Emerging Home Digital Networking Needs

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Abstract

In this paper, the situation of an emerging home network environment is examined. There are four driving needs for a home network. They are home automation, home computer, digital audio and video distribution, and digital access network. In the past, the home network is driven by home automation and analog audio and video distribution systems. Most recently, the effort on the development of a digital home network has been driven by emerging digital access and digital consumer electronics technologies. The system requirements are analyzed for different home network applications. The possibility of use IEEE 1394 protocol for a digital home network is explored.

1. Introduction

The interaction to many electronic devices have become daily routines in a home environment. A typical household probably has more than three remote controllers and telephones ring many times daily. There are regular electrical appliances, such as microwave oven, electronic appliances, such as VCR, communication appliances, such as telephone, and information appliances, such as computer, in a home environment. An electrical or electronic device is usually located at a particular location in a home. The easy of use convenience can be provided if an appliance device can be controlled at a different location through a home network. The same convenience can be further enhanced when multiple appliances and control devices are networked together. A network is also essential for sharing information at different locations. With shared information, networked devices can become much more intelligent.

2. Emerging Home Networking Needs

In a residential environment, people usually at least encounter 2 to 3 separate wiring systems: power wiring, telephone wiring, and cable TV wiring. Additional special purpose wiring systems are usually found for the home security system, remote speakers, PC Local Area Network (LAN), etc. All these wiring systems use different types of wires, carry different types of signals, and serve different types of purposes. As the intelligence level of these subsystems increase due to the ever popular use of microcomputer chips, there emerges a need to make all these subsystems talking to each other. A unified home network would also minimize the wiring confusion and cost. In this section, the current situation and the near future trend of the home network is examined through 4 different but related applications. They are home automation, home computer network, digital audio/video equipment, and digital access system.

2.1. Home Automation

Hobbyists have been experimenting with the centralized control of home lighting and appliances for many years. The idea is to coordinate the switch on or off of a few lights and/or appliances at the same time through a simple command via a central switch panel or a remote controller. Centralized commands could also be initiated through a pre-programmed timer according to certain sequences. Each command can control a different set of lights/appliances. A simple example might be to turn one room's light on while turning the hall way's off. We can identify lots of useful switch on/off combinations associated with different situations and/or routine tasks. Since the corresponding control signal is relatively simple and all lights and/or appliances use the electric power, the centralized command can be transmitted through the power lines.

The key to control of lights and appliances lies in the ability of the products to communicate. Control of lights in older homes is provided by a simple mechanical switch which physically connects or disconnects the power to the light fixture, and many appliances include their own power switch but lack the ability to communicate with other devices in the network. Many manufacturers are now developing control communications into the products they sell. In order to effect remote control and automation of older lighting and appliances, the installer must add a communication device to the component that they want to control. In many cases, this is as easy as replacing the light switch or receptacle (power outlet) that provides power to the component.

The nature of these devices in a home network is very similar to that of other networks such as those used by computers. Each switch or module has a unique "address" which it recognizes itself as. When a control signal is broadcast through the network, all of the modules in the network can "hear" the commands, but only those to which the signal is addressed will pay attention to the signal and provide a response. The manufacturers of various switches and modules provide some variations in how an address is set. Most switches and modules which use power line carrier either allow the installer to set an address with rotary dials on the face of the module, or include built-in addresses which are preset at the factory.

After the switches and modules are installed, the user simply add a "controller" to effect controls through a particular device. Controllers are available to provide controls through hand-held remotes, wall mounted keypads, telephones, computers, televisions, touch screens, voice response, or other systems such as the security or HVAC systems. Most controllers used with power line carrier are simply attached to a system by plugging them into a nearby power outlet (plug & play). Some power line carrier controllers are attached to the system by hardwiring them with nearby power wires.

2.2. Home Computers

It is estimated that there are PCs in 30% of US households. Among these families, many has more than one PC. Family members use PC not only for work at home but also a variety of other interesting things. PCs are used for home finance, educational, and entertainment purposes. PCs are generally connected to the phone line through a fax/data modem. The new model PCs are coming equipped with a multimedia package that usually includes CD-ROM, stereo speakers, answering machine, speaker phone, video conference camera, or a TV tuner.

For a family with multiple PCs, it is worth while to network them together. Through a home computer network, many facilities on the most advanced PC of the family can be shared with the rest of PCs. That includes hardware facilities such as a disk drive, a CD-ROM drive, and a printer connected to a particular PC and software programs. The networking could make valuable resources available for multiple access at different rooms of a house. The networking could also eliminate redundant software installation and conflict copies of user data files.

With a relatively low data traffic compared with the office environment, the home computer networking task can be easily accomplished using a low cost Ethernet such as 10BaseT. For two PCs inter-connected, only two Ethernet cards are required with one installed in each PC. The connection between 10BaseT Ethernet cards is made with Category 3 or 5 data grade unshielded twisted cable (UTP) which can be installed as the conventional home telephone wiring. If more than two Ethernet cards are involved, a 10BaseT Ethernet hub is required. The general 10BaseT Ethernet has a star configuration with the hub located at the center and all Ethernet cards connected to the hub.

2.3 Digital Audio/video Equipment

Consumer electronics are evolving into digital formats. There is a need to interconnect consumer electronic devices through digital links to preserve the fidelity of the contents. For example, the distortion would be further minimized if the output of a CD is directly connected to an amplifier in its digital format. Further more, the output from a CD can be transmitted to audio equipment at another room at a certain distance away without any loss of sound quality via a digital transmission link with a tolerable error rate. A digital transmission link could also make the Direct Broadcast Satellite (DBS) receiver signal in the original compressed format available to a PC or TV with certain decompress capabilities. Let us examine a few examples of consumer electronics digital interface format.

The Compact Disc (CD) was originally designed for the digital recording of high fidelity music sound. During the recording the music sound is sampled at 44.1 kHz and at an Analog to Digital Conversion (ADC) resolution of 16 bits for both left and right channels. The information rate is 1.4112 Mbps. The left and right channels are interleaved. A delay buffer in the CD player is required to re-synchronize these two channels. To minimize the effect of playback bit error, a 25% redundancy Reed-Solomon code is used during the recording. An interleaving in conjunction with the Reed-Solomon coding is also used to spread out burst error which can be caused by a scratch on the CD. With the coding overhead, the data rate becomes 1.764 Mbps.

With the same format, the same CD size and the same track density, CD-ROM has been developed as a computer peripheral with a storage capacity of 650 Mbytes. A CD-ROM drive in a computer can be used to play CD music. On the other hand, the data transfer rate of a CD-ROM drive has been customized to match those of silicon memory devices and magnetic disc drives. CD-ROM drives with different data transfer rates are available. The data transfer rates for CD-ROM are 2.4 Mbps for double speed , 4.8 Mbps for quad speed, and 7.2 Mbps for six-speed.

There are CD-I (Interactive) and CD-ROM/XA (eXtended Architecture) using the same CD format. Their data transfer rate is similar to CD-ROM.

There are compressed video/audio signals available inside a DBS receiver. Currently the compressed signal is beamed down from three Geo-stationary satellites. DBS1 uses 16 120 watt transponders while DBS2 and DBS3 are configured to each use 8 240 watt transponders. We have a total of 32 broadcast transponders available now. The video is compressed using the MPEG-2 syntax with an information rate of between 4 and 9 Mbps. MPEG II can deliver broadcast quality compressed video signal with information rates between 4 and 9 Mbps. Specifically for information rates of 2 Mbps, 4 Mbps, and 6 Mbps resolutions of 352x400x24, 544x480x30, and 704x400x30 can be realized respectively. The audio is compressed with the MPEG-1 layer II encoding with a information rate of between 32 kbps to 384 kbps.

The compression can achieve 3-4 TV channels per transponder for high quality or 5-6 TV channels for lower quality. Film can be compressed at 7-8 TV channels per transponder for 25 fame per second and mostly constant back ground image. DBS uses a statistical multi-program encoder called a StatMux that dynamically varies the bit rate according to video content taking into consideration other programs multiplexed on the same transponder.

The transmission bandwidth is 20 MHz per transponder with a 10 MHz guide band between each transponder. QPSK modulation is used for the satellite to earth link with carriers between 12.2 and 12.7 GHz. The transmission throughput is therefore 40 Mbps each transponder. In high mode which relates to the 8 transponder per satellite configuration the information rate is 30 Mbps and the 10 Mbps overhead is used for error control. In low mode which relates to the 16 transponder per satellite configuration the information rate is 23 Mbps and the 17 Mbps overhead is used for error control. High mode has 3 dB higher SNR. The error control is implemented with a combination of Trellis code and Reed-Solomon code.

Currently, the output from the DBS dish electronic box can not be splitted into multiple outputs with the conventional splitter because of the high bandwidth of from 800 MHz to 1280 MHz. There is a multiple output box available for a higher price or you have to buy a special split box. You can use multiple decoders at different rooms in conjunction with a multiple output dish box. Dedicated coaxial cables are required to connect the dish box to decoders. In another configuration, the signal from decoder box can be carried to TVs at different rooms via the home coaxial cable wiring on an empty channel slot. A RF remote controller can be used to talk to the decoder across rooms.

A digital camcorder is a combination of a digital camera and a digital video recorder. The current specifications of digital VCR for consumer-use define a sampling rate of 13.5 MHz with an ADC resolution of 8 bits. The video information rate is reduced using the conventional DCT compression technique. A (149, 138) Reed-Solomon code is then used on the compressed signal for error correction. The compressed video rate is 25 Mbps. The stereo sound can have 12 bit or 16 bit ADC resolution with sampling rates of 32 kHz, 44.1 kHz, or 48 kHz. A (14, 9) Reed-Solomon code is used on the audio signal for error correction. The rough tape data transfer rate is 38 Mbps with audio signal taking 2.814 mm and video taking 27.588 mm over each 32.890 mm long track.

2.4. Digital Access Systems

The DBS can also be viewed as the downstream channel of a digital access network. The upstream channel of the DBS can be provided through a voice band modem for an asymmetrical digital access system. We can see the principle of this asymmetrical system at work through the DBS's pay per view mechanism. Besides voice band modem, another existing digital access network is the basic rate ISDN channel which is becoming available in most area. Higher transmission rate digital access systems under development including HFC cable modem and symmetrical or asymmetrical digital subscriber lines.

2.4.1. ISDN Basic Rate Access Line

The basic rate ISDN line has a transmission throughput of about 160 kbps divided into two B channels of 64 kbps each and one D channel of 16 kbps plus some operational overhead. A customer side ISDN basic access rate transceiver can be installed as a PC card or a part of an ISDN telephone set. A stand alone ISDN basic access transceiver can also be configured with an S/T-interface. The S/T-interface can then be accessed by multiple terminals through a dedicated premises/house wiring system.

An ISDN to POTS Converter (IPC) can also be used to connect a conventional telephone set, a conventional FAX machine, or a voice band modem to the ISDN line. The IPC can have either a U-interface or a T-interface for the ISDN line and it should carry out the A/D and D/A conversion, signaling and power supply functions for the POTS line. With some built in intelligence, the IPC should also be able to perform some data/voice multiplexing functions. The multiplexing can be implemented within 2 B channels or within each B channel if packetized applications are available. A variety of applications can be realized with the combination of an NT1 and a multiple function IPC as illustrated by the drawing for the AT&T ExpressRouter 2000 product. That IPC also have data interface for PC applications.

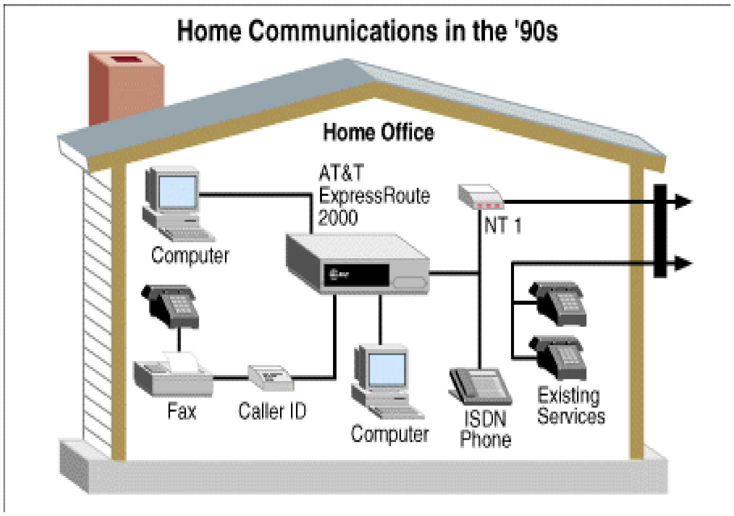

Figure 1. An ISDN Based Home Network

2.4.2 Digital Subscriber Lines

HDSL is a high speed version of the basic access rate ISDN U-interface. HDSL operates at 5 times the speed of the U-interface. Two HDSL transceivers in conjunction with 2 twisted pair can provide a repeaterless T1 service. The HDSL is designed to carry the T1 payload confirming both delay and phase jitter requirements. A single HDSL transceiver with a single twisted pair loop can provide a residence with a full-duplex transmission throughput of 768 kbps. Since the HDSL is originally designed as a T1 replacement no home multiple access architecture has been devised. A home multiple access architecture can be developed based on either circuit switched or packet switched traffic. The best choice might be a dynamic combination of both based on real time usage.

The ADSL was originally developed to deliver a transmission throughput of 1.544 Mbps in the downstream direction with a limited upstream transmission throughput of 16 kbps. The contents of the downstream channel was believed to be the MPEG I compressed video. The upstream traffic would be the control signal. A unique feature of the ADSL is that the POTS, including the phone sets and the residential wiring, can remain functioning. This 1.544 Mbps ADSL has been successfully implemented with the Carrierless AM/PM (CAP) technology. Most recently, The 1.544 Mbps ADSL is also used for data applications. A home network will be useful to extend the high rate data channel to multiple PC/TV terminals.

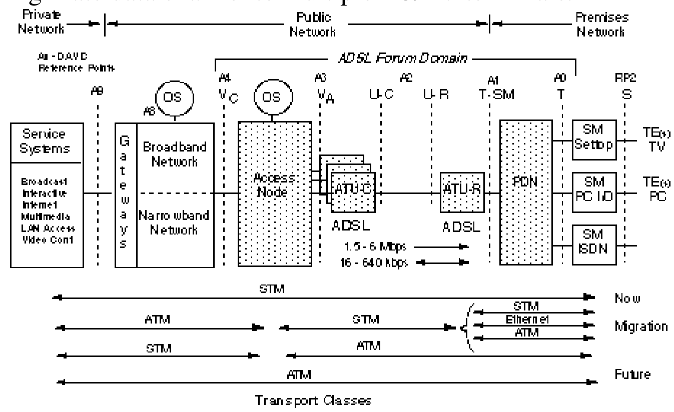

Figure 2. ADSL and Related Network Interface

VDSL transmits high speed data over short reaches of twisted-pair copper telephone lines, with a range of speeds depending upon actual line length. The maximum downstream rate under consideration is between 51 and 55 Mbps over lines up to 1000 ft (300 meters) in length. Downstream speeds as low as 13 Mbps over lengths beyond 4000 ft (1500 meters) are also in the picture. Upstream rates in early models will be asymmetric, just like ADSL, at speeds from 1.6 to 2.3 Mbps. Both data channels will be separated in frequency from bands used for POTS and ISDN, enabling service providers to overlay VDSL on existing services. At present the two high speed channels will also be separated in frequency.

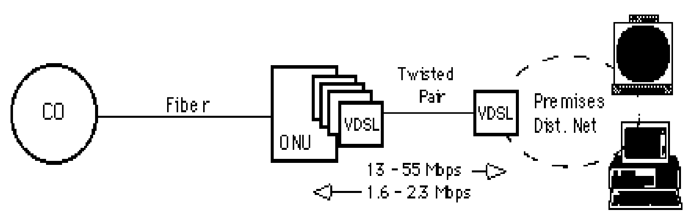

Figure 3. The Concept of VDSL

2.4.3 Hybrid Fiber/Coax (HFC) Modem

In contrast to the telephone subscriber loop, CATV subscribers share the same coaxial cable with a much wider bandwidth. This bus structure is very cost effective at providing broadcasting TV signal to a big population of subscribers. New transmission scheme and communication protocol are under development for providing two-way interactive services through the same CATV coaxial cable distribution plant.

In the downstream direction, from the headend to subscribers, digital channels are planned at a spectrum above the analog TV channels. Digital channels will still fill a 6 MHz bandwidth as defined by the analog system. In each 6 MHz digital channel a transmission throughput of up to 30 Mbps can be realized using advanced modulation and coding techniques. For data application the throughput can be shared among a group of users with each of them has the opportunity of realizing a peak throughput of up to 30 Mbps.

In the upstream direction, the use of the spectrum below the analog TV channels is considered. In the upstream direction not only the available bandwidth is much more limited but also the problem of multiple access to the transmission media should be resolved. In a frequency band of between 5 MHz and 45 MHz, about 30 1.3 MHz QPSK channels can be realized. Each QPSK carrier is cable of a throughput of about 1.544 Mbps. Higher transmission throughput can be realized by using a few carriers at the same time.

In a short summary, the home automation brought an early start for equipment interconnection and house wiring, existing personal computer networks provided examples for high throughput interconnection, and the information sources and appliances presented the desire to have a versatile home digital network.

3. A Distributed Home Network Architecture

3.1. Home Networking Options

To do a home network, we can choose from a variety of transmission media. They are unshielded twisted pair (UTP), coaxial cable, plastic optical fiber (POF), and radio frequency (RF) wireless. Power line and infrared wireless might only be good for low rate control data transmission. The existing unshielded twisted pair telephone wiring is not likely to be used for high rate transmission due to both the cable quality and the wiring configuration. The quality of existing CATV coaxial wiring is also to be examined. The frequency characteristics of coaxial cable and splitters are to be qualified. Attention also need to be paid to the craftsmanship of the installation.

Over these transmission media, relatively simple line codes are to be used to reduce the home network cost. For the same reason, extensive signal processing within the home network transceiver might need to be avoided. A home network will likely to carry both data and isochronous traffic. The data application might be related to Internet access, work at home, telecommuting, etc. The isochronous traffic might cover voice, video conference, home audio/video distribution applications.

3.2. A Proposed Architecture

We generalized the near future home environment as having digital access network, home wiring, and information appliances. Currently, only a subset of them are wired together creating redundancy on access network, home wiring, and information appliance.

We first assume that there is an existing home network system which satisfy the transmission need of a combination of data and isochronous traffic in terms of transmission rate and error rate. The information appliances such as set top box, PC, or home audio and video equipment can have the optional home network transceiver build in. We then can ask the digital access network providers to have the same home network capability. That can be realized by using a gateway attached right at NIU of the digital access network. This distributed gateway approach could result to little manual installation at home.

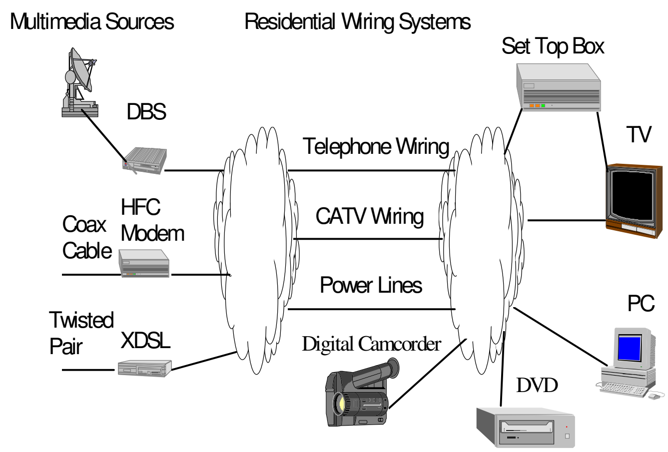

Figure 4. The Emerging Home Networking Needs

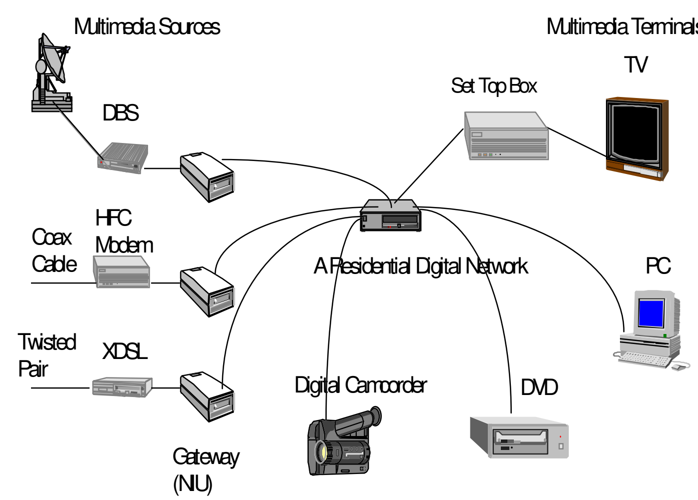

Figure 5. A Distributed Home Network

In conjunction with an existing NIU, a gateway can be constructed with mainly three parts: a data buffer, a processor, and a home network transceiver. The function of the gateway includes: data format conversion, home information appliance probe signal detection, icon generation, menu generation, and operation monitoring.

The data format conversion is necessary to at least buffer different transmission rate for the home network and the digital access network. Some frame format conversion and operational task such as CRC check might also be necessary. The gateway needs to make sure that operational handshake needs to be performed properly for both home network and digital access network.

A gateway with the proper home network transceiver, which is installed in conjunction with a Network Interface Unit (NIU), can be directly plug into a home network. When a user activates a information appliance, a TV connected to a set top box or a PC, the terminal first broadcast a probe signal to all gateways connected to the home network. Each gateway respond to the terminal with limited information about its backbone access network in the format of an icon. The user then select the desired icon. The terminal will communicate to the corresponding gateway to request more information. The selected gateway will respond with more detailed information in the form of a menu and starts connecting the access network to the user terminal. It is expected that the service provide has provided enough access network information to the gateway manufacture and the manufacture has in turn built them into the gateway.

3.3. Using 1394 for Home Network

An Ethernet such as 10BaseT or a fast Ethernet such as 100BaseT can be used for the purpose of a home network with a data grade UTP house wiring. Because it's designed for data traffic, the transmission performance of isochronous traffic such as video conference might not be guaranteed. On the other hand, the IEEE 1394 can handle both data and isochronous traffic well at a data rate above 100 Mbps. Actually, the IEEE 1394 has been adopted for the Local Peripheral Network part of the home network by VESA. The IEEE 1394 can be developed to be used as a general home network transmission system over data grade UTP house wiring.

The IEEE 1394 is originally designed to run on a specific type of twisted pair at a distance of 3 meters to connect computer peripheral devices. With two pairs carry data and timing separately, the 1394 transceiver can be made relatively simple. By the selection of multiple level line code and some simple transmitter preshaping techniques, it is expected that the 1394 protocol cab be carried over data grade UTP at a distance of 50 meters and a transmission throughput of 52 Mbps. Similar efforts in providing a transmission throughput of about 50 Mbps have been successful in Ethernet and FDDI activities.

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