# A comparison of competing broadband in-home technologies

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Connecting each house to a broadband access network represents an unprecedented opportunity to offer added-value services and broadband Internet access to residential users and expand the customer base beyond the corporate environment. Home networks, however, may be the last barrier to end-to-end multimedia service provisioning. Although a large number of houses have PCs, modems or multimedia network-enabled appliances, the majority are not equipped to support their interconnection, and most consumers are unwilling or cannot afford large-scale home rewiring. This paper reviews the available home-networking technologies and provides a comparison of the competing broadband in-home technologies. The focus is on technologies that do not require rewiring the home, either reusing the existing wiring or using wireless technology. The paper also discusses the residential gateway (RG) initiative, which provides a single point of convergence between the in-home and the access networks.

## 1 Introduction

Until recently the major obstacle to the 'digital networked house' was the access network. For years, an inadequate network infrastructure and the huge cost of new installations hindered broadband access at home; this was the well-known 'last mile problem'. However, innovations in broadband access technology and investments in access infrastructure have now brought the information superhighway to just outside the main door of a critical mass of houses worldwide. A number of competing emerging access techniques, ranging from copper enhancements (ADSL, SDSL, VDSL) and fibre-to-the-home (FTTH) to wireless local loop (WLL), have been tested and evaluated and their large-scale deployment is underway[1].

Now the new barrier to end-to-end broadband service provisioning is the home network. A large number of houses have PCs, modems or multimedia network-enabled appliances, yet most of them are not equipped to support their interconnection. The most daunting cost of home networking is the cost of the cabling installation. Installing wires in an existing home is difficult and is not a solution amenable to the mass market. Moreover, most consumers are unwilling or cannot afford the large-scale rewiring of their home. Thus most of the focus has been put on so-called 'no-new-wires' solutions that eliminate the need for installing wires. These solutions are based on existing in-home cables and wireless technologies.

Today, more than 50 candidate technologies, working groups and standard specifications for home networking exist (Fig. 1). In this paper, we will analyse and compare some of the most widely accepted, foreseen or advanced home-networking technologies. In Section 2 we present the technologies that require new wires; in Sections 3 and 4 emphasis is put on technologies that reuse existing home wiring networks or are wireless, respectively. After the technologies have been presented, they are briefly compared in Section 5. In Section 6 a home network architecture is discussed and the residential gateway (RG) initiative is introduced.

## 2 Technologies with new wiring requirements

The technologies that require new structured wiring provide a safe way to deploy new services in the home environment as they have been tested in the enterprise and business sectors. Among the various technologies that fall into this category, Ethernet, Universal Serial Bus (USB), and IEEE 1394 deserve particular consideration.

*Ethernet*

Ethernet is the default local-area network (LAN) technology for PCs and perhaps the most widespread and well-known LAN technology used in corporate and enterprise networks. It is formally defined as the IEEE 802.3 standard and uses either BNC (Bayonet–Neill–Concelman) or unshielded twisted pair

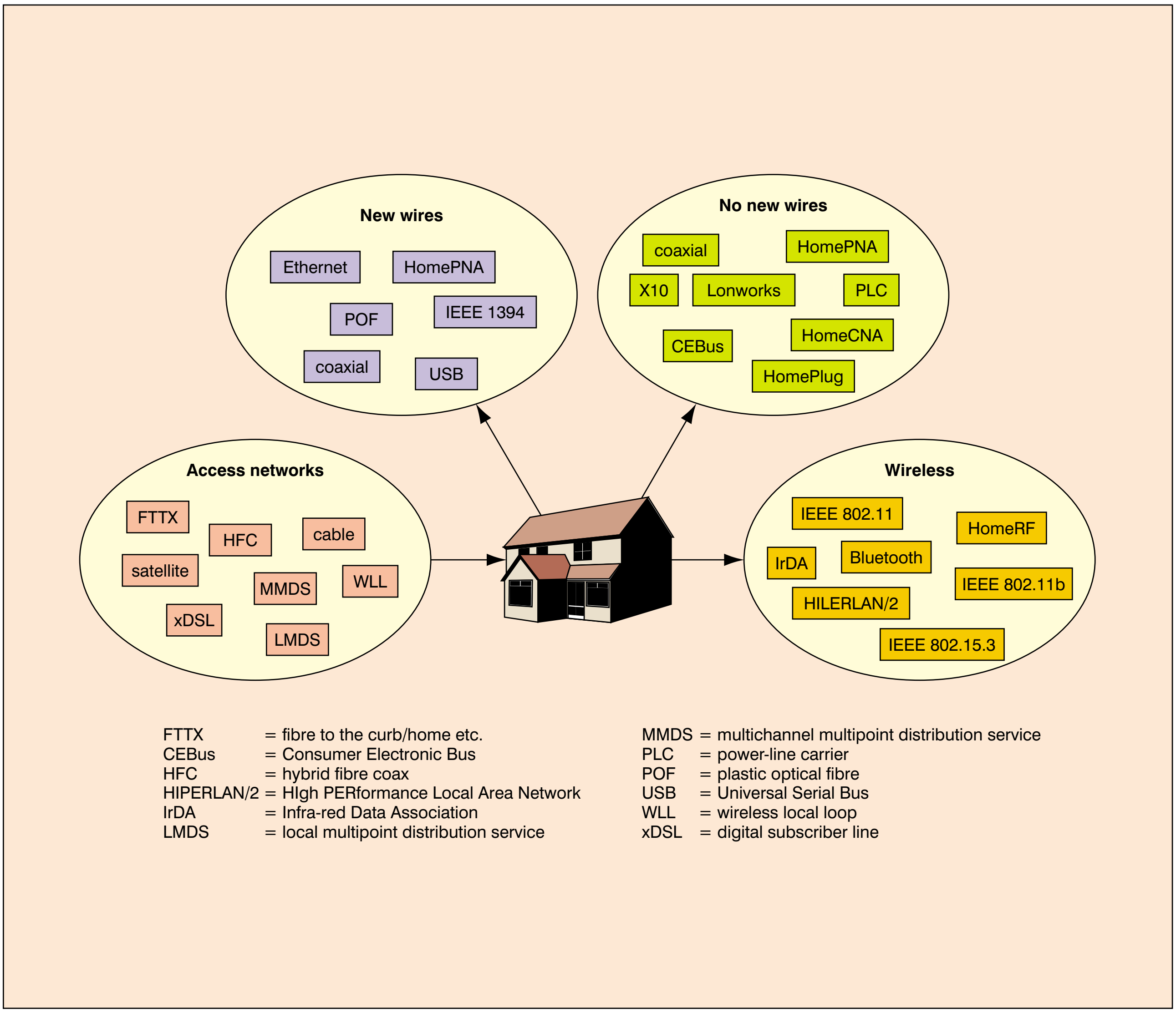



**Fig. 1 Access and in-home network technologies**

(UTP) wiring in bus and star topologies, respectively. Ethernet is a mature technology, with proven speeds up to 100 Mbit/s over Category 5 UTP (UTP-5) wiring. Its installation and configuration are simple and familiar, and it is expected to play an important role in home networking, especially for new homes. Moreover, it is supported by a plethora of vendors, who have driven the cost of the devices, network interface cards (NICs) and wiring to very low prices. Unfortunately, in addition to the rewiring requirement, it suffers from a lack of inherited quality-of-service (QoS) support, which is required by many multimedia-aware applications such as video, audio, and voice telephony. This problem is overcome by using either complementary QoS techniques (e.g. DiffServ, IntServ, MPLS) to control the available bandwidth resources or switched Ethernet network devices to isolate the traffic between different subnetworks. Finally, as Ethernet is a broadcast medium network, content providers have formed a Copy Protection Technical Working Group (CPTWG) whose aim is to endorse movies via content encryption and so to control distribution. This is quite important in the case of blocks of flats that share the same in-building network.

*Universal Serial Bus (USB)*

USB aims to replace all the various serial and parallel port connectors with one standardised plug'n'play interface. The main advantage of USB in home networks is its ability for 'hot-swapping' (i.e. plugging in or unplugging devices without interrupting the operation of other devices) of multiple peripherals in a daisy-chain architecture. As most PCs today have at least two USB ports on-board that are accessible from outside the case, and as most operating system providers include device drivers for USB in their standard distributions, connecting new USB devices is more or less an automatic process. Moreover, USB enables the power requirements of a device to be sensed automatically and then delivered, eliminating in many cases the need for additional power supplies.

USB provides both asynchronous data transfer and isochronous audio/video streaming channels. USB 2.0 promises transfer rates up to 460–480 Mbit/s, covering the requirements of bandwidth demanding devices such as digital cameras, hard-disk drives, and DVD (digital versatile disk) drives. USB is supported by many very large PC hardware and software manufacturers and by the USB Implementers Forum (http://www.usb.org), which is trying to make USB the *de facto* communication standard for all peripheral devices. However, USB may not achieve dominance in home networks. Apart from the requirement for new wiring, the reason for this lies in the rather limited acceptance that it has found until now in the business environment, where existing equipment uses different interfaces (PS/2, serial, parallel, Ethernet). This may be reflected in home networks, with USB limited to short-distance connections between peripherals.

*IEEE 1394*

IEEE 1394 (i.Link or Firewire)[2] was initially proposed for entertainment appliances, but soon turned into an emerging standard that targets all consumer multimedia networks. Though IEEE 1394 does not specify a physical medium, in most cases it utilises copper or plastic optical fibre (POF). POF provides the advantages of glass optical fibre (GOF), as well as lower cost and easier use. Initially, GOF received more attention, due to its wide acceptance in the telephone industry, but recent developments have made POF a contender for a large number of data and audio applications[3].

IEEE 1394 implements an easy to set-up, hot-plugging, scalable, bus architecture that requires no terminators or device IDs. It is able to provide speeds of 100, 200, or 400 Mbit/s (an 800 Mbit/s version has now been announced) for peer-to-peer communication and allows a mix of transfer speeds on the bus, enabling the interconnection of devices with different speed capabilities and costs. Furthermore, it supports both asynchronous and isochronous types of data transfer, and guarantees data transport at a predetermined rate utilising isochronous data channels. Currently, many standardisation bodies and committees, including DVB (Digital Video Broadcasting), DVC (the Digital VCR Conference) and the Consumer Electronic Association's (CEA's) R4.1 and R7.4 Versatile Home Network (VHN) subcommittees, have adopted IEEE 1394 as their default interface for broadband, low-cost, digital communications.

## 3 Technologies that reuse existing home wiring

Most houses world-wide are equipped with structured wiring, at least for electricity and phone distribution, and a large percentage of new buildings also have coaxial cabling for (cable) TV delivery. Reutilisation of these networks for data distribution poses a very good opportunity for in-home networking, as it minimises installation costs. The following subsections discuss the main competing technologies and protocols.

*Power-line technologies*

The power distribution network, also called power-line tree due to its tree topology, is the most widely available home network. For more than 10 years, various committees and standardisation bodies have tried to develop a technology able to utilise the power-line network for in-home data transfer.

CEBus (Consumer Electronic Bus) power-line carrier technology was the one of the first attempts to transport messages between household devices using the home's 120 V AC electrical wiring. In late 1995, CEBus became part of an umbrella standard known as Home Plug 'n' Play (HPnP) and a universally understood translation called CAL (Common Applications Language). CAL promotes interoperability among various home-control technologies, e.g. X-10, Lonworks, IrDA and A/V Bus. At the end of 1999, the Consumer Electronics Association formed the Data Networking Subcommittee R7.3, and began work on a high-speed power-line carrier (PLC) standard. PLC technology aims to deliver burst data rates up to 20 Mbit/s over power-line cables. More recently, HomePlug Alliance was formed in order to build a cost-competitive technology that uses the existing powerline and offers connectivity at Ethernet-class data rates at any power outlet, while coexisting with already-popular devices that use residential power lines to communicate. HomePlug consists of 12 founding members (3Com, Cisco Systems, Compaq, Conexant, Enikia, Intel, Intellon, Motorola, Panasonic, RadioShack, SONICblue, and Texas Instruments), and more than 80 companies participate.

All these technologies, however, share the same network with many home appliances (e.g. motors, microwave ovens, switch-mode power supplies) that generate substantial impulse and wideband noise. These loads also create a time-varying environment, altering both the impedance of the line as well as the noise environment[4]. Different technologies take widely differing approaches to coping with this mesh environment depending on the applications they are pursuing. Technologies and algorithms including orthogonal frequency-division multiplexing (OFDM), rapid adaptive equalisation, wideband signalling, forward error correction (FEC), segmentation and reassembly (SAR), and token passing MAC (Media Access Control) layers are employed to enhance transmission robustness, increase the bandwidth, guarantee the quality and provide both asynchronous and isochronous transmission. Athough trials are underway worldwide, the proposed solutions, prototypes and products only cover the requirements for control applications; they are not yet mature enough to win a large share of the broadband home-network market.

*HomePNA*

HomePNA[5] is being defined by the Home Phoneline Networking Association (http://www.homepna.org), whose aim is to promote and standardise technologies for home phone-line networking, and to ensure compatibility between home-networking products.

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 Mbit/s mainly for control and home automation applications; HomePNA v2.0 provides up to 10 Mbit/s. Future versions promise bandwidths up to 100 Mbit/s. To meet latency requirements and guarantee QoS, HomePNA v2.0 provides 8 priority levels and an improved collision resolution technique that reduces the quality problems of Ethernet.

*Home Cable Network Alliance (HomeCNA)*

HomeCNA[6] is a strategic alliance aiming to standardise the physical aspects of the home coax network. HomeCNA has gained broader acceptance by proposing a multi-industry standard, and collaborative cross-endorsement of other key standards, such as VHN (Versatile Home Network), UPnP (Universal Plug and Play), and CableHome.

Apart from the cable operators' signals, the HomeCNA specification also proposes a frequency allocation scheme that enables the home coaxial network to be reused as the physical medium for higher layer technologies by utilising unused frequency bands. For example, IEEE 1394 signals may be modulated onto the coax cable to extend the IEEE 1394 network beyond the local audio/video (A/V) cluster.

## 4 Technologies with no-wiring requirements

The 'no wires' RF technologies are considered to be the holy grail of the home network and are expected to play a key role in winning wide acceptance for the digital house. Among the RF technologies, Bluetooth, which provides a simple and cheap solution for short distances, and IEEE 802.11b, which is an established, proved and mature technology, are expected to capture the greatest share of the market for different applications.

*Bluetooth*

Bluetooth is intended 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. Bluetooth is a short-range (10 cm to10 m) frequency-hopping wireless system providing up to 1 Mbit/s in the unlicensed 2·4 GHz band. There are also efforts to extend the range of Bluetooth with higher-power devices[7], and Bluetooth v2.0 aims to provide data rates of up to 10 Mbit/s. The Bluetooth wireless technology supports both point-to-point and point-to-multipoint connections. Currently up to 7 slave devices can communicate with a master radio in one device by forming a 'piconet'. Several piconets can be linked together in an *ad hoc* networking mode; this allows extremely flexible configurations to be established such as might be required for meetings and conferences.

Bluetooth is ideal for both mobile office workers and small office/home office (SOHO) environments. For example, once VoIP (Voice over Internet Protocol) is established, it can be used to switch automatically between cellular and in-home wireless phones when a user enters their home or office. Of course the low bandwidth capability permits only limited and dedicated usage, and prevents Bluetooth being used for in-house multimedia networking.

*IEEE 802.11*

IEEE 802.11 is the most mature wireless protocol for wireless LAN communications. It has been tested and deployed for years in corporate private and public environments, and is one of the major candidate technologies for home networking. The IEEE 802.11 standard[8] supports several wireless LAN technologies in the unlicensed bands of 2·4 and 5 GHz, and uses the same MAC protocol for two physical (PHY) layer specifications, namely direct-sequence spread spectrum (DSSS) and frequency-hopping spread spectrum (FHSS) technologies. Infra-red technology is also supported, but this has not really been adopted by any manufacturer.

Initially, IEEE 802.11 systems operating in the 2·4 GHz band provided data rates of up to 2 Mbit/s without any inherited QoS. Wide acceptance of the standard, however, resulted in new versions and enhancements being initiated. The IEEE 802.11b PHY layer specification achieves data rates of 5·5 and 11 Mbit/s by using complementary code keying (CCK) modulation. Recently, the IEEE 802.11g task group has drafted a standard that achieves data rates greater than 22 Mbit/s by adopting either single-carrier trellis-coded 8-phase shift keying (PSK) modulation or OFDM schemes. Finally, in the unlicensed 5 GHz band, the 802.11a technology supports data rates of up to 54 Mbit/s using OFDM schemes. In parallel, the IEEE 802.11e task group is working 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.

*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 the *ad hoc* networking mode, depending on the existing network conditions, a device may join or leave a group or subnetwork, and play the role of a master or a slave node[9].

The IEEE 802.15.3 physical layer has some similarities with IEEE 802.11b. Both operate in the unlicensed 2·4 GHz frequency band and employ the same symbol rate of 11 Mbaud. However, 802.15.3 is designed to achieve data rates from 11 to 55 Mbit/s and is targeted at distribution of high-definition video and high-fidelity audio. It uses 5 types of modulation formats: trellis coded (TCM) QPSK (quadrature phase shift keying) at 11 Mbit/s, uncoded QPSK at 22 Mbit/s, and 16/32/64-quadrature amplitude modulation (QAM) at 33, 44 and 55 Mbit/s, respectively (TCM). The base modulation format is QPSK (differentially encoded). Depending on the capabilities of the devices at both ends, the higher data rates of 33–55 Mbit/s are achieved by using 16, 32, 64-QAM schemes with 8-state 2D trellis coding. Finally, the specification includes a more robust 11 Mbit/s QPSK TCM transmission as a drop-back mode to alleviate the well-known hidden node problem. 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[10].

IEEE 802.15.3 is optimised for short-range trans-

Table 1: Comparison of in-home wireline technologies

| | Medium | Network | Bandwidth, Mbit/s | QoS | Features | Applications |
|---|---|---|---|---|---|---|
| ***Technologies that require new wires*** | | | | | | |
| **Ethernet** | UTP Cat 5 | – | 10/100 | Not inherited | Wide accepted | SOHO/Internet |
| **USB v2** | Copper | – | ≤ 480 | Supported | Plug'n'play/hot-swappable | Interconnection of peripherals |
| **IEEE 1394** | POF | – | ≤ 400 | Synchronous/ asynchronous | Hot plugging, scalable, bus/peer-to-peer architecture | Digital TV, entertainment network |
| ***Technologies that reuse existing networks*** | | | | | | |
| **PLC** | Copper | Power line | ≤ 20 | Not supported | Wide network availability | Home control/ automation |
| **HomePlug** | Copper | Power line | ≤ 100 | Not supported | Wide network availability | Home control/ automation, Internet |
| **HomePNA v2.0** | Twisted pair | Phone line | ≤ 10 | 8 priority levels | Limited only by the phone outlets | Home control/ automation, Internet |
| **HomeCNA** | Coaxial | Cable TV | ≤ 200 | Supported | Mixes protocols in unused bands | Analogue/digital TV, Ethernet, IEEE 1394 |

Table 2: Comparison of in-home wireless solutions

| | Bluetooth 1.1 | Bluetooth 2 | 802.11a | 802.11b | 802.11g | 802.15.3 | HIPERLAN/2 |
|---|---|---|---|---|---|---|---|
| **Freq. band, GHz** | 2·4 | 2·4 | 5 | 2·4 | 2·4 | 2·4 | 5 |
| **Data rate, Mbit/s** | 1 | ≤10 | ≤ 54 | ≤ 11 | ≤ 22 | ≤ 55 | ≤ 54 |
| **Range** | 10 cm–10 m | 10 cm–10 m | Up to 300 m with bandwidth degradation | | | 10 m | ~10 m |
| **Current drain, mA** | <30 | <30 | >350 | < 350 | | < 80 | N/A |
| **Complexity** | 1× | 1·2× | 4× | 1·3× | ~3·5× | 1·5× | 1·5× |
| **QoS** | Voice support | Voice + video support | Inherited in 802 .11e. Backwards compatibility is questionable. | | | Guaranteed | Guaranteed |
| **Video channels** | – | 1 | 5 | 1–2 | 2–3 | 10 | 10 |

mission limited to 10 m. This enables the production of low-cost devices and integration into small consumer devices such as flash cards or PC cards. The physical 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.

*HIPERLAN/2*

HIPERLAN/2 is the European proposal for a broadband wireless LAN operating at data rates of up to 54 Mbit/s at the physical layer in the 5 GHz frequency band[11]. It is supported by the European Telecommunications Standards Institute (ETSI) and is being developed by the Broadband Radio Access Networks (BRAN) group.

HIPERLAN/2 is a flexible radio LAN standard designed to provide high-speed access to a variety of networks, including third-generation mobile core networks, ATM (asynchronous transfer mode) networks and IP-based networks, and also for private use as a wireless LAN system. Basic applications include data, voice and video, with specific QoS parameters taken into account.

At the physical layer HIPERLAN/2 uses OFDM to transmit the analogue signals, as this modulation is very efficient in time-varying environments. Above the physical layer, the MAC protocol has been built from scratch and implements a type of dynamic TDMA/TDD (time division multiple access/time division duplex) scheme with centralised control.

## 5 Technology comparison

It is quite difficult to choose amongst all these mature and emerging technologies. Table 1 and Table 2 summarise the characteristics of the wireline and wireless technologies, respectively.

Of the technologies that require new wiring, Ethernet is one of the major contenders. It is a mature and proven

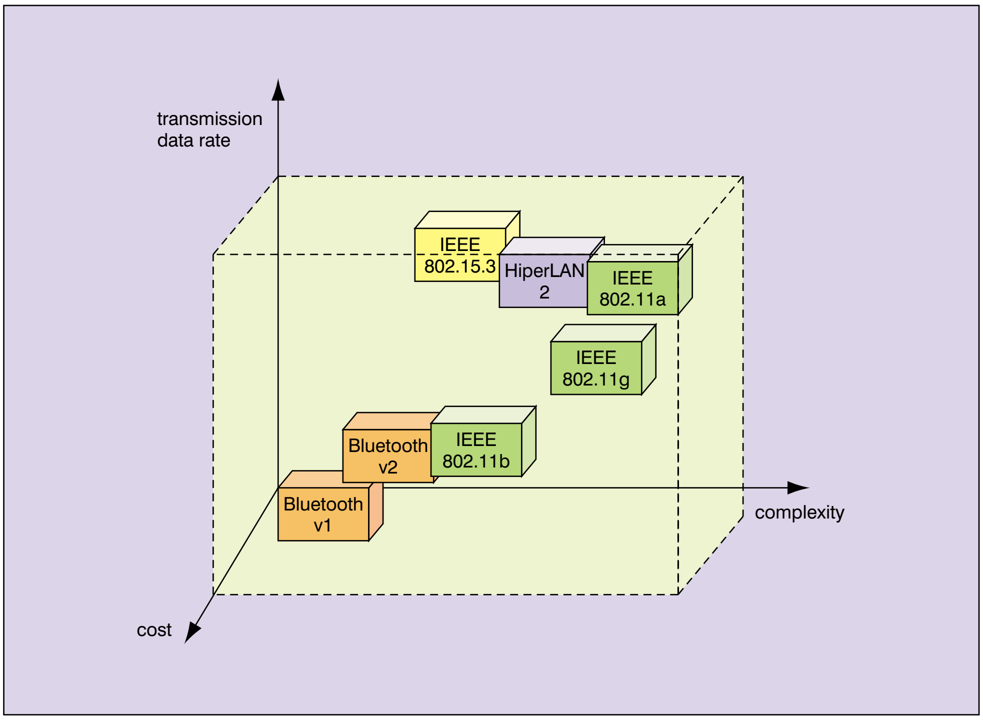



**Fig. 2 Comparison of home wireless technologies**

technology whose installation and configuration are simple and familiar. It is not a coincidence that the majority of set-top boxes, cable and DSL (digital subscriber line) modems have an Ethernet interface and many telecom operators ask for home networking products with multiple switched 10/100 BaseT Ethernet interfaces. However, Ethernet does not support QoS and isochronous transmission. This is an area for IEEE 1394. IEEE 1394 has the capacity to carry multiple digital audio and video streams around the house simultaneously, and provides support for digital copy protection. USB, although it has many features, may not prove to be a key player in the home-network domain. Physical medium and protocol considerations aside, however, technologies that require new structured wiring are expected to be more popular in the new home construction market, as it is not easy to persuade homeowners to drill through walls and retrofit their home with cables.

For reasons of cost and simplicity, it is rather obvious that the 'no rewiring' technologies will get the major share of the existing home market. Of the technologies that reuse existing wiring, the home coax network is a very good contender. In new buildings especially and in some developed countries a high percentage of houses are already wired with coax, mainly for analogue TV distribution. Worldwide, however, there is not a critical mass of wired houses, so coax is unlikely to be the general solution for home networking. On the other hand, the power-line and phone-line approaches are expected to play an important role, but may not dominate. Power-line still has to overcome some transmission limitations (e.g. high-interference, low-bandwidth capabilities) related to the power network architecture and devices, while HomePNA may only be complementary to other technologies. The reason for this lies with the telephone wiring architecture—each room has a limited number of telephone jacks and these are situated in inconvenient places. For example, in a typical bedroom the telephone jack is at the head of the bed, whereas most TVs and PCs are not and so new locations will have to be wired. Finally, many houses have two or more independent telephone lines, and so devices that are connected to different phone lines are physically isolated.

It is the RF technologies that are expected to lead to wide acceptance of the digital house. Among these, the established, proven and mature IEEE 802.11 technology and Bluetooth, which provides a simple and cheap solution for short distances, are expected to capture the lion's share of the market for different applications.

Implementations of IEEE 802.11 are in volume production and available from many vendors. Corporate users are already familiar with it and many have 802.11-enabled laptops. Thus if they use 802.11 at home, they may reuse their corporate laptops and keep their personalised working environment unchanged. Moreover, 802.11 and 802.11b can co-exist, providing an upgradable network that is able to support data rates of up to 11 Mbit/s—sufficient even for compressed video distribution. The major drawback of IEEE 802.11 is its lack of QoS and isochronous transmission slots. IEEE 802.11e is going to provide QoS via the new MAC layer, but backwards compatibility is ambitious. Finally, though many vendors already support *ad hoc* networking, the standard itself has no such provisioning. IEEE 802.15.3 is a competitor to IEEE 802.11a, as it promises comparable rates, though it operates in the 2·4 GHz band. This is quite important, since the 5 GHz band is prohibited for outdoor usage in many countries, including Japan. IEEE 802.15.3 is also being promoted as Bluetooth v3.0, however it is expected that its chip sets will be at least 50% larger in size, cost and complexity. Fig. 2 shows a graphical comparison of wireless technologies.

Taking into account all pros and cons, IEEE 802.11 variations are foreseen as a very good candidate for the in-

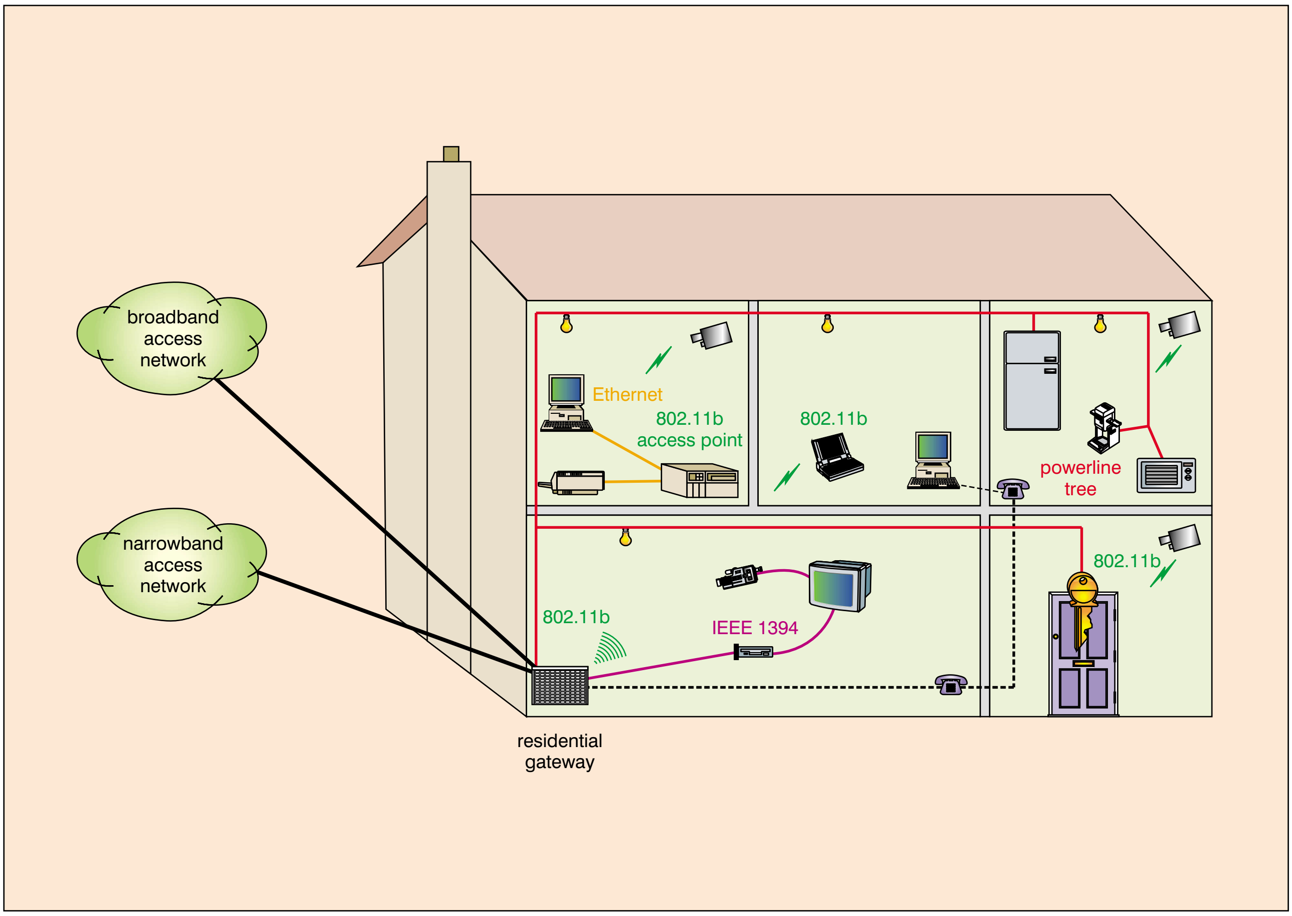



**Fig. 3 A reference home network architecture**

home access network, complemented by IEEE 802.15.3 and HIPERLAN/2 products when they become available. However, for technological, economical, political and simplicity reasons, it seems more likely that the in-home network will be a combination of various broadband/ narrowband, new/ existing, mature/emerging, wireless/ wireline technologies.

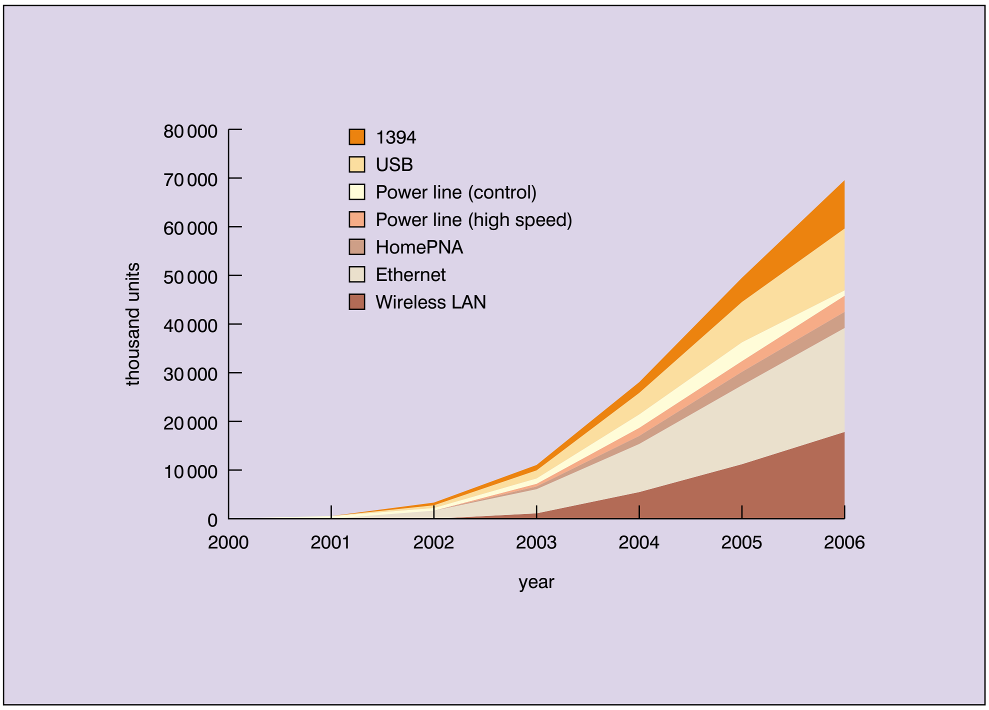
## 6 Home networking architecture

Fig. 3 shows a reference architecture for a digital in-home network. The house is connected to the information superhighway and the Internet via a broadband access network. Potential technologies for this access network include xDSL (e.g. asymmetric, symmetric and very-high-speed digital subscriber line—ADSL, SDSL, VDSL), hybrid fibre coaxial (HFC), FTTx (e.g. fibre-to-the-curb [FTTC], fibre-to-the-home [FTTH]), and wireless (e.g. wireless local loop [WLL], satellite)[12]. The traditional narrowband access network (e.g. PSTN [public switched telephone network], ISDN [integrated services digital network]) may also be available.

Fig. 3 shows four interfaces for the in-home network: power-line, phone-line, IEEE 1394 and IEEE 802.11b. The lights, house automation, security system and home appliances (e.g. microwave oven, refrigerator, coffee machine, main entrance) are connected to the power-line tree. One or more phones are connected to the phone-line tree as well, possibly, as low- to middle-rate data devices, such as a PC with a phone-line card. The home entertainment network (e.g. a set-top box with a TV set, a digital camera or a DVD player) can be interconnected utilising the IEEE 1394 protocol. Finally, an IEEE 802.11b wireless LAN interconnects the wireless terminals (e.g. laptops or personal digital assistants) and provides roaming capabilities. An access point could also be sited at a different location in the house (e.g. in a home office) to act as a bridge between the wireless LAN and a wired Ethernet segment.

The demarcation and interconnection device between the access and the in-home networks is the residential gateway (RG). This provides the network termination (NT) and modem functionality, and provides interfaces to and interoperation between the various in-home networks. It carries out switching functions for telecommunication, computing and entertainment service deliveries to the end-users, and at the same time provides overall control and management for a variety of electrical and electronic appliances. Its role within the end-to-end network architecture is to offer transparent access to a diversity of services offered by network operators and service providers while allowing for the introduction of new, added-value services. The RG or the user—via the RG—may also control most of the in-home appliances (e.g. automatically or remotely start the coffee machine or the house heating), forward telephone calls, control the security system, etc.

Fig. 4 **Residential gateway units per network interface (Source: In-Stat/MDS)**




*Market potential and interfaces*

Fig. 4 shows a prediction by In-Stat/MDR[13] of the number of RG network interfaces that will be installed worldwide. Note the importance of power-line network, the large increment in wireless LAN and IEEE 1394 interfaces, and the ongoing importance of Ethernet. These results are presented in a different way in Fig. 5. According to the same market study and forecast, the IEEE 1394 and the wireless LAN interfaces will win an important percentage of the in-home network market, while USB and Ethernet will maintain their share of the market. On the other hand, power-line will almost disappear for control applications but will be partially utilised for high-speed networking applications.

*RG architecture*

The RG architecture may be modular or compact. The modular RG has a decentralised, expandable design, the philosophy being to accommodate any viable interface and protocol by transferring the complexity to the interface card. To lower the cost, a set of interfaces may be selected, in order to implement an RG that covers specific residential user and telecom operator needs. Compact RGs are less modular and scalable, but are cheaper. This is a very important factor in the consumer electronics arena. Fig. 6 shows a compact RG prototype that provides an ADSL access interface, three IEEE 1394 interfaces, two Ethernet 10/100BaseT interfaces, two serial RS232 interfaces, one USB interface and one PC Card slot which can support an IEEE 802.11b interface or any other user request. Other versions may carry a selection of PSTN/ISDN, optical or cable, Bluetooth etc. interfaces.

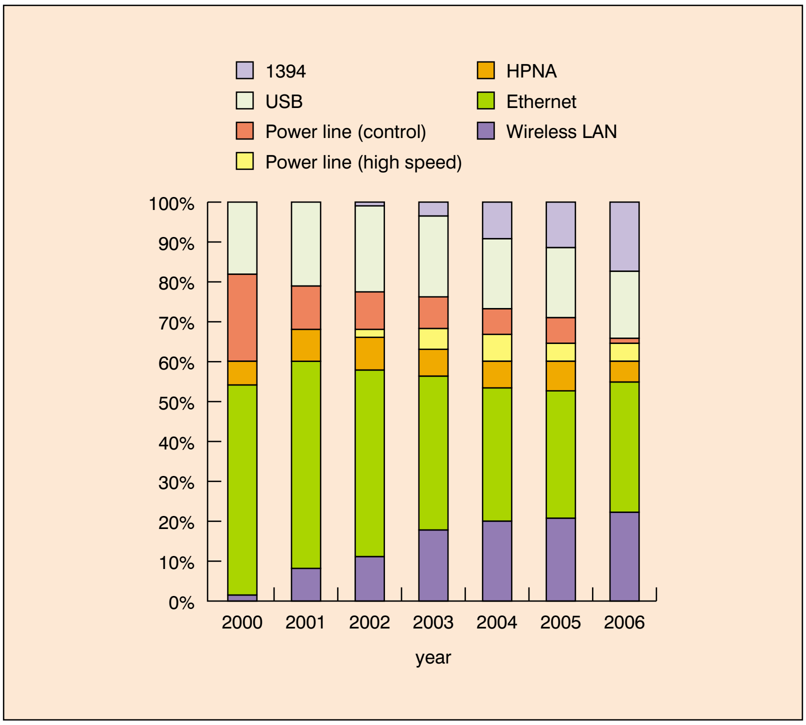



**Fig. 5 Home network interfaces percentage (Source: In-Stat/MDS)**

*RG ownership*

Another critical, yet quite complex, issue of the business model is RG ownership. Four RG ownership models can be highlighted:

- *End-user ownership:* The subscriber buys the RG device and interfaces. He can select the device and the network/service provider but is responsible for installation, upgrading and solving any compatibility problems.

- *Provider ownership:* The network/service provider pays for the RG, which is regarded as part of the access network. The subscriber is tied to the device and service provider, however the cost of the RG is totally covered by the provider(s).
- *Promotional ownership:* The user acquires the RG at a promotional price, subsidised by the provider, but must sign up to a long-period (1–2 years) contract to buy services from the specific provider. A basic monthly charge makes up for the initial investment of the provider.
- *Shared ownership:* The provider offers the RG device and some basic interfaces (e.g. access and Ethernet) for free or at a promotional price, but extra interfaces for in-home networks (e.g. IEEE 802.11, Firewire) are acquired by the end-user.

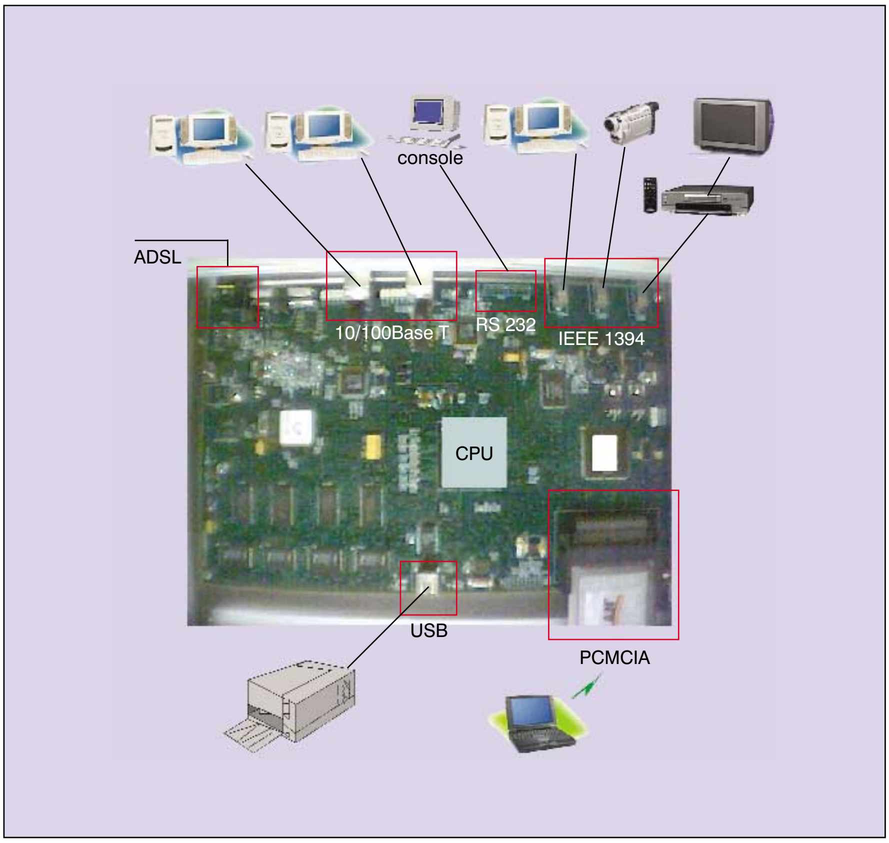



**Fig. 6 Compact architecture RG prototype**

Comparing the above ownership models, promotional and shared ownership seem more realistic as (*a*) they do not burden unilaterally the end-user or the provider, (*b*) they minimise the initial cost and (*c*) they tie the customer to a specific network/service provider. Of course, depending on the market being targeted and the social impact, any service combination can be regarded as meaningful enough for the subsidy of the associated interfaces.

As shown by the In-Stat/MDR forecast in Fig. 7, residential gateways represent an emerging market worldwide. It is important to note that not only the US market but also the European and Asian markets will be ready for broadband services in a couple of years. Residential gateways are expected to play a critical role in home networks, mainly because they offer considerable opportunities to operators and service providers to supply end-to-end broadband services to residential users.

## 7 Conclusions

In this paper we have reviewed a range of already deployed and emerging home-networking technologies, focusing on the 'no new wires' category. Of this category the power-line technologies utilise the most common in-home network, but they suffer from noise and interference due to the power-line network/wiring environment. Phone-line technologies offer a superior performance due to their better network architecture, but they are limited by the number of phone sockets and their locations in the house. Where available, a coaxial network with enhancements is also a very good alternative solution for carrying higher layer protocols. Of the 'no-wires' technologies, which are expected to dominate the home network domain, IEEE 802.11b is the most widespread and mature wireless solution; emerging technologies such as IEEE 802.15.3 and HiperLAN/2 aim to provide enhanced features. For short distances, low cost and limited power consumption, technologies like Bluetooth are envisaged. Finally, of the technologies that need new wiring, IEEE 1394 over plastic optical fibre is promising, while 10/100BaseT UTP-5 Ethernet will be used especially for home offices.

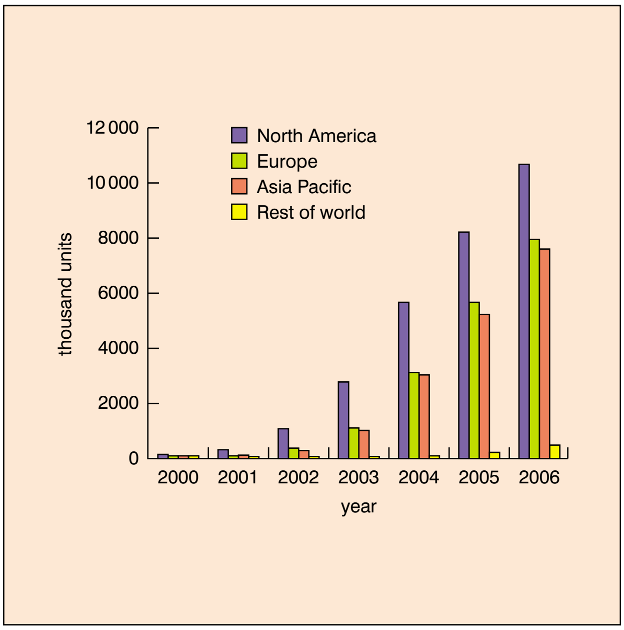



**Fig. 7 RG regional forecast (Source: In-Stat/MDS)**

We have also presented a potential in-home network architecture and introduced modular and compact architectures for the residential gateway. It is important also to note that, apart from the physical medium and the RG functionality, interoperability between devices from different manufacturers has to be achieved at higher layers. HAVi (http://www.havi.org), Versatile Home Network (VHN) (http://www.global.his.com), UPnP (http://www.upnp.org) and European Home System Association (EHSA) (http://www.domotics.com/homesys/Ehsa.htm) are four candidate higher layer protocol stacks that are expected to provide for in-home device interoperability.

It must be emphasised that the home network infrastructure and the residential gateway are just two of the aspects to be considered. Success will depend on the effectiveness, usability and cost of the network system as a whole. Services will only be able to attract customers if they can provide the appropriate functionality and flexibility, fulfil user requests, guarantee the agreed quality, supply sufficient content, and compare favourably with standalone systems.

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