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Home Networking Using Phoneline Wiring

Until recently, home networks depended on special cables (typically requiring professional installation) to link PCs, audio-video equipment and peripheral devices together, which could be expensive and problematic if the hardware components were in different rooms of the house. Thanks to recent technological developments, consumers can use their already installed telephone wiring systems to link multiple computers and digital appliances around the house. This article examines the key phoneline technology that promise to deliver the holy grail of home networks without the need to run hundreds of meters of new data cables inside the walls of households.

HOME NETWORKING CHALLENGES

Home networking is the group of technologies that provide the ability to distribute data, voice and video between information appliances in the home. This allows several appliances to share resources and a common broadband access.

Commercial networks are designed primarily to carry data between computers. They typically use fiber optic, twisted pair or coaxial cables to minimize noise and interference on the network. Most homes do not have dedicated high-speed network cabling installed and the labor costs required to install such wiring is too high for homeowners to fund on their own. For home networking to be successful, solutions must exist that utilize existing wiring infrastructures. Thus, the challenge for companies who are creating technologies for networking our homes need to be based on the following criteria:

- The technology needs to leverage existing wiring infrastructure (phonelines and powerlines)
- It needs to be easy to install and maintain
- To reduce complexity the technology needs to use existing standards and software platforms
- It needs to include a quality of service (QoS) mechanism that provides low latency for telephony and other voice applications
- Data rates more than 10 Mbps need to be supported to allow consumers distribute live video around their homes.
- Needs to be relatively cheap and more importantly the technology needs to provide a level of security

One of the main requirements for mass proliferation of home networks is the ability of homeowners to utilize existing wiring infrastructure in their homes. Reuse of the phoneline wiring infrastructure has become the dominant 'no new wires' home networking technologies. The remaining part of this chapter explores the issues and technologies associated with these new and emerging technologies.

ABOUT PHONELINE BASED HOME NETWORKS

Home networking using phonelines connects consumer devices such as PCs, TVs, DVD and MP3 players to each other and to the Internet using regular phone jacks. There are however several issues that need to be addressed before the success of phoneline-based home networking systems is guaranteed. These include:

- Random Wiring Topologies: Rather than the hub structure of business networks, the home phoneline wiring system is a random "tree," and something as simple as plugging in a telephone or disconnecting a fax machine changes the tree structure.
- Signal Attenuation: The random tree network topology of phone-line wiring system can cause signal attenuation. In simple terms, attenuation means a reduction of signal strength during transmission of data across the home network. The attenuation on a phone-line network is normally caused by open plugs and not terminated appliances.
- Signal Noise: Appliances, heaters, air conditioners, consumer appliances and telephones can introduce unwanted signal noise onto the phone wires.
- Consistency in Service Levels: The network must be able to function reliably and deliver consistent service levels despite changes that result from someone picking up the phone, accessing a Web site, or an answering machine recording a message.
- Jacks: Phone jacks are not found everywhere in the home. US households tend to have multiple phone jacks, while households in other countries, particularly Europe, are often limited to one or two phone jacks. In addition, the physical location of those jacks with respect to the devices that need to be networked is another problem.

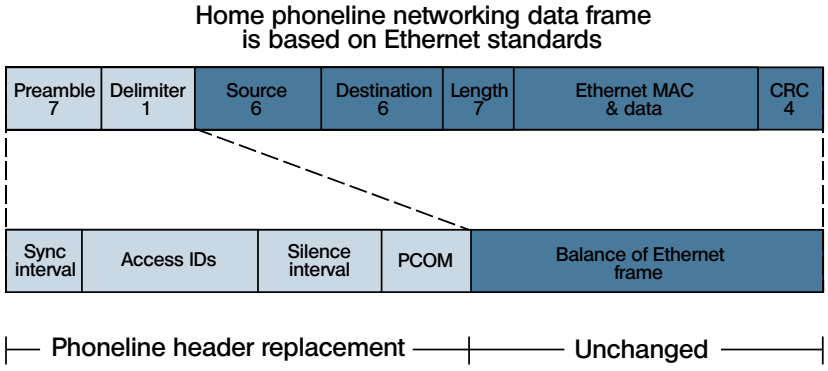

Figure 1. HomePNA Data Frame (Leveraging Ethernet Technology).

HOMEPNA (HOME PHONE-LINE NETWORKING ALLIANCE)

The HomePNA is a consortium of more than 130 companies seeking to develop specifications for interoperable, home networked devices using existing phone wiring. It was established to define standards and technologies that will overcome these technical issues. The group created a de facto industry standard when it published an easy-to-use, cost-effective and proven 1Mbps home phoneline networking technology as its 1.0 specification. The technology allows PCs, peripherals and other consumer devices to connect with each other and the Internet without interrupting standard telephone service. This is by utilizing existing telephone wiring requires no costly or disruptive rewiring of the home. HomePNA announced its first step in the development of its second-generation home phone-line networking technology (HPNA 2.0). Last year the organization announced the completion and release of its much-anticipated second-generation home phone-line networking technology. The new specification brings a faster 10Mbps technology to phone-line networking, while at the same time maintaining backward compatibility with HPNA 1.0 technology. The new technology uses selective portions of the 2-30MHz frequency band to achieve these data rates. In addition to increasing data speeds within the home, HomePNA is working to incorporate their technologies into a range of electronic appliances including: PC's, ADSL modems, cable modems, digital televisions, set-top boxes and IP based Web phones. Lets examine each component of a HPNA based network and see how they work together.

HOMEPNA 2.0 TECHNICAL ARCHITECTURE

HPNA has come to be known as the de facto industry standard for telephone based home networking. It is a robust technology that can achieve data rates up to 32Mbps in approximately the same bandwidth as the HPNA 1.0 system and be forward compatible with future appliances operating at speeds up to 100Mbps. It supports up to 500 feet of phone wire between devices connected to RJ-11 jacks. The following key components make up a phone-line based home network.

1. Network transport technologies

Leveraging Ethernet Technology: Home phoneline networking technology uses standard Ethernet technology, adapting it where necessary to overcome the challenges presented by the home phone-line environment. It includes standard IEEE 802.3 compliant Media Access Control (MAC) and CSMA/CD (Carrier Sense Multiple Access/Collision Detect) as the access method for sharing the base-band signal on the home network bus. Under the Ethernet standard, information is bundled into a package called a frame. Figure 1 depicts the home phone-line networking data frame.

Data originating from applications within an information appliance connected to a home network is formed into standard 802.3 Ethernet data frames, and is passed to the phone-line physical layer (PHY). The PHY circuitry then strips off the first 8 octets of the Ethernet frame (the preamble and delimiter fields), and replaces it with a PHY header designed specifically for the rigors of phone-line networking. At the receiver, the reverse process is executed. This approach enables home phone-line networking to leverage the tremendous amount of Ethernet-compatible software that exists today while meeting the needs of the home environment.

Spectral Compatibility: An additional requirement of home phoneline networking is the coexistence of multiple services on a single piece of telephone wire. For example, members of the household will need to make telephone calls, while other members of the family may be using the home network for data transfer purposes. A common method for simultaneously operating multiple data and voice services over a single pair of wires is multiplexing. Multiplexing is a technical term used to describe the combination of multiple signals (analog or digital) for transmission over a single line or media. There are a number of different multiplexing techniques used to combine different types of signals. HomePNA decided to use a technique called Frequency Division Multiplexing (FDM). This multiplexing technique assigns each communications service a frequency spectrum that is different from all others.

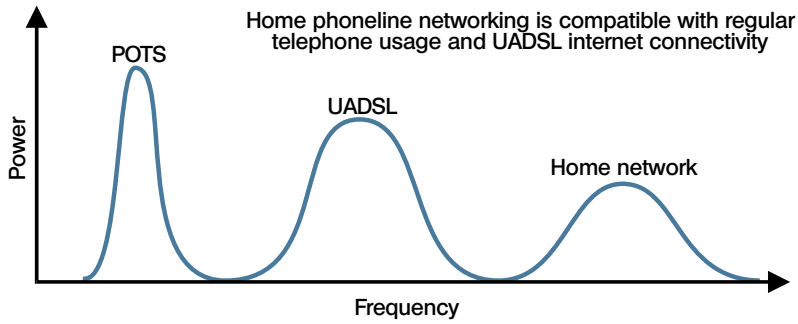

Figure 2. HomePNA Spectral Usage (Spectral Coexistence).

Through the use of frequency-selective filters, devices using one type of service can exchange information without interference from other services that communicate in another frequency band. A filter is a device that contains a pattern through which data is passed. Only data that matches the pattern is allowed to pass through the filter. The home network operates in the frequency range between 5.5MHz and 9.5MHz, voice communications operate in 20Hz - 3.4kHz, and UADSL services occupy 25kHz - 1.1MHz. Figure 2 depicts the spectral usage of three services that can share home phone wiring. POTS, UADSL (universal asynchronous DSL) Internet connectivity, and home phone-line networking share the same line by operating at different frequencies.

High Performance Encoding: Home phoneline networking technology uses time modulation line coding method to increase the data throughput and allow reliable transmission of data over the unknown cabling system of home phone wiring. It incorporates an adaptive circuit, which can dynamically correct for varying environmental conditions characteristic of residential phonelines. Both, the transmit and receive circuits continually monitor line conditions and adjust settings accordingly. The receiver circuit of the PHY layer adapts to the varying noise levels on the wire while the transmitting circuit is adapting output signal strength to match requirements of other receivers. The 'Squelch' algorithm sets the minimum and maximum signal levels. The receiver can filter out extraneous noise that otherwise might compromise data transmission and reception.

2. Wiring

The Ethernet technology found in corporate office environments was originally designed to support four types of wiring systems - thick coaxial cable, thin coaxial cable, unshielded twisted pair and fiber-optic cable.

Since these types of expensive cabling systems are not available in most homes, HPNA decided to leverage existing infrastructure provided by phone wire inside the home. The use of the phone wiring system means that every RJ-11 modular jack (a standard phoneline connector) in the house becomes a port on the home network as well as a phone extension. Each appliance that forms part of the home network is known as a node.

3. Network Interface Cards

All the appliances on a HomePNA based home network need an adapter to control the I/O to the home network. The network interface card (NIC) acts as the physical interface between the appliance and the telephone cable. Without the card, digital appliances would be unable to connect to the network or each other. Network cards are typically connected to each computer or information appliance via an interface slot.

After the card has been installed, the telephone cable is attached to the card's port. Once this connection is made, the computer is physically linked to the home network. All network cards are equipped with onboard microprocessors. The microprocessor is the central point from which the card's various functions are coordinated. The roles of the network card are to:

- Prepare data for transmission
- Send data across the in-house network
- Store data prior to transmission
- Control the flow of data between the digital appliance and the transmission medium

The NIC also acts as a translator. When receiving data, it translates electrical signals from the telephone cable into bytes that the processor in the digital appliance can understand. And when transmitting data, it translates the computer's digital signals into electrical pulses that the telephone cable can carry. HomePNA cards contain the necessary hardware and software routines that are stored in read-only memory that allow you to create a home network using the existing in-home phone wiring system. Some HomePNA certified adapters come with connectors known as RJ-45. These interfaces are slightly wider than RJ-11 connectors and can be used to connect into a sophisticated data wiring system.

4. Software (Operating Systems (OS))

As mentioned previously, every device on a home network needs an OS with networking capabilities. Once a NIC is installed, a driver is required to communicate with other appliances on the network. It is also very important that the driver is configured correctly. If the driver communicates commands to the network card quickly and clearly, the card will operate efficiently. If the card is not configured correctly by the driver, the card will perform less effectively. This will slow up net-

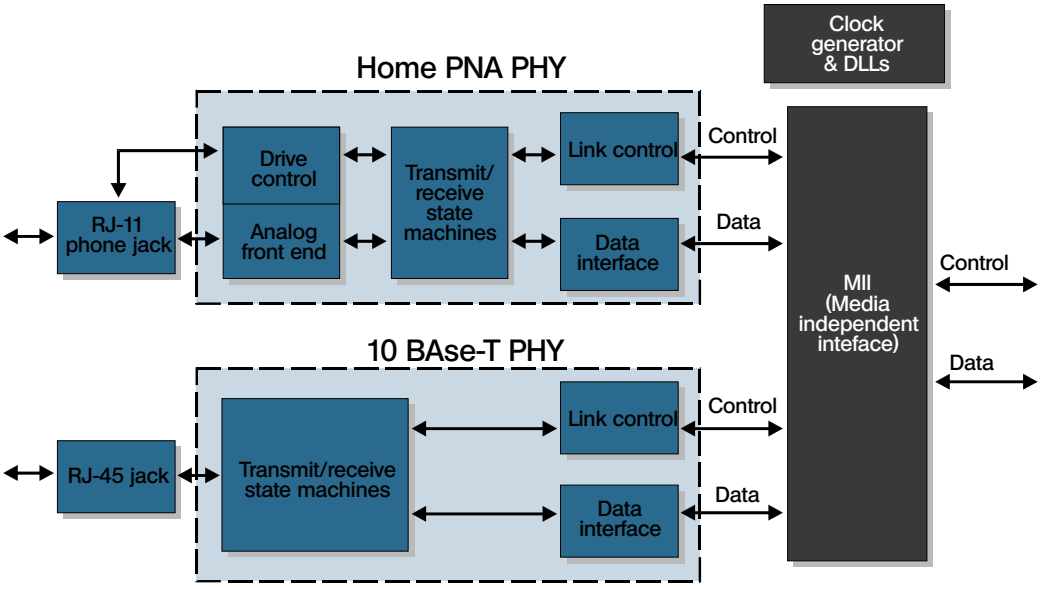

Figure 3. HomePNA and Ethernet PHY Layer.

work performance as a whole. HomePNA has decided to use the NDIS (Network Driver Interface Specification) driver model that is integrated with most of the Microsoft Windows OS.

NDIS provides the consumer with a simplified plug-in driver architecture. At the lowest boundary layer NDIS contains a driver that is specific to the telephone wiring transmission medium. The layer above this contains a platform independent driver called a miniport. This layer interfaces through a standard Application Programming Interface (API) to the NDIS layer and this layer in turn communicates with the transport protocols that are running across your home network. A major advantage of the NDIS software model is that network cards can be installed in a telephone based home network without requiring a truck roll from your local service provider.

KEY FEATURES OF HOMEPNA

- **Leverages Existing Standards**: The importance of leveraging standards cannot be overestimated. Given the popularity of IEEE-802.3 Layer 2 networking across the Internet infrastructure, HPNA has chosen a technology that uses 802.3 framing and Ethernet behavior.
- **Quality of Service (QoS)**: The initial motivation for home networking is sharing resources among multiple PCs such as Internet access, files, and printers. However, the ultimate applications that will dominate home networks are the transport of digital audio, digital video, and digital voice (IP telephony). Latency in voice connections must be controlled below 10 to 20 ms on the home network segment if voice quality is to be maintained. Streaming video and audio connections must receive an application-determined minimum bandwidth from the network. Although the aggregate throughput rate of 10Mbps for HPNA 2.0 is more than adequate for many application scenarios, burst loads presented by TCP transfers between PCs, without some QoS mechanism, would at times make the network unable to meet the latency and guaranteed bandwidth service requirements. Furthermore, bandwidth allocation within a given class of service should be fair. The traditional Ethernet MAC 2 layer exhibits a phenomenon known as packet capture, which can result in long access latency distributions. The HPNA 2.0 MAC layer introduces eight priority levels and an improved collision resolution technique that eliminates packet capture.
- **Robustness**: The primary difference between twisted-pair Ethernet and other technologies is the qual-

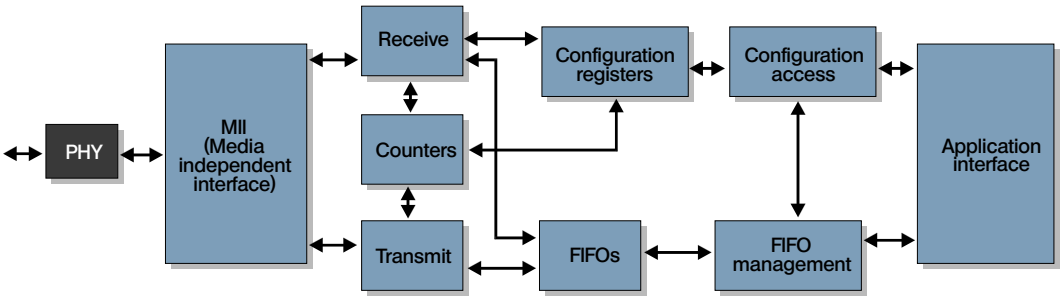

Figure 4. HomePNA and Ethernet MAC Layer.

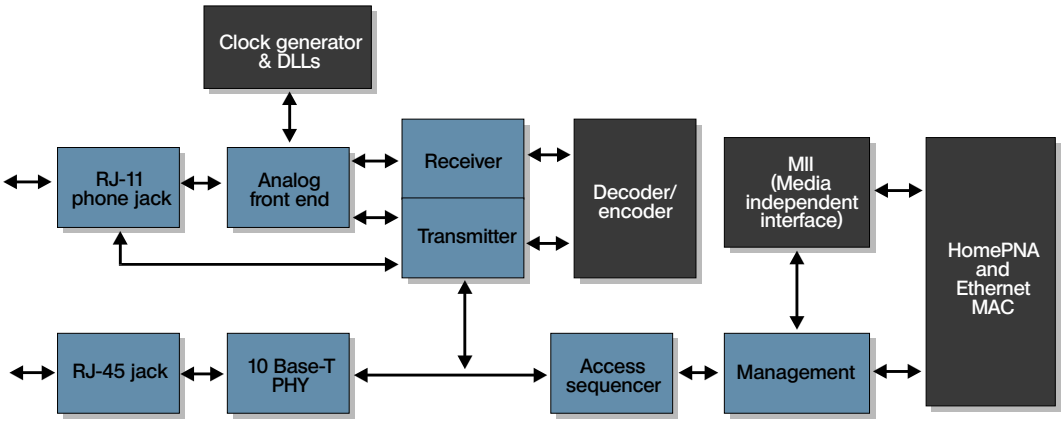

Figure 5. HomePNA PHY and MAC Layers.

ity of the communications channel. Running over Category-5 cable, Ethernet encounters a channel that has a number of very nice properties. They include point-to-point communication, proper termination, a well-characterized channel response and very low cross talk. In contrast, all of the no-new-wires media available for networking within homes have the problem that the communications channel can be severely impaired. HomePNA has developed a robust suite of technologies that are capable of overcoming the challenges associated with networking appliances on a typical in-home phone wiring system.

- **Performance**: History has taught us that higher network speeds are always better. In the context of a home networking environment several external influences persuade us that we require at least 10 Mbps. The common broadband access technologies such as ADSL and the DOCSIS cable modems require home net-works with data rates of 6 Mbps or more to share the access bandwidth. Moreover, applications such as multiple DVD streams or high-definition digital video make it easy to imagine that even 10 Mbps isn't enough. Therefore, the alliance designed the HPNA 2.0 system to achieve data rates above 10 Mbps in approximately the same bandwidth as the HPNA 1.0 system.
- **Future Proof**: Once installed, home networks are likely to remain in place for many years. Worse yet, as home network interfaces become embedded in appliances, it may become almost impossible to replace them. Thus, a good home-net-working technology ideally has built into the current generation a plan for interoperability with future generations.

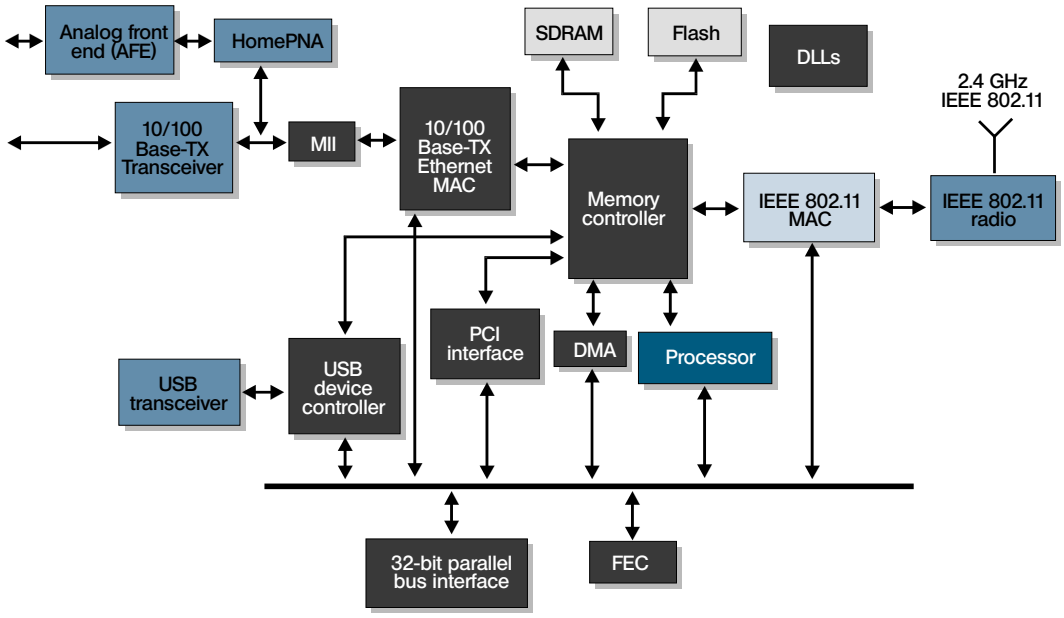

Figure 6. Spartan-II FPGAs Enable (HPNA to Wireless LAN) Technology Bridges..

HomePNA has been designed to be forward compatible with future stations operating at speeds up to 100 Mbps.

- **Security**: HomePNA provides excellent security. This is because each home has a unique phone circuit (phone number) from the phone company's central office.
- **Cost**: Finally, there is the issue of implementation cost and complexity. As has become very well understood over the last ten years by the computer and networking industries, volume is everything. With decreasing prices for computer equipment-especially for the home-a successful home-networking technology must be inexpensive. A typical HomePNA card will cost you around $100.

HOMEPNA 2.0 PRODUCT RANGE

Some of the products that will use HPNA 2.0 technology are:

- PCs and PC peripherals (printers, scanners)
- Broadband access devices - digital modems (cable, xDSL, satellite)
- Network hubs
- IP telephones
- Digital TVs and set-top boxes
- Home security and automation
- Network (Internet) appliances

MARKET OUTLOOK FOR PHONE-LINE HOME NETWORKING

With over 400 million email messages sent just last year, home networking comes at the thrust of the Internet's popularity. According to a recent IDC report, there is upside short-term and long-term growth predictions for phone-line home networking. The analyst group predicts that by 2004, phone-line technologies will account for 72% of the total home networking market's installed base.

XILINX SOLUTIONS FOR PHONELINE HOME NETWORKS

Figures 3, 4 and 5 show the PHY and MAC layers of the HomePNA. Xilinx Spartan-II FPGAs provide low cost HomePNA functionality in consumer products and provide an interface from HomePNA to other home networking technologies. While most ASSPs interface to a couple of popular interfaces only, programmable solutions enable connectivity to multiple interfaces such as USB 2.0, wireless LANs, Bluetooth, HomeRF, IEEE 1394, Ethernet, etc. Programmable logic in the systems allows the manufacturers to future proof their solution. Shown in figure 6, low-cost Xilinx Spartan-II FPGAs provide bridges to multiple disparate technologies.

Conflicting specifications and lack of a clear direction create the need for FPGA-based technology bridges. It is also quite likely that some of these conflicts may never get resolved. It would be nearly impossible and cost-prohibitive for a supplier of home networking products to cater to all the various specifications and changing needs. At the same time betting on the success of one single product may preclude them from being successful in the marketplace. In the technology bridge example, Xilinx Spartan-II FPGAs are at the heart of the technology bridges, which usually connect unlike technologies - such as wireless LANs to HomePNA. With the HomePNA, IEEE 802.11a and HiperLAN2 specifications still not defined, it seems ideal for the MAC and MII (media independent interface) to be programmed in an FPGA.

SUMMARY

Home networking is not a growing reality with a promise to penetrate homes and SOHOs in large volumes. Being a cost sensitive and evolving market, HomePNA products require low-cost programmable logic solutions. Programmable logic solutions allow customers to realize time-to-market and time-in-market advantages. Spartan-II FPGAs with increased densities, system-level features, an extensive IP portfolio and low costs, provide an ideal solution for consumer products, which will be HomePNA enabled. Spartan-II FPGAs provide interoperability between different technologies, which is essential for the success of this market ■

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