# End-User Perspectives on Home Networking

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## ABSTRACT

While many families have PCs and broadband modems, connecting them together as a network, especially if they are in different rooms, is challenging. The problems multiply as consumer electronics devices become enabled for broadband and their networking needs diverge. The authors discuss the evolving situation in the home, user needs for networking, and the growing set of problems faced by users. The article describes major home networking approaches and raises some of the questions to be considered in designing home networks for the future.

## THE SITUATION IN THE HOME

In the United States and many other countries, many homes have personal computers, and an increasing percentage have more than one PC; current estimates are that about 60 percent of U.S. homes have PCs, and that nearly half of these homes have more than one PC. Many people use notebook PCs purchased by their employers and often use these at home, so more than half of U.S. PC homes have multiple PCs in use. Most of these PCs are used to access the Internet for email, Web browsing, and other applications.

Service providers all around the world are offering broadband access services, including those using cable modems, several types of digital subscriber line (DSL), fixed wireless, one- and two-way satellite, power line, and several types of fiber. In markets with significant PC penetration, the primary reason people subscribe to broadband is to access Internet applications at high speed and stay connected continuously ("always on").

While it is relatively easy to connect a broadband modem to a single PC, it's much harder to share the modem among multiple PCs, especially if they are in different rooms of the house. Once families get broadband access, they find that they need a home network to share broadband services across multiple PCs. Once they start using the network, they also find value in sharing files and peripherals.

"Cable/DSL routers" provide an easy way to get started with home networking. They include some form of built-in home networking — Ethernet, wireless, phone line, or power line — and many families have bought them for security and to avoid surcharges by broadband access providers for additional IP addresses.

The past few years have witnessed rapidly growing sales of consumer digital media devices: digital video cameras, digital still cameras, MP3 players, DVD players and jukeboxes. Many portable telephone systems use digital technologies. Digital video recorder (DVR) sales are growing, and DVR functionality is being included in digital set-top boxes. Digital TV sales are also growing. Some companies have introduced "home media centers" to act as home servers for audio and video media.

Many of these devices are connected together today to form isolated "micronetworks." USB is used to connect printers, scanners, MP3 players, and digital still cameras to individual PCs. IEEE 1394 ("FireWire") is used to connect video cameras to PCs. Ethernet connects PCs to broadband modems. A bewildering variety of analog and digital interfaces are used to interconnect DVD players, DVRs, digital TVs, and digital set-top boxes with other audio and video components. These networks are isolated from one another: a digital camera connected to one PC is not "visible" to other PCs in the home.

New digital consumer electronics (CE) devices like digital cameras and camcorders make it easy to capture family events and include pictures in documents. Content is starting to be created by users of the new CE devices, not just by professional organizations. This new category of people who create their own content has been called "prosumers," and CE devices make it increasingly easy to become one.

Homes have many types of wires in their walls to connect devices to sources. Each type of wire was installed and optimized for a specific purpose: electrical wires to connect to power sources, telephone wires to distribute telephone service around the home from the incoming telephone line; and coax cables to distribute video from cable or satellite feeds.


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## Many and Diverse User Needs

In speaking about "user needs," we recognize that each user is an individual with specific needs based upon his or her lifestyle, economic situation, education, and so on. For the purpose of this overview we will focus on the "typical consumer," whom we assume is neither a real "techie" nor a Luddite. We envision a person who might shop for consumer electronics and home networking at large specialty stores.

With many devices in the home today, and more coming, here are some user needs that home networking can address.

¶When users have a broadband modem and more than one PC, and especially when the PCs are in different rooms, they need a network so the PCs can share the connection to the outside, share files, and share peripherals.

¶If people are concerned about protecting systems and data in the house from outside intruders, they need a firewall.

¶People who bring notebook PCs home from the office want to connect them to the home PC and broadband modem. Lots of people are setting up wireless networks for this purpose.

¶Many people are "ripping" CD tracks, downloading MP3 tracks to their PC hard drives, and tuning into Internet radio on their PCs. They would like to listen to music and Internet radio on their home stereo systems, and they will need networks to connect these systems to their PCs or directly to the Internet.

¶People would like to integrate diverse telephony systems and services — wired and wireless, analog and IP-based digital — and share them across the house. Among the choices they'd like to make are having their mobile phone act as a cordless extension when within reach of the house, and conversely letting the wired phones make calls with their wireless plans when that is economically beneficial.

¶People want to be able to choose services that best meet their individual needs, and don't want to be "locked in" to a single service provider. The process of "mixing and matching" services should be seamless; people don't want to re-configure each time there's a change.

¶They want to transfer information from personal digital assistants (PDAs), digital cameras, and digital camcorders to PCs anywhere in the house without having to unplug them from one place and plug into another.

¶People want to store and share consumer-created digital photos and videos throughout the house, and then use the broadband connection to share them with family and friends.

¶As more and more video content becomes digital, people would like to display video content from any source — the broadband connection, VCRs, DVDs, and DVRs, PCs, and the coming home media server — on any screen in the house — whether a PC, a TV, a game console, or a Web tablet.

¶In this time when people are increasingly sensitive about the safety and security of their family and possessions, they want systems to keep intruders at bay and report fire or other dangerous situations. While at the office, they'd like to keep an eye on the children. Before returning from vacation, they'd like to adjust the temperature.

¶Above all, users want to accomplish these things in ways that are affordable, reliable, unobtrusive, easy to learn, and easy to use.

## Application Performance Requirements

To fulfill all the user needs described above, the broadband home network will need to support five categories of digital applications: data, telephone, audio, video, and automation. Each category has different performance requirements:

**¶Data applications** include the shared use of Internet text and data — mostly Web browsing, email, and chat. It also includes sharing data and peripherals between PCs and other broadband appliances. Most of these applications will work satisfactorily at data rates of 5 Mb/s or less. These applications do not require any specific performance specifications and will operate satisfactorily on a best effort basis.

**¶Telephone services** include all forms of interpersonal voice communications. Starting with conventional voice services, it will expand over time to include call forwarding and conferencing, and later add video telephony and integrated multimedia communications. Voice services require very low data rates (15–64 kb/s) while video requires somewhat higher rates (128–384 kb/s). Voice and video are highly sensitive to jitter and delay, and operate most satisfactorily over networks designed to support quality of service (QoS) in terms of bandwidth, delay, jitter, bit error rate, and so on.

**¶Audio applications** include the distribution of digital audio from CDs, MP3 files, Internet radio, and a home media server throughout the house to any set of loudspeakers and headphones. These applications require data rates from 128 kb/s to about 1 Mb/s (depending on compression) and operate most satisfactorily over networks designed to support QoS.

**¶Video applications** include the distribution of digital video content from the broadband connection, DVD players, and the home media server to any video screen in the house - whether on a PC, a TV, a game console or a Webpad. It also includes the networked connection between digital video cameras, servers, and viewing devices. The video will come in many formats including conventional standard definition (SD) and high definition (HD). SD video requires 1.5–8 Mb/s per channel, while HD requires 19.39 Mb/s per channel. These applications operate most satisfactorily over networks designed to support QoS.

**¶Telemetry and control** includes a wide variety of applications often labeled *smart home*. These include lighting and audio/video controls; external monitoring and control of electricity and gas; home security, including external access to monitoring video cameras; home appliance servicing; and in-home communication between appliances. While these applications generally require very low bandwidth and will operate satisfactorily on a best effort basis, security and alarm applications require the service to be always on and operate with very high reliability.

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| Differentiator | Structured wiring | Existing wiring | Wireless |
|---|---|---|---|
| Best uses | New construction and remodeling | Interconnecting stationary devices | Mobile devices such as notebook computers and webpads |
| Cost | High (for installation) | Low | Low |
| Useful lifetime | Very long | Short | Short |
| Number and location of "outlets" | Wherever needed | Multiple electrical outlets in each room; several rooms with telephone outlets; few rooms with coax outlets | Ideally throughout home |
| Current data rate (Mb/s) | 100 | About 10 | About 10 |
| Future data rate (Mb/s) | 1000 or more | 30–100 | 25–100 |
| Security | Very secure | Less secure | Less secure |
| Standardization | Well-defined global standards | Competing standards | Competing standards |

**Table 1.** *Broadband home networking by physical medium.*

## Home Networking Choices

In this section we first describe several broad approaches to home networking, and then specific technologies within each approach.

Many different types of broadband home networking are now available. Although each addresses some of the user needs and application performance requirements described above, none completely satisfies the needs for all applications; new technologies are being developed that better address the needs. While some hope exists for a single technology that would satisfy all user needs, we believe it is more likely that a combination of technologies will be used in many homes.

Broadband home networks can operate over various physical media. These can be organized into three broad groups: structured wiring, existing wiring, and wireless.

- **Structured wiring** requires installing new cabling in the walls. Both the cabling (typically unshielded twisted pair [UTP] or fiber) and its installation are defined by standards (http://www.cabletesting.com/Cabling_ Standards_Documents_Overview.html for an index to worldwide structured cabling standards).
- **Existing wiring** makes use of electrical, telephone, or coax wiring already installed in the walls.
- **Wireless** avoids the use of wires by transmitting through the air.

Table 1 compares these approaches based on today's technologies.

### Structured Wiring Technologies

Structured wiring provides high bandwidth and excellent security. To handle the full range of current applications, a complete installation today requires several types of cabling, including UTP for telephone and data, and coax for video.

Fast Ethernet at 100 Mb/s over UTP [1] is widely used for data applications. While it has sufficient bandwidth for video, it presently does not include QoS support.

As HD video moves into homes, many believe that a "home backbone" network based on structured wiring will be required to interconnect sections of the home. The Electronics Industry Association (EIA) and CEA are developing the R-7.4 VHN Home Network Standard for this purpose; see [2] for a summary and current status.

### Existing Wiring Technologies

Since structured wiring is quite expensive to install in an existing home, many companies are developing technologies based on the existing wiring in the walls of the home.

- **Phoneline** technologies use existing telephone wiring. The Home Phoneline Networking Alliance (HomePNA; http://www.homepna.org) has defined a 2.0 specification at about 10 Mb/s (the earlier 1.1 specification was about 2 Mb/s). Proprietary technologies operate at much higher speeds and are in contention for the 3.0 specification.
- **Powerline** technologies use the existing electrical wiring. There are many competing technologies. The HomePlug Powerline Alliance (http://www.homeplug.org) has brought several vendors together, and CEA R7.3 is working to define standards (http://www.ce.org/Technology_and_Standards/Technology_and_Standards_Committees.asp).
- **Coax** technologies use coax cabling. A Home Cable Network Alliance (HomeCNA; http://www.homecna.org) is working to define a specification.

Table 2 compares these technologies.

### Wireless Networking

Wireless networking is perhaps the most attractive approach for the home, since it avoids the cost of pulling new wires and the challenges of using existing wiring. There are many competing technologies and associated standards and advocacy groups:

- **IEEE 802.11** (http://standards.ieee.org/getieee802/802.11.html) is a family of evolving standards, originally designed for enterprise networking and now moving into the home. 802.11b at 2.4 GHz is the current version. 802.11a at 5 GHz is the future, although the proposed 802.11g at 2.4 GHz may be a "bridge" technology.
- **HomeRF** (http://homerf.org) is a family of wireless LAN technologies specifically

designed for the home. While the current generation of HomeRF is incompatible with 802.11b, the group appears to be favoring 802.11a as the next generation.

- **Bluetooth** (http://www.bluetooth.com) was designed for short-range personal networking and is being extended for longer range.
- **HiperLAN** (http://www.hiperlan2.com) is a family of ETSI standards for wireless LANs. These are similar to the 802.11 family but include QoS and support asynchronous transfer mode (ATM) as well as Ethernet.
- **Ultra wideband** (http://www.palowireless.com/uwb) is based on low-power spread spectrum.

Table 3 summarizes these wireless networking technologies.

## What Users are Facing Today

When users try to interconnect various home devices and services, they want to find technologies that fit the tasks they want to accomplish, work in the home environment, and don't become obsolete quickly. They find it hard to obtain unbiased, reliable information, and assistance.

Matching technologies to user needs is difficult, since each home networking technology best solves a different problem or set of problems. *Wireless networks* seem most appropriate for mobile devices like notebook PCs, PDAs, phones, and Web tablets. Since many offices have installed 802.11b, it is a logical choice for connecting business portable PCs to home PCs and the broadband modem. *HomeRF* is optimized for carrying isochronous data and therefore carries portable telephone services and PC data through the same infrastructure.

Most technologies are promoted as a "do it yourself" solution, but users often encounter problems. *Ethernet* is easy within a room, but it's hard to build a structured wiring network properly. *Wireless networks* often suffer from "dead spots" and interference from microwave ovens and portable phones, while phone line and power line networking are sensitive to the specifics of existing home wiring. There are few tools to help the user to identify and resolve these problems.

Obsolescence is a serious concern. Viewed against the full range of needs discussed above — voice, data and video — all of today's home networking technologies are in their infancy. While the second-generation wireless and phone line technologies provide sufficient bandwidth for broadband modem sharing and printer sharing, they are at best marginal for sharing digital video media. Fast Ethernet has the bandwidth, but doesn't provide QoS.

| | Phone line | Power line | Coax |
|---|---|---|---|
| Current data rate (Mb/s) | About 10 Mb/s | 1–10 Mb/s | TBD |
| Future data rate (Mb/s) | 30–100 Mb/s | 20–30 Mb/s | TBD |
| QoS support | Yes | Yes | TBD |
| Standardization stability | Stable | In flux | In flux |

**Table 2.** *Home networking technologies using existing wiring.*

Users seeking to find assistance might visit a retail store, look on the Web, ask a friend, or hire a professional. Each has an associated set of difficulties.

Retail stores provide a plethora of choices but often with confusing labels and placement. Store salespeople generally have little knowledge of the differences in technologies and their suitability to a user's needs.

The Web has a great deal of information, but the novice may find it difficult to distinguish fact from myth or a thinly disguised commercial to promote a particular technology or company.

Asking a technologically savvy friend's advice may be a good starting point, but the advice will often be based on the friend's particular set of needs and physical environment, which might not match those of the intended user.

Obtaining professional assistance seems like a natural answer, but finding a professional for planning and installing home networking is difficult while the field is in its infancy. Traditional installers of home theatre in organizations like CEDIA [3] are starting to define training and certification programs. These often focus on the upper-end market, since people willing to spend generously on home theatre and A/V equipment are also good candidates for spending on home networking.

Other potential sources include electronics and computer retailers who are looking to transition their low margin product businesses via higher margin service offers, and service providers like telephone and cable companies who also have the potential to provide such services. The Internet Home Alliance [4] is launching an individual certification program for residential systems integrators.

When the service provider is the one to offer such services, the needs of the individual user and those of the service provider may be in conflict. Users want to minimize the monthly payment to their service provider and to maintain

| | IEEE 802.11 | HomeRF | Bluetooth | HiperLAN | Ultra wideband |
|---|---|---|---|---|---|
| Frequency spectrum | 2.4 GHz today, 5 GHz future | 2.4 GHz | 2.4GHz | 2.4 GHz today, 5 GHz future | 3–6 GHz |
| Current data rate (Mb/s) | About 10 | About 10 | About 1 | About 10 | NA |
| Future data rate (Mb/s) | 54 | NA | TBD | 54 | 100 |
| QoS support | No; planned for future | Yes | Yes | Yes | Planned |

**Table 3.** *Wireless home networking technologies.*

*The North American cable industry is developing a set of specifications for home networking under the name Cable Home™; future networks will probably need to conform to those specifications to obtain the full service from cable operators.*

their flexibility to switch service providers if they are dissatisfied or see better service offers. Service providers want to maximize the returns from each customer and to keep the customer closely linked to their particular services.

The simplest case may be to build a new home and design and install the infrastructure before the walls go up. But selecting the right wiring to meet today's needs and prepare for tomorrow's (especially preparing for digital television) is not easy; only a few home builders have understood the opportunity and allied themselves with experts in a position to offer competent advice and implement it.

## Considerations for Home Network Designers

When developing new home networking solutions, network designers have many issues to consider. Here are some of the questions they might want to consider in the context of the evolving situation and user needs. We've grouped the questions into several categories, beginning with factors outside the home that influence home networking design.

### Outside the Home

**Is the network designed for a home with a broadband connection? What speed does the connection run at?** Dialup Internet services operate at 33.6–56 kb/s. By contrast, most cable modem and DSL services in North America today operate asymmetrically at about 1.5 Mb/s "downstream" toward the home (some DSL services run at lower speeds) and a much lower speed upstream. In some parts of Europe, fiber-based services operate symmetrically at 100 Mb/s. These place very different demands on home networks.

**Is the network optimized for a particular type of broadband access, or is it designed to work with several or all?** Besides speed considerations, the particular form of broadband access may impose other requirements on home networking systems. As an example, the North American cable industry is developing a set of specifications for home networking under the name Cable Home™ [5]; future networks will probably need to conform to those specifications to obtain the full service from cable operators. Telephone companies may well develop a different (and likely incompatible) set of specifications.

**What services come to the home now over the broadband connection — and what will be coming in the future?** While broadband connections are used mostly for Internet access today, many other applications — telephony, music, radio, and television — are moving rapidly from analog to digital formats. MP3 audio and Internet radio are moving into homes now; IP telephony is not far behind; and digital television will be in many U.S. homes over the next few years (as it already is in many parts of Europe). In parts of Scandinavia and Italy, all of these applications are already being carried to the home over fiber. As these new applications move from the PC to more appropriate home appliances, the home infrastructure needs to be ready to handle them.

**Is the network required to support third-party services?** Several organizations are developing specifications to support "open" services in the home on various devices, including PCs and digital set-top boxes — these include the Open Services Gateway Initiative (OSGi) (http://www.osgi.org/), OpenCable [6], and DVB-MHP (http://www.mhp.org).

**Who will select the network: the end user, a broadband access provider like a cable or telephone company, a third-party service provider, or a professional installer?** Each of these has very different criteria for selecting one technology or implementation over another.

### Inside the Home

**Who are the intended users?** What works for one set of users may not match the needs of another. A solution designed for the "techie" won't fit the needs of users who want "plug and play." Network designers can benefit by considering research from groups that segment users and investigate their attitudes toward technology. Observational research, derived from a mix of anthropology and ethnography, along with usability tests, can be a valuable tool, particularly for products and services to be used in the home. Such research has been conducted at AT&T Broadband Labs [7, 8] and Intel, and is increasingly being used by consumer products companies.

**What services will the network carry? Is it optimized for a specific service — data, voice, audio, or video — or is it designed to integrate multiple services?** While it is possible that a single unified technology will support all the applications in the house — data, voice, audio, and video — we believe most homes will have multiple networks carrying multiple media. The networks will be interconnected by a backbone home intranet. Some think that VHN [2] will provide that backbone.

**What devices connect to the network now and in the future?** We discussed some of these devices earlier, and more come to the market every day. Residential gateways and home media servers are the latest devices designed to interconnect throughout the home.

**What protocols are used to interconnect networks and to interoperate with PCs?** Universal Plug and Play (UPnP) (http://www.upnp.org) was designed as a protocol suite to link PCs with many types of consumer electronics devices.

**What legacy networks connect to the new network? What kinds of devices are required to interconnect them?** Many homes have X-10 networks and would like to connect them to PC applications. We are starting to see bridges between UPnP and X-10.

**What is the bandwidth budget for each networked service, now and in the future? How many simultaneous streams will the network carry for each service?** For example, each "standard definition" digital video stream requires 4–6 Mb/s, and some require more. Each high-definition video stream requires 19.39 Mb/s. None of today's home networking technologies (except Category 5E structured wiring) has sufficient bandwidth to carry one HDTV stream, much less multiple streams.

**What are the QoS requirements for each supported service?** While data services usually work

satisfactorily with best effort networking, media services — video, audio, and voice — need mechanisms for priority transmission and resistance to jitter and noise.

**What other devices are already in the home?** What is the potential for interference between these devices and the new home network? Interference between portable phones, microwave ovens, and Wi-Fi networks are a well-known problem. Power line networking is likely to uncover a range of similar problems.

**How resistant is the network to a power failure? Do services require backup power?** Primary telephony may require battery backup in the home network for lifeline services.

**What is the expected lifetime of the technology — is it a near-term solution or a long-term one?** How commensurate is technology lifetime with its cost structure? The second-generation networking technologies work reasonably well, and their prices have dropped dramatically. Customers could buy these technologies to address their near-term needs, and replace them when they see additional needs and when more advanced technologies are available.

### Installation and Support

**What protocols are required to facilitate installation and maintenance?** Industry groups have been working on protocols to facilitate installation, service provisioning, and remote support. For example, UPnP is designed to permit zero-configuration "invisible" networking with automatic discovery across a wide range of devices, and is particularly suited for homes with PCs in the networks. The OSGi specifications are designed for the delivery of managed services. Many new devices are supporting one or both of these open specifications.

**Is the technology intended for "do it yourself" users or professional installers? Will the user maintain the network after it is installed, or will an outside firm provide this service?** This is probably the single biggest issue facing designers. The needs of end users and professional installers are very different. Professionals can be expected to engineer proper network designs, to follow complex installation instructions, and to buy specialized test equipment and learn to use it properly. End users need pre-engineered solutions and simple (preferably no) written instructions.

## Conclusions

Home network designers face a multidimensional challenge. Although it is tempting to focus almost exclusively on the technical aspects of the design work, it is dangerous to do so. Considerations regarding the breadth of function, intended users, home environment, projected lifetime, who will install and maintain, and the impacts of impending standards — whether official or de facto from converging market sectors — all play a critical role in the ultimate success of what has been designed.

*Considerations regarding the breadth of function, intended users, home environment, projected lifetime, who will install and maintain, and the impacts of impending standards all play a critical role in the ultimate success of what has been designed.*

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## Biographies


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