x</td>
</tr>
<tr>
<td>QoS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Throughput</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td>≤10 Mbps</td>
<td>≤10 Mbps</td>
<td>2 Mbps</td>
<td>11 Mbps</td>
<td>54 Mbps</td>
<td>22 Mbps</td>
<td>11–55 Mbps</td>
<td>54 Mbps</td>
<td>108 Mbps</td>
</tr>
<tr>
<td>Effective</td>
<td>≤6 Mbps</td>
<td>≤6 Mbps</td>
<td>≤1 Mbps</td>
<td>≤7 Mbps</td>
<td>≤31 Mbps</td>
<td>≤12 Mbps</td>
<td>≤30 Mbps</td>
<td>≤31 Mbps</td>
<td>≤72 Mbps</td>
</tr>
<tr>
<td>Regional support</td>
<td>Worldwide</td>
<td>US/Asia</td>
<td>Worldwide</td>
<td>US/Asia</td>
<td>Worldwide</td>
<td>Worldwide</td>
<td>Worldwide</td>
<td>Europe/ Japan</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Promoters</td>
<td>2000+</td>
<td>&lt; 50</td>
<td>200+</td>
<td>&lt; 100</td>
<td>&lt; 100</td>
<td>~ 100</td>
<td>~ 50</td>
<td>&lt; 50</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>Target application</td>
<td>Cable</td>
<td>Voice/data</td>
<td>Data</td>
<td>Data</td>
<td>Data</td>
<td>Data</td>
<td>Audio/Data</td>
<td>Data</td>
<td>Voice/data</td>
</tr>
</tbody>
</table>

Backwards compatibility is questionable.
most of the in-home appliances (e.g. automatically or remotely start the coffee machine or the house heating), forward the telephone calls, control the security system.

7. CONCLUSIONS

In this survey, we have reviewed the major available technologies and standardization efforts in the home network area, and provided a comparison of the competing broadband in-home technologies. Lower layer technologies and standards are categorized based on their physical medium requirements in technologies that reuse existing in-home wiring infrastructure, wireless technologies and technologies that target new houses. Moreover, we have discussed technologies that aim to provide convergence between multiple in-home and access networks.

It is the authors’ opinion that multiple technologies will be finally used in the home network. Technologies that require new structured wiring (Ethernet, IEEE 1394) provide a secure way to deploy new services; however, they are expected to be more popular in the new home construction market, as it is hard to request from the homeowners to drill through walls and retrofit the home with cables. Between the ‘no rewiring’ technologies, the powerline and phoneline are the most convenient; however, they suffer from inherent architectural, stability and performance limitations. Wherever installed, coax wiring may be the backbone of the home network, carrying the Ethernet and the IEEE 1394 signals between the rooms and the house floors. In the mid- to long-term, the ‘no-wires’ technologies are foreseen to dominate. Current deployed (e.g. IEEE 802.11b, HomeRF) and emerging (e.g. IEEE 802.15.3, HiperLAN/2, IEEE 802.11a, 5-UP) will cover the main in-home networking requirements, while for short distances and low cost communication, Bluetooth is envisaged. The RG is expected to play a key role in the consumer electronics networking and automation systems, because they introduce great opportunities for added value end-to-end broadband services.
What should be underlined, however, is that the consumer electronics networking infrastructure and the RG are only two of the aspects to be considered. Success will be based on the effectiveness, usability and cost of the end-to-end network system as a whole. Unfortunately for the consuming public, more than the technology itself, the future of the Digital Home is based on the operators’ and industrial giants’ strategic decisions.

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**Kostas Pramataris** was born in Boston, U.S.A. He received his Dipl-Ing Degree in Electrical & Computer Engineering from the National Technical University of Athens (NTUA) and a PhD in the area of broadband telecommunication architectures. Since 1997, he has been working for Lucent Technologies, first as a technical consultant to Bell Laboratories Homdel, NJ and subsequently as senior member of Technical Staff of Forward Looking Work Dept. of Lucent Technologies in Huizen, The Netherlands. K. Pramataris was actively involved in research projects on hardware design and transmission theory for broadband networking technologies (ATM, HFC, ISDN, VoIP) and video distribution. He participated in several EU research projects, some of which are: ACTS ATHOC, RACE BRAVE, ESPRIT BC3 and INRAM, IST PRO3. In the INRAM he was responsible for the development of a high performance IC component for sophisticated buffering of multiple high bandwidth data streams, while in the PRO3 a programmable protocol processor. In Lucent Technologies, K. Pramataris manages development of state-of-the-art telecommunication hardware for access systems, IP switching, ASIC design, DSP and FGA programming, and switched digital video systems.