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Research Report

Issues in Home Networking

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Abstract

Home networking is one of the fastest-paced and largest potential markets in electronics, not due to home automation, but driven by information services offered through Internet, interactive TV, and advanced telephone services. A standardized home local area network (Home LAN) implemented in the right way will pave the way to enormous business and technical opportunities. Internet will penetrate homes, and using Internet protocols all the way to the home as well as inside the home, represents an attractive enabling solution for generalized home networking. Next-generation Internet protocols will support the required additional functionality like control operations, quality of service, streaming media distribution (isochronous service), and mobile communications.

This report sketches the current home networking environment and derives essential architectural requirements. It contains relevant market figures and describes prospective services to be supported together with their communications requirements. The report then characterizes the most important enabling technologies and gives a list of programs and initiatives pursued in the home networking arena. Following a few concluding remarks, an Appendix with restricted distribution outlines three research areas aiming at different aspects of home networking: Technology enhancement, proof of concept for a candidate architecture, and product prototyping.

1. Environment

Home automation in combination with the widespread use of personal computers (PCs) in the home and, more recently, the provision of new information services to residential customers, promise tremendous business and technical opportunities. Household appliances, equipment, and other home electronic devices are all becoming significantly more intelligent and can now offer network features that allow otherwise unrelated household products to work together. “Home networks” are the interconnections among the information, entertainment, security, and environment control appliances found in the home as well as the connections with external networks. Home networking is considered one of the fastest-paced and largest potential markets in electronics. A fundamental requirement for exploiting this market is the definition of an integrated multi-purpose local area network for the home (i.e., home local area network “Home LAN” [1]). Consequently, a growing number of standards committees and industry working groups have started taking an interest in home networking.

Digital technology forms the basis of computing and most modern telecommunications. It has begun to have a direct impact on broadcasting as advanced digital signal compression and transmission techniques enable both terrestrial and satellite broadcasters to make more efficient use of the radio spectrum and to deliver signals of more consistent quality. Cable TV operators will also deploy digital technology to extend the capacity of their systems and to offer their customers enhanced services like personalized on-demand video programming. ‘Wireless local loop’ systems that use digital coding together with very high-frequency microwaves and cellular architectures, will emerge as a further distribution option for TV programming. Digital technology also enables the more creative use of video material – combining it with other media to create interactive multimedia services such as teleshopping and distance learning.

Utilities and companies in the energy services sector have been concentrating on the home automation business for many years, searching for standardized system solutions that will give them load control opportunities and competitive advantages. Although there is general agreement that homes need to be managed more cost effectively, the lack of a uniform standard for home automation has prevented the widespread innovation of products and services. In the past, households have not been very interested in home automation, but with the growing acceptance of on-line information services and home PCs (62% of US families with incomes of ≥$75,000 own a home computer and 75% of the PCs bought in the US are going to households that already have a PC), home networking is moving to the center stage**.** Cable providers offer high-bandwidth “to-the-home” networks, whereas telephone companies are building their own broadband networks. The local multipoint distribution system (LMDS) is a new microwave technology that uses a 300 MHz band at 31 GHz for two-way delivery of data, Internet, video, television, and telephone services, bypassing the local loop; data rate is 44.736 Mbit/s downstream and 3.3 Mbit/s upstream. Utility companies are deploying fiber-optic networks. Direct broadcast satellite (DBS) technology creates the potential of supplying the some 100 million US households with high-bandwidth MPEG digital television. All these developments will deliver broadband communications to the home, and it will become the challenge of home networking to distribute the information once inside the home. With the passage of the Telecommunications Act of 1996, new companies have entered the market, which has increased competition and will bring even more new services to the residential consumer.

Appliances such as video cassette recorders (VCR), camcorders, and game machines will be connected to an integrated home network that will enable new multimedia services. Desired standardization in the home will lower costs and accelerate the use of in-home networks. These in-home networks have to be integrated with each other and with access networks, enabling new differentiated services (e.g., Internet access, video telephony, wireless capabilities). According to a recent International Data Corporation (IDC) report, the market for information appliances, i.e., low-cost, easy-to-use, digital consumer electronics devices providing access to the Internet or to Internet-like services, will explode over the next few years. The future of home networking is thus tightly coupled with the further development of the Internet in the residential sector [2]. Moreover, broadband ATM (Asynchronous Transfer Mode) networks will proliferate as a communications delivery standard to the residence and potentially promote the deployment of ATM technology even inside the home [3].

2. Home Network Requirements

Currently, no network technology exists to provide the functions necessary to cost-effectively connect different “islands” of technology in the home and simultaneously to access multiple external service providers. Standards are needed that are flexible enough to support all existing uses and that also assist unforeseen future services while still being compatible with the network infrastructure.

In order to ensure that any device in the home can exchange information with any other device and can access any available service, a common inter-networking protocol is required to enable a basic level of communication among all devices in the home. Capabilities of this networking protocol include isochronous transmission (of multimedia data), locating of resources (devices and applications in the home), addressing of resources, network management, and network configuration. Security, especially firewalls to the outside world, must be an important design consideration. The inter-networking protocol must also ensure that higher-layer protocols can be specified independently of the underlying networks and their link layer protocols. The latter requirement allows the incorporation of new communications technologies into the home network without perturbing the existing networks and devices.

The current power-line, twisted-pair telephone, and coaxial-cable TV networks will stay in the homes for a long time to come, and new digital networks (e.g., using 10BaseT wiring, fiber premise cabling, RF, or IR) will be put in place *in addition* to them. Thus there must be provisions in the network architecture for low-cost, low-bandwidth devices to stay on their own network and not have to handle high-speed data and decode complex protocols. As a direct consequence, interoperability between home networks from low to high bandwidth must be supported. In addition, as future VCRs will store, send, and receive video data digitally, the transition from current analog or mixed analog/digital networks to a totally digital information distribution in the future must be possible.

Based on its own research [4], Intel Corporation summarizes the most essential home network requirements in the order of their priority: (1) ease of use, (2) no new wires, (3) accessible from anywhere in the home, (4) low price, (5) fast enough to match data rates to the home, (6) interoperable with popular networking protocols such as TCP/IP, and (7) becomes an industry standard.

3. Market Figures and Statistics

A recent ABI report on home automation systems [5] identifies five major groups of household functions currently suited for automation: lighting controls, security, communications, energy management, and audio/video. Utility functions aside, the market for custom-installed multifunction systems in the US in 1997 stood at roughly $100 million; nearly 20% of US homes have a security system. In 10 years, that market will probably approach $700 million or more, and continue to grow at an annual rate of 21%. Most homes and apartments will then have either automatic lighting, a central station security system, or both. Home automation segment shares of the US market in 2007 are predicted to be: 25% security, 22% lighting, 20% communications, 19% energy management, and 14% audio/video.

In the United States, 98% of households have access to communications through telephones. By year-end 1997, 18 million out of the nearly 99 million US households had more than one telephone line; this is up 30% from 1996. About 50% of the additional lines were dedicated to on-line usage.

The 1996 average of 2.4 telecommunications subscriptions per household is expected to rise to 3.2 in the year 2000, and higher-income households are expected to have five lines in 2000. Yet already 99% of US households own television sets!

Computers are penetrating the modern home faster than ever with more than 40% of American households having at least one PC. In high-income homes, PC penetration is over 80%. 14 million homes currently have two PCs, and that figure is expected to rise to over 20 million during 1998 and to 35 million in 2000 (i.e., 61% of the projected 57 million PC households in the US). According to Dataquest, the number of multiple PC homes is growing faster than the number of single PC homes! These are the consumers who are looking for a way to share their computers and peripherals. Note that PC conflicts within families go beyond TV conflicts because interactivity and the smaller screen of PCs make them difficult to share. In addition, expanding home usage of the Internet (penetrating more than 25% of US households during 1998), increasing speeds of the Internet link to the home, Internet content becoming more extensive, telecommuting, teleshopping, and growing multi-user needs are all driving the demand for home networking.

In late 1998 or early 1999, Microsoft plans to extend Win NT 5.0 to support several home-computing features, including improved hardware acceleration for video games and *instant-on* support. A full-blown consumer Win NT is planned to be released after the turn of the century. It will have a refined user interface, meant to be more intuitive for home users, and it will support home networking as well as large data downloads from the Internet.

According to a recent IDC forecast [6], the worldwide information appliance marketplace is expected to grow at a 97% consecutive annual growth rate from $915 million in 1997 to $13,737 million in 2001. An “information appliance” is a low-cost, easy-to-use, consumer-focused digital electronic device designed to bring the features and benefits of the Internet to consumers on a mass scale. Leading the revenue opportunity are Internet smart handheld devices with $733 average selling price and 10.59 million units sold in 2001. Second on the list are Internet screenphones in the price range of $200-300 and a volume of almost 7.57 million units in 2001. Following closely behind are Internet gaming devices, with 13.23 million units shipped in 2001, representing a $1.62 billion opportunity.

To date, market penetration and consumer awareness of networked home systems are low. Less than 5% of US households enjoy even a low level of integration; and only half of the consumers are aware that consumer products can be tied together for enhanced control. This contrasts sharply with the strong interest of consumers, two of three of whom would like to distribute their cable or satellite programs to multiple TVs in the house and use their TVs to check who is at the door; 59% want to listen to music in any room from a single stereo; 54% are interested in networking two or more home PCs for sharing hardware, software, and files (1996 CEMA study).

Communication and information products have emerged as the US consumer electronics industry’s largest revenue stream, exceeding those derived from its traditional video and audio categories. Sales of communication and information products to US dealers topped $21.6 billion, representing 35% of industry-wide sales.

US Digital TV broadcast rollout schedule [7]: More than 20 US television stations have voluntarily agreed to begin transmission of digital TV by the fall of 1998. In May 1999, digital TV is expected to cover 30% of households in the top 10 TV markets, rising to 50% of households in the top 30 TV markets by November 1999. By May 2002, digital transmission facilities are envisioned in all 211 commercial US TV markets. Since digital TV channels consume more bandwidth than analog ones (20 MHz vs. 6 MHz), given premises wiring cannot handle the same number of digital channels. Analog terrestrial TV broadcasts will stop in 2006, forcing corresponding equipment upgrades.

The European interactive television market will be worth close to $1 billion by 2002. Internet access to the television set through specific consoles, such as Microsoft’s WebTV or an empowered set-top box are expected to account for $160 million and $285 million, respectively, in Europe.

Fueled by the latest incarnation of Microsoft's handheld operating system, Windows CE 2.0, 1998 will see a 47% increase in worldwide sales of standard handheld devices. These include pocketable organizers such as 3Com's *PalmPilot* (with worldwide sales of 1.6 million in its first year) as well as more robust handheld PCs such as Casio's *Cassiopeia* and Philips' *Velo*. WinCE 2.0 includes scaled-down versions of Word, Excel, and Internet Explorer, support for color screens, and built-in networking support. Since its merger agreement with CommQuest Technologies, Inc., also **IBM** has the design skills, methodologies, and unique SiGe technology to create a wide variety of hand-held communications and computing devices connected to voice and data networks.

According to Grayson Evans of the Training Company, a specialist in teaching home automation installation classes, most US homes have no in-wall wiring at all. For TV reception, they rely on rabbit-ear antennas or a cable that comes through a window or wall from an outside aerial or cable service. Also in-home phone networks are virtually non-existent, because phone wiring was added in a similar manner by the telephone company when service was ordered. Only within the past 10 – 15 years have builders prewired new homes for phone and cable TV services, with wiring adequate for these analog services but mostly insufficient for digital networks. Among pre-wired homes, almost all use RG4 or RG59 coax cabling and Cat-1 phone wiring (Note that digital satellite TV service requires quad-shielded RG6 coax cables!). Surprisingly, more than 5 million Digital Broadcast Satellite (DBS) subscribers have performed the retrofit to RG6 cabling, indicating that high-end entertainment drives early adopters.

4. Supported Services

The following important service classes and enabled applications have been identified for the home network by the VESA Home Network Committee (see Section 6.5):

Entertainment services — distribution of video and audio in the home, video games, control of audio-video (A/V) devices such as TVs, VCRs and set-top boxes.

Communication services — voice telephony (wired and wireless), video telephony, video conferencing, distance learning, remote access to corporate networks.

Information services — Internet access, on-line service access, PC storage and printer sharing, news and information on demand, home shopping, home banking.

Home automation services — energy management, premises security, lighting and appliances control.

The functionality of various typical home automation applications is described in some detail by the following paragraphs:

Home Appliance Management and Integration involves control and maintenance of appliances and devices in the home through an in-home network.

Security Systems Management involves the maintenance and management of a home security system with automatic notification of appropriate authorities in the event of an alarm.

In-Home Power Regulation and Management involves management of utilities over a network and automated meter reading (remote switching of home appliances, diagnostics and tests on utility equipment).

Video Intercom Service requires a digital camera to be connected to the in-home network and have the picture appear on the user's television or PC screen.

In the following a characteristic subset of possible communication services has been selected to provide directions for the specific bandwidth requirements of the home network architecture:

Broadcast: Broadcast services provide multiple users with immediate, real-time access to multiple sources of TV/Radio/Data programming. This includes services such as Pay-Per-View, Pay-TV, and conventional open access TV. There are two broadcast configurations: The first broadcast configuration provides interactivity between the user and the service/network/content provider and requires an upstream information flow via a narrow back channel. The second configuration, which is a subset of the first one, provides interactivity between the user and processes running locally in the set top unit, and has no requirements for an upstream information flow.

Delayed Broadcast: This is a specific broadcasting application where the service provider or end-user selects a scheduled broadcast program to be stored at the network or service provider for delivery at a later time. The time of delivery may or may not be scheduled at the time of the application request. Besides ordinary TV programs, the broadcasted information could be electronic newspapers, computer software, commercial brochures, travel information, and any other digital information.

Movies on Demand: This term refers to network-delivered services that offer the functionality of a home VCR in the play mode. Despite the specific name, this category includes all services that use audio-video data.

Near Video on Demand: This is a service that improves the availability of (typically) movies, without requiring a dedicated point-to-point connection to each server. The service is also known as Enhanced/Advanced Pay-per-View. It covers pure broadcast of video (in a multiplexed manner) with no real interaction between the user and the service/network provider. On a regular satellite or CATV system, all titles are broadcast all the time; the user merely selects the channel that provides him with the closest start time as indicated by an Electronic Program Guide. To effect a "pause", the user selects another copy of the same title that started at a later time; successive start times of the same movie are typically staggered by 15 minutes. The "Intelligent" Near Video on Demand (IN-VOD) application automatically finds the appropriate channel to re-select after a pause is executed.

Teleshopping: This application allows the user to browse video catalogues or virtual shops to purchase products and services. The user may be presented with information using different media (video, text, motion video with audio or graphics). After having made a choice, the user may order the product.

Telework: In this service the user establishes a session via a service provider, activates and controls local and distant applications, and communicates with a collaborator through audio, video and data. Thus tele-cooperation, multimedia collaboration, or generally Computer Supported Cooperative Work (CSCW) are supported.

Games: This application allows users to play a game via a network-delivered service. It involves users interactively participating in quick response, real-time entertaining games in the home (program is loaded into the set top unit) or over the external network using a "game machine" located at the service provider. Certain games are characterized by speed and reaction time, imposing very strict delay requirements and sometimes demanding high-speed graphics.

The bandwidth required to support the above services together with their expected holding times are extracted from [8]:

Service	**Downstream**		**Upstream**	
	Bandwidth	***Holding Time***	***Bandwidth***	***Holding Time***
Broadcast	3.0 Mbit/s	120 min	64 kbit/s	0.1 min
Delayed Broadcast	3.0 Mbit/s	30 min	64 kbit/s	0.1 min
Movies on Demand	3.0 Mbit/s	110 min	64 kbit/s	0.1 min
Near Video on Demand	3.0 Mbit/s	110 min	64 kbit/s	0.1 min
Teleshopping	384 kbit/s	7 min	64 kbit/s	0.7 min
Telework	384 kbit/s	60 min	384 kbit/s	60 min
Games	384 kbit/s	60 min	64 kbit/s	60 min

5. Enabling Technologies

Today, home "networks" predominantly consist of a tangle of power line, cable TV and telephone wires. They are frequently poor to mediocre in quality and typically installed with cost saving rather than data transmission in mind. For the home networks of the future, developers around the world are working on a great variety of transmission solutions ranging from broadband ATM on Category 5 unshielded twisted pair (UTP) wires or on plastic optical fibers (POF) [9] to advanced modulation schemes over electrical power lines, hybrid fiber and coax (HFC), and also on wireless networks.

Many years of work in product and development laboratories, committee rooms and in the field have provided manufacturers and contractors with a number of choices in enabling technologies and standards they can apply to make systems integration and automation happen in the home. Among the most pervasive and high profile bus protocol architectures for the home are the following examples:

5.1

X-10 modules were the first commercially available contraptions that could control lights, appliances, heating and air conditioning units through power wires. Using the 50 or 60 Hz power as a carrier, 120 kHz signal bursts are modulated as the power voltage crosses through zero. The presence of a burst indicates a digital 1, the absence of a burst a digital 0. A simple addressing protocol allows each unit in a common wiring environment to be identified individually. The protocol involves 16 address groups (*House Codes*) and 16 individual addresses (*Unit Codes*) resulting in 256 possible unique addresses. Six simple control commands are allowed. For sending a signal that includes both address and command, the protocol requires transmission of 48 bits, taking 800 ms in a 60 Hz or almost 1 s in a 50 Hz environment.

X-10 is both a standard and a manufacturer. Products are called "Power Line Carrier" (PLC) devices and include light switches, remote controls, security systems, television and computer interfaces, and telephone responders. PLCs are installed worldwide in over 4 million homes. The technology is inexpensive; light switches are available for as little as $10, remote controls start around $15. PLC technology saves labor and wire, since the ability to send control signals from point A to point B does not require additional wiring. IBM's Home Director Product applies the X-10 technology (see Section 6.16).

X-10 offers only a standard for power line communications and does not support any of the other transmission media of the home environment like twisted pair, coax, IR, RF, and fiber optics. X-10 is based on a 20-year old concept, many of the X-10 devices only communicate one-way, and its inherent limitations regarding data rate and addressing are severe. Hence X-10 is not considered as a solution for future home networking discussed in this report.

5.2 LonWorks

LonWorks is the implementation of a proprietary control protocol developed 1990 by Echelon Corp. for the control and automation of devices in both residential and industrial environments. Transceivers are available for power-line and twisted-pair wiring in the form of hardware and firmware on special Neuron chips manufactured and sold worldwide by Motorola and Toshiba. Of the nearly 2 million Neuron chips shipped to date, about 75% have gone into industrial control. A plug-in module for LonWorks costs $50-80.

Since June 1997 the LonWorks protocol is available for porting to any processor under license from Echelon. In August 1997, the Electronic Industries Association's Integrated Homes System technical committee (see Section 6.8) formed a sub-committee to consider an additional EIA standard for home networking based on LonWorks. The interim standard number assigned to LonWorks is EIA/IS-709.

LonWorks uses Manchester encoding to generate 1's and 0's, allowing communication among intelligent control devices through power-line wires, low-voltage twisted pair, coax, IR, RF, and fiber optics, respectively. The LonWorks power-line communications standard includes three options. Two spread spectrum transceivers are offered, one using the frequency range from 100 kHz to 450 kHz and communicating at 10 kbit/s, and another using the band 9 kHz to 95 kHz at the rate 2 kbit/s. A third transceiver option applies narrowband technology in the frequency range 125 kHz to 140 kHz (European CENELEC standard C-Band) and transmits 5.4 kbit/s. Transmissions are based upon variable-length packets, depending on how much data is included. The minimum packet size is 64 bits, taking 6.4 ms to transmit a packet at the highest rate. LonWorks uses device addresses that are set in hardware at the factory or by the installer, and support up to 32,000 individual devices in a network. Each node in the network contains embedded intelligence that implements the protocol and performs control functions. The protocol also offers a defined language of 32 control commands.

5.3 CEBus

The Consumer Electronic Bus (CEBus) specification for home networks was developed jointly by the Electronics Industry Association (EIA) and the Consumer Electronics Manufacturers Association (CEMA, see Section 6.8); in 1992 it was released as standard EIA-600. CEBus is an open-architecture set of specification documents which define protocols for how to make consumer products communicate through any of the five potential home media power-line wires, twisted pairs, coax cable, IR, and RF. CEBus allows any node to communicate easily with any other node irrespective of the transmission medium through which the communication is sent. Communication is two-way with a uniform 10 kbit/s transfer rate, regardless of the transmission medium and requiring no buffers. This enables devices to stay "on-line" only for a relatively short time period, thereby minimizing collisions and producing a rather instantaneous response. Linked subsystems communicate with one another using the Common Application Language (CAL), a key piece of the specification also defined as an own standard EIA-721 that some observers see as the glue that will link various in-home networks of the future.

For power line transmission the standard includes spread-spectrum modulation. Each burst begins at 100 kHz frequency and increases linearly with time to 400 kHz during a 100 µs interval. Both a burst (referred to as the "superior" state) and the absence of a burst (referred to as the "inferior" state) create similar digits, so a pause in between is not necessary. A digit 1 is created by an inferior or superior state that lasts 100 µs, and a digit 0 is created by an inferior or superior state that lasts 200 µs. Consequently, the transmission rate is variable, depending on how many bits are 1's and how many are 0's; the average rate is 7,500 bit/s. Two-way transmissions are based on variable-length packets with the minimum packet size of 64 bits transmitted within 8.5 ms on the average. Device addresses are set in hardware by the factory and include 4 billion possibilities. The standard comprises a defined language (CAL) of many object-oriented control commands.

The CEBus communications hardware, language, and protocol is available on a chip produced by Intellon Corp. Typical costs for a plug-in module are $50-80. Intellon also sells "developer kits" based on RF spread-spectrum technology to anyone wanting to develop a CEBus compatible product. The architecture can be extended to cover also arbitrary data streams, however, these are allocated to separate channels of appropriate capacity, and the home bus remains in the control domain. Thus multimedia data streams are switched on and off, and are distributed between controlled nodes. In fact, this solution represents a combined network rather than an integrated network and requires one or more separate protocol stacks to support all communications other than mere control data.

Further development work is being conducted by the CEBus Industry Council (CIC). More details on CIC are given in Section 6.11.

5.4 IrBus

The Infrared Data Association (IrDA) approved the IrBus communication standard in February 1998. IrBus is an infrared bus to interactively control home electronic appliances within a communication range of 25 feet and to exchange relatively small amounts of data. It transmits at 75 kbit/s using a 1.5 MHz pulse-sequence modulation and supports up to eight peripherals at a time, including mouse, keyboard, joystick, gamepad, remote-control units, and PDAs.

IrBus was developed from a joint proposal by HP, Intel, Microsoft, and Sharp and meets the IrDA bi-directional command and control market requirements. IrBus will not interfere with equipment that complies with IrDA 1.0 or IrDA 1.1 standards, even within the same room. Sharp Corp. intends to be the first supplier of IrBus devices late in April 1998.

5.5 USB

The Universal Serial Bus (USB) was introduced in June 1995 by a group of computer vendors including Compaq, DEC, **IBM**, Intel, Microsoft, NEC, and Northern Telecom as a simplifying peripheral-connection architecture. The bus protocol specifications combine serial, parallel, mouse, telephony, and keyboard ports into a single standard. This will enable hot, active “plug-and-play” of peripherals, and any available port can be used for any peripheral devices. USB supports real-time, isochronous bi-directional communications and features bandwidths of up to 12 Mbit/s. This data rate enhances significantly the current 1 Mbit/s for parallel ports and 2 Mbit/s for serial ports. It thereby benefits multimedia applications because present serial and parallel computer ports have insufficient bandwidth for digital audio, high-performance gaming, and digital telephony.

USB is in wide-spread use among PC manufacturers and may well be implemented for various devices other than the traditional computer peripherals. It makes it easy for the users to add new peripherals to their PCs, without having to open the enclosure. USB provides the PC with new and enhanced capabilities such as computer telephony integration (CTI) in homes [10] and video conferencing, and enables the development of new and creative audio and video products for home entertainment. USB is fully supported in the PC 98 System Design Guide, a reference document designed to promote innovation and interoperability among PC OEMs and independent hardware vendors.

5.6 IEEE 1394

IEEE 1394 is an international standard, low-cost high-speed digital peer-to-peer interface that will integrate entertainment, communication, and computing electronics into consumer multimedia. Originated by Apple as a desktop LAN (known as “FireWire”) and further developed by IEEE, 1394 is a hardware and software standard for serially transporting data at 100, 200, or 400 Mbit/s. Different-speed devices may mix on the bus and data transfer can be asynchronous and isochronous, allowing low-cost implementations of time-critical multimedia interfaces. 1394 has hot-plug and “plug-and-play” capability; it allows to chain up to 63 devices in a flexible topology without terminators, device IDs or complicated setup requirements.

IEEE 1394 involves the low three ISO protocol layers plus a Serial Bus Management process that connects all three layers. The physical layer performs fairness arbitration, bus management provides overall configuration of the serial bus in the form of optimizing arbitration timing, guaranteeing adequate electrical power for all devices on the bus, assigning which 1394 device is the cycle master, assigning isochronous channel ID, and basic notification of errors. The 1394 standard requires that a device be within 4.5 m of the bus socket. Up to 16 devices can be connected in a single chain, so a device could be as far away as 72 m from the computer.

The 1394 standard is intended to be the pervasive means of hooking up the next generation of digital devices. According to promoters, IEEE 1394 is the “interface of choice” for digital video, consumer electronics and multimedia. When more digital devices are equipped with this standard interface, they can be plugged into each other, instead of a computer. Many new extensions to the existing standard are currently under development in the 1394 Trade Association (see Section 6.12).

6. Related Programs and Initiatives

Not only manufacturers, research groups, and system designers are taking interest in the area of home networking. A growing number of standards committees and industry working groups have also become active in this area. This section describes some of these activities and product solutions beginning with three research projects of the European Community in the Advanced Communication Technologies and Services (ACTS) program.

6.1 ACTS program AMUSE (AC011)

"Advanced MUltimedia SErvices for residential users". Investigates the feasibility and viability of future commercial interactive multimedia applications like interactive TV, using advanced technology such as ATM end-to-end transmission protocols and MPEG video compression techniques. These multimedia services are provided to residential users. The end user in the AMUSE project is the viewer at home, and residential user trials will be conducted.

6.2 ACTS program IBCoBN (AC101)

"Integrated Broadband Communications on Broadband Networks". Researches broadband multimedia communication applications to the residential customer using Cable (or Community Antenna) TeleVision (CaTV). Develops new markets and applications supporting the expansion of broadband networks to the home.

6.3 ACTS program SMASH (AC018)

"Storage for Multimedia Application Systems in the Home". Develops a tape-disk mass storage system for domestic use. Will supply data-storage devices for the home user of broadband multimedia systems.

6.4 TIA/EIA TR-41.5.1

The Telecommunications Industry Association (TIA)/Electronic Industry Association (EIA) subcommittee TR-41.5 "Multimedia Building Distribution Systems" is involved in developing industry standards for the "Residential Gateway" [11]. Publicly available is Draft 1.0 of a "Multimedia Premises Reference Architecture" [8]. The committee holds regular meetings towards improving the proposal; **IBM** is represented by Thomas Toher, Marketing Unlimited, D&ID Strategic Direction, RTP NC.

6.5 VESA Home Network Committee

The Video Electronics Standards Association (VESA) Home Network Committee (VHN), founded in 1995, is under charter to develop an open industry architecture standard for consumer digital home networks. **IBM** is among the approximately 50 participants. The Committee's goals are to provide an interoperability specification which will allow the orderly transfer of information from any device to any other device in the home, between different networks, from low to high bandwidth, and from analog to digital. This specification will also provide directory services for devices in the home and a common interface on the home side of the Network Interface Unit (NIU).

After a Call for Proposal (published in August 1995) four basic technologies were proposed, from which IEEE 1394 was chosen as the base from which to develop the home network backbone. Standardization of this backbone (goal: 100 Mbit/s through Cat-5 UTP over distances of 100 m) and inter-networking issues are currently being worked on. Wireless networking is an area that the committee is also beginning to investigate.

6.6 Home Automation Association (HAA)

HAA is an association of companies who share the commitment to develop, market, and service automated products and services to enhance home entertainment, appliances, communications, security, safety, and energy. Members are product producers, product sellers, and general service providers. The PC makers Compaq, **IBM**, and Novell, among others became members to help drive the home-networking market forward.

6.7 Custom Electronic Design & Installation Association

CEDIA is an international trade association of companies. These companies specialize in planning and installing electronic systems for the home – typically media rooms, single or multi-room entertainment systems, home automation and communication systems, and integrated whole-house subsystems providing control of lighting, security and HVAC (Heating, Ventilation and Air Conditioning) systems. The association was founded in September 1989 and has a total membership of more than 1,200 member companies.

Custom installation is a new, rapidly growing field, which is not widely known outside the consumer electronics industry. CEDIA's purpose is to build recognition and acceptance for this specialized field, and to speak up for its interest in addressing industry, government, and the marketplace. CEDIA is also working for the establishment of industry standards with respect to the design and installation of home electronic systems.

6.8 Consumer Electronics Manufacturers Association

CEMA is a sector of the Electronics Industries Association (EIA) and represents a trade association whose primary members are US consumer electronic manufacturers. With four targeted subdivisions, CEMA's Communication and Information Products (CIP) Division encompasses the vast array of electronic products and devices that keep the world connected. The Integrated Home Systems Subdivision has the mission to promote the growth, development and expansion of the integrated home systems industry. **IBM** executive William R. Thompson (Director of Marketing Consumer Options, RTP) currently serves as vice chairman of this influential group.

6.9 Digital Audio-Visual Council (DAVIC)

The purpose of DAVIC is to promote the success of emerging high-quality interactive digital audio-visual applications and services, by the timely availability of internationally agreed specifications of open interfaces and protocols that maximize interoperability across countries and applications/services. DAVIC's primary instrument towards achieving these goals is the production of *Technical Specifications*.

DAVIC 1.0 Specification (published in January 1996) selected a set of tools allowing the deployment of systems that support initial applications such as TV distribution, near video on demand, video on demand, and some basic forms of teleshopping (for definitions see Section 4). Each future version of the Technical Specifications provides more functionalities while keeping backwards compatibility with previous versions. DAVIC 1.1 (agreed in September 1996) added tools to support basic "Internet Capability", the addition of microwave broadcast networks, set-top units that are network independent, and set-top units that can behave as virtual machines. DAVIC 1.2 (agreed in December 1996) added tools enabling TV networks to provide Internet services at high speed to TV and PC users, as well as defining HDTV formats and systems for conditional access. Note that DAVIC is the only organization worldwide integrating high-quality video and audio with the technologies used in the Internet! DAVIC 1.3 (agreed in September 1997) added comprehensive Service and Network Management, multiple broadcast servers, mobile reception, scalable audio, content and meta-data packaging, Java APIs for Digital Video Broadcasting (DVB) service information, and a new concept of "Contours" – the first instances are Enhanced Digital Broadcast and Interactive Digital Broadcast.

Established in August 1994, the DAVIC membership currently includes more than 200 companies from more than 25 countries around the world and representing all sectors of the audio-visual industries: computer manufacturers (including **IBM**, with Peter P. Schirling from department STB Platform Manager at the Burlington Plant, as member of the Management Committee and the Finance and Audit Committee), consumer electronics, telecommunication equipment, broadcasting, telecommunications, CATV; as well as a number of government agencies and research organizations. Meetings are held quarter-annually in different continents of the world.

6.10 Simple Interactive PC (SIPC)

Simple Interactive PC (SIPC) is the vision guiding many of the investments that Microsoft is making in software and hardware advances to make the PC as simple, convenient, and approachable as an "appliance" – turned on immediately and hassle-free. Bill Gates unveiled at the Windows Hardware Engineering Conference (WinHEC96) the technologies of SIPC that will make the PC platform the center of entertainment, communications, and productivity in both home and office, providing the ease of use and convenience of a consumer appliance. Among the SIPC presentations by Microsoft, connectivity was demonstrated between the PC and consumer electronics using Universal Serial Bus (USB) and IEEE 1394 (in the radical new "sealed-case" PCs, the bus connectors are both in front and in the back for daisy-chaining multiple peripherals) which has added momentum to the IEEE 1394/FireWire standard for high-speed serial data transfer (see also Section 5.6). Other key technologies for SIPC include OnNow for instant accessibility and the Win32® Driver Model for simplified driver development and low-latency support for applications. Leading hardware companies like Compaq, HP, Intel, Phoenix, and Toshiba have endorsed the SIPC framework and are developing products designed to advance the SIPC initiative and its associated technologies.

6.11 CEBus Industry Council (CIC)

CIC's charter is to establish and support a thriving Home Networks Industry. CIC is a multi-industry organization of some 25 companies (including **IBM**), incorporated as a non-profit trade corporation, to develop and enlarge the market for products compliant with the CEBus standard EIA-600 and/or the Common Application Language (CAL) standard EIA-721 as implemented in the "Home Plug 'n Play Specification" (HomePnP). This specification was released by the Interoperability Technical Committee of CIC as a provisional standard on March 31, 1997, giving manufacturers a chance to build and test products in a "PlugFest" environment. The council maintains the value of its certification marks while facilitating interoperability among products and with multiple transport protocols through the maintenance of the Standard and Specification, its application base, product testing, and conformance certification.

CIC's programs and activities are aimed towards accelerating the evolution from stand-alone products to network products in the home. Its HomePnP Specification provides uniform implementation rules for those using EIA's Common Application Language as their communication language for home network products. HomePnP is the definite reference for those using CAL because it contains CIC's common product identifiers or "Approved Industry Specific Contexts". Using these identifiers, all the features for interactive communication of an electronic product can be described; thus a product can broadcast its state or a command to others, receive a command to modify its state, or simply receive a request polling its state.

6.12 Trade Association

Originally promoted by Apple Computer, more than 60 vendors now belong to the 1394 Trade Association. Computer companies backing IEEE 1394 include Apple, Adaptec, Advanced Micro Devices, AT&T, Cirrus Logic, NCR, **IBM**, Lexmark, Microsoft, Molex, National Semiconductor, Philips, Seagate, Skipstone, and Texas Instruments. The following Japanese consumer electronics companies are also members of the association: Sony, Matsushita, Mitsubishi, FujiFilm Microdevices, Panasonic Communications & Systems Co., Canon, Toshiba, and Yamaha.

Individual study groups are working on extensions to the 1394 standard including gigabit speed for cables (IEEE 1394.2), 100 Mbit/s for backplane implementations, longer distance cables using copper wire and plastic fiber (IEEE 1394.1), A/V command and control protocols, 1394-to-1394 bridges (IEEE 1394.3), and 1394 gateways to other communication interfaces such as ATM.

6.13 Home Radio Frequency Working Group (HRFWG)

In a press event during CTEXPO on March 4, 1998 the formation of HRFWG was publicly announced. The group intends to establish an open industry specification for unlicensed RF digital communications for PCs and consumer devices in and around the home. The HRFWG is led by core members Compaq Computer Corporation, Ericsson Enterprise Networks, Hewlett-Packard, **IBM** (Dennis Moeller, Aptiva Development, RTP NC, is Technical Steering Committee representative), Intel, Microsoft, Philips Consumer Communications, Proxim, and Symbionics; it is supported by Butterfly Communications, Harris Semiconductor, Intellon, National Semiconductor, Rockwell Semiconductors Systems, and Samsung Electronics America.

The group is expecting to publish the open specification for home wireless communications by late 1998. This new Shared Wireless Access Protocol (SWAP) defines a common interface that supports wireless voice and data services in the home. SWAP operates in the unlicensed 2.4 GHz ISM band and uses frequency-hopping spread spectrum modulation. The 100 mW technology was derived from existing cordless telephone (DECT) and wireless LAN (IEEE 802.11) standards. It supports 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 the delivery of high-speed packet data. Data security and data compression will be provided, and up to 127 devices per network can be connected. The first SWAP-compatible commercial products are scheduled for the second half of 1999.

6.14 Lucent HomeStar

Lucent Technologies has introduced HomeStar, a wiring scheme enabling homeowners to network and distribute audio/video data to entertainment systems, PCs, fax machines, satellite TV, security systems, and telephones. HomeStar complies with the TIA/EIA 570 Residential Wiring Standard and the CEBus standard for home automation and control, but is equally suited for use with other protocols such as LonWorks or even X-10 (see Section 5). The system components include a *Service Center* to provide a central distribution point for all of the signals that travel through the HomeStar wiring system, *Distribution Cables* which carry all the signals from the Service Center to multi-access points (outlets) throughout the home, and *Outlets* that connect all telephones, TVs, VCRs and computers to the HomeStar wiring system. The system features true end-to-end Category 5 performance for clear, uninterrupted data transmission over unshielded twisted pair (UTP) cable.

6.15 Tut HomeRun

Tut Systems Inc.'s innovative HomeRun® networking technology bridges the connectivity chasm by providing a high-speed data network over the existing in-home telephone wiring, without modification and without disturbing normal telephone service. HomeRun creates a 1.3 Mbit/s Ethernet LAN using the complex, random-tree type topologies typically found in existing home telephone wiring. Inexpensive HomeRun adapters connect between the computer and any standard RJ-11 phone jack. Applying FDM, the networking signals and standard telephone service coexist transparently on the same wires. Transmission technology is based on Tut's patent-pending Time Modulation line code (TM32), noise suppression circuits and collision sensors. HomeRun connects multiple devices across distances of up to 500 feet without requiring special terminations, filters or splitters. HomeRun is fully compatible with the Ethernet MAC layer standard (i.e., IEEE 802.3 CSMA/CD with a new physical layer) and meets FCC regulatory requirements (Part 15 Class B and Part 68).

Together with Microsoft and third-party vendors a true plug-and-play, Ethernet-compatible HomeRun-based platform will be released which enables multiple PCs, peripherals and other devices, such as IP telephones, to connect simultaneously to each other and to the high-speed Internet and intranet services.

6.16 IBM Home Director

Home Director's easy-to-use software and simple plug-in hardware provides greater security and convenience for the home by managing the house without the need for expensive additional wiring using existing power lines. Up to 256 lights, appliances, and other devices can be controlled any time, also during the absence of the home owner. Powerful remote access features allow one to control Home Director from the comfort of a couch, from across town or from anywhere in the world. Home Director is based on the popular X-10 home automation technology (see Section 5.1) and thereby supports thermostats, exterior light controls, interior light switches, alarm interface modules, wall outlets, and many other specialty modules.

In January 1998, IBM selected Savoy Automation, Inc., creator of *CyberHouse*, to provide key technology for the next planned phase of Home Director. CyberHouse integrates off-the-shelf home subsystems with PC-based applications such as electronic mail, fax, telephony, and paging. Its TCP/IP client-server architecture enables remote and mobile users to dial into their home PCs either directly or via the Internet. IBM plans in its next-generation offerings of Home Director to also exploit other information media such as RS-232 for subsystem integration and TCP/IP for remote access to the home.

7. Conclusions

The apparent trend of consumers having multiple computers and information appliances in the home has created a need for a home networking environment that manages the communication among devices in the home and integrates the emerging information services from the entertainment, utility, financial, and telecommunications industries. To date, the adoption of networking technologies in the home has been inhibited by the high cost and impracticality of extra wiring, and the multiple incompatible wireless communications standards, respectively.

Around the world, deregulation of the telecommunications industry is unleashing competition in the residential market among telephone carriers and cable TV service providers and more recently also with utilities and other newcomers to the field. Even PC makers are stepping up to help drive the home-networking market forward. Clearly, PC makers see a business opportunity. But before that opportunity translates into revenues, the networking concept must be developed into an ingenious communications technology that offers real value to the consumers.

The success of the in-home network market is critically dependent on open industry standards, developed and maintained with input from a diverse cross section of organizations, industries, corporations, and individuals. The primary objective of home networking is in essence to develop a set of interface standards between the broadband residential access networks and the internal communication networks required for the services inside the consumer's home as well as among these different-bandwidth in-home networks which are based on the distinct media types of the home environment and are bound to stay there for some more time.

Internet will definitely penetrate homes, and using Internet protocols (IP) all the way to the home as well as inside the home, represents an attractive albeit luxurious enabling solution for generalized home networking. Next-generation Internet protocols will support the required additional functionality like control operations, Quality of Service (QoS), streaming media distribution (isochronous service), and mobile communications that will help making such a solution feasible.

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Appendix: Areas of Research

The information given in this Appendix is considered proprietary and has restricted distribution. A full version of the report including the Appendix can be requested directly from the authors (E-mail: *dm@zurich.ibm.com* or *sct@zurich.ibm.com*).