Power Line Communications: An Overview – Part II

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***Abstract* - Following up on our previous work, Power Line Communications: An Overview – Part I, we discuss the standards involved in PLC technology and name the established standards. We then concentrate on the HomePlug standard in detail. Our prime focus is on these standards: HomePlug 1.0 and HomePlug AV as these have become the basis for the world's most widely deployed PLC systems.**

An overview of the HomePlug standards is presented which discusses the technology in the Physical and MAC layers. It also discusses the QoS issues and compares the performance of HomePlug AV with HomePlug 1.0.

Keywords: Latest technology, Power Line Communications, PLC, HomePlug 1.0, HomePlug AV.

I. INTRODUCTION

Power lines were originally devised to transmit electric power from a small number of sources (the generators) to a large number of sinks (the consumers) \in the frequency range of 50-60 Hz. It is a fact that power transmission towers and lines are some of the most robust structures ever built. Historically, the PLC technology has very limited applications but now we are witnessing the possibility of it being acclaimed universally as a prime mode of long-haul data communication.

With the inevitable arrival of broadband access, the demand for sending digital voice, video and Internet data within the home increases continuously. While retrofitting the houses and neighborhoods with special wires is one option, it is expensive and time consuming. PLC Technology allows the use of the existing and widespread power distribution infrastructure to provide high speed networking capabilities along with many other benefits.

In our previous paper [1], we have discussed all of these things introduced here in detail and have discussed the historical as well as current applications of PLC. We have also seen the structure of a PLC standard i.e. its layers and protocols it can potentially use.

Section 2 of this paper discusses the standards on PLC that are available to us. The preceding sections are dedicated to HomePlug Standards as already mentioned.

II. STANDARDS

As mentioned earlier, X10 is a de facto standard also used by RadioShack's Plug'n'Power system. However, several competing standards are evolving including the HomePlug Powerline Alliance, Universal Powerline Association, ETSI, and the IEEE. It is unclear which standard will come out ahead. We will just give a passing mention of current standards in the market and will treat the HomePlug as it is most widely deployed.

A. *IEEE Standards*

IEEE is currently working on developing standards for PLC and in 2008 the work is expected to be complete. The IEEE standards that are still in working group form are:

1) IEEE P1675

"Standard for Broadband over Powerline Hardware". Its working on hardware installation and safety issues.

2) IEEE P1775

"Powerline Communication Equipment - Electromagnetic Compatibility (EMC) Requirements - Testing and Measurement Methods". Its focused on LC equipment, electromagnetic compatibility requirements, testing and measurement methods.

3) IEEE P1901

"Draft Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications". Its working for delivering broadband over power lines.

B. OPERA

OPERA (Open PLC European Research Alliance) is a R&D Project with funding from the European Commission. It aims to improve the existing systems, develop PLC service, and standardize systems. [2]

C. POWERNET

POWERNET is a R&D Project with funding from the European Commission. It aims to develop and validate a 'plug and play' Cognitive Broadband over Power Lines (CBPL) communications equipment that meet the regulatory requirements concerning electro-magnetic radiations and can deliver high data rates while using with low transmit power spectral density and working at low signal to noise ratio. [3]

D. Universal Powerline Association (UPA)

The Universal Powerline Association (UPA) aligns industry leaders in the global Powerline Communications (PLC) market and covers all markets and both access and an in-home PLC technology to ensure a level playing field for the deployment of interoperable and coexisting PLC products to the benefit of consumers worldwide. UPA promotes products based on the UPA Digital Home Standard for home networking applications and on the Opera standard for BPL Power line access applications. [4]

UPA standard is a strong standard and is contributing towards the upcoming IEEE P1901 standard.

E. CEPCA

Consumer Electronics Powerline Communications Alliance (CEPCA) (Sony, Mitsubishi and Panasonic) is developing powerline technologies which can offer speeds up to 170 Mbit/s. [5]

F. ETSI PLT

The project will progress the necessary standards and specifications to cover the provision of voice and data services over the mains power transmission and distribution network and/or in-building electricity wiring[6]. The standards will be developed in sufficient detail to allow interoperability between equipment from different manufacturers and co-existence of multiple powerline systems within the same environment. Harmonized Standards will be developed to allow presumption of conformity with the relevant EU/EC Directives.

G. HomePlug Powerline Alliance Standards

The HomePlug Powerline Alliance is a trade group consisting of over 65 member companies. It was founded in March 2000 by leading technology companies to provide a forum for the creation of specifications for home power line networking products and services. The Alliance's mission is to enable and promote rapid availability, adoption and implementation of cost-effective, interoperable and standards-based home power line networks and products. The Sponsors and members of the Board of Directors of the Alliance include: Comcast, Earthlink, GE, Intel, Linksys, Motorola, Radio Shack, Samsung, Sharp, and Sony. Because HomePlug technology is based on the contributions of multiple companies from around the world, the resulting standards offer best of class performance. The HomePlug Powerline Alliance has defined a number of standards:

1) HomePlug 1.0

It is the specification for connecting devices via power lines in the home

2) HomePlug AV

It is designed for transmitting HDTV and VoIP around the home

3) HomePlug BPL

It is a working group to develop a specification for to-the-home connection

4) Homeplug CC

The Command and Control is a low-speed, very low-cost technology intended to complement the alliance's higher-speed powerline communications technologies.

III. THE HOMEPLUG 1.0 STANDARD

In 2000, the HomePlug organization developed the HomePlug 1.0 standard which became the basis for the world's most widely deployed power line communication system. Here we look at some of its features in brief while their details can be found in [7].

A. Summary of Physical Layer Features

Orthogonal Frequency Division Multiplexing (OFDM) is the basic transmission technique used by the HomePlug. OFDM is well known in the literature and in industry [8] and is used in DSL, IEEE 802.11a and 802.11g standards and distribution of TV signals. The OFDM used by HomePlug is specially tailored for powerline environments. It uses 84 equally spaced subcarriers in the frequency band between 4.5MHz and 1MHz. Cyclic prefix and differential modulation techniques (DBPSK, DQPSK) are used to completely eliminate the need for any equalization. Impulsive noise events are overcome by means of forward error correction and data interleaving. HomePlug payload uses a concatenation of Viterbi and Reed-Solomon FEC. Sensitive frame control data is encoded using turbo product codes.

Channel adaptation is achieved by Tone Allocation, modulation and FEC choice. Tone allocation is the process by which certain heavily impaired carriers are turned off. This significantly reduces the bit error rates and helps in targeting the power of FEC and Modulation choices on the good carriers. HomePlug allows for choosing from DBPSK 1/2, DQPSK 1/2 and DQPSK 3/4 on all the carriers. The end result of this adaptation is a highly optimized link throughput.

B. Summary of MAC, Frame Formats and Channel Access Mechanism Features

Since home networks should be able to support a diverse set of applications ranging from simple file transfer to very high QoS demanding applications such as Voice-over-IP (VoIP) and Streaming Media, HomePlug 1.0 addresses these needs.

HomePlug MAC is modeled to work with IEEE 802.3 frame formats. This choice simplifies the integration with the widely deployed Ethernet. HomePlug MAC appends the Ethernet frames with encryption and other management before transmitting it over the powerline. A segmentation and reassembly mechanism is used to in cases where the complete packet cannot be fit in a single frame.

HomePlug technology uses two basic frame formats. A Long Frame consists of a Start of Frame (SOF) delimiter, Payload and End of Frame delimiter (EOF). A Short Frame consists of a Response Delimiter and is used as part of the Stop-and Wait automatic repeat request (ARQ) process. ARQ mechanism causes retransmission of corrupt packets, thus reducing the packet error rate.

The channel access mechanism used by the HomePlug MAC is a variant of the well-known CSMA/CA protocol. The overall protocol includes a carrier sensing mechanism, a priority resolution mechanism and a backoff algorithm.

The carrier sense mechanism helps HomePlug nodes to synchronize with each other. At the heart of this mechanism are the delimiters. HomePlug technology uses a combination of Physical Carrier Sense (PCS) and Virtual Carrier Sense (VCS) to determine the state of the medium (i.e., if the medium is idle or busy and for how long). PCS is provided by the HomePlug PHY and basically indicates whether a preamble signal is detected on the medium. VCS is maintained by the HomePlug MAC layer and is updated based on the information contained in the delimiter. Delimiters contain information not only on the duration of current transmission but also on which priority traffic can contend for the medium after this transmission. PCS and VCS information is maintained by the MAC to determine the exact state of the medium.

The Priority resolution mechanism provides prioritized access of the medium in a highly distributed manner and allows up to four different priority levels.

The backoff algorithm used by HomePlug MAC is designed to provide high network utilization (which manifests itself as high network throughput) even under heavily loaded conditions. It is also tailored to seamlessly integrate with the priority level construction and the applications that each of these priorities is expected to support.

C. QoS Features

HomePlug MAC is designed to provide guarantees of QoS. This enables HomePlug based home networks to support applications like VoIP and Streaming media. Below is a list of some of the salient features:

- Supports up to 4 different priority classes based on VLAN tag (IEEE 802.1Q),
- Completely distributed approach reduces the implementation complexity,
- Optional support for contention free access,
- Segmentation and Reassembly ensures that higher priority traffic does not get excessively delayed due to on going lower priority packet transmission,
- Aggressive backoff algorithm for higher priority traffic (Priority 3 and Priority 2) ensures lower latencies,
- Variable packet discard timer and maximum retry limit ensures that excessively delayed packets are discarded.

IV. THE HOMEPLUG AV STANDARD

In this section, we give an introduction to HomePlug AV specification and summaries of its Physical and MAC Layers [9]. We then give a comparison of it with HomePlug 1.0 Standard.

HomePlug AV (HPAV) represents the next generation of technology from the HomePlug Powerline Alliance. Its purpose is to provide high-quality, multi-stream, entertainment oriented networking over existing AC wiring within the home, while addressing interoperability with HomePlug 1.0. HPAV employs advanced PHY and MAC technologies that provide a 200 Mbps (million bits per second) class powerline network for video, audio and data. The Physical (PHY) Layer utilizes this 200 Mbps channel rate to provide a 150 Mbps information rate with robust, near-capacity communications over noisy power line channels. The Medium Access Control (MAC) Layer is designed to be highly efficient; supporting both TDMA and CSMA based access with AC line cycle synchronization. The TDMA access provides Quality of Service (QoS) guarantees including guaranteed bandwidth reservation, high reliability and tight control of latency and jitter. The CSMA access provides four priority levels. AC line cycle synchronization provides superior channel adaptation in the face of common line cycle-synchronized noise. The Central Coordinator (CCo) controls the activities of the network, allocating time for CSMA use and scheduling the TDMA use.

Here we will provide a diagram of the HPAV architectures and summaries of its physical and MAC layers.

A. *The HPAV Architecture*

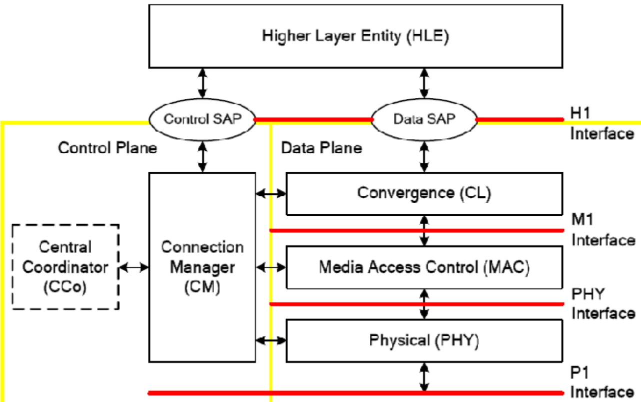

Figure 1: HPAV Architecture

B. *Summary of Physical Layer*

HomePlug AV employs a number of additional features to achieve the higher throughputs required in the targeted set of applications. [10]

- Turbo codes with varying code rates are employed to gain additional resilience to noisy environments, and increase coding gain over the concatenated codes of HomePlug 1.0.
- Coherent modulation is supported, and modulation types include BPSK, QPSK, 8-QAM, 16-QAM, 64-QAM, 256-QAM and 1024-QAM
- To enable coexistence between HomePlug 1.0 devices and HomePlug AV devices, the HomePlug AV PHY is equipped with the ability to send and receive HomePlug 1.0 frame control signals, and it utilizes a similar synchronization scheme (all devices thus have the ability to detect packets of either system).
- Several robust modes of operation are provided in HomePlug AV for the communication of network synchronization information, for session setup, multicast and broadcast modes. For example, a 10 Mbps broadcast mode can be employed on the vast majority (99%) of all power line channels without the requirement of exchanging channel information between transmitter and receiver.
- Channel Estimation is a critical element of the HomePlug AV system. In addition to the line cycle synchronization ability discussed above, HomePlug AV employs higher order modulations up to 1024 QAM, supports variable bit-loading (each carrier individually selects modulation type according to the SNR it observes), monitors carrier signal-to-noise ratios without the explicit need for channel estimation frames (estimates SNR on bit-loaded packets), and is able to track changes in the channel with high efficiency (93% of ideal, i.e. a priori channel and noise information).

C. *Summary of MAC Layer Features*

HPAV provides connection-oriented Contention Free (CF) service to support the QoS requirements of demanding AV and IP applications. This Contention Free service is based on periodic Time Division Multiple Access (TDMA) allocations of adequate duration to support the QoS requirements of a connection. HPAV also provides a connectionless, prioritized Contention based service to support both best-effort applications and applications that rely on prioritized QoS. This service is based on Collision Sense Multiple Access/Collision Avoidance (CSMA/CA) technology. HPAV implements a flexible, centrally-managed architecture. The central manager is called a Central Coordinator (CCo). The CCo establishes a Beacon Period and a schedule which accommodates both the Contention Free allocations and the time allotted for Contention-based traffic. As shown in Figure 2, the Beacon Period is divided into 3 regions:

1) Beacon Region
2) CSMA Region
3) Contention-Free Region

The CCo broadcasts a beacon at the beginning of each Beacon Period; it uses the beacon to communicate the scheduling within the beacon period. The beacons are extremely robust and reliable. The schedules advertised in the Beacon are persistent—i.e., the CCo promises not to change the schedule for a number of Beacon Periods—and the persistence is also advertised in the beacon so that the transmitting station for a connection can confidently transmit during its persistent allocation(s) even if it has missed several beacons within the advertised persistence of the schedule. This provides additional continuity even if a few beacons are missed. The CSMA periods are also persistent so that stations wishing to send CSMA traffic can do so even if they miss a few beacons.

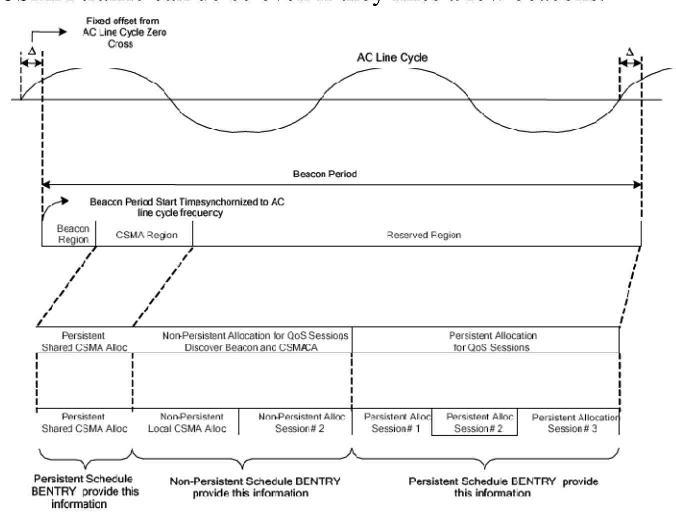

Figure 2: Example of Beacon Period Structure

The MAC layer provides both Contention (CSMA) and Contention Free (CF) services through the respective regions in the Beacon Period. The CCo-managed Persistent Contention Free (PCF) Region enables HPAV to provide a strict guarantee on Higher Layer Entity (HLE) QoS requirements. An HLE uses the Connection Specification (CSPEC) to specify its QoS requirements. The Connection Manager (CM) in the station evaluates the CSPEC and, if appropriate, communicates the pertinent requirements to the CCo and asks the CCo for a suitable Contention Free allocation.

If the CCo is able to accommodate the connection request, it will ask the stations to “sound” the channel. This allows the stations to perform the initial channel estimation. The Tone Map is communicated from the receiver to the transmitter; the channel estimation is also communicated in abbreviated form to the CCo to help it determine how much time should be allocated to the connection.

More intricate details of the working can be found in the technical white papers from the vendor.

D. *MAC Control and Data Planes*

HomePlug AV will use a two-level MAC framing scheme.

Incoming MSDUs are packaged with minimal overhead into MAC frames, which then form a MAC frame stream. This is treated as a byte stream by the segmentation process, which forms fixed-size segments for reliable transmission. Each segment is given a header and trailer that allow it to be encrypted, sent, decrypted, and delivered independently as a PHY Block (PB). The PB header contains sequence numbers that support reassembly of the original MAC frame stream from segments delivered out of order. It also contains information that allows MAC frame resynchronization after a portion of the MAC frame stream is lost. Each PB is sent in its own FEC block, and the PB check sequence allows uncorrectable FEC blocks to be detected reliably. Each PB can be individually acknowledged using a selective acknowledgement response, and only the damaged PBs are retransmitted. This results in a highly efficient framing and error correction scheme as illustrated in Figure 3.

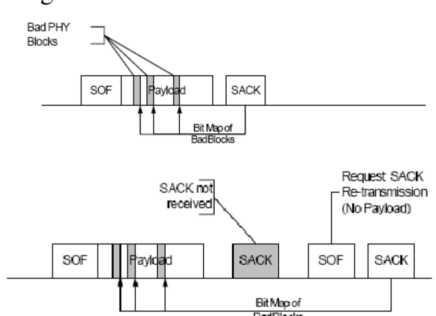

Figure 3: Normal SACK Transmission. Lost SACK & retransmission of SACK.

E. *System Performance Compared to HomePlug 1.0*

- Experimental systems of HomePlugAV have been field tested in houses, suggesting that on average a HomePlug AV system achieves 10 times the data rate of a 1.0 system. For example, the average PHY layer data rate measured in a large number of homes and a large number of outlet pairs per home is approximately 85Mbps. The increase is due (approximately) to the following factors.
- More Bandwidth (50% more used bandwidth)
- More Power (Transmit PSD is 2.2dB higher, due to lower peak-to-average ratio)
- Coherent transmission (improves ~2.5dB over differential transmission in HP1.0)
- Higher Order Modulation (modulates up to 1024QAM, taking advantage of higher SNRs when available)
- Powerful Forward Error Correction (Turbo Codes have about 2.5dB advantage over concatenated codes of HP1.0)
- Smart Channel Adaptation (full variable bit-loading, unsolicited channel information updates, line cycle adaptation)
- Efficient Signaling (minimal framing overhead, minimal cyclic prefix)
- Additional Signal Processing

V. CONCLUSION

This overview, along with the knowledge presented in [1] given a sufficiently complete overview of the PLC technology, its evolution and potential. In [1], a PLC standard was given as general, but here, the focus is on the HomePlug standards along with the mention of all the other standards applicable to PLC technology. Most of these standards are fledgling, with the HomePlug standard being the actually applicable one. It is thus the standard of choice because it addresses the PLC issues in the robust way while providing good quality of service (QoS).

We have provided valuable references for a full-fledged technical knowledge base needed to understand and become up to date with PLC technology and the HomePlug Standards. We hope that the readers and new researchers in the PLC arena will find this overview as a cornerstone for their base in the subject because this paper combined with [1] gives an overall understanding of the topic in a concise and quick way. It is meant for jump-starting the reader enabling him to quickly focus his attention to the finer technicalities and detailed understanding of the PLC technology.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

[1] Yousuf S., El-Shafei M., "Power Line Communications: An Overview - Part I." Proc. of the 4th International Conference on Information Technology, Dubai, Nov. 2007. pp 218-222.

[2] http://www.ist-opera.org/

[3] http://www.ist-powernet.org/

[4] http://www.upaplc.org/

[5] http://www.cepca.org/home

[6] http://portal.etsi.org/plt/Summary.asp

[7] The HomePlug 1.0 Technical White Paper.

[8] Proakis, J.G., *et al*, "Digital Communications", McGraw Hill, 1995.

[9] The HomePlug AV Technical White Paper

[10] Afkhamie K. H., Katar S., Yonge L., Newman R., "An Overview of the upcoming HomePlug AV Standard", IEEE. 2005.