THE POWERLINE AS THE HIGH-SPEED BACKBONE OF A HOME NETWORK

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The powerline is inherently the most attractive medium for home networking due to its universal existence in homes, the ubiquity of outlets and the simplicity of the power plug. In comparison, the phone line suffers from too few connection points and wireless from congestion at 2.4 Ghz as well as interference. As such, there is great potential for the powerline to act as the backbone for the full range of home networking applications provided that the powerline is reliable, secure and robust enough to meet the needs of the most demanding applications without compromise. However, the powerline is a noisy and erratic medium presenting a difficult problem to solve for home networking pioneers. Furthermore, without properly considering the current and future application needs of a home network, an approach to solving this problem may be doomed to failure by not taking into consideration the critical factors for delivering a true home network backbone.

DETERMINING KEY REQUIREMENTS

Attempting to solve the problems of powerline home networking requires a careful assessment of how home networks will be used. To date, technophiles and early adopters have mainly driven the market for home networking because of their need to access a variety of applications, including Internet communications, electronic commerce, and telecommuting through a network. Typically, these early adopters have had the financial and technical capabilities, not to mention the patience, required to purchase, install and operate a home network.

Broad penetration of the home network into the mainstream consumer market has had limited success due to a lack of understanding of the benefits of a home network, and the relatively high barriers when choosing, purchasing, installing, and managing a home network. Because the home networking market has not grown as rapidly as first estimates predicted, manufacturers are adapting and changing their consumer offerings to be more appealing, accessible, and understandable. Specifically, the industry is shifting its focus from PC-centric productivity applications to compelling applications that enhance a consumer's lifestyle at home such as entertainment, Internet surfing, and telephony. Parks Associates' Broadband Access@Home survey indicates that 47% of consumers are interested in a device that streams music from a PC to a stereo system. Such applications require the transmission of large multimedia files that require reliable high-speed network access.

The applications expected to drive home networking into the mainstream will no longer be just PC centric but will comprise a much larger entertainment component that is CE centric. The requirements of these various applications have different levels of demand on the network and consequently the backbone must be all things to all applications. It must simultaneously provide high bandwidth and be extremely versatile and robust. For streaming audio and video, it must be an open data pipe, like the passing lane on the Autobahn, with a clear path and no other traffic. To all applications, ***every*** electrical outlet in the home must be an interface to the network at all times. To all OEMs, the price must low enough to enhance the sales of their host products or systems.

QOS WITHOUT COMPROMISE™

Once we understand where the world is going, we can focus on the requirements with the highest common denominators and the most overarching impact on a powerline home network design. One of the more critical requirements for designing a home network is the ability to serve ALL types of applications, including IT, entertainment, telephony and control/automation. In particular, the requirements for multimedia entertainment (streaming audio & video) and telephony heavily determine the approach required in terms of QoS (Quality of Service). The challenge has been to overcome the hostile powerline environment to maximize the consumer experience with:

- high speeds for multimedia applications
- true, continuous, and non-bandwidth limiting multicast and broadcast support, for instance, for Universal Plug-n-Play and audio/video stream-casts
- prioritization of the network for quality audio, video and voice transmission
- multiple node connectivity and scalability in a wide variety of homes

while ensuring :

- low latency
- low application jitter
- low cost of commercialization
- compliance with FCC power emission regulations

These key requirements for a home network backbone must be weighed against the harsh reality of the home powerline environment. The fundamental technical approach taken to arrive at a viable solution must not cut corners or impose compromises in order to achieve the consumer application cost targets. If the solution does not address all of the requirements for the home network backbone, it will not be successful.

TAMING THE BEAST

Recently Adaptive Networks became the **first and only** company to properly satisfy these requirements by “cracking the powerline code”--with comfort and room to spare. Adaptive Network's patented approach uses adaptive equalization at the receiver permitting dynamic adaptation to the inconsistencies of a powerline. Equalization in this case is very similar to the equalizer on a good stereo system. Each room has different acoustics that vary with frequency. A room with carpeting, upholstered furniture and heavy drapes will attenuate the highs. An equalizer lets you boost the highs so you hear the sound the way it was intended. Our equalizer boosts the signal at different frequencies to account for differences in attenuation caused by the powerline allowing the receiver to “hear” the powerline signal as it was intended. Furthering the analogy, if you have a centralized audio amplifier and a single equalizer with speakers in each room, you can only get one room right. Boost the highs for the family room, and a living room without carpeting or heavy drapes will sound tinny. You need an equalizer for each room so the sound is the same everywhere. By using a receiver design with adaptive equalization, we ensure every receiver “hears” exactly the same signal. This gives Adaptive’s transceiver the ability of true “broadcast” and “multicast” signals to every outlet in the home at the same time and at the maximum data rate. Other technologies either have to emulate multicast by sending the signal to each outlet separately, as a round-robin unicast operation thereby significantly reducing the data rate.

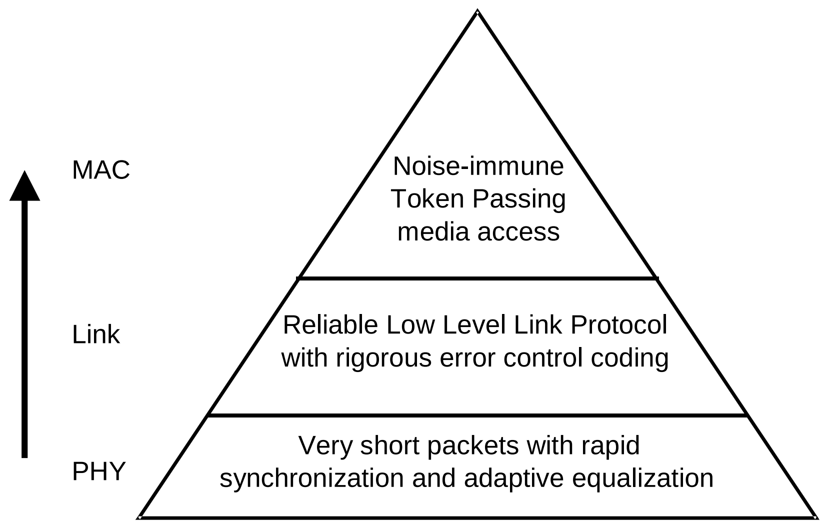
Consider as a common example, the ramifications of UPnP discovery (Simple Service Discovery Protocol). At any time, and quite often, UPnP compliant devices initiate SSDP sessions to discover each other. SSDP sessions, by definition, are multicast operations. Because Adaptive’s technology does not compromise the data throughput of the network to perform multicast operations, other network activities are not adversely affected. However, other powerline technologies, must switch to the emulated multicast operation that drops the data throughput of the entire powerline network. The adversity of this can be seen in the drop in throughput that may cause failure of the network to support even a single, CD quality MP3 file stream. As more UPnP devices continue their SSDP sessions, the network becomes continually compromised.

Developing adaptive equalization and synchronization (the ability to rapidly synchronize all receivers to a transmitted signal), on the surface, may seem like a time consuming endeavor but with nearly two decades of building powerline carrier products for the commercial and industrial marketplace, Adaptive Networks knew that in the long run, it was a critical piece of the solution. Now QoS with sufficient speeds can be delivered without having to make sacrifices with other necessary elements of the technology. The patented technology is completely contained within OSI layers one and two and provides:

- Speeds of 20 Mbps raw, 5 Mbps steady state payload throughput
- True, continuous broadcast and multicast support
- No compromises to OSI layers 3-7

HIERARCHICAL APPROACH

The approach necessary to achieve this breakthrough is hierarchical, satisfying each and every requirement for delivering a reliable home networking backbone. This approach combines:

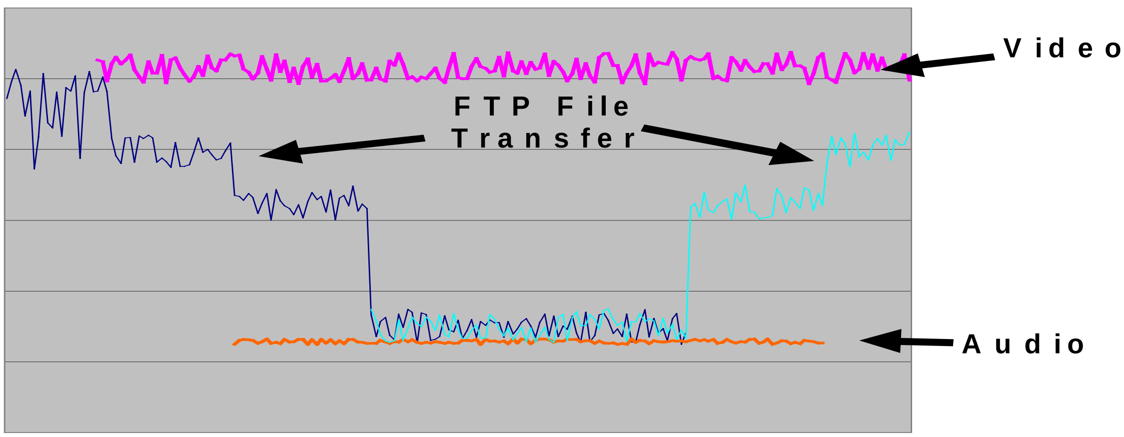


QoS

A token passing MAC is uniquely suited to the requirements of both reliable transfer of control in a noisy medium and support for multimedia (QoS). False synchronization, missed transmissions, and near-far problems that are inherent to a noisy medium such as the powerline are best addressed with a token passing deterministic access scheme. On the powerline it is difficult to distinguish between a signal and noise. Token passing transfers control of network access deterministically, ensuring only one token holder at any time even in a noisy environment. As the location of each node is different, each node receives a transmission subject to different distortion and noise. There is thus the possibility that some nodes will miss a transmission that other nodes hear. In token passing, nodes cannot transmit unless they hold the token, so there is no possibility that nodes will transmit during another node's transmission.

The token passing MAC includes the use of a Token Rotation Time (TRT). The TRT is a fixed value that sets the maximum amount of time a station must wait for the token. This value is chosen to balance the worst-case access latency against network bandwidth being consumed for non-productive token passing overhead. Adherence to the TRT results in low latency that is necessary to support multimedia.

When nodes gain access to the network they are limited to their allotted Token Hold Time (THT). The THT is the amount of time a station is allowed to transmit before it must pass the token to the next station. Enforcing a THT ensures that all nodes receive their fair allocation of network bandwidth. The use of priorities based on traffic type when allocating network access allows delay-sensitive traffic to first gain access to the network and maintain its required bit rate allocation.



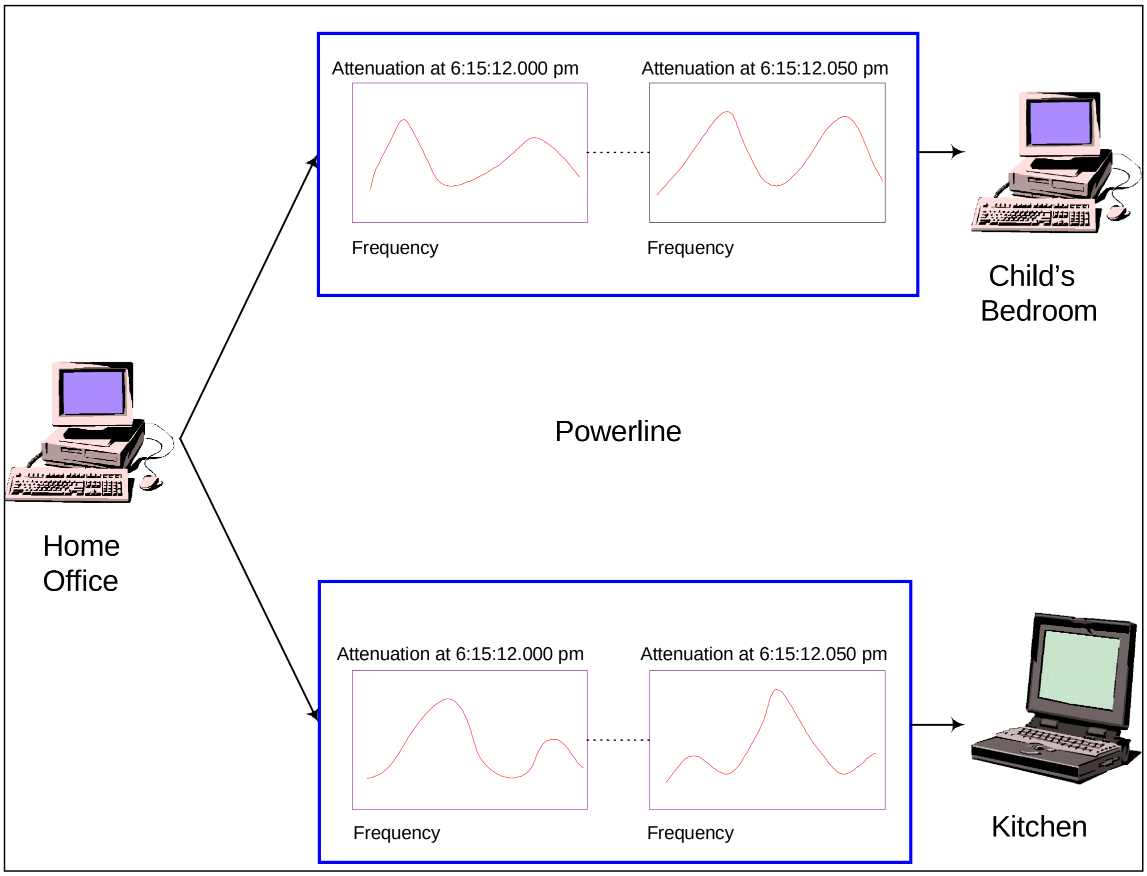
Simultaneous file transfer, video and audio streams over Adaptive Networks powerline with steady prioritization of multimedia using Chariot software by NetIQ

Segmentation and Reassembly (SAR) is integral to the architecture. Short powerline frames are derived from segmentation of the typical packet. Segmentation into short frames ensures (1) that high priority traffic is not delayed by maximum-sized Ethernet data packets and (2) adherence to the THTs. For example, ensuring the efficient transport of packets means that multiple phone conversations do not affect each other or the response times of multi-user games.

HOME-WIDE CONNECTIVITY

The value of a powerline-based home networking backbone will be judged, in part, by the connectivity that it offers. The first consumer experience of this network will be when a communications-enabled device is plugged into the wall with the expectation that it becomes available on the network. If it does not immediately work, and possibly needs to be plugged into a second or third location to get it to work, the consumer's perceived value of that powerline network will be degraded. Connectivity at all electrical outlets in a home is an absolute necessity.

The approach taken by Adaptive Networks' is one that addresses the medium-specific challenges in a hierarchical manner from the physical layer to the MAC. Signal attenuation is both time-dependent and frequency-dependent, as a consequence of the complex impedances of all devices plugged in as well as by signal reflections. Similarly, noise varies over both time and frequency.



A wideband, spread spectrum transmission would ensure some portion of the transmitted spectrum would be received, albeit with significant distortion due to the multiple peaks and valleys of the powerline transfer function. Adaptive equalization is required to correct for this distortion. Furthermore, a network rather than a point-to-point must be supported. Multiple nodes must therefore receive any transmission, subject to different distortion at different locations and times. Consequently, all nodes adaptively equalize to a transmitter, without any adaptation by the transmitter to a specific receiver.

Due to the time-varying characteristics of the noise and attenuation, the longer the minimum signaling period, the greater the probability of a corrupted transmission. Fast synchronization enables the data to be transmitted in short frames, which in turn maximizes the probability of reception, enables adaptive equalization on a frame basis, and serves as the foundation for low latency isochronous communications.

RELIABILITY

Regardless of physical layer implementation, bit errors may occur. Forward Error Correction (FEC) and an embedded low-level link protocol incorporating Automatic Repeat Request (ARQ) further maximize the probability of recovering any received frame.

LOW-COST IMPLEMENTATION

With good partitioning between analog and digital signal processing, the physical-layer solution through the error-control coding can be implemented in low-cost silicon in a pure CMOS process.

NO ROOM FOR COMPROMISE

Powerline network technologies have historically induced significant compromises within higher layers of the network protocol stacks. For instance, consider that these 'legacy' powerline protocols have been based on a point-to-point “train, send, and retrain” model. Essentially two nodes that require communication attempt to train to each other for a short duration, and to each other only. Once trained, they perform their data payload transfers. While this may work for point-to-point communications it cannot, by the very definition of point-to-point training, work for true multicast or broadcast operations. Such models are therefore inherently incapable of supporting Universal Plug-n-Play, audio or video multicasts, or any other such operation.

Until Adaptive Network's patented approach, such was the reality of powerline home networking. First, the powerline is truly a hostile medium with significant variations over time. To handle this, adaptive equalization is required to respond to these changes at a moments notice. Second, demanding applications like audio or video entertainment require prioritization to insure proper and sufficient bandwidth. Lastly, ALL of the powerline networking technology’s underlying functionality must be met or else the technology will be rendered useless. So, for instance, meeting speed or multicast requirements is only useful if you are able to comply with FCC Part 15 regulations as well as being able to coexist with other network topologies. The technology must meet the critical needs of home networking without giving up the basic requirements—no room for compromise.

CONCLUSION

Starting with a powerline-optimized physical layer as the foundation, the architecture described here adds forward error correction, ARQ, SAR, and a token passing MAC to yield an "as good as wire" 10^{-9} BER that looks to the world like an Ethernet NIC. Using Adaptive Network's patented technology for powerline signal processing combined with a low-cost embedded controller, a reliable, multimedia-capable home powerline network backbone is achieved.