



**An Overview of
Adaptive Networks Technology**

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Introduction

Adaptive Networks was formed in 1983 to develop and market silicon-embedded networking technology for use in wiring environments that exhibit adverse or electrically hostile conditions, in particular, electrical powerlines. Adaptive's technology solves the problem of using existing wiring, sometimes referred to as a "no new wires" solution, for multimedia digital networking and communications. Over the past few decades, the networking industry has spent many hundreds of billions of dollars "pulling" new wires, such as fiber optic, Category 5 or coaxial cables, throughout buildings and homes, specifically to support data network communications between computers and other devices. Adaptive has developed technology that allows data networks to operate in the same reliable fashion over existing wiring, including electric grids and in-building power lines.

Adaptive Networks' core technology has a proven track record, evidenced by the successful use of Adaptive's powerline chipsets in several commercial and industrial applications. The technology is sold as silicon-embedded solutions for different data communication bandwidths including the AN192 (19.2 kbps throughput, 135 kbps raw), the AN1000 (100 kbps throughput, 270 kbps raw) and the new PowerStream™ products (5 Mbps throughput, 20 Mbps raw). The success of the AN192 and AN1000 led Adaptive to consider expanding its revenue potential by providing its technology for use in higher bandwidth applications such as LANs, VoIP, Home Networks, etc. In 1996 Adaptive Networks began development of advancements to its technology that achieve robust, high-bandwidth communications over the same, potentially adverse infrastructure as the AN192 and AN1000. This effort has resulted in technologies that provide reliable communications up to 20 Mbits even under such adverse conditions as the existing electrical grid and home AC electrical wiring.

The technologies developed by Adaptive Networks are applicable to communications over any media where noise or signal integrity is an issue, in particular, powerline, existing twisted copper pair (e.g., longer-distance VDSL), cable, and wireless. Working at the PHY and MAC layers, the developed technologies optimally take into account the requirements that noisy and distorted media impose on these layers (see Appendix). (Additionally, the digital equalization technology may have applicability to other areas of signal processing, such as audio equalization.) The technologies are covered by multiple patents (a total of eleven are anticipated, including five already granted) and are implemented.

Signal Processing for Noisy and Frequency-Selective (Distorted) Media

Equalization and Noise Filtering

Adaptive Networks has developed technology for digital equalization that, on a frame-by-frame basis, "on-the-fly", i.e., instantaneously, constructs the optimal frequency-domain equalizer (FDE) for each frame incorporating knowledge of both the channel and noise (thereby constructing an optimal channel and noise filter). Noise includes both wideband and narrowband noise and the channel is subject to severe frequency-dependent attenuation, i.e., signal distortion. Adaptive's on-the-fly FDE enables:

- network performance by allowing all receivers to receive from any transmitter, i.e., enabling broadcast/multicast
- continuous optimal performance with regard to both throughput and low-latency communications for dynamic media

by eliminating the need to use conventional techniques of:

- transmitter training to the receiver which does not allow for broadcast/multicast and introduces significant latency for dynamic channels (as feedback from the receiver to the transmitter is required for training)

- requiring a convergence period, resulting in suboptimal equalization during equalizer convergence, or lack of convergence on dynamic channels
- time-domain equalization, which cannot handle large delay spread and high data rates, where intersymbol interference (ISI) is spread over large numbers of symbols.

Adaptive Networks has also developed technology for analog frequency-domain equalization for lower-data-rate implementations.

Synchronization

Adaptive Networks has developed technology for fast synchronization on a network where data is transmitted in short frames and synchronization is required to each frame. Synchronization is achieved under both low SNR (including both wideband and narrowband noise) and significant frequency-dependent attenuation (i.e., received signal distortion).

Adaptive has developed the use of precise inter-frame gaps and predictable responses to enforce receiver synchronization windows to maximize the reception ability in a noisy medium.

Adaptive has also developed lower-complexity synchronization and oversampling techniques to use both single-bit ADCs and lower-frequency clocks.

Wideband Modulation

By distributing the energy of each symbol over a wide frequency spectrum, severe-frequency dependent attenuation and noise has minimal impact on error probability. Adaptive's technology enables a simple transmitter implementation and allows the signal processing to be concentrated at the receiver, enabling all nodes on a network to hear any transmitter.

Error Correction

Adaptive Networks has developed technology for improved error correction, achieving low decoding-delay and short block lengths. By using multiple layers of correction, soft error correction, and a parallelized decoding architecture that is integrated with the timing of the received bit stream, short frames (as required by the network protocol) can be decoding without introducing latency into the network and with significantly improved error rates.

Communications and Network Protocols for Noisy and Frequency-Selective (Distorted) Media

MAC

Adaptive Networks has developed technology to address the MAC issues of noisy-medium access control, ensuring QoS guarantees can be met, and multiple networks coexisting on a shared medium. Adaptive's MAC technology includes:

- the use of a novel token-passing loop architecture to solve the problem of conventional token passing on a noisy medium
- the use of a three-way handshake method to ensure a reliable transfer of control on a noisy medium
- a "multi-home" MAC protocol to manage multiple logical networks on a single shared physical medium

- the use of a single elected node to perform traffic scheduling, maintain QoS guarantees and token-passing loop administration without a single point of failure; this delivers the benefits of a wireless TDMA base-station architecture without a single point of failure
- the reduction of token-passing/polling overhead while maintaining QoS guarantees
- a scalable architecture that can provide a minimal implementation for low-cost devices

Link and SAR

Adaptive Networks has developed technology to provide transparency to the upper protocol layers from the unreliable nature of noisy media and enforce QoS guarantees. Adaptive Networks' Link layer technology includes:

- data segmentation and reassembly (SAR)
- the use of a selective reject ARQ protocol for best-effort errorless delivery of data packets
- guaranteed packet order and no duplicate packets within a priority
- support for Quality of Service (QoS); higher priority packets take precedence and have minimal delay due to packet decomposition
- data encryption

On-Demand Telephony Services

Adaptive Networks has been awarded US Patent Number 5774526 (with associated international applications in various stages), with claims covering:

- Various identification models for connecting digital, non-telephone-wiring network devices to connected devices on the telephone-wiring network.
- Billing for services created using the claims of 1) above.

The patent is network-technology-independent and contemplates any system that uses a non-telephone wiring network to provide primary or secondary, on-demand telephone service to individual users and/or devices. Non-telephone wiring specifically includes powerline and CATV. The patent covers telephone services, including VoIP, whereby any person can interface a telephone or other device on-demand to the non-telephone wired network and receive telephone services.

Appendix: An Overview of Powerline PHY and MAC Issues

Physical Layer Issues

At the Physical layer, any location must be able to send bits to any other location in a house. However, the underlying technology must match the transmission requirements of the powerline that are dynamic both in time and location.

If a technology can support a link between a pair of nodes under static conditions and cannot support a high bit rate under changing conditions or to multiple receivers simultaneously, it will not support a network, nor will it deliver consistent throughput in the dynamic powerline environment.

On a powerline network the requirement is for a network where multiple nodes communicate with one another at varying points in time.

Adaptive uses a wideband approach, whereby the transmitter transmits the same signal to all receivers and each receiver equalizes to the characteristics of the received signal, where the equalization is instantaneously determined:

- at its location; and
- at the time received.

Because the adaptation is at the receiver, all receivers can hear each transmitter and there is no delay of a feedback loop to receive any transmission. This approach is well suited to the dynamic time and location-dependent powerline environment. Moreover, because in Adaptive Network's solution all receivers to hear each transmitter, it is the only solution that can provide multicast and broadcast support without significantly degrading the performance of the Physical layer.

Media Access Control (MAC) Issues

Assuming the Physical layer works, then the next most critical issue for providing a robust, high-speed network is the MAC protocol. In discussing the MAC, the reader should consider that the days of a data-only network appear to have passed. Home networking solutions must also support the isochronous requirements of voice, audio, video and device control. This Quality of Service (QoS) provisioning cannot be done by the Physical layer alone. It can, however, be successfully achieved via a design in which QoS is incorporated in the MAC and Link layer protocols. By doing so, the solution can successfully provide:

- Minimum guaranteed bandwidth
- Fairness in bandwidth allocation
- Bounded access latency
- Short packet handling

It often seems reasonable, if not desirable, to use an existing and well understood MAC protocol instead of defining a new one. The nature of powerline communications, however, presents problems that existing MAC protocols cannot overcome. The MAC protocol should instead use a token-passing-based protocol such as that used in the Adaptive's technology.

Adaptive Networks' technology implements a token-passing approach. Token passing inherently provides nodes with deterministic access to the network and, by definition, then inherently supports QoS.

The type of access method also determines the network's ability to handle large numbers of nodes. Once the active node population increases, a CSMA-type approach will suffer from contention and the resulting sustainable throughput will correspondingly, and significantly, decrease. Token passing, however, does not suffer this degradation since it is the most efficient means of providing access under this scenario. When the available bandwidth is spoken for, the network does not waste precious time letting the contenders fight over who gets their turn next; it is much more efficient to have a deterministic model of when each node's turn has arrived.

Quality of service (QoS) is a set of technologies that manage the effects of congestion on application data traffic by allocating network resources optimally rather than allowing the network to saturate under an unsustainable load. In a data-only network, a best effort delivery is adequate. However, when supporting multimedia traffic such as voice, audio, and video, best effort delivery will not support the application. The important point is that applications have particular requirements that must be met in order to function properly. For example, a voice conversation generates short packets at a set frequency. Networks handle these requirements by providing minimum guaranteed bandwidth, fairness in bandwidth allocation, and bounded access latency.

QoS Concepts

The following list gives a brief overview of important QoS concepts and relationship to the application requirements.

- **Short packet handling**
Applications requiring low latency and short packets should not be treated the same as large size data packets.
- **Minimum guaranteed bandwidth**
Applications such as voice, video and audio require a set minimum bandwidth to achieve a good user experience.
- **Fairness in bandwidth allocation (Resource Allocation)**
Allows multiple applications to seamlessly work while providing adequate resources to ensure a pleasant user experience
- **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.

The choice of a non-deterministic approach limits the ability of the access method to handle QoS requirements. For example, it becomes difficult to guarantee an application that it will have reliable periodic access to the network, when the node's access to the network is subject to the traffic loading at the time. If the traffic load on the network is light, with few QoS requirements, the penalty for a non-deterministic approach may be manageable, however, it is important to understand the target market for a powerline-based home networking product. The view of the CEA (and the cable industry) is that QoS guarantees are a key requirement as the home network will be used for more than just PCs sharing an Internet connection and a printer.

The types of applications run on the network are an important factor in determining the capacity requirements of the network. Assessing the performance based on transferring sequences of large packets will not give a true indication of how the network will perform in a typical home environment. Applications such as web browsing and voice generate a large share of small packets. This is why it is important to look at how the network handles packets of varying sizes.