

Home Networking: Home Infrastructure Design

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1. Introduction

Wiring a home used to be a straightforward task. In the past, most decisions concerning the wiring of a new home were left up to the homebuilder and little thought was given to adding any additional wiring to older homes. Most homes were wired for basic household services - one telephone line with single-jack connection points in most rooms, cable television outlets in several areas, and electrical outlets in numerous convenient locations. However, with today's fast-paced, ever-changing technology, where security systems, fax machines, computer modems, home entertainment systems, environment control systems, and high-speed Internet access are now considered commonplace, current home wiring methods cannot adequately accommodate the networking of these technologies. Today, homeowners and homebuilders must be aware of the need to build sufficient wiring into the home. Just like roads and highways need good planning to allow for better flow of traffic, so does a home's wiring. The Yankee Group has predicted that by the year 2003, there will be 800,000 homes with structured wiring [1]. In preparation for the present and future advancing technologies, the builders and owners of such homes must be knowledgeable on how to design and "future proof" the home's networking infrastructure.

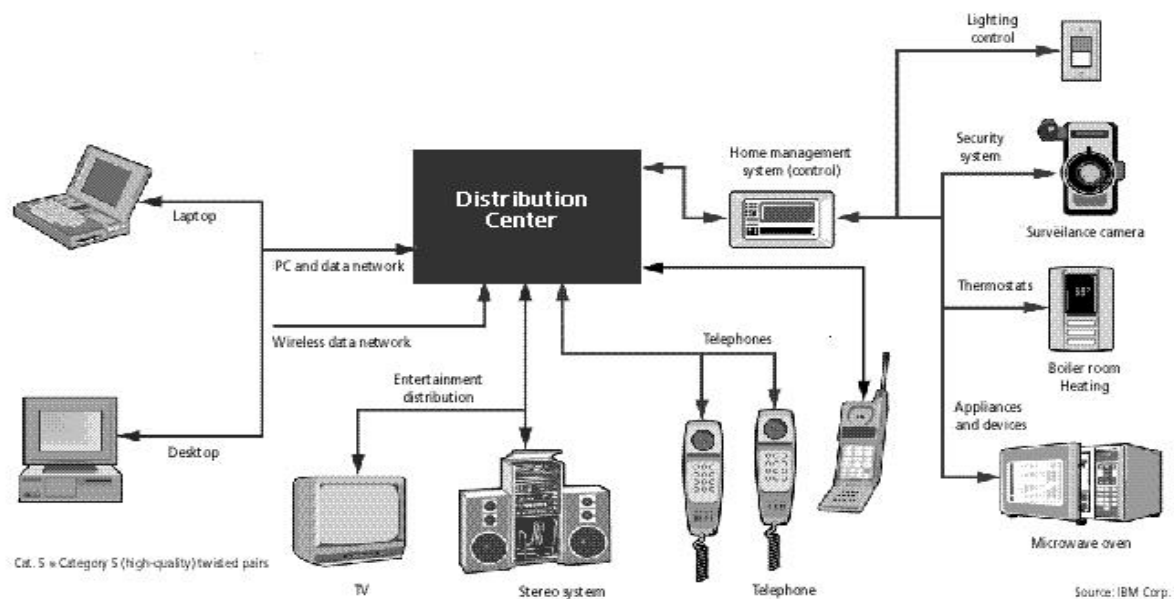
When considering home infrastructure requirements, one must first understand the definition of a home network, what functions it provides, and what services it supports. The concept of a home network has grown beyond the connection and communication between two or more computers to mean the connection and communication between all appliances, devices and operating systems within a home. A home network is a system that allows for conveniences such as faster access to the Internet, computer networking, lighting control, distribution of audio/video signals, and control and monitoring of home security and environment systems. This network creates the opportunity to make many household operating systems more efficient through automation and to significantly increase a homeowner's quality of life. Some specific examples of what today's home network can provide to the homeowner include:

- Linking a video monitor in a baby's room to a television in the kitchen.
- Linking security cameras to a television so that a person at the front door can easily be viewed.
- Linking a telephone caller ID system to the television so that when the phone rings, the caller's identity flashes on the television screen.
- Providing remote access to home appliances, such as lights and environmental control systems.
- Providing hookups in multiple rooms and wiring so that multiple home computers and printers can be networked.
- Linking multiple CD players and providing for remote control of each. [2]

Figure 1 shows an example of the elements of a home network that might be connected with the home's wiring infrastructure.

Figure 1: Example of Home Network Elements [1]

A home network employs the new generation of interactive voice, data, video, audio, multimedia products and communications services. The home infrastructure, as defined in this paper, is that which provides the communication means between all elements of such a home network. The primary purpose of this paper is to make a recommendation for the design of this home infrastructure. This recommendation has been carefully developed so as to take into consideration both current and future home networking technologies' infrastructure requirements. Also, standards that define each element of the home infrastructure will be cited and three current



vendors' home infrastructure products will be presented.

2. Distribution Center

The Distribution Center performs several functions to help "future-proof" a home's wiring infrastructure. One important function of the distribution center is that it operates as a tandem point for external service offerings such as CATV feeds, Satellite DBS TV feeds, telephone service and Internet access, all to be distributed throughout the home. The Distribution Center is the central point of the residential infrastructure and the external service termination point as shown in Figure 2 [3,4,5].

Another function of the Distribution Center is to house and power modules that are responsible for sharing and distributing multiple services that can originate either internally or externally. Once these services are delivered to the Distribution Center, it is necessary to have an individual module for each service that is to be distributed over the network. The scalability of the modular design allows the consumer to add additional services by simply installing specific modules [3,4,5].

The most commonly used modules used to support a home network include the following:

- **Telecom Module** - Provides connections for basic telephone and high-speed digital data services such as ISDN (Integrated Services Digital Network) or DSL (Digital Subscriber Line). See Figure 3 for an example of a telecom module.
- **Video Module** – Has the ability to deliver multiple services. Its primary function is to distribute external video signals originating from CATV or Satellite service providers. The video module also distributes internal video such as a VCR, DVD player, or a security camera. Secondly, assuming Internet access is available through the local cable provider, the video module manages the delivery of data.

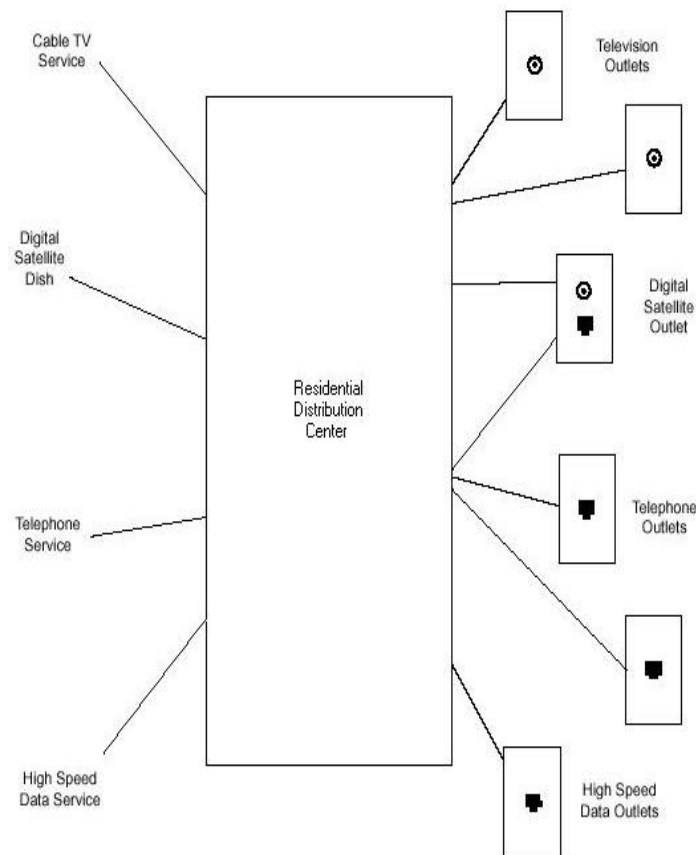


Figure 2: Distribution Center [3]

- **Audio Module** - Distributes audio to multiple rooms and zones within a home.
- **Network Interface and Hub Module** – Distributes computer network capabilities to multiple connection points within the home. For example, multiple users can share a single printer, scanner, etc.

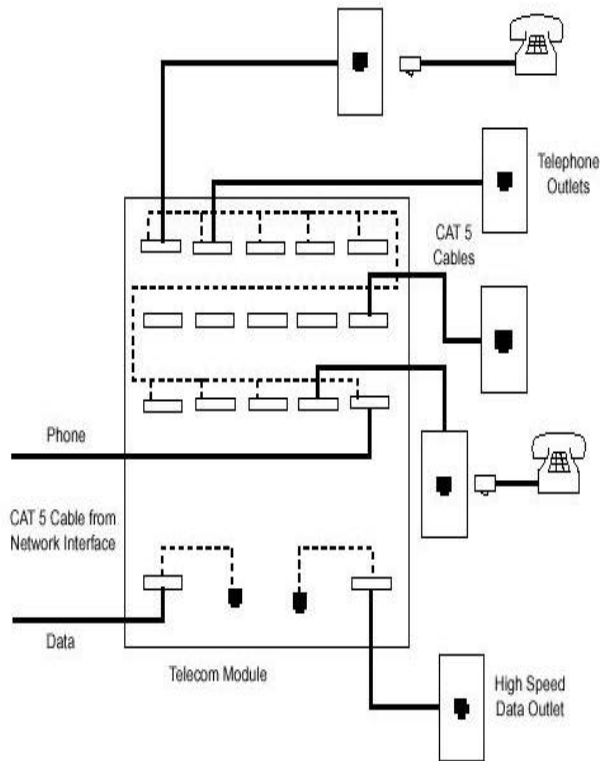


Figure 3: Telecom Module

3. Home Infrastructure Wiring and Cabling

In order to have a home network, there must be a medium to distribute the different services throughout the home. Today's evolving technologies are requiring line speeds of up to 155 Mbps [5]. The type of media used depends on which services will be transmitted, the cost of installation and materials, and the situation each home presents to installing the media. The choice of media depends on the situation the installation presents. For this reason, the choice of media has been broken down into two categories, new homes and existing homes.

3.1 New Homes

Networking a home will take full advantage of future service offerings by service providers and increase the resale value of the home. In order to minimize cost and installation time, the best time to install cabling is when the home is being constructed or when major construction work is being done.

During initial construction, home network infrastructures can easily be "pre-wired" by installing the proper cabling to all rooms at a fraction (1/5) of the cost that would be incurred after construction [6]. The installation of all home network cabling is much the same as installing any other cabling throughout the home. Even though initially, services are not needed in a particular room, it is wise to install the cabling anyway, while installation costs are cheaper. This leaves open the option to upgrade the home network even years after installation is complete.

The network infrastructure would start at a central patch panel and most likely be distributed by a home run, hybrid star/bus topology to “smart jacks” in each participating room. Telephones, televisions, computers, appliances, etc., are then networked together, and have the potential to take full advantage of future vendor networking service offerings.

There are many different types of cabling available to serve as a medium for the services mentioned. Category 5 twisted pair in conjunction with RG 6 coaxial cable are currently the standard and are anticipated to be the standard in new homes for the near future. Category 3 twisted pair corresponds to voice grade quality and can achieve data rates up to 16 Mbps. Category 5 on the other hand, over limited distances and with proper design, can achieve data rates up to 100Mbps [7]. Category 5 twisted pair is readily available today to support industry standard links that include Ethernet standards as defined by IEEE 802.3. RG6 cable is a type of coaxial cable, used typically for carrying video signals, such as CATV signals, DSS signals, and video camera signals in a typical HCS environment. Sometimes RG-59 is substituted for RG-6, but this is not recommended. RG-6 has a thicker center conductor, and a better shield, allowing for better signal quality, better interference immunity, and longer working distances than RG59 [8].

Broadband systems, with either twisted pair or coaxial copper cable, support standard CATV distribution to 77 channels or more. For these applications, copper distribution for the home is extremely economical and provides good performance.

Lucent currently manufactures a hybrid cable that consists of one 4-pair Category 5 cable and two RG6 coaxial cables in a single jacket. Because all cables are in one jacket, only one pull would be needed to each room, this provides a low cost installation.

Fiber is another option that can be used as a medium. The most popular fiber today is 62.5/125-micron multimode; it is the universal standards-based fiber for all LAN applications. It covers all types of data listed above and extends coverage to include 622 Mbps ATM, 1 Gbps Ethernet, and beyond [9]. One drawback today is that multimode fiber is a digital data network medium, not generally used for analog signals like voice. Cost is another factor currently working against fiber in the home, but the price of installed fiber is slowly reaching cost parity. Another drawback to fiber is that every endpoint connecting to fiber must have an optical to electrical converter in addition to transceiver electronics. To provide network reliability, especially for telephone service in times of blackout, battery backups will be needed in the transceivers at all ends of each fiber run in the house.

Taking into account what the future may hold, the broadband capabilities of fiber make it a formidable choice as a medium. It is anticipated that in the distant future, devices such as telephones, televisions, etc. will have the electronics for use with fiber built in (transceiver and converter). Interfaces will only be needed with legacy equipment. Since fiber could support just about all services, it is highly possible that someday, fiber can become the only medium found in the household, replacing twisted pair and coax cabling altogether.

The task of actually installing all of these different mediums is the same as installing any other cabling in the household, except in the case of fiber where care must be taken not to induce any macro bends (sharp bends that cause excessive attenuation) in the fiber cabling during installation.

3.2 Existing Homes

In order for home networking to become truly successful, it must break into the existing (legacy) home market. Installing new cabling as described in the section above is the preferable method of installing a home network in an existing home, but many times this may not be cost effective due to the difficulty of running the additional cabling needed. Fortunately, installing new cabling is not the only available option. There are networking packages currently being offered that will provide infrastructure over existing wiring in the home. Along with using existing twisted pair phone wiring, and coaxial cable TV wiring, technology is available to use existing electrical wiring, and wireless RF technology.

Electrical cabling reaches into every living space in virtually all homes. Companies such as Enikia Corp. and Adaptive Networks, Inc. have developed Powerline transceiver technology that exploits the abundance of existing electrical cabling. High speed Powerline transceivers follow the CEBus (EIA600) standard. This is an open standard that specifies the technology and the parameters for communications using power lines, twisted pair, coaxial cable, wireless and infrared [1]. Many Powerline transceiver manufacturers utilize the CEBus (EIA600) standard. CEBus Powerline Carrier uses spread spectrum technology to overcome communication impediments found within the home's electrical powerline. Spread spectrum-signaling works by spreading a transmitted signal over a range of frequencies, rather than using a single frequency. The CEBus Powerline Carrier spreads its signal over a range from 100Hz to 400Hz during each bit in the packet. However, instead of using frequency hopping or direct sequence spreading, CEBus Powerline Carrier sweeps through a range of frequencies as it is transmitted [10].

Using CEBus spread spectrum technology, Powerline Ethernet transceivers currently operate at 10Mbps [11]. But in the near future, throughput is expected to reach 100Mbps. The transceivers can adapt to standard off the shelf Ethernet controllers' [12]. Silicon chips embedded in each device connected to the powerline transmit and receive data, making it possible to easily establish networks to communicate with everything plugged into the line, from personal computers and cash registers to utility metering equipment, and vending machines [13].

Another alternative medium for use in existing homes is short-range wireless technology. Wireless technology can provide high speed, low cost digital RF radio that allows for robust, real-time wireless communication. Wireless technology can utilize a number of different standards that are available. IEEE 802.11, BRAN (Broadband Radio Access Network), SWAP (Shared Wireless Access Protocol) and Bluetooth can achieve data rates of up to 1.6-54Mbps, 1.152Mbps, 2Mbps and 1Mbps respectively. One company, ShareWave Inc., claims it's technology is designed specifically to enable home networks to address virtually all consumer needs for performance, reliability, scalability, upgradeability, interoperability, security, and ease of use [14]. Such technologies provide good throughput; however, the effectiveness can vary, depending on the size of the house, the proximity of other wireless networks, and other sources of noise. Security is also a major concern with this type of medium.

Finally, existing cabling in the home such as Category 3 twisted pair and RG59 coax can be utilized to provide reasonable throughput. Since the cabling is already installed in the home, the cost of utilization would be little if any.

Figure 4 Illustrates the projected number of home networked households in the United States and the technology utilized. It is expected that the number of home networked households will increase to over 6 million in the year 2003 from 600 thousand in 1999.

Home-networked households in the United States, in thousands

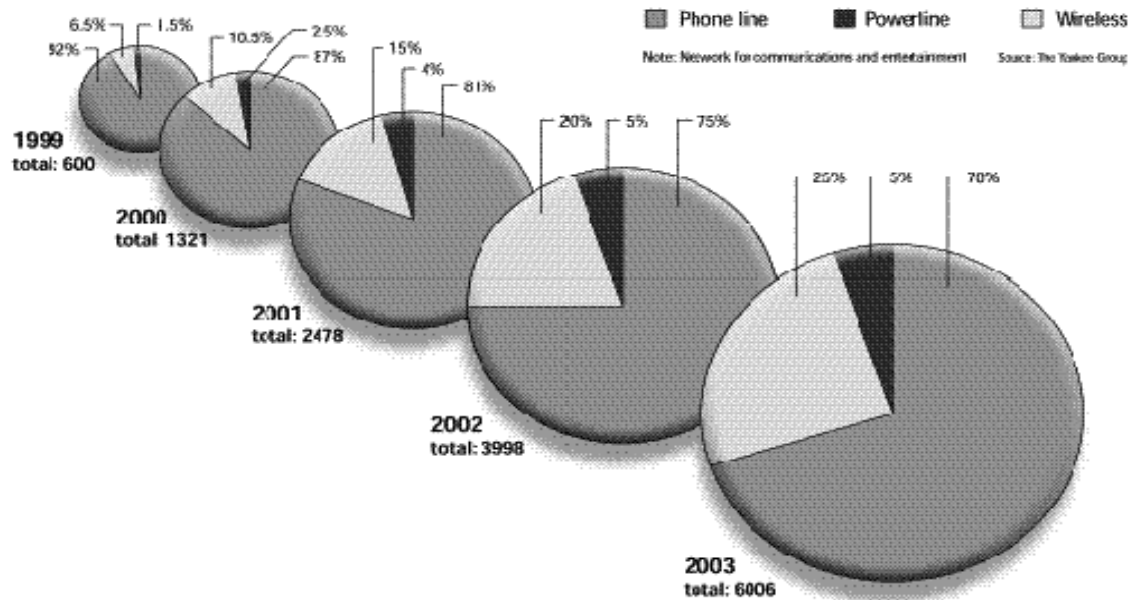


Figure 4: Projected home networked households Source: the yankee group

These alternative methods would most likely be the only choices for people living in apartments and condominiums and some homes where cabling would not be very practical. However, enough bandwidth can be provided for present and future services using these methods.

4. Home Infrastructure Topology

For the home infrastructure wiring, there are two key wiring topologies available; a bus topology and a star or home run topology. Important factors to consider when selecting a topology for a home infrastructure include the affect on bandwidth availability, ease of troubleshooting, and resistance to failure. The EIA/TIA has defined the bus and star in their wiring standards.

In a bus topology, the wiring or cabling is serially connected from one room to the next, as shown in Figure 5. The main connection to the signal source is at the Distribution Center, where the telecommunications service provider's high-speed connection would terminate into the home.

In a bus topology, the total bandwidth is shared among all connection points. This means that as each user accesses the home network from various connection points, the bandwidth availability of the home network decreases for each user.

Another characteristic of the bus topology is the susceptibility to failure. If the wiring between any two rooms is broken, all connection points beyond the point of failure will not be functional. If the point of failure is close to the distribution center, a particular home network element may be rendered completely unusable. In a complex bus topology, it is often difficult to determine where the fault lies along the bus.

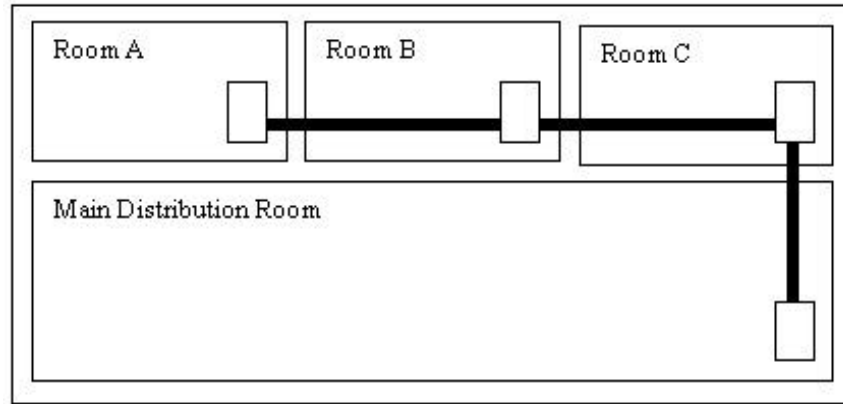


Figure 5: Bus Topology

In a star topology, each connection point in a room has a dedicated connection to the Distribution Center as shown in Figure 6. This layout has several advantages over the bus topology. First, the total bandwidth that is delivered to the Distribution Center is also delivered to each connection point and not shared with the connection points in other rooms when using a switched hub in the Distribution Center. As a result, a user in room A wishing to utilize the home network will have the same availability to the network as the user in room B that may already be accessing the same service. Neither user will experience a decrease in availability.

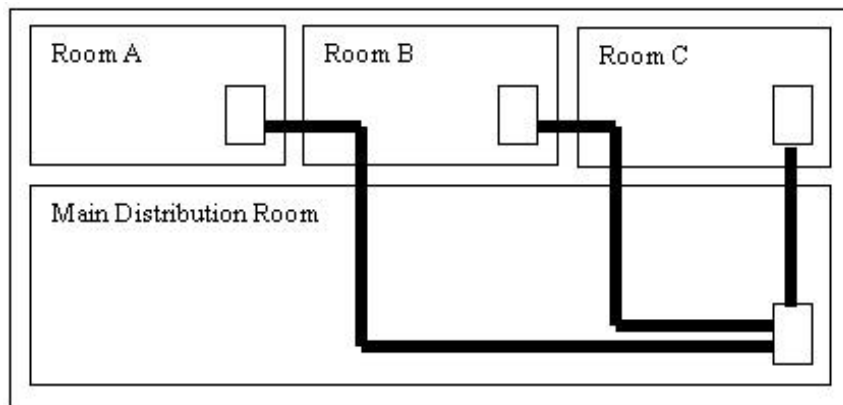


Figure 6: Star Topology

The star topology also makes the home network less susceptible to failure. If the connection point in any particular room is not working, the rest of the network is unaffected. In this case, troubleshooting is much less time consuming and less complicated than when using the bus topology.

Another option is using a hybrid topology; which would be some combination of the bus and star topologies. A hybrid topology might be used when a long cable run is required to deliver access to a connection point in a room that is located furthest from the Distribution Center. In this case, the consumer may want to “daisy-chain” the cable to multiple connection points in the

same room to save on the cost of multiple long cable runs. Although a pure star topology is most desirable, a combination of the star and bus topologies may be the most cost efficient solution.

Availability of dedicated bandwidth to each connection point coupled with the higher resistance to overall network failure makes the star topology most desirable. However, where cost and ease dictate, a hybrid topology can effectively be utilized.

5. Outlet and Jack Interfaces

Another home networking aspect to consider is what kind of interfaces a typical “jack” might have. Today, consumers are familiar with typical phone jacks that provides phone service, and typical coaxial cable jacks that provides cable TV service. In the future, vendors and service providers will have to decide on what kind of cabling they will support and what kind of jack they will put on a typical faceplate. Many vendors are proposing a jack that would provide connectivity to many different types of services. The most popular services include phone (RJ-11), cable (female F), distributing direct broadcast satellite (female F) to many rooms, audio (banana plug), and data service (RJ-45). RJ45 is the standard used for computer networks. Many Home Automation devices also use it. RJ11 is the standard used for residential phones lines. RJ11 connectors are smaller than RJ45 jacks and work when plugged into RJ45 jacks. Most RJ11 connectors have only four wires. Most RJ45 connectors have eight wires. RJ11 usually only supports two telephone lines. The most common used wiring standards are T568A for RJ45 and 6x4 Quad for RJ11 [15].

The exact configuration varies from vendor to vendor, but a typical layout is shown in Figure 7.

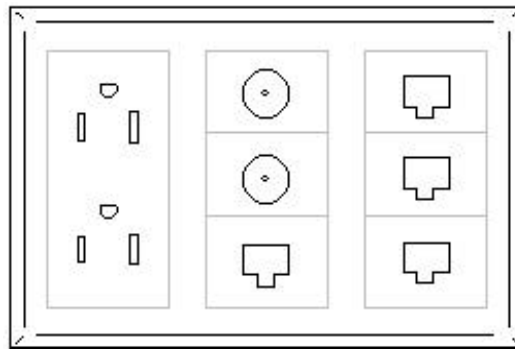


Figure 7 – Outlet and Jack Interface

As the figure indicates, there would be power outlets, interfaces for telephones, coaxial cable, and data connections. The connections from the phone, cable or satellite, and high-speed data access service providers should all terminate into the Distribution Center and each room would have the appropriate interfaces on its jacks to support the required service for that particular room. Also, the Distribution Center should accommodate flexible wiring schemes when service requirements of one room change.

Other services such as home security do not need an interface on the jack and will most likely be hard-wired in the home since surveillance cameras usually are not moved once installed. For

home networks, the “jack” will have to support more than just phone service. One room may have a TV, computer, and telephone, while another room may have a computer, telephone, and an audio application. A jack that has all these types of connections should be able to accommodate each user’s needs and the change in these needs as time goes on.

6. Infrastructure Vendors

The home networking market shows great potential and has already caught the eye of Corporate America. Many vendors, such as IBM, Lucent and AMP, currently have wiring packages readily available for installers and homebuilders to deploy. The vendor’s sales pitch is based on the idea that networking your home will take full advantage of current and future service offerings and increase the resale value of your home. These systems are explored below to show the available features and show product trends.

6.1 Lucent Technologies HomeStar® Wiring System

Lucent Technologies has a home network product offering called HomeStar® which is a family of in-home network products designed to support the networking needs of the modern family. The Lucent system is comprised of a residential distribution center cabinet called the “Service Center”, service distribution modules, a star-wired topology, structured wiring system and an array of different outlets to terminate cabling. This product is fully scalable to accommodate the smallest to largest user.

The star-wired cabling consists of two RG-6 coaxial cables and one Category 5 4-pair modular cable. One coaxial cable is used for broadband video input from external sources such as CATV, and the other is used for internal video sources such as DVD/VCR playback. The CAT-5 cable can be used for either telephone or LAN applications.

The HomeStar® system offers a choice of many different outlet configurations. These are dependent on what was made available at the wall in terms of cabling. Lucent outlets are comprised of a universal, telecom/data, telecom and specialized outlet. The universal outlet is the most common outlet consisting of two coaxial F-type connectors, and one modular 8-position jack. The telecom/data outlet consists of one, two or three modular 8-position jacks for twisted pair cabling only. The telecom outlet is used to mount a telephone to a single gang box in the wall. The specialized outlets can be made to host any combination of CAT-5 or coaxial cable configurations [3].

6.2 OnQ® Structured Wiring System and Home Management System

AMP is another corporation that has invested in this emerging market. Their product is called OnQ®, and is very similar to the Lucent product. The OnQ® system is comprised of a residential distribution center cabinet, service distribution modules, a star-wired topology, structured wiring system and an array of different outlets to terminate cabling. The OnQ® system provides home automation functionality that allows the end-user to program or personalize the lighting, HVAC, Security System, etc. This product is fully scalable to accommodate the smallest to largest user.

The OnQ® enclosure houses numerous service modules that are used to distribute the different services that the end user chooses. These are the telecom, video, audio and LAN modules.

The OnQ[®] star-wired cabling consists of RG-6 coaxial cables, Category 5 4-pair modular cables and 18 gauge speaker cables. The coaxial cable is used for CATV, and Satellite signals. The CAT-5 cable can be used for either telephone or data signals. The 18-gauge wiring is used for audio signals.

The OnQ[®] cabling terminates into various OnQ[®] outlets that are provided as kits. The outlets contain a Female F Connector, modular RJ-45 jack, keyed modular RJ-45 jack, and binding post/banana jack. The F connector is used with video signals. The modular RJ-45 jack is used with telephony devices such as telephones, modems or fax machines. The keyed modular RJ-45 jack is used with digital data associated with ISDN, DSL or 10BASE-T LAN. The binding post/banana jack is used for speaker connections. The outlets are specialized per use and per what cabling is associated with the outlet. These are fully customized to fill any configuration [4].

6.3 IBM Home Director[®] System

IBM has a product offering which is similar to the two previous products called the IBM Home Director[®]. IBM is focused not on the structured wiring infrastructure or terminating outlets, but on the centralized distribution center.

The centralized distribution center is referred to as the Home Director[®], and is offered in a one-size scalable enclosure located at the center of the wiring structure. Interior to this enclosure is the centralized location of different service distribution modules. These are telecom, video and LAN service modules.

The structured wiring scheme is the same star-wired topology with RG6 coax for video applications and CAT-5 for LAN and telephony applications. The telecom module distributes telephone service and high-speed digital data such as ISDN and ADSL. The video module distributes television signals from antenna, CATV and Satellite sources. The video modules also support two way transmission that allows the cable companies to offer high speed digital data services such as Cable Modem service. The LAN module serves as 10BASE-T hub for distributing or sharing computer resources such as files or printers between computers.

The Home Director[®] star-wired cabling consists of RG-6 coaxial cables and CAT-5 4-pair modular cables. The coaxial cable is used for CATV, Satellite and modulator signals. The CAT-5 cable can be used for either telephone or data signals [4].

7. Summary

A homeowner building a new house or renovating an older home has reason to be concerned about the wiring infrastructure in his or her home. Today's computers, audio, video, lighting, telecommunications, and security systems require more sophisticated wiring than ever before. The homeowner or homebuilder can realize tremendous benefits by wiring a home to accommodate today's devices and tomorrow's smart appliances [16].

When selecting a design for a home's infrastructure, the homebuilder or homeowner must consider all elements of the infrastructure; the distribution center, service modules, cabling and wiring, and the outlet and jack interfaces. The elements of the infrastructure are best arranged in a star topology. This arrangement will maximize the user's bandwidth availability, ease of troubleshooting, and resistance to failure. At the core of the star-wired home infrastructure lies a Distribution Center and service modules which work together to share and distribute services over

the home network. The Distribution Center and service modules can be built to accommodate all of the cabling and wiring needed to support both current and future home networking technologies.

The installation of cabling and wiring within the home may vary with the situation each home presents to installing the medium. However, despite any installation issues, a home network will maximize the industry standard link capabilities if the home is furnished with Category 5 twisted pair and RG6 coaxial cable to each connection point within the home. Fiber can also provide support to a home network. However, the consumer must be aware that there are a variety of drawbacks when using fiber. Other alternatives include wireless RF technology and Powerline networking. These technologies should be considered if the twisted pair or coaxial cable networking is not feasible. Depending on the home infrastructure technology deployed to support the home network, outlet and jack interfaces can be created as needed at each connection point.

Proper installation of a home's infrastructure will allow the consumer to make limited or full use of a home network with the ability to incorporate changes in device protocols in the future. The consumer can have distributed video and audio for more convenient and compelling entertainment; easier and more powerful ways to share data from home computers; energy savings via access to utility pricing signals; convenient access from the home to a host of services, from banks to stores to maintenance; whole house control; and much more.

8. References

- [1] Amitave Dutta-Roy, "Networks for Homes", IEEE Spectrum Magazine, December 1999
- [2] Smith, Jerd, "The Hot-Wired House", *Rocky Mountain News – Mile HighTech*, June 8, 1998.
- [3] AMP Incorporated. "OnQ Structured Wiring System and OnQ HMS Home Management System". AMP Publication 889122. Release 2. August 1997.
- [4] Lucent Technologies, "HomeStar® Wiring System Overview".
<http://www.lucent.com/networks/homestar/techdescription.doc>
- [5] International Business Machines Corporation. "The Home Network Connection Center".
<ftp://ftp.pc.ibm.com/pub/special/haze/hdhncc.pdf>
- [6] Lucent Technologies, "Cable to Connect Communications in the Sophisticated Home of Today and Tomorrow" Jan. 1, 1998
- [7] Future Smart Networks, "Benefits and Cost Comparisons", www.futuresmart.com
- [8] William Stallings, "Data and Computer Communications 5th edition", Prentice Hall ©1997
- [9] Brian Karas, "Home Cabling Systems Part 1, The Basics" Home Toys Magazine, October 1998
- [10] Lucent Technologies, "Optical Fiber for Residential Customers and the HomeStar Wiring System" Feb. 20, 1997
- [11] CEBus Industry Council Inc., "Powerline Carrier Overview", www.cebus.org

- [12] Enikia Corp., “10Mbps Powerline transceivers”, www.Enikia.com
- [13] Adaptive Networks, “High Speed Powerline Communications for Home Networking Now Possible”, January 19, 1999
- [14] ShareWave Inc., “www.sharewave.com/Home_Net/Solution/solution.html”
- [15] Doug Moses, “Low-Voltage Wiring (Telephones)”, Home Toys Magazine, February 1998
- [16] Greengard, Samuel, “Down to the Wire”, *Source Home Economics*, March 1998.