The Powerline as a Reliable Multimedia-Capable Home Network

Home Networking Requirements

To meet the requirements of almost all potential users, a home networking solution must deliver reliable network connectivity without new wiring. Only the truly adventurous technologist will struggle with the installation of cabling.

The home networking user has neither access to support staff, nor a comparable budget (witness home PC price trends). Simplicity is paramount. “Access points wherever I need them.” Most people will expect this level of connectivity. Imagine the alternative scenarios. “Gee, I thought I had a phone jack in that room.” “Whaddayamean it’s on the other side of the room.” “Why can’t I connect from the basement playroom.” The network must fit the consumer’s requirements, not vice versa.

Furthermore, no one will tolerate a painstakingly slow download every time more than one user comes on the network. The value of a network is created by the multiplicity of devices that can be connected, often simultaneously.

Consumers expect low cost, adequate bandwidth, and coverage everywhere. Additional to these basic expectations, there are technical requirements upon a home networking solution to support multimedia.

The days of a data-only network have passed. Any home networking solution must additionally support the isochronous requirements of voice, audio, and video. This QoS (Quality of Service) support for multimedia must be integral to the design of the MAC and Link layers. A physical layer technology alone cannot provide QoS, rather the following must be incorporated in the MAC and Link protocols:

- **Minimum guaranteed bandwidth** – When you start a voice conversation, you expect to be able to complete it. People will not tolerate being cut off due to a temporary lack of network bandwidth.

- **Fairness in bandwidth allocation** – Just because I started my download before you decided to make a call, doesn’t mean that I get to tell you to try again later.

- **Bounded access latency** – Voice, audio, and video traffic needs consistent and regular access to the network. Jitter with video and pops, crackles, and delays with voice will not be acceptable.

- **Short packet handling** – No matter how fast you talk, you still generate only a small amount of digitized bits every 10-20 ms. Real-time traffic can result in frequent, but very short packets. The network must not penalize this type of traffic by expanding these short packets to large minimum-sized packets resulting in inefficient utilization of the network.

A Powerline Home Networking Solution

The AC powerline is a very compelling medium of choice. Powerline does not require the additional cost of a 2.4 GHz RF front end. Unlike phone line, many access points are available in every room by virtue of the electrical code. Table 1 compares the Adaptive Networks powerline implementation with the alternative media of RF and phone line.

	Adaptive Powerline	RF	Phone Line
Cost	Low	High	Low
Access points	Many	Many*	Few
Network throughput (Mbps)	5-10	1-4	1-10

*RF subject to spotty coverage

Table 1. A comparison of powerline, RF, and phone line as home network solutions.

To arrive at a powerline home networking solution, first the medium-specific problems must be recognized, then addressed hierarchically. Signal attenuation is both time-dependent and frequency-dependent, as a consequence of (1) the complex impedances of all devices plugged in and (2) signal reflections. Similarly, noise varies over both time and frequency. By comparison with a DSL link, the frequency and time dependencies are dramatically more severe (Figure 1).

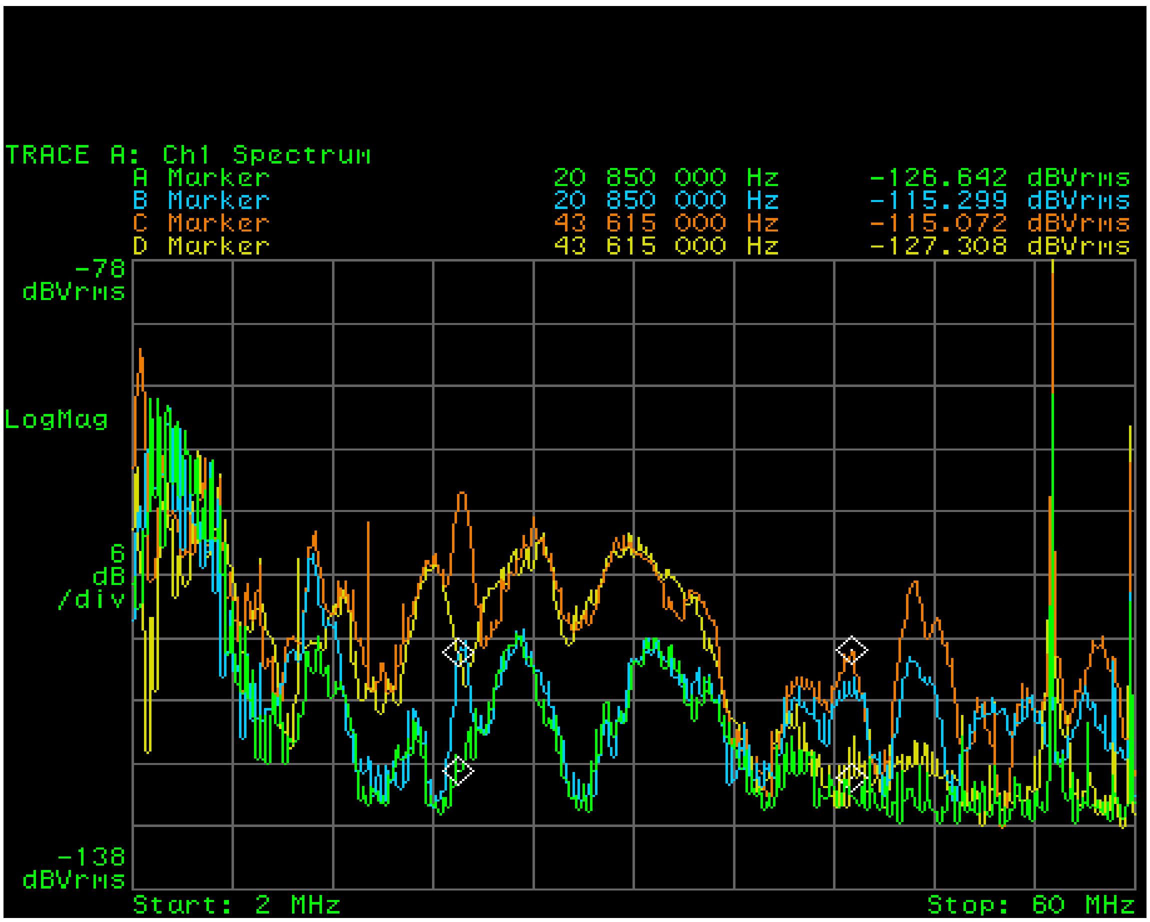

Figure 1. Frequency-dependent signal attenuation (blue and brown traces) and noise (green and yellow traces) versus frequency taken at two different times for the same physical powerline link.

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, unlike DSL, a network rather than a point-to-point link is required. Multiple nodes must therefore receive any transmission, subject to different distortion at different locations and times (Figure 2). Consequently, all nodes adaptively equalize to a transmitter, without any adaptation by the transmitter to a specific receiver.

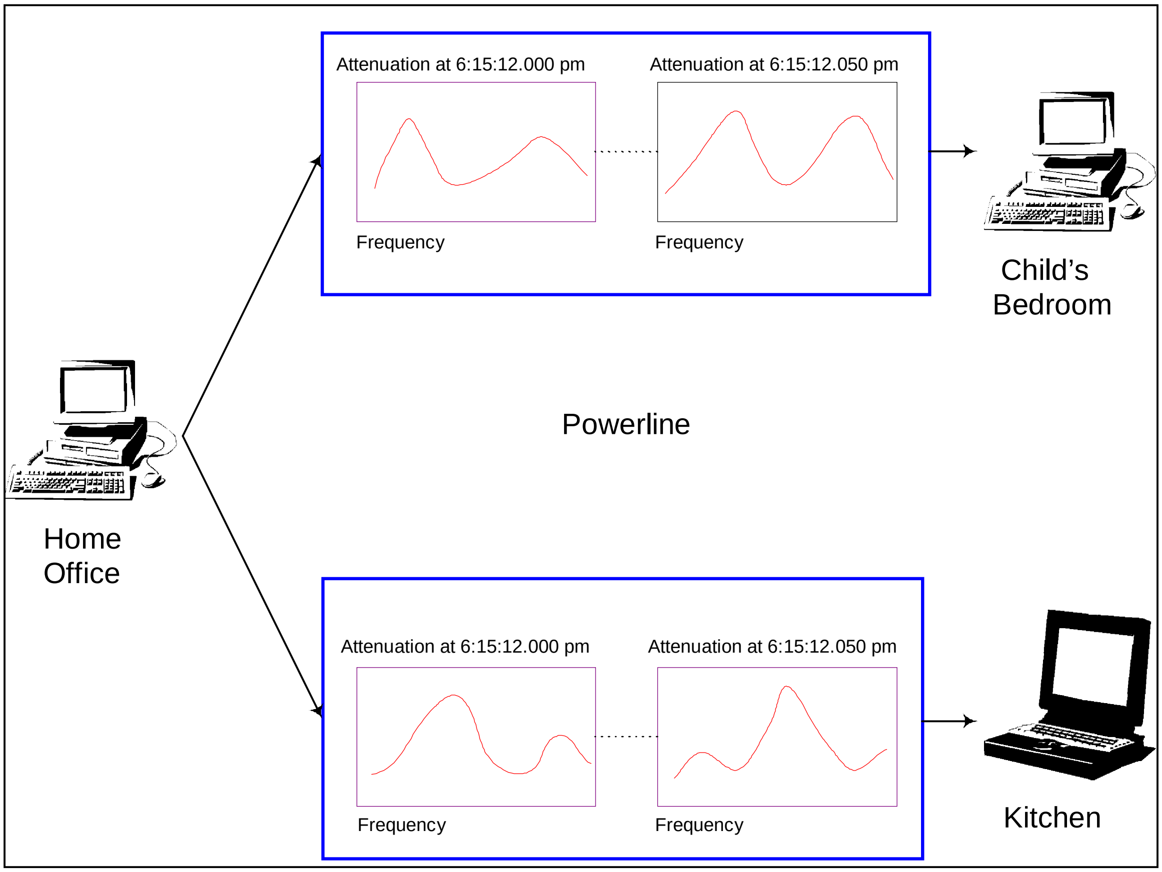

Figure 2. The same powerline transmission is subject to different distortion at different locations and times.

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.

No matter how robust the physical layer solution, there will be bit errors. 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.

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.

A token passing MAC is uniquely suited to the requirements of both reliable transfer of control in a noisy medium and support for multimedia. 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.

Segmentation and Reassembly (SAR) is integral to the architecture. Short powerline frames are derived from segmentation of the typical packet. Additional to the physical layer benefits discussed above, this 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 will neither affect each other nor the response times of multi-user games.

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 a powerline signal processor combined with a low-cost embedded ARM-based controller, you have a reliable, multimedia-capable home network (Figure 3).

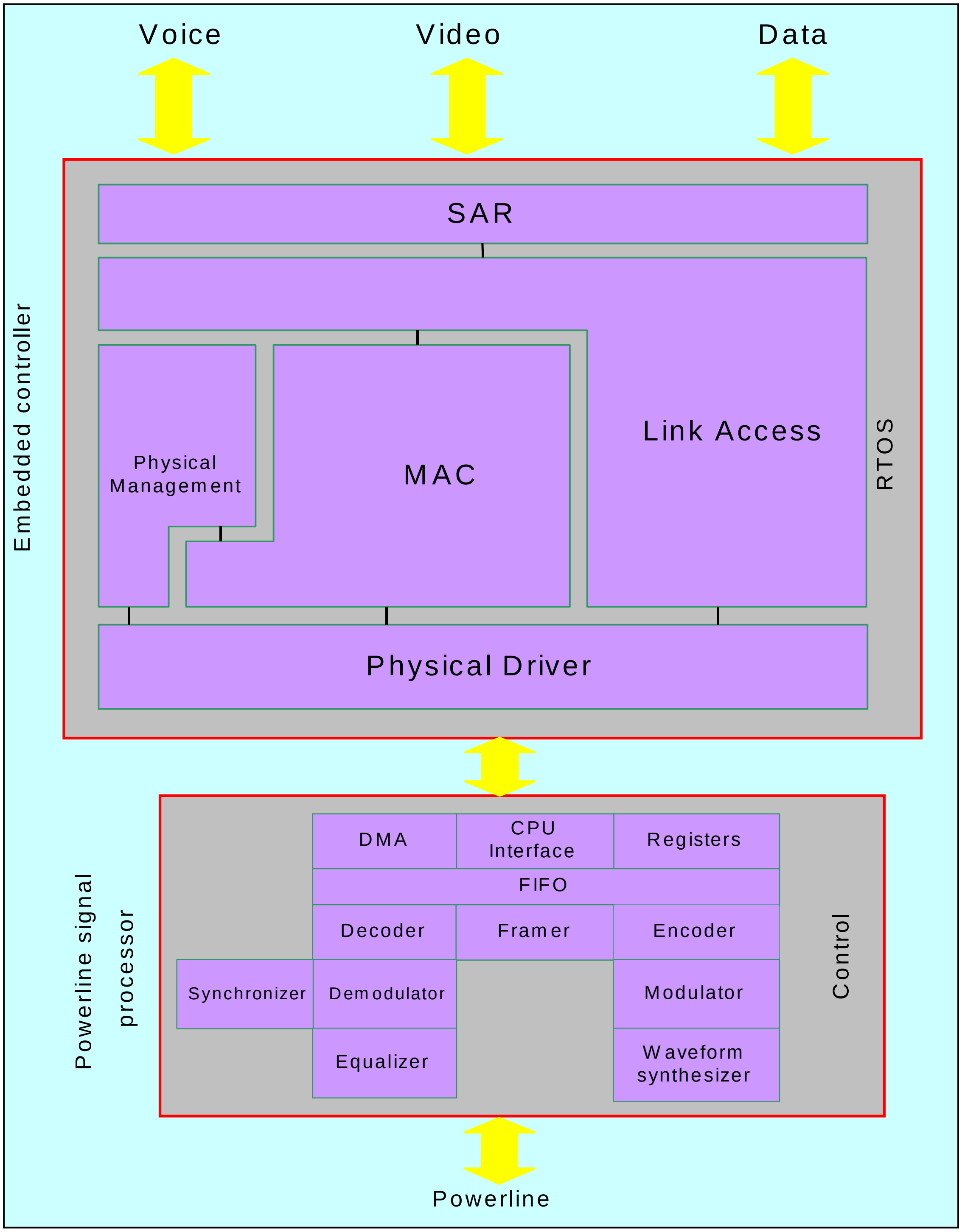

Figure 3. A reliable multimedia-capable home network is realizable in a powerline signal processor combined with a low-cost embedded ARM-based controller