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Digital Home Specification

White-paper

About this Document

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1. Executive Summary

The Universal Powerline Association (UPA) is an industry group formed with the objective of creating specifications for coexistence and interoperability of different broadband powerline technologies. The UPA has a universal scope, and its specifications are focused on both access and in-home applications, including worldwide coverage and considering requirements from manufacturers, service providers and all parts related to the PLC world.

On March 2005, UPA announced an initiative for the creation of a Digital Home Standard (DHS). The purpose of UPA DHS is to provide a complete specification for silicon vendors for designing integrated circuits for voice, video and data distribution using power lines.

This white paper provides an overview of UPA DHS specification v1.0, which was approved by UPA in February 2006, and covers the key areas of the PHY and MAC layers as well as descriptions of the higher layers.

The main features of UPA DHS technology are:

- 1536 carrier-OFDM modulation;
- adaptive bitloading, with physical layer data rate of 200 Mbps
- collision-free and flexible TDMA MAC;
- master/slave control architecture;
- peer-to-peer data transmission architecture;
- two operational bandwidth modes (normal mode and coexistence mode);
- physical spectral efficiency up to 8 bits/sec/Hz.;
- flexible PSD mask allowing frequency band notching dynamically and remotely;
- technology independent coexistence layer to allow coexistence between Access/In-home, In-home/In-home and future systems;
- 3DES encryption;
- advanced QoS with 8 priority levels;
- data isolation between neighbouring networks;
- compatible with the Open PLC European Research Alliance (OPERA).

2. About UPA

2.1 Mission

The Universal Powerline Association (UPA) [<http://www.upapl.org/>] aligns industry leaders in the global Power Line Communications (PLC) market and covers both access and 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 members share a vision of openness and a federated PLC world to harmonize and share standards and regulations globally.

2.2 Objective

The UPA aims to act as a catalyst for the growth of PLC technology by delivering UPA certified products that comply with agreed specifications. The UPA focuses on time-to-market, guaranteeing high performance and maximizing the usage of the spectrum for both access and in-home audiovisual and data networking PLC applications to the benefit of all players in the PLC value chain.

2.3 UPA Coexistence Standard

On June 2005, UPA published a document that specified a protocol for ensuring coexistence of several powerline technologies sharing the same medium. This document, which is available from specs@upapl.org, describes an advanced protocol for dynamic sharing of the channel using both dynamic frequency-division and time-division mechanisms. The specification supports simultaneous operation of one access network and up to three different in-home networks.

2.4 UPA DHS

On March 2005, UPA announced its initiative to create a Digital Home Standard (DHS). The purpose of DHS is to provide a complete specification for silicon vendors for designing integrated circuits for voice, video and data distribution using power lines.

Continuing the effort that had already been made by the Open PLC European Research Alliance (OPERA) [<http://www.ist-opera.org/>] project that focused on the specification of Broadband Access, UPA has undertaken the task of developing the PHY and MAC for in-home applications, achieving compatibility between Access and In-home networks.

2.5 UPA certification

The UPA Certification Working Group celebrated an UPA plugtest during first quarter 2006 as the first step on a path to the future certification of UPA products. This event was focused on digital home products, testing against the UPA DHS version 1.0 and UPA Coexistence Specification.

Several products from different manufacturers passed the tests, and were labelled as "UPA Plug Tested", ensuring performance, coexistence and interoperability.

In the next certification event, products certified by the UPA will bear the UPA compliance label, a customers' guarantee of reliability, on all UPA certified power line products and applications.

2.6 UPA DHS Key Features

UPA DHS specification will include all the necessary features required for high-speed audio/video distribution inside the home. The specification has been designed with two different scenarios in mind: managed and unmanaged in-home powerline networks:

- 1536 carrier-OFDM modulation;
- adaptive bitloading, with physical layer data rate of 200 Mbps;
- collision-free and flexible TDMA MAC;
- master/slave control architecture;
- peer-to-peer data transmission architecture;
- two operational bandwidth modes (normal mode and coexistence mode);
- physical spectral efficiency up to 8 bits/sec/Hz.;
- flexible PSD mask allowing frequency band notching dynamically and remotely;
- technology independent coexistence layer to allow coexistence between Access/In-home, In-home/In-home and future systems;
- 3DES encryption;
- advanced QoS with 8 priority levels;
- data isolation between neighbouring networks;
- compatible with the Open PLC European Research Alliance (OPERA).

3. Applications of indoors powerline technology

Several applications take advantage of powerline technology. This whitepaper focuses on two of them:

- high-speed Audio/Video (AV) Home Networking;
- Triple-Play Services Distribution.

3.1 High-speed AV Home Networking

Applications like high-definition video streaming between Media Center computers, Set-Top-Boxes, Personal Video Recorders, etc require performance levels that are currently only achievable with UPA DHS PLC technology. These devices share two key needs: very high speed requirements (20-40 Mbps) and no mobility advantage (TVs and STBs cannot move around the home).

In this document, these applications are grouped under the name of “High-speed AV (Audio/Video) Home Networking”.

Because it is not attenuated by concrete/brick/metal walls, UPA DHS technology is the only technology that provides whole-house coverage solution for High-speed AV (Audio/Video) Home Networking. UPA DHS’ transmission characteristics are very stable and predictable, thus improving the end-user experience. Two examples of application are shown in the figures below.

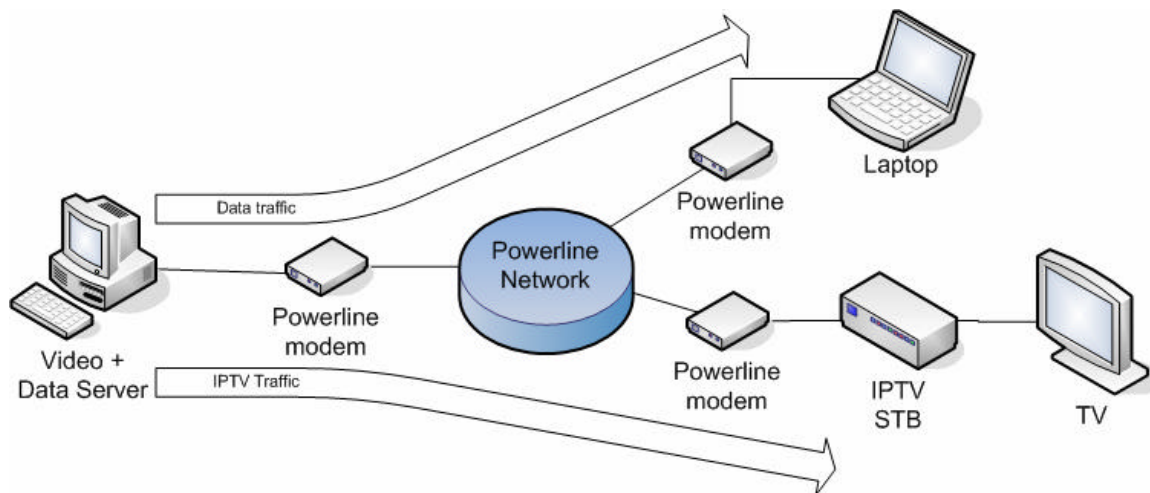


Figure 1 Video distribution In-home, internal server, no external connection.

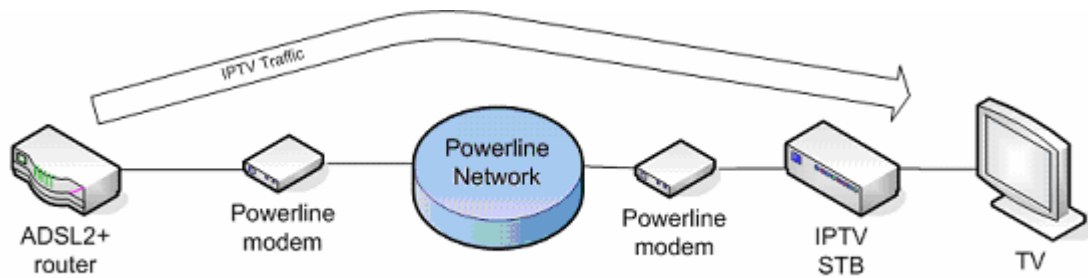


Figure 2 Video distribution In-home, external signal from other technologies.

3.2 Triple-Play Services Distribution

Competitive pressures in the broadband market are forcing telecommunications service providers to offer more complete services. One key trend is the provision of video services by DSL providers, who are competing with cable companies to provide “Triple Play” services consisting of video, voice and data, using only the telephone twisted pair.

One of the most important barriers to the provision of these services is the fact that the entry points of the twisted pair into the home are seldom close to the television. This leaves the home owner and the service provider with the problem of bridging the distance between the television with the phone socket, or more specifically between the set top box and the residential gateway. This connection poses a problem for operators because potential customers are not willing to add new cabling in their home, and because the installation of customer premises wiring represents an expensive contribution to the operator’s costs.

Installing fixed wiring to distribute digital video around the home is not only expensive for operators and unappealing for subscribers, but also restricts where in the home subscribers can use services to those where new wiring has been installed. With UPA DHS technology, it is possible to enjoy Triple Play services anywhere in the home, or deploy multiple services, for example having one set top box for video in the living room and another in the bedroom.

In many cases, subscribers are unwilling to upgrade to Triple Play services either because of the inconvenience of home wiring or for aesthetic reasons. Consumer resistance to new home wiring places a severe limitation on the available market for Triple Play services. UPA DHS is solution that does not require new wiring. This means that a complete home installation can be made without drilling a single hole or extending any structured cabling.

Many operators are currently looking at ways to make their offer more attractive by adding value to their broadband services. UPA DHS technology allows operators to provide subscribers with a complete home media network, allowing photos, home-movies and other content stored on a home PC, as well as IPTV and video-on-demand services, to be viewed on a TV set anywhere in the home.

3.2.1 Using broadband powerline technology over other media

Although UPA DHS technology was designed for usage over powerlines, this does not preclude its usage over different “metallic” media.

The UPA DHS high-frequency signal is transmitted independently of whether there is power in the line or not (a coupling unit isolates 50-60 Hz power from the transmitter/receiver).

Several companies have developed products that make use of UPA DHS' PHY and MAC over non-powerline media, mainly coaxial cables. This application is especially interesting for two reasons:

- in some geographical areas (mainly the North American residential market) there is a large installed base of in-home coaxial cables for TV distribution. For obvious reasons (shielding, controlled impedance, fewer devices connected), the coaxial cable is a much better transmission media than power lines. Any UPA DHS will operate at nominal speed (200 Mbps) almost 99.9% of the time when coaxial cables are used for transmission;
- device manufacturers can develop hybrid powerline/coaxial devices that make use of coaxial cable when it is available in a specific location, but use power lines when coaxial cable is not available (see Figure 3 for a sample block diagram of a hybrid device).

The possibility of deploying hybrid coaxial/powerline networks (see Figure 3) represents a huge advantage of UPA DHS technology over any other alternative.

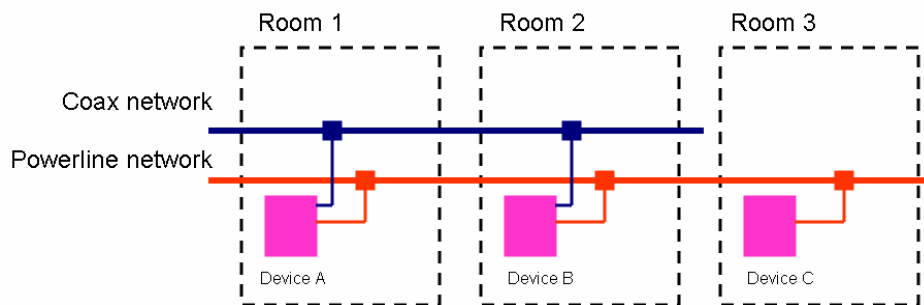


Figure 3 Block diagram of Hybrid coaxial/powerline network

Devices A and B transmit their high-frequency signal over both coaxial cable and power lines simultaneously. When Device B receives the signal from A, it will probably receive a much stronger signal from the coaxial cable than from the power line. As propagation over coaxial cable is very good, the signal-to-noise ratio will be very high, thus guaranteeing transmission data rates of 200 Mbps in 99.99% of situations. On the other hand, when Device B receives the signal from C, it will only receive signal from the power line, and no signal from the coaxial cable. In this case, performance will be dependent on the signal-to-noise ratio in the power lines, which will typically provide data rates in the 100-200 Mbps range.

4. UPA DHS Technology Specification

4.1 Layered Reference Model

The UPA DHS specification uses a Layered Reference Model, shown in Figure 4, to describe the different levels of its protocol stack. The Layers are defined as:

- PHY Layer defines the physical data transmission format on the medium;
- MAC Layer defines how different nodes are allocated transmission opportunities;
- LLC Layer defines how error free communication is achieved between nodes;
- Convergence Layer defines how standard protocols such as 802.3 Ethernet are mapped to the UPA DHS protocol and how the data encapsulation is made;
- Layer Management defines how each of the layers is configured and adapted to changing network conditions.

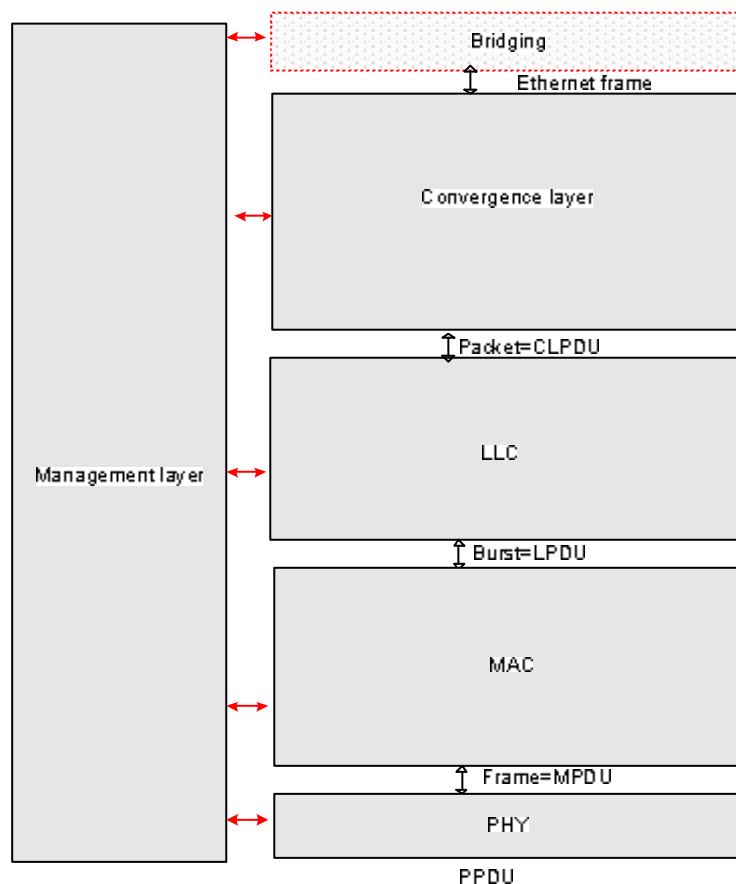


Figure 4 UPA DHS Layered Reference Model

In addition to these layers, mechanisms are provided for Encryption and Coexistence.

4.2 Physical Layer

The Physical Layer is based on Orthogonal Frequency Division Multiplexing (OFDM). OFDM has been chosen as the modulation technique because of its inherent adaptability in the presence of frequency selective channels, its resilience to jammer signals, its robustness to impulsive noise and its capacity of achieving high spectral efficiencies.

Concatenation of four-dimensional trellis Reed-Solomon forward error correction, specially tuned to cope with the very special powerline channel impairments, assures high performance in the worst case.

4.2.1 Bandwidth Capabilities

Most of the features that allow 200 Mbps data transmission reside in the Physical layer. The UPA DHS PHY features configurable frequency bands, with bandwidths of 20 or 30 MHz.

This bandwidth flexibility has been included in the system in order to support Frequency-Division (FD) coexistence mechanisms between UPA DHS in-home networks and OPERA access networks.

In its 30 MHz mode, UPA DHS systems provide a maximum physical throughput of exactly 240 Mbps, with information rates up to 158 Mbps.

4.2.2 Notching Capabilities

Broadband powerline employs frequencies that in some particular locations may be licensed to different radio services, like amateur radio, etc. Legal regulation in different countries may impose limitations on which frequencies can be used by powerline communications and which frequencies must be avoided (exclusion bands). Regulations are typically country-specific, so powerline communications products may be forced to use different frequencies depending on the country where they are used.

Spectral notching is a technique used for avoiding exclusion bands. Notches are created by turning off those OFDM sub-carriers that fall in the exclusion bands, thus eliminating the amount of energy transmitted in those bands.

UPA DHS uses windowed-OFDM modulation that allows programmable notches with a depth of up to 40 dBs, with a negligible loss of performance.

UPA DHS technology allows device manufacturers to create customised notch configuration for each country, without requiring any hardware changes.

Figure 5 shows an example of the type of arbitrary Power Spectral Mask that the UPA DHS system can achieve.

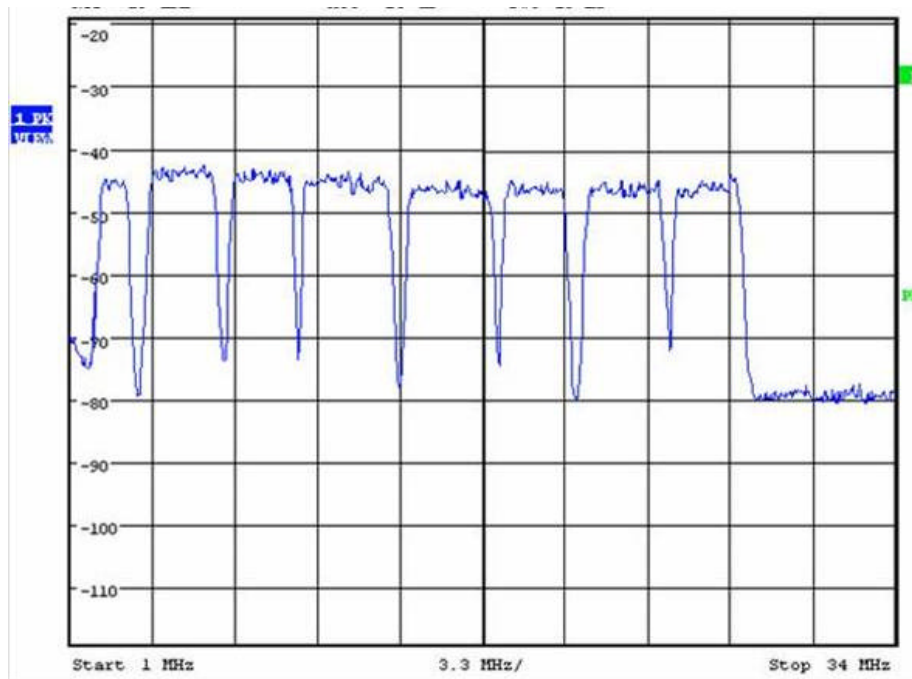


Figure 5 Example of a Power Spectral Mask with arbitrary nocthes

Additionally, in the case of a change in regulation, products that are already deployed in the field can be upgraded easily in order to guarantee compliance, avoiding costly product replacements.

4.2.3 The UPA DHS OFDM Symbol

The OFDM symbol uses 1536 sub carriers, with modulation densities from 2 to 10 bits per sub carrier applied independently to each of the sub carriers. The reason for choosing this high number of sub carriers is two-fold:

- achieves high accuracy when estimating channel Signal-to-Noise Ratio and adapting the modulation of each carrier accordingly;
- achieves very narrow notches, with small impact in neighbouring sub carriers.

4.2.4 Adaptive Bit-loading

Modulation parameters for each transmitter/receiver pair are adapted in real-time depending on channel quality parameters for each carrier. Figure 6 depicts an example of this functionality. The Signal-to-Noise Ratio (SNR, in black) is measured for each carrier and the optimum modulation (Bits-per-Carrier, BPC, in blue) is chosen, with the objective of achieving the maximum transmission speed while maintaining the desired Bit Error Rate (BER).

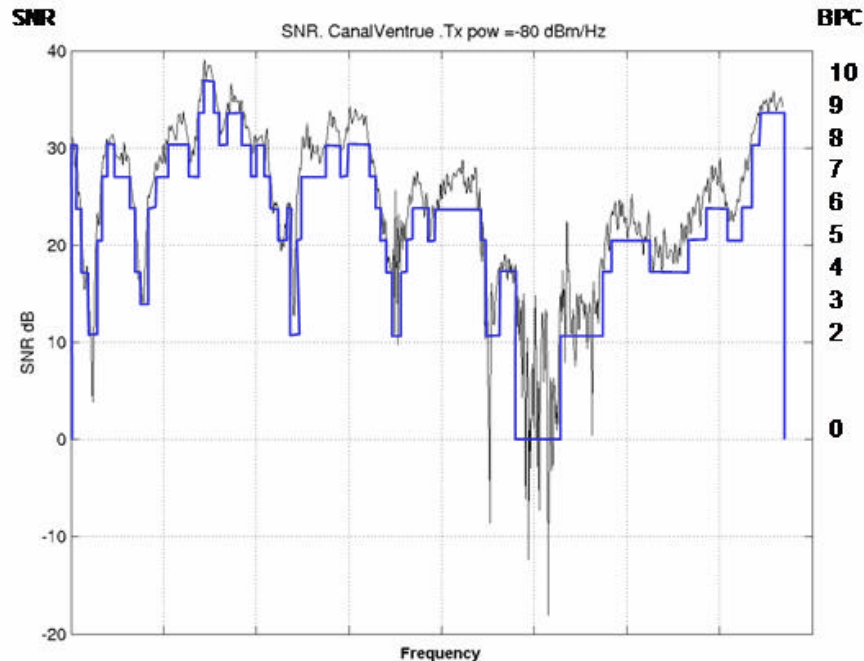


Figure 6 Sample "Signal-to-Noise Ratio" (SNR) and bitloading map for a sample powerline channel

4.2.5 Forward Error Correction

The PHY provides two different levels of reliability represented as two different bit streams.

The most reliable mode, known as HURTO, is reserved for information such as frame headers and control information that is critical for the correct operation of the system. In order to achieve such a high reliability, special Forward Error Correction, interleaving and frequency redundancy (depicted in the diagram as HURTO mapping) are used, jointly with a very robust modulation, to ensure the correct demodulation in the reception side, even in the worst channel conditions.

Normal data information can be transmitted using adaptive mapping to match tightly the channel characteristics in order to obtain the highest possible throughput for each case. This adaptation includes not only the bits per carrier that can be used for a certain desired bit error rate, but also a dynamic Reed-Solomon configuration for each of the transmitted packet, depending on the channel state.

Once the OFDM symbol has been constructed, a four-dimensional Trellis Coded modulation is performed, increasing the reliability of the transmitted signal.

4.2.6 Symbol Transmission

After each carrier has been independently modulated, the whole frequency-domain signal is processed by an IFFT block. After this block, the cyclic prefix is added, and the transmission window is applied.

The final block represents the Analog Front End and the coupling unit to inject the final OFDM signal into the power line channel

4.3 Medium Access Control (MAC) Layer

4.3.1 Advanced Dynamic Time Division

UPA DHS technology uses an Advanced Dynamic Time Division (ADTDM) MAC that is optimized for Audio/Video distribution scenarios, where high performance, stringent bandwidth reservation, strict traffic prioritization and QoS are a must. The ADTDM MAC provides collision-free access for the channel to all the nodes in the power line network according to different service priorities. These can be adjusted to suit different types of applications, ranging from data, VoIP, Video on demand, etc.

The arbitration of the channel access is controlled by a centralized entity in the network in a way that adapts to the different topology possibilities, ensuring that all transmissions are compliant with the defined QoS profile. All nodes in the network are considered in the sharing mechanism, including hidden nodes, ensuring that any node in the network could have access to the channel if required.

UPA DHS MAC also provides flexibility, including different scheduling transmission formats depending on impulsive noise and channel impedance.

4.3.2 MAC Network Entities

At the MAC level, any UPA DHS device can play one of the following roles:

- Access Point: Access Point (also known as “master”) devices control the access to the channel of the other devices, and make sure that resources are allocated in a way that satisfies QoS requirements. Access Points are responsible for generating the channel “token” and distributing this token to the rest of devices in the network. The master will be also responsible to assign resources only to active nodes, avoiding loss of performance and ensuring maximum throughput at all times;
- Repeater: a repeater is a device that receives packets addressed to another device and re-transmits them;
- End-Points: an end-point (also known as “slave”) is a device that is not an Access Point or a Repeater.

At boot time, every device is an End Point. Access Points and Repeaters are elected automatically once the network starts operation.

UPA DHS provides mechanisms to ensure that:

- there is always one and only one Access Point in a given UPA DHS network;
- every device is connected to the network either directly through the Access Point or indirectly through a repeater.

4.3.3 Channel Arbitration and Tokens

At any given time, the Access Point is responsible for deciding:

- the optimum set of parameters for the operation of the MAC protocol depending on the number of devices in the network, the type of traffic that is being transmitted, etc;
- how much channel time is given to each device.

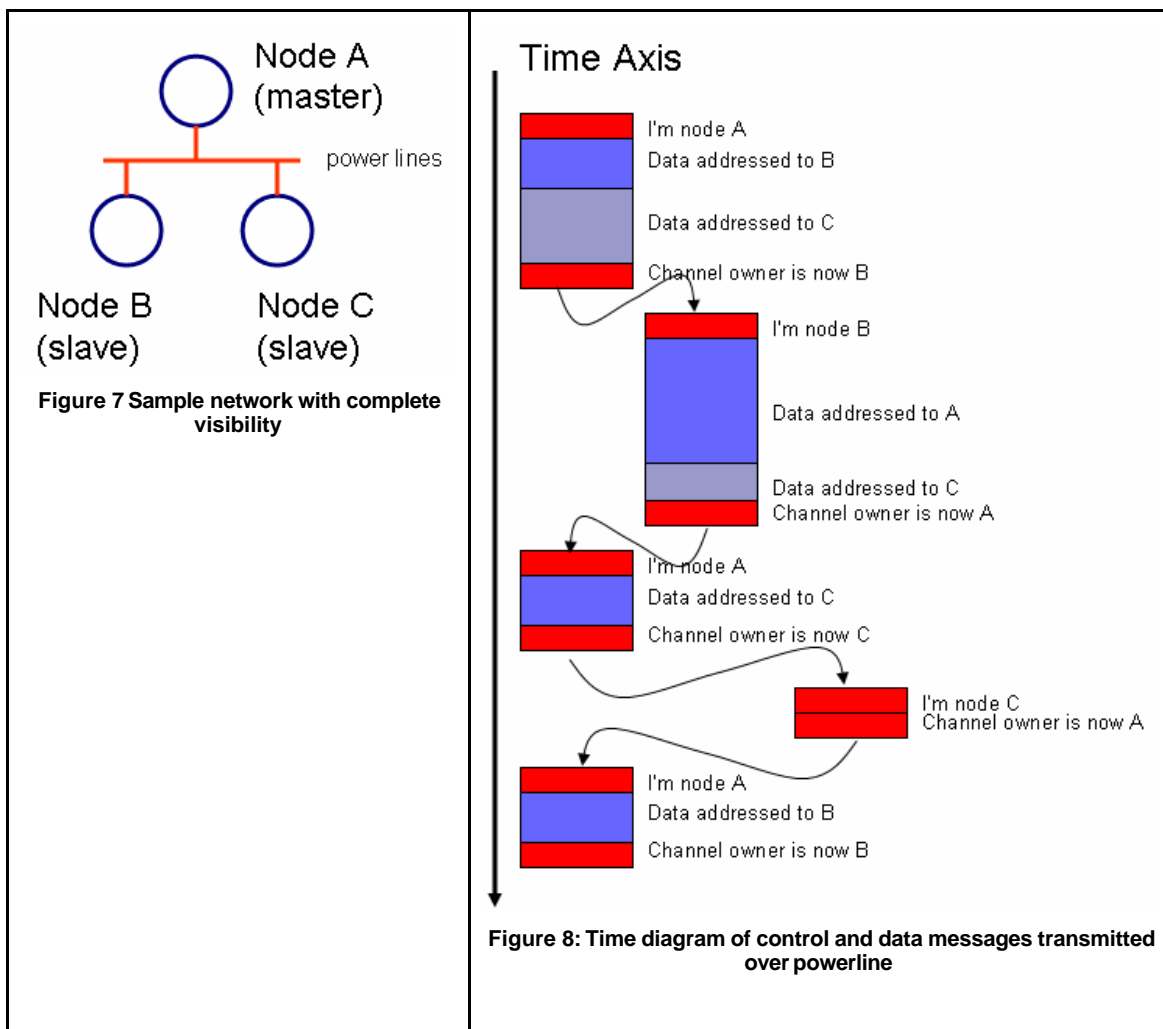
A graphical example of the operation of the MAC protocol is given in Figure 7 and Figure 8. Figure 7 depicts a sample network with three nodes (one Access Point and three End Points). All three nodes have direct visibility of each other, so they can communicate directly. The time evolution of a possible communication scenario is shown in Figure 8:

1. Node A (the Access Point) starts the communication process:
 - a. It transmits a short control message, announcing that the following powerline frames come from Node A. This short control message also includes additional PHY-level information (required for the receivers to configure the right reception gain and the OFDM demodulators).
 - b. It then transmits a data burst addressed to Node B, followed by another burst of data addressed to Node C.
 - c. Finally, it sends another control message yielding the channel control to Node B. This control message includes information about the maximum time that node B can make use of the channel.
2. After receiving the token from Node A, Node B can start transmission over the power line channel:
 - a. As before, it transmits a short control message, announcing that the following powerline frames come from Node B.
 - b. It then transmits a data burst addressed to Node A, followed by another burst of data addressed to Node C.
 - c. Finally, it returns the channel control to node A (the Access Point).
3. After having the token returned from B, A is now the “channel owner” again:
 - a. As before, it transmits a short control message, announcing that the following powerline frames come from Node A.
 - b. It then transmits a data burst addressed to Node C.
 - c. Finally, it sends another control message yielding the channel control to Node C.
4. After receiving the token from Node A, Node C can start transmission over the power line channel. In this specific case, Node C does not have any data to transmit, so it will return the token immediately to Node A.
 - a. Node C transmits a short control message, announcing that the following powerline frames come from Node C.
 - b. It immediately returns the channel control to node A (the Access Point).

5. Now Node A is again the channel owner, and the cycle can start over again.

This dynamic MAC mechanism has several advantages:

- only one node is transmitting at any given time;
- collisions are completely avoided;
- the Access Point has total control over how much time each node has control of the channel;
- there is a deterministic upper bound on how much time it will take for a given node to gain access to the channel (bounded channel access latency), which is critical for AV applications;
- negligible bandwidth is wasted if a given node does not have any data to transmit, as channel control can be returned immediately to the Access Point.

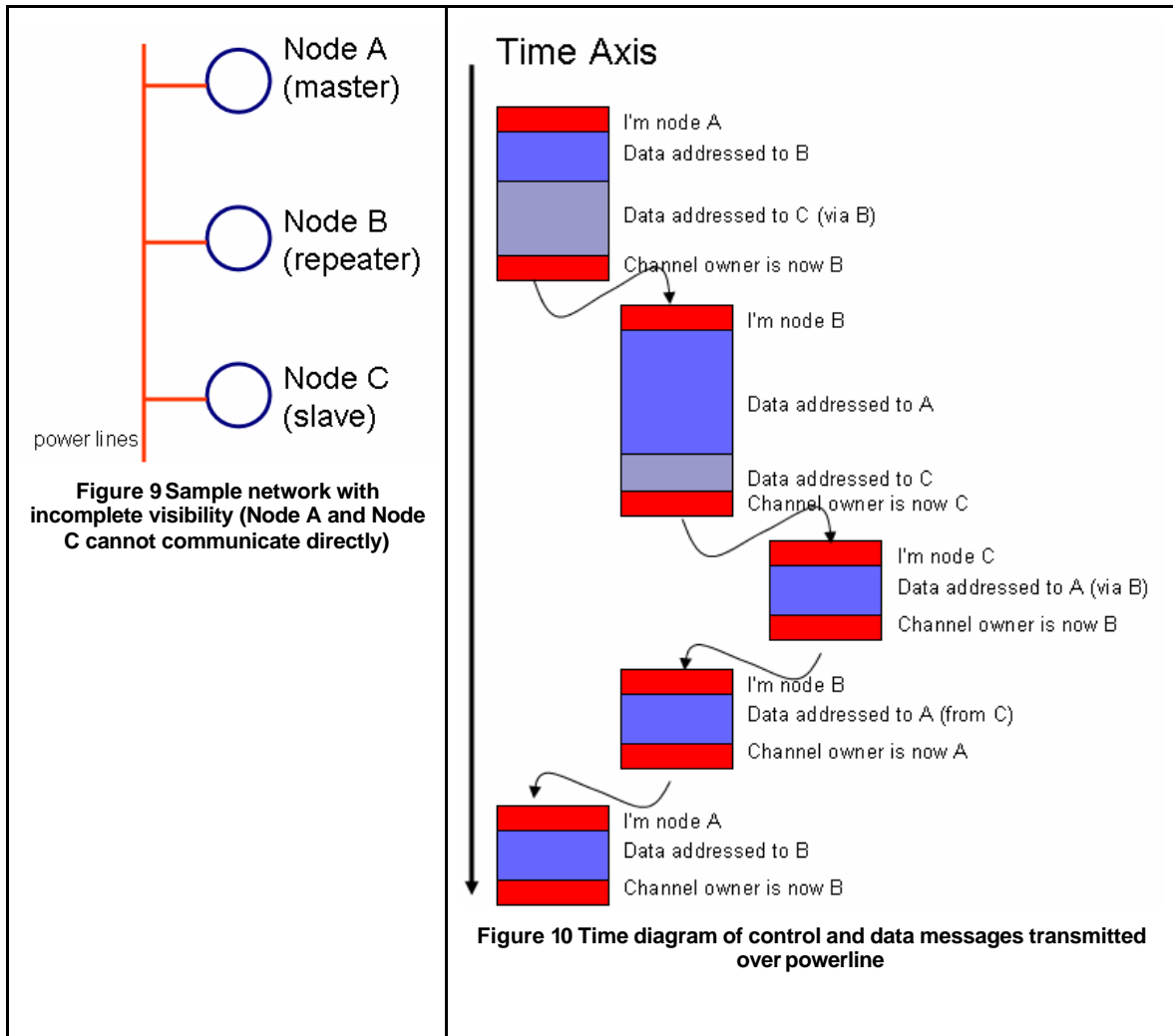


This token-passing scheme is very powerful and flexible, and it can be extended to networks where not all nodes can “see each other” directly (partial or incomplete

visibility). In these situations, one device can act as a repeater for both data and control messages.

Figure 9 shows a network with “incomplete visibility” (Node A and Node C cannot communicate directly). Figure 10 shows the time diagram of a sample communication scenario in such a network, in which Node B (repeater) must play the role of a bridge between Node A and Node C:

1. Node A (the Access Point) starts the communication process:
 - a. It transmits a short control message, announcing that the following powerline frames come from Node A.
 - b. It then transmits a data burst addressed to Node B. After this, it sends another burst of data which is addressed to Node C. This mechanism allows Node A to transmit data to Node C using Node B as an intermediate repeater.
 - c. Finally, it sends another control message yielding the channel control to Node B.
2. After receiving the token from Node A, Node B can start transmission over the power line channel:
 - a. It transmits a short control message, announcing that the following powerline frames come from Node B.
 - b. It then transmits a data burst addressed to Node A, followed by another burst of data addressed to Node C (part of the data information in this burst comes from Node A, and part may come from Node B itself).
 - c. Finally, it forwards the channel control to node C.
3. After receiving the token from Node B, Node C can start transmission over the power line channel:
 - a. It transmits a short control message, announcing that the following powerline frames come from Node C.
 - b. Node C sends a burst of data which is addressed to Node A
 - c. Finally, it returns the channel control to node B (the Repeater).
4. After receiving the token back from Node C, Node B can start transmission over the power line channel:
 - a. It transmits a short control message, announcing that the following powerline frames come from Node B.
 - b. Node B sends a burst of data which is addressed to Node A (with information originated at C).
 - c. Finally, it returns the channel control to node A.
5. Now Node A is again the channel owner, and the cycle can start over again.



The MAC protocol includes a whole set of auxiliary mechanisms (not discussed in this whitepaper) to guarantee the correct operation of the protocol. There are sub-protocols for:

- handling new nodes joining the network;
- automatic discovery of the network topology, allowing nodes with incomplete visibility to communicate with other nodes out their reach, making use of intermediate repeaters;
- optimization of communication topology, ensuring maximum performance and throughput between two nodes of the network, using direct communication or allowing repetition mechanism;
- learning which hosts/devices are reachable via each powerline device, based on an 802.1d learning model;
- handling nodes being disconnected from the network;

- token recovery in case of having one node disconnected while it was the channel owner;
- new Access Point selection in case of having the Access Point disconnected from the network.

4.3.4 Types of MAC Frames

There are three main types of frames:

- *data frames* contain PLC bursts as payload. UPA DHS nodes may include PLC bursts addressed to several destinations in the same frame in order to maximize efficiency;
- *channel estimation frames* are sent periodically by every node so that communicating nodes can estimate their channel and adjust the number of bits per carrier suited for that channel;
- *access frames* are used by Access Point and Repeater nodes to invite new nodes to join the power line network. Upon reception of an access frame, new nodes contend for access to the channel using a back-off algorithm. After contention is won, both nodes (the Access Point or Repeater that sent the Access frame and the new node joining the network) initiate the connection (setting up QoS parameters, negotiation of modulation parameters, etc).

4.3.5 Burst Format

Each frame is made up of a series of Bursts, which contain data transmissions between individual logical links in the system. Within each burst, a burst header indicates the logical link identifying the receiving and transmitting nodes, followed by the payload data formatted as a series of Codewords.

4.3.6 Codeword Format

Codewords are transmission sequences consisting of a pure Data Payload followed by a number of bits of Redundancy. Codewords are formed using a variable-rate Reed-Solomon block encoder.

4.4 *Link Layer Control (LLC) Layer*

The LLC Layer in UPA DHS ensures the error free transmission of data between pairs of power line nodes. This is done in transmission by encoding the Data Payload provided by the Convergence Layer into sequences of Codewords. These Codeword Sequences, called Bursts, are transmitted between node pairs using an optional acknowledgement scheme.

4.4.1 Burst structure

A burst is composed of a Burst Header delimiter followed by a data payload including one or several fragmented and/or completed packets. A Burst Header delimiter without any following data payload is used to send ACK when there are no data to be sent.

Figure 11 shows how the mapping/encapsulation of an Ethernet 802.3 frame is performed in UPA DHS, in the case that a packet has to be fragmented in several bursts.

1. The packet is split to fill the payload sections of the codewords, to which Reed-Solomon redundancy data will be added.
2. A header is added to each codeword that carries information required for later merging all codewords together into the original Ethernet frame.
3. Groups of codewords are concatenated into a burst.

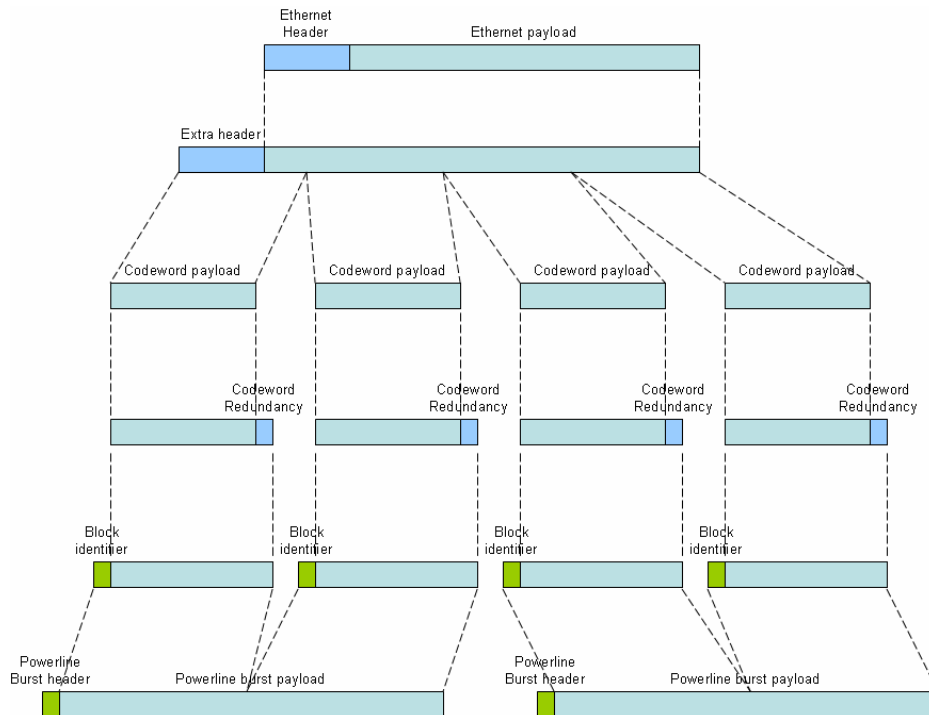


Figure 11 Generic Mapping of an Ethernet frame into PLC-level bursts

4.4.2 Burst Acknowledgement Scheme

UPA DHS uses a “Sliding Window” protocol for managing reliable end-to-end transmission of data frames. Each burst has a “burst identification number”. During normal system operation, the receiver sends an acknowledgement (ACK) of the last “burst identification number” correctly received.

The ACK protocol, shown in Figure 12, works as follows:

1. firstly, the “left node” transmits a series of bursts (with identification numbers 1, 2 and 3) to the “right node”. The “left node” keeps those bursts in the transmission buffer, in case they need to be retransmitted;
2. due to channel noise, burst #3 is corrupted. Only bursts 1 and 2 are correctly received;
3. the “right node” nexts sends a control message to the “left node”, acknowledging that the last successfully received burst was burst #2;
4. the “left node” then removes bursts #1 and #2 from the transmission buffer and retransmits burst #3;
5. this time, burst #3 is correctly received, so the “right node” sends a new control message acknowledging that burst #3 has been correctly received;
6. after receiving the ACK, the “left node” removes burst #3 from the transmission buffer.

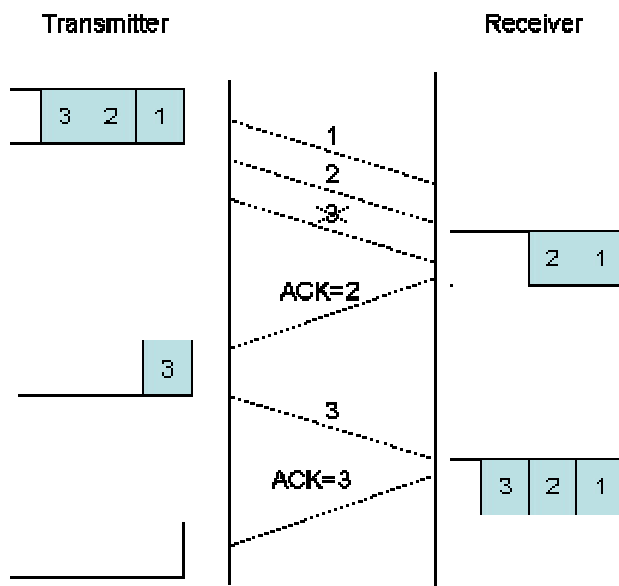


Figure 12 Burst Acknowledgement Scheme

This ACK protocol provides several advantages:

- a group of several bursts can be sent to a given node, without waiting for each specific burst to be acknowledged. This allows for longer transmission frames, which increases efficiency;
- packet losses at the power line level are hidden from the application layer, which only perceives an “Ethernet-like” zero-loss channel.

4.5 Convergence Layer

The function of the Convergence Layer is to encapsulate packets coming from external applications (typically 802.3 Ethernet frames, although other encapsulations could be defined) before passing them to the LLC for transmission.

The Ethernet frame is encapsulated into a powerline packet, which is basically formed from the original Ethernet frame plus a powerline header that includes information such as powerline-level priority, OVLAN (an extension of VLAN), broadcast control information, etc.

4.5.1 Virtual LAN Management

Virtual LAN (VLAN) management allows an UPA DHS network to be separated into different independent isolated sub-networks that can be managed independently.

In addition, the standard 802.1q VLAN, is extended with additional OVLAN tagging capabilities, providing an additional tagging field that can be used independently of the standard 802.1q VLAN tags.

4.6 Layer Management

4.6.1 Control protocols

UPA DHS defines a specific format for exchanging control information between nodes that uses SNAP encapsulation in regular Ethernet frames. The main control protocols are:

- adaptive bit-loading protocol used to exchange bit-loading tables to adapt the transmission characteristics to the channel;
- access protocol used to accept new nodes in the network;
- port solver protocol used to exchange addressing information between nodes;
- cluster discovery protocol used to discover nodes that can transmit simultaneously without interfering each other, so that spatial reuse can be achieved;
- connection admission protocol to reserve resources for data flows;
- automatic management of crosstalks between not synchronized systems used when two independent networks interfere each other.

4.6.2 Spanning Tree Protocols

Spanning Tree protocols are fully configurable by the operator, including the improved Rapid Spanning Tree algorithm specially developed and optimized to match powerline network topology particularities. This advanced algorithm takes into account not only the structure at network level, but also PHY layer parameter to obtain the best networks paths in the network.

4.7 Quality of Service (QoS)

High-speed AV Home Networking or Triple Play Services distribution using power lines are very demanding applications, for one simple reason: they must provide huge amounts of bandwidth (in the 20-40 Mbps range) with very high stability and QoS, at a very large percentage (99%) of outlets in the home.

The system must provide smooth video delivery even under difficult conditions like intermittent noise, interference from neighbouring powerline networks or a network with simultaneous low priority data traffic.

UPA DHS implements capabilities to transport traffic with different service requirements and to handle each traffic type with the appropriate Quality-of-Service (QoS) level.

UPA DHS includes several mechanisms to enforce QoS for powerline applications:

- traffic classification;
- Centralized Bandwidth management.

4.7.1 Traffic classification

In order to handle different services and applications adequately, UPA DHS devices identify the class of service to which each specific Ethernet frame belongs. Although the way to do this is implementation-specific, the recommended mechanism is using a “Service Classifier” module. The Service Classifier module is responsible for determining the priority level of each frame according to a set of established rules.

The Service Classifier entity, shown in Figure 13, works as follows:

- incoming frames are inspected, one by one, looking for patterns that the Service Classifier can use for determining priorities;
- once the priority has been determined, a “tag” is added to the frame, so that it can later be identified by other entities of the UPA DHS specification;
- the set of programmable rules are typically of the following type:
 - Rule 1: If the byte in offset AA of the Ethernet frame is BB, then the priority of the packet is CC;
 - Rule 2: If the byte in offset DD of the Ethernet frame is EE, then the priority of the packet is FF, and so on.
- typical default rules for the Service Classifier could be: decide priorities according to bits in 802.1p field, or according to bits in IPv4 TOS field, etc.

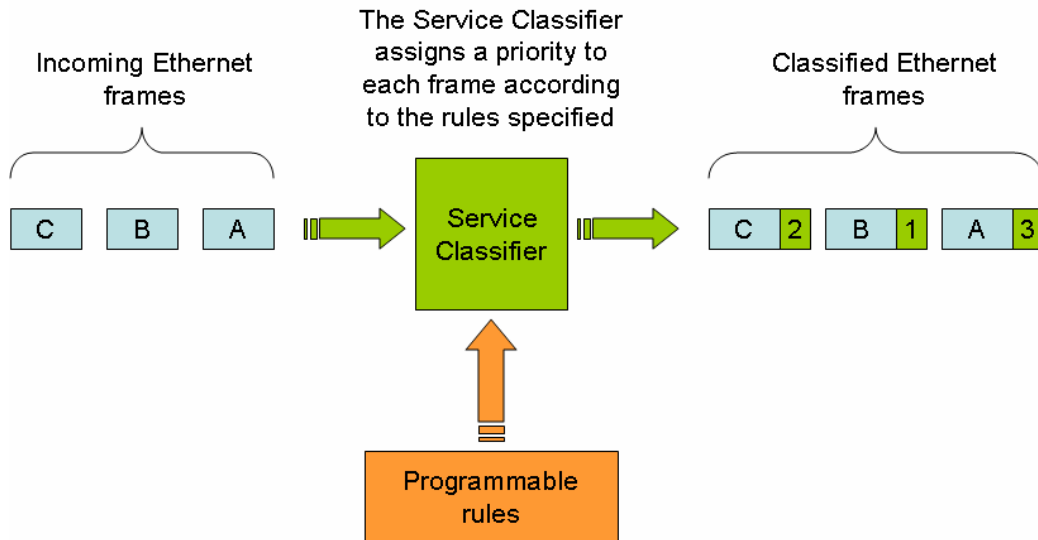


Figure 13 Service Classifier Module

4.7.2 Centralized bandwidth management

One of the advantages of having a master/slave dynamic ATDMA MAC is that the system can easily support very sophisticated QoS algorithms, including bandwidth reservation, latency guarantees, etc.

In UPA DHS MAC, the Access Point device allocates channel access time to each device in a centralized manner, having complete information about the network, including the bandwidth requirements of each application, the available data rate between any pair of devices, etc.

The UPA DHS specification is very flexible, in the sense that it allows device manufacturers to implement very flexible QoS algorithms, specifically optimized for their application, while maintaining compatibility with UPA DHS baseline specification.

4.8 Security Mechanisms

UPA DHS implements two mechanisms to ensure privacy and security:

- isolation of logical networks, using the concept of “Network Identifier”;
- encryption of data communications, using a hybrid 3DES/DES encryption scheme.

Both mechanisms are independent and can be used either with or without the other.

4.8.1 Network Identifier and neighbouring networks

Two UPA DHS will only communicate (i.e. exchange data) if they have the same “Network Identifier” (Net-ID). Devices with different Net-IDs will still “see each other”, and they will peacefully share channel bandwidth.

The Network Identifier in UPA DHS is similar in functionality to the 802.11 Service Set Identifier (SSID).

In addition, Ethernet filtering is implemented, preventing:

- Ethernet frames from one customer leaking into a neighbouring customer (for security reasons);
- Ethernet frames from one powerline sub-network (for example, an LV cell) leaking into another powerline sub-network (for security reasons and in order to avoid the problem of bridge tables filling up with unnecessary MAC addresses).

4.8.2 3DES Encryption

UPA DHS specification includes a powerful security structure based on 168-bit Triple DES (3DES) encryption that guarantees the privacy of communications established between UPA DHS devices.

UPA DHS specifies that each device must support several encryption keys, thus having the possibility of communicating with different devices, using different encryption keys.

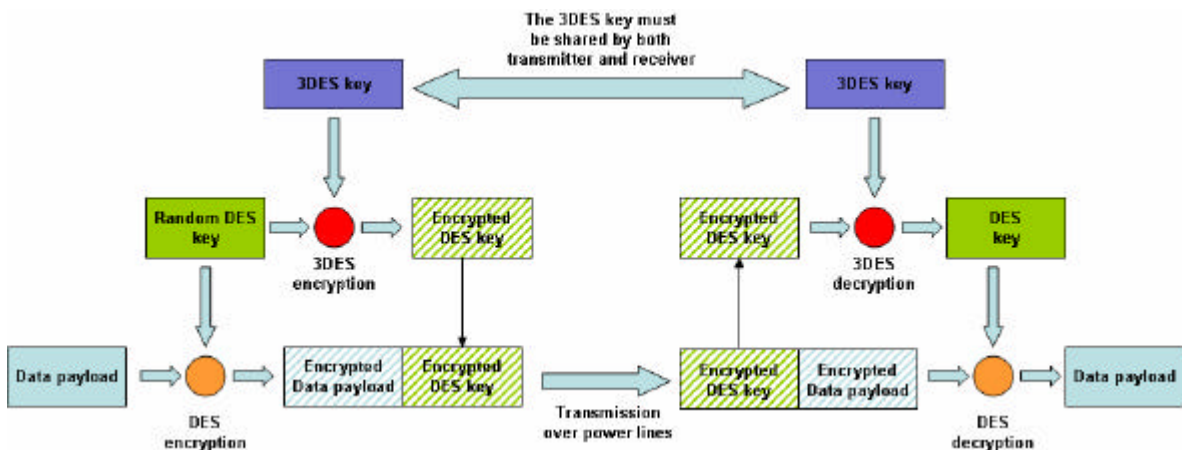


Figure 14 Hybrid DES/3DES encryption mechanism

UPA DHS encryption is based on a hybrid 3DES/DES encryption architecture. A diagram of this architecture is depicted in Figure 14. The encryption mechanism works as follows:

1. both transmitter and receiver have to agree on a common 3DES (168 bits) encryption key. This is achieved typically by having the end-user enter the same key in both devices using a configuration tool or any other mechanism;
2. once a new data frame needs to be transmitted, a new random DES (56 bits) encryption key is created;
3. the data frame is encrypted with the DES key;
4. the Random DES key is encrypted with the common 3DES encryption key, and appended to the encrypted data frame;
5. both the encrypted data frame and the encrypted DES key are transmitted through the powerline channel;

6. the receiver obtains the encrypted DES key and decrypts it using the common 3DES key;
7. the receiver uses the decrypted DES key for decrypting the encrypted data frame;
8. the receiver obtains the decrypted data frame.

The advantages of this system are:

- the 3DES key is never transmitted over the powerline channel;
- a new random DES key is generated for every new data frame, thus completely eliminating the risk of a potential eavesdropper guessing the DES key by doing a long term analysis of the transmitted data;
- the rather resource intensive process of performing 3DES encryption is only applied to the short DES key (56 bits), instead of being applied to the whole data frame (potentially several kilobytes);
- a relatively simple encryption process (DES encryption) is applied to the data frame, thus saving silicon area and computing power.

4.9 Coexistence Mechanisms

On June 2005, UPA published a document that specified a protocol for ensuring coexistence of several powerline technologies sharing the same medium. This document, which is available from specs@upapl.org, describes an advanced protocol for dynamic sharing of the channel using both dynamic frequency-division and time-division mechanisms. The specification supports simultaneous operation of one access network and up to three different in-home networks.

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