The Powerline as a Reliable Industrial Network

Introduction

Over the past few decades, the networking industry has spent many hundreds of billions of dollars “pulling” new wires throughout buildings, 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 industrial and commercial applications. The technology is sold as embedded solutions for different data communication bandwidths including the AN192 (135 kbps raw, 19.2 kbps throughput) and the AN1000 (270 kbps raw, 100 kbps throughput).

The PowerConnect™ Powerline Communications Architecture

Adaptive Networks’ powerline communications technology is based upon a hierarchical design. Each level of the design is optimized specifically to overcome the inhospitable characteristics of the powerline environment.

Both substantial noise and frequency-dependent signal attenuation are found on every powerline. Unlike dedicated wiring, without well-designed error control coding, bit errors will occur at unacceptably high rates. Actual error-free data throughput is always a fraction of the raw data rate.

Adaptive Networks’ wideband modulation, fast synchronization, adaptive equalization, error control coding, and network protocols, provide immunity from powerline attenuation and noise. With a raw rate of 134.4/268.8 kbps, the AN192/1000 can provide a 19.2/100 kbps throughput at less than a 10^{-9} error rate, equivalent to that of dedicated wire.

The Power Connect™ solution implements the Physical and Data Link layers of the ISO Open Systems Interconnection (OSI) Reference Model.

The Powerline Physical Layer

In general, a wideband system will exhibit improved noise immunity over narrowband systems on the powerline. However, using the traditional spread spectrum approaches (direct sequence, frequency hopping, chirp) does not solve the difficulty of signal synchronization in the presence of constantly-changing noise and frequency-dependent attenuation.

Adaptive Networks’ approach is based upon a unique physical layer wideband spread-spectrum-like technology that provides very rapid synchronization. Synchronization is achieved under both low SNR (including both wideband and narrowband noise) and significant frequency-dependent attenuation (i.e., received signal distortion). Rapid synchronization is an important component of a fast, practical, and reliable powerline communications system and is achieved in an adaptive detection process. As part of

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the Adaptive Networks protocol, data is transmitted in short frames. The start of a frame is quickly detected in a parallel synchronization process.

Another important component of a reliable and robust wideband powerline communications system is a method of adaptive equalization of the received signal. The physical layer provides such a method, which maximizes the received signal even in the presence of frequency-dependent noise and attenuation. 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.

The Reliable Low Level Link Protocol

Several key features of a data link layer are required for reliable operation of large, multi-node networks on the powerline are:

- data segmentation and reassembly to create reliable communications
- rigorous error correction and detection
- effective adaptive equalization
- reliable transfer of control

Only a certain amount of contiguous information can be sent before it is almost a certainty that a transmission will be corrupted. This suggests a requirement for transmissions of short frames on the powerline. To further ensure the integrity of any frame of data, it is necessary to use both error correcting and detecting codes - forward error correction to minimize the number of retransmissions, and error detection to know if there is a need for a retransmission on a frame basis. Each frame should be acknowledged by the receiver before the transmission proceeds to the next frame. To implement this low-level link protocol, segmentation and reassembly is used to break up the higher level packet into such short frames.

Another benefit of the low-level link protocol is the effectiveness of adaptive equalization. Powerline conditions can change on the order of a few milliseconds, and the receiver must be able to adapt to these changing conditions. Using a low-level link protocol built upon short frames, the receiver can adapt on a frame basis and, because acknowledgments are required, no information is lost.

Using forward error correction (FEC) and automatic repeat request (ARQ) developed specifically for the powerline environment, the data is transferred with an effective throughput of 19.2/100 kbps at an error rate of 10^{-9}, using a raw data rate of 134.4/268.8 kbps. This provides both the required reliability and bandwidth.

To provide reliable multi-access network communications, Adaptive Networks developed a noise-immune token passing protocol. For example, transfer of the token between nodes is done via a three-way handshake ensuring a transfer of control without loss of the token.

The Token Passing Media Access Method for the Powerline

Different media access algorithms have been demonstrated on dedicated wire. The algorithms are generally based on either a carrier sense technique such as CSMA/CD or token passing. However, results for other media are not transferable to the powerline.

Token passing solves three problems that the powerline medium presents for a carrier sense technique:

1. On the powerline, there is insufficient communications reliability to distinguish between noise and signal. This makes carrier sense especially difficult. Nodes will back off when there are no contending devices transmitting on the powerline.

   Token passing does not require collision detection by the nature of its structure. There is only one token holder at any point in time. A reliable three-way handshake is used to transfer the token between nodes. This ensures an orderly transfer of control without loss of the token.

2. Because the powerline characteristics are different for each node, a node will not necessarily hear every transmission on the powerline. In carrier sense, a node may thus incorrectly determine that the channel is quiet and start transmitting in the middle of another transmission.

   In token passing schemes, nodes cannot transmit unless they hold the token. Therefore there is no possibility of nodes starting to transmit in the midst of another node's transmission.

3. In CSMA/CD, each listening node hears a summation of the transmissions of each transmitting node, where the transmission of each transmitting node is transformed by the characteristics of the particular powerline electrical network seen between its position and the listening node. Thus each listening node will in general hear a resultant transmission that is not a simple sum but is a summation with cancellation and distortion due to the different transformations of each node's transmission. Collision detection under these conditions is difficult.

   In token passing, these types of communication problems are easily resolved by the token holding node, which acts as an arbiter of any ambiguities.

Token passing yields additional benefits that cannot be obtained with carrier sense, such as deterministic access under heavy loads, fair allocation of the network bandwidth, and detection of failed nodes.

Applications

Adaptive Networks' powerline communications technology, including the AN48, AN192, and AN1000, has been proven in the field in a broad group of applications worldwide. Our powerline communications technology has served demanding, mission critical industrial and commercial applications with products that are frequently relied on to operate 24 hours a day, 7 days a week in the harshest environments The AN192 is the high data rate standard for communications aboard refrigerated container ships as selected by the International Organization for Standardization (ISO). The AN192 and the AN48 comply with international standards such as IEC TC57 Distribution Automation Using Distribution Line Carrier Systems for remote meter reading. The technology has found acceptance in applications such as shipping, utility applications including remote meter reading, factory automation, retail point-of-sale, mass transportation, mining oil and gas telecommunications, undersea cabling and government.