Work Package:	WP3
Type of document:	White Paper
Date:	01/02/06

IST Integrated Project No 507667

Circulation:

- ☒ **Public**
- ☐ **Confidential**
- ☐ **Restricted**

OPERA TECHNOLOGY WHITE PAPER

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GLOSSARY AND ACRONYMS

ACK	Acknowledgement
ADTDM	Advanced Dynamic Time Division Multiplexing
AS	Access System
AV	Audio/Video
BPC	Bits Per Carrier
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
DAC	Digital to Analogue Conversion
DES	Data Encryption Standard
DHCP	Dynamic Host Configuration Protocol
EC	European Commission
EMC	Electro-Magnetic Compatibility
ETSI	European Telecommunications Standards Institute
FD	Frequency Division
FP6	Framework Program 6
HE	Head End
HURTO	High Ultra Reliable Transmission for OFDM
IFFT	Inverse Fast Fourier Transform
IHS	Inhome System
IQ	In-phase and Quadrature
IST	Information Society Technologies
LLC	Logical Link Control
LV	Low Voltage
MAC	Medium Access Control
MIB	Management Information Base
MV	Medium Voltage
NMS	Network Management System
OFDM	Orthogonal Frequency Division Multiplexing
OPERA	Open PLC European Research Alliance
OVLAN	Optimized VLAN
PDU	Protocol Data Unit
PHY	Physical Layer
PLC	Powerline Communication
PSD	Power Spectral Density
PSTN	Public Switch Telephone Network
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Service
RFC	Request For Comments
RP	Repeater
SLA	Service Level Agreement
SNAP	SubNetwork Access Protocol
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise Ratio
TD	Time Division
VLAN	Virtual Local Area Network
VoIP	Voice over IP

REFERENCES

[1] OPERA D59. OPERA Specification

1 Executive Summary

The OPERA technology allows powerlines to be used to provide high performance internet connectivity. Following a two year effort and an outlay in excess of 20M€ by the European Union backed consortium, this is the first open Powerline specification, opening the doors for technology providers to build interoperable products.

This white paper provides an overview of the technology specifications defined by the OPERA Project [1], covering the main technical aspects of the OPERA specifications, including an explanation of the key areas of the PHY and MAC layer as well as descriptions of the higher layers.

2 About OPERA

OPERA is an initiative to foster the deployment of PLC by developing technology to allow powerlines to be used to provide high performance low cost broadband access service everywhere. OPERA has a budget of about 20 Million Euros, including a funding of 9 Million Euros from the European Commission in the framework of the FP6 call of the IST program.

The project provides a technology which enables electrical infrastructure to be adapted to provide competitive, HAM radio friendly PLC-based broadband services requiring low investment costs and minimum maintenance effort.

The OPERA project aims not only to provide a PLC standard but to share its vision of a world where operators and subscribers benefit from this revolutionary technology:

- Operators benefit from the availability of standard interoperable PLC equipment that allows the deployment of networks at low cost and the re-use of electricity network infrastructure.
- Subscribers benefit from a wider range of options for broadband access services especially where alternative technologies are not available.

The simplicity of network integration with different technologies and complete end-user coverage contribute to the deployment of these added-value services over broadband such as smart home, video streaming, e-health, telephony, tele-surveillance etc.

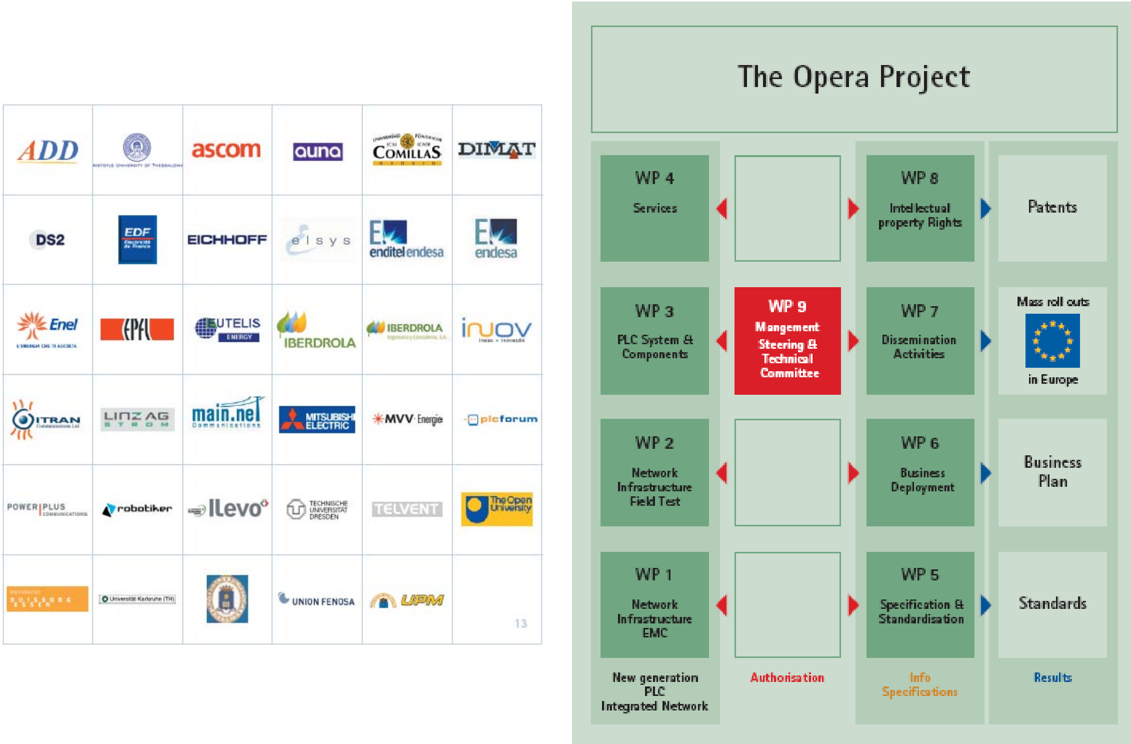


Figure 1 OPERA members and structure

2.1 OPERA Members and structure

The OPERA consortium involves the main stakeholders in PLC: electric utilities, equipment manufacturers, technology providers, universities, engineering consultancy companies and telecom operators.

All these partners have committed themselves to collaborate under the umbrella of the EC IST program and work together to achieve OPERA objectives.

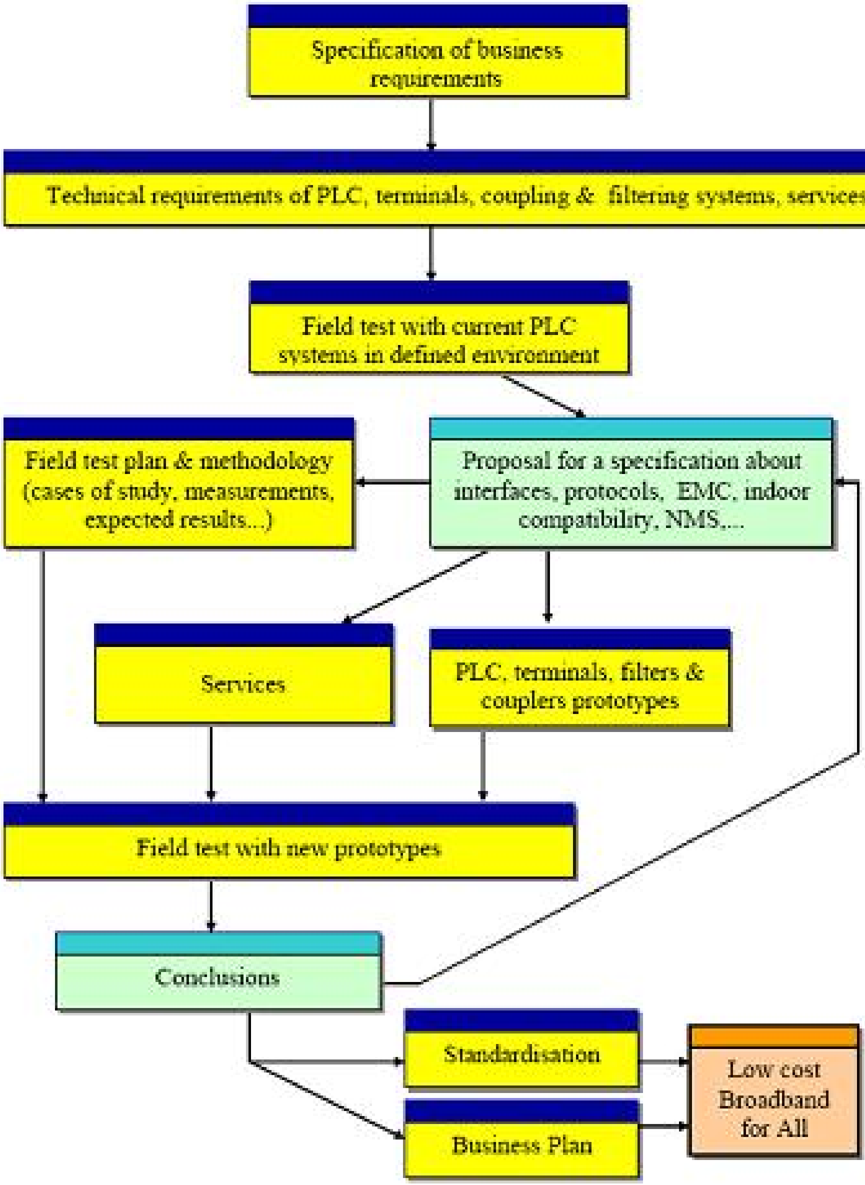


Figure 2 OPERA Project Overview

2.2 OPERA Time line

The OPERA project officially started its activities on January 1st 2004 (IST proposal/contract number 507667) and ran until the end of January 2006. Since the beginning a number of important milestones have been achieved:

- In November 2004, the OPERA Steering Committee endorsed a technology Selection Process based on the Marketing and Functional Requirement Document submitted by the Standardization Working Group of OPERA. This process led to the selection of a powerline communications technology to be used as baseline to develop and complete the OPERA Powerline Communications (PLC) solution. The baseline technology delivers speeds of more than 200 Mbps and is based on OFDM High Density modulation. It provides a high dynamic range (90 dBs) and offers Frequency Division and Time Division repeating capabilities.

- In August 2005, the field trials started, using prototypes from different equipment providers, which are compatible with the selected technology baseline. Four locations were selected to conduct the field/user trials: Ivrea, Italy (ENEL/WIND); Madrid, Spain (Iberdrola); Linz, Austria (Linz Strom); Lisbon, Portugal (EDP).

- An "OPERA Contribution to ETSI" indicating the main aspects of the technology, was submitted in September to the European standardization body ETSI.

- The OPERA Specification has been developed in the OPERA Specification Working Group, and has been approved on January 31st for its public release.

2.3 OPERA Key Features

The OPERA Specification has several features that make it advantageous to operators, related to powerline performance and network management as well as regulation matters:

- +200 Mbps OFDM modulation.
- Configurable frequency bands (width and spectral location).
- PHY spectral efficiency up to 8 bits/sec/Hz.
- Flexible PSD mask allowing frequency band notching dynamically and remotely controlled from the management centre, without any local intervention.
- A special robust mode to be reliable in the most difficult channels.
- Technology independent coexistence layer to allow coexistence between Access/In-house and future systems.
- 3DES encryption.
- Support for impulsive noise mitigation techniques.
- Time Division and Frequency Division repeaters can be used. The technology allows an unlimited number of repeaters to guarantee full coverage.
- QoS with 8 priority levels.
- Bandwidth control.
- Spatial Reuse Algorithm.

2.4 OPERA Deployment Model

The OPERA PLC network is composed of three types of PLC units:

- Head End Equipment (HE) which connects the PLC network to the backbone infrastructure.
- Repeater Equipment which is used to extend the coverage of the network.
- Customer Premises Equipment (CPE): connects the end user to a PLC access network.

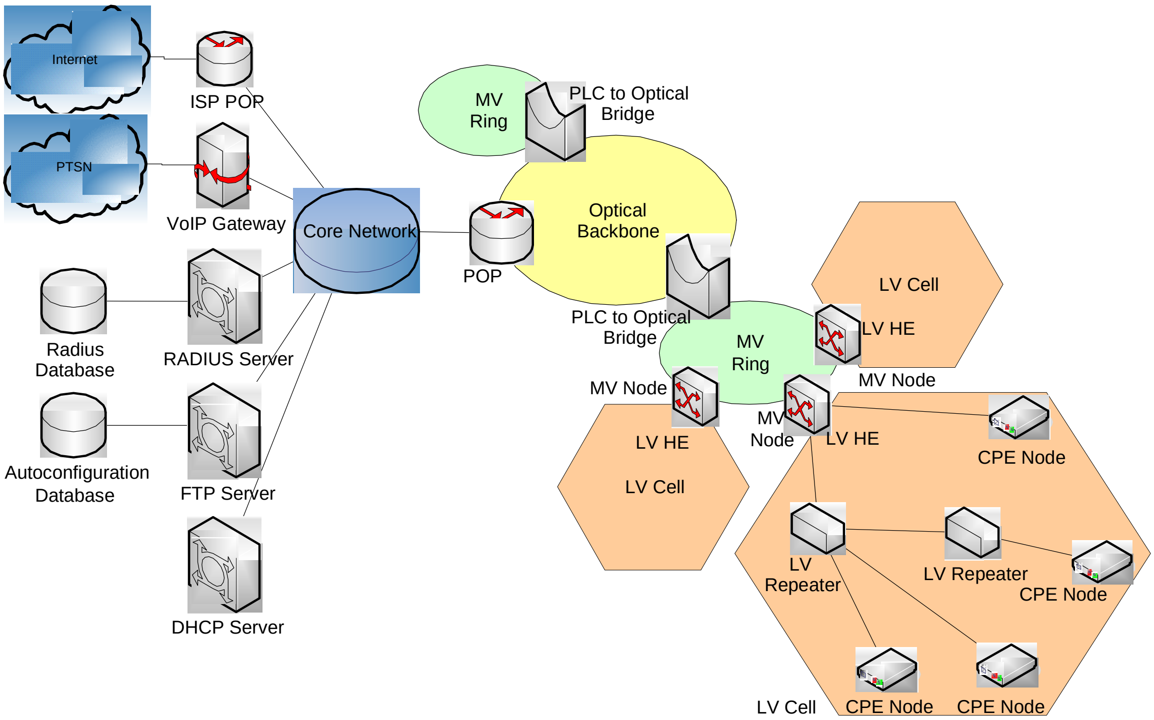


Figure 3 OPERA Powerline Access Topology

The OPERA Powerline Access Topology Model breaks the network down into a number of levels. Centrally, a core network provides core switching and management functions such as gateways to the Internet and PSTN, RADIUS authentication, DHCP services and Storage of network configuration data. To provide very wide area networking links, an optical fiber network is used to connect to remote medium-to-low voltage transformer sub-stations. As low cost alternative to optical fiber, the data link can be channeled onto medium voltage (MV) power-lines allowing the connection of all the sub-stations.

The electricity network which spans from each medium-to-low voltage transformer to the electricity users fed by those transformers is known as a LV cell. The PLC connectivity within a LV cell is provided in a tree topology, with a Head End (HE) which usually connects the LV cell to the medium voltage network. Customer Premises Equipment (CPE's) may be connected directly to the HE or through a series of Repeaters (RP). Repeaters increase the range of the PLC signal by retransmitting the signal that they receive either at a different frequency to the signal that they receive (Frequency Division) or in different time slots (Time Division).

3 The OPERA Specification

3.1 Layered Reference Model

The OPERA specification uses a Layered Reference Model 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 handles packets segmentation and grouping and defines how error free communication is achieved between nodes
- Convergence Layer defines how standard protocols such as 802.3 Ethernet are mapped to the OPERA protocol and how the data encapsulation is made.
- Layer Management defines how each of the layers is configured and adapted to changing network conditions.

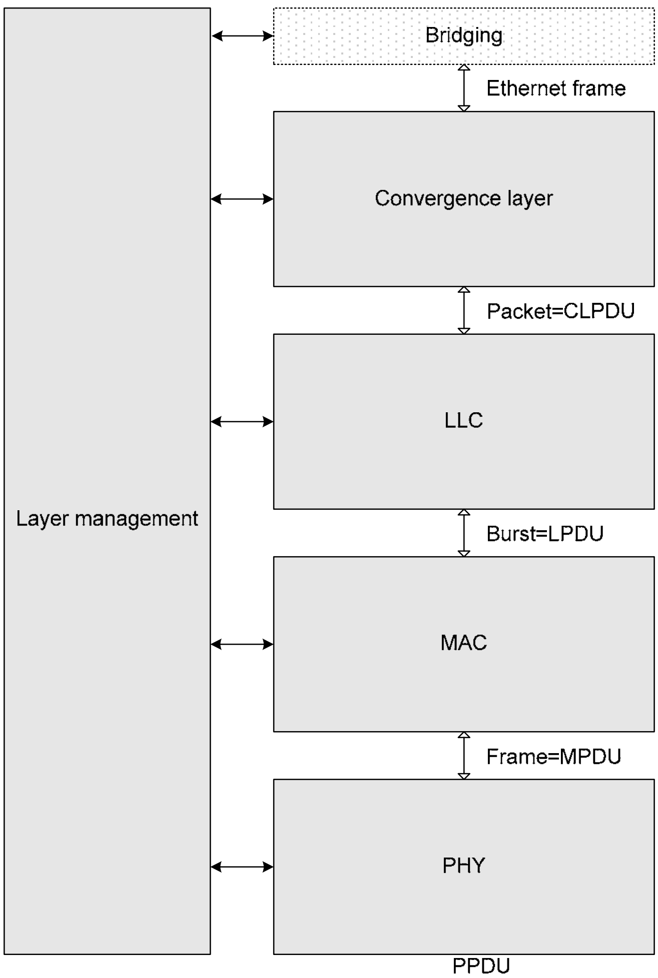


Figure 4 OPERA Layered Reference Model

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

3.2 OPERA Transmission Format

3.2.1 Frame Format

There are two main types of frames: Regular frames and Channel estimation frames. Regular frames are used to carry data between nodes, and are terminated by a token. Regular frames contain as payload PLC bursts which may be addressed to different destinations in the same frame in order to maximize efficiency. Depending on the type of token, they can be classified in six different types:

- *Data frames* contain a token that gives access to the channel to other node.
- *Silence frames* are similar to data frames but the token is retained by the transmitting node.
- *Polling frames* are used by Head End and Repeater nodes to update the state of the connections. Periodically, Idle nodes are polled to check if they have data pending for transmission and can be added to the Active node list. Upon reception of a polling frame, a node responds with a short (much shorter than the data symbol) unmodulated signal if the node has data to send. Idle nodes do not receive tokens, therefore not wasting channel resources.
- *Access frames* are used by Head End and Repeater nodes to invite new nodes to join to the powerline 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 Head End 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).
- *Access Reply frames* are sent as response to Access frames.
- Non-returnable Data frame are used to give access to the channel to several nodes simultaneously, thus providing spatial reuse. The Spatial Reuse capability increases greatly the performance of the network maximizing the aggregate capacity of the whole PLC cell.

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.

3.2.2 Burst Format

Each regular 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.

3.2.3 Codeword Format

Codewords are transmission sequences consisting of a pure data payload followed by a number of bits of redundancy. The codewords are not necessarily word matched with the underlying symbol transmission, determined by the parameters managed by the PHY Layer Protocol.

3.3 Physical Layer

The Physical (PHY) 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.

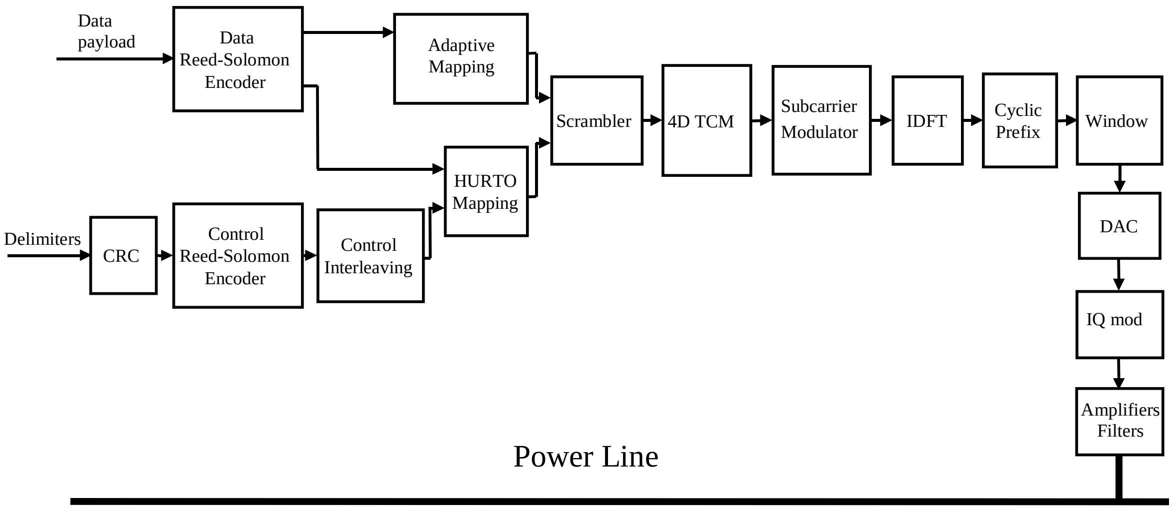


Figure 5 Transmission PHY layer

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

3.3.1 Bandwidth Capabilities

Most of the features that allow +200 Mbps data transmission reside in the PHY layer. The OPERA PHY features configurable frequency bands, with bandwidths of 10, 20 or 30 MHz.

This bandwidth flexibility has been included in the system in order to support Frequency-Division (FD) repeating capability and coexistence mechanisms.

In its 30 MHz mode, OPERA systems provide a maximum physical throughput of 204.94 Mbps.

3.3.2 Adaptive Bit Loading

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

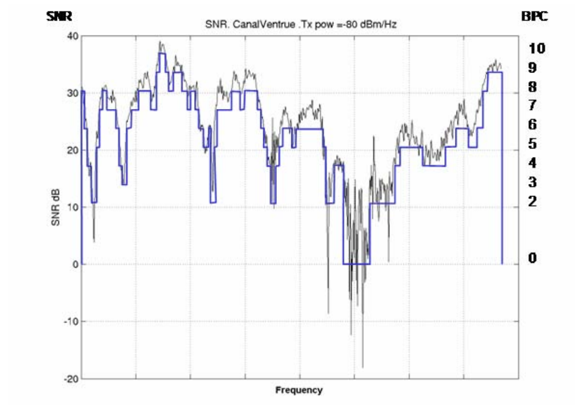


Figure 6 Sample "Signal-to-Noise Ratio" (SNR) and bit loading map for a sample powerline channel

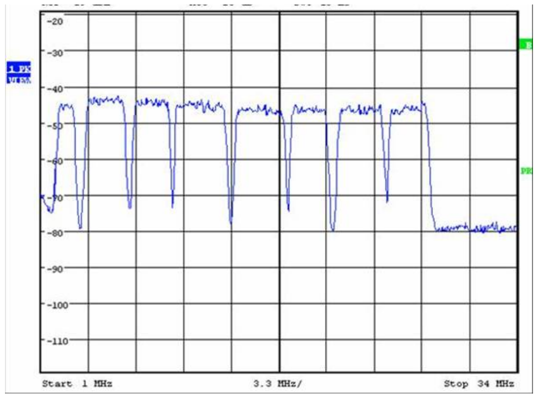


Figure 7 Example of a Power Spectral Mask with arbitrary notches

3.3.3 Notching Capabilities

Broadband powerline employs frequencies that in some geographical areas may be licensed to different radio services, such as amateur radio bands. 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 were they are used.

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

OPERA uses windowed-OFDM modulation that allows programmable notches with a depth of up to 30 dBs, with a negligible loss of performance.

OPERA technology allows device manufacturers to create customized notches configuration for each country, without requiring any hardware changes at all.

Figure 7 shows an example of the type of arbitrary Power Spectral Mask that can be achieved with OPERA system.

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

3.3.4 The OPERA 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:

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

3.3.5 Forward Error Correction

The PHY layer provides two different levels of reliability.

- The most reliable mode is known as HURTO mode, reserved to information that is critical for the correct operation of the system, such as burst headers and control information. In order to achieve such a high reliability, special Forward Error Correction, interleaving and frequency redundancy (depicted in Figure 5 as HURTO mapping) is used, jointly with a very robust modulation, to assure the correct demodulation in the reception side, even in the worst channel conditions.
- Normal data information can be transmitted using adaptive mapping to tightly match the channel characteristics, obtaining the highest possible throughput for each case. This adaptation includes not only the bits per carrier that can be used for a given desired bit error rate, but also a dynamic Reed-Solomon configuration for each of the transmitted bursts, depending on the channel state.

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

3.3.6 Symbol Transmission

After each subcarrier 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 blocks represent the IQ modulation (that allows placing the transmission band at different frequencies), the Analog Front End, and the coupling unit to inject the final OFDM signal into the powerline channel.

3.4 Medium Access Control (MAC) Layer

3.4.1 Advanced Dynamic Time Division

OPERA technology uses an Advanced Dynamic Time Division Multiplexing (ADTDM) MAC which 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 to the channel to all the nodes in the powerline network according to different service priorities, which can be adjusted to suit different types of applications, ranging from data, VoIP, Video on demand, etc.

OPERA implementation of ADTDM combines dedicated, random, and under-demand channel sharing mechanisms under a distributed hierarchical access protocol. 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.

3.4.2 MAC Network Entities

At the MAC level, any OPERA device can play one the following roles:

- Head End: Head End 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. Head Ends are responsible for generating the channel “token” and distributing this token to the rest of devices in the network.

- Repeater: a repeater is a device that receives the token from the Head End and forwards it to other devices that are out of reach of the Head End.
- CPE: Customer Premises Equipment is a device that is not a Head End or a Repeater.

3.4.3 Channel Arbitration and Tokens

OPERA uses a dynamic MAC mechanism which has several advantages:

- Collisions are completely avoided, removing a source of uncertainty in the latency of the transmissions.
- The Head End has control over how much time each node owns 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.
- No bandwidth is wasted if a given node does not have any data to transmit, as channel control can be returned immediately to the Head End.

In the following pages the 3 cases of usage of the MAC are shown:

Figure 8 shows a network with "complete visibility" (Nodes A, B and C can communicate directly). Figure 9 shows a network with "incomplete visibility". Whilst nodes A and B can communicate directly, as can nodes B and C, the attenuation between A and C is such that communication between these nodes is only possible by node B repeating the signal

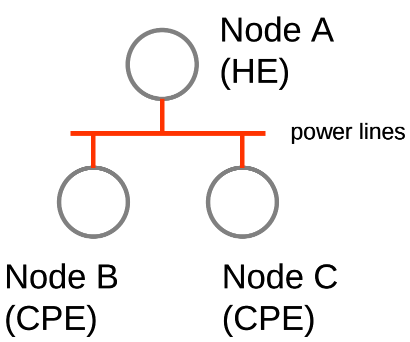


Figure 8 Sample network with complete visibility

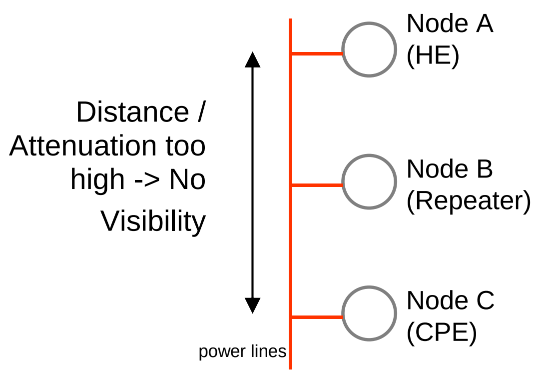
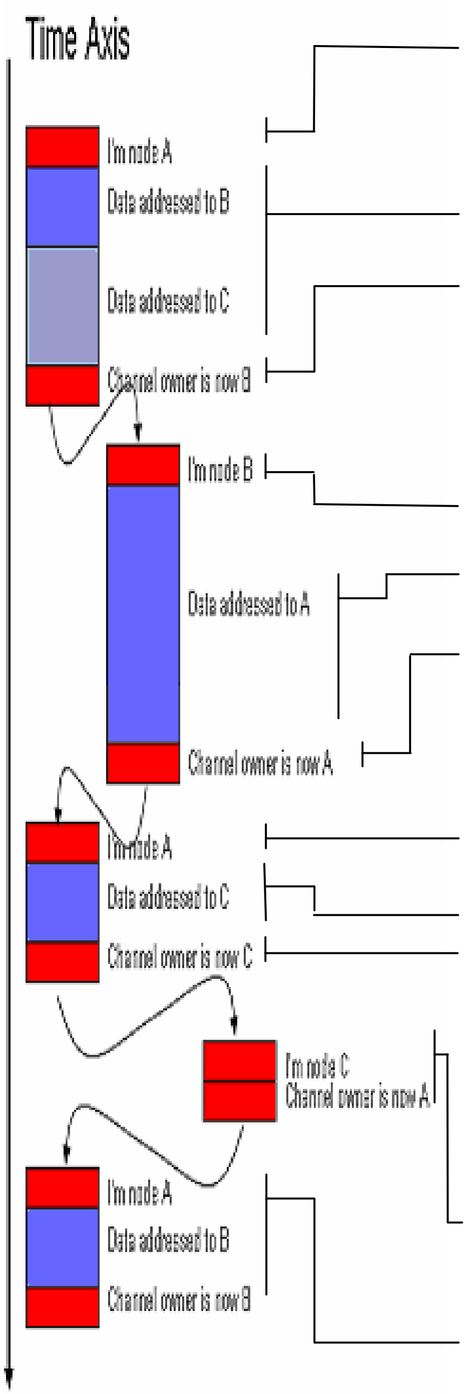


Figure 9 Sample network with incomplete visibility
(Node A and Node C cannot communicate directly)



Node A (the Head End) starts the communication process:

It transmits a short control message, announcing that the following powerline frames come from Node A. This short control messages also includes additional PHY-level information (required for the receivers to configure the right reception gain and the OFDM demodulators).

It then transmits a data burst addressed to Node B, followed by another burst of data addressed to Node C.

Finally, it sends another control message (token) 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.

After receiving the token from Node A, Node B can start transmission over the powerline channel:

As before, it transmits a short control message, announcing that the following powerline frames come from Node B.

It then transmits a data burst addressed to Node A.

Finally, it returns the channel control (i.e., the token) to node A (the Head End). This must happen before the period of time included in the original token expires.

After having the token returned from B, A is now the "channel owner" again:

As before, it transmits a short control message, announcing that the following powerline frames come from Node A.

It then transmits a data burst addressed to Node C.

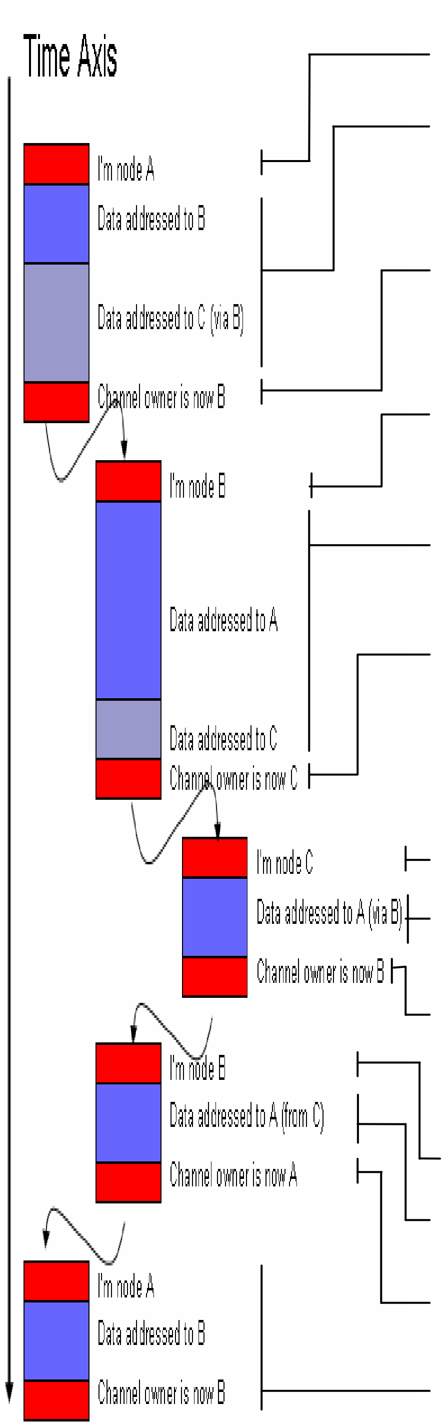
Finally, it sends another control message (token) yielding the channel control to Node C, including information about the maximum time that node C can make use of the channel.

After receiving the token from Node A, Node C can start transmission over the powerline channel. In this specific case, Node C does not have any data to transmit, so it will return the token immediately to Node A.

Node C transmits a short control message, announcing that the following powerline frames come from Node C. It immediately returns the channel control (i.e., the token) to node A (the Head End).

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

Figure 10 Token Passing in a Sample network with complete visibility



<u>Node A (the HE) starts the communication process:</u>

It transmits a short control message, announcing that the following powerline frames come from Node A.

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.

Finally, it sends another control message (token) 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.

<u>After receiving the token from Node A, Node B can start transmission over the powerline channel:</u>

It transmits a short control message, announcing that the following powerline frames come from Node 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).

Finally, it forwards the channel control (i.e., the token) to node C.

<u>After receiving the token from Node B, Node C can start transmission over the powerline channel:</u>

It transmits a short control message, announcing that the following powerline frames come from Node C.

Node C sends a burst of data which is addressed to Node A.

Finally, it returns the channel control (i.e., the token) to node B (the Repeater).

<u>After receiving the token back from Node C, Node B can start transmission over the powerline channel:</u>

It transmits a short control message, announcing that the following powerline frames come from Node B.

Node B sends a burst of data which is addressed to Node A (with information originated at C).

Finally, it returns the channel control (i.e., the token) to node A (the HE). This must happen before the expiration time of validity period included in the original token sent from A to B.

<u>Now Node A is again the channel owner, and the cycle can start over again.</u>

Figure 11 Token Passing in a Sample network with incomplete visibility

3.4.4 MAC Auxiliary Mechanisms

The MAC protocol includes a whole set of auxiliary mechanisms to guarantee the correct operation of the protocol:

- Sub-protocol for handling new nodes joining the network.
- Sub-protocol for automatic discovery of the network topology, allowing nodes with incomplete visibility to communicate with other nodes out their reach, making use of intermediate repeaters.
- Sub-protocol for learning which hosts/devices are reachable via each powerline device, based on an 802.1d learning model.
- Sub-protocol for handling nodes being disconnected from the network.
- Sub-protocol for token recovery in case of having one node disconnected while it was the channel owner.

3.5 Link Layer Control (LLC) Layer

The LLC Layer in OPERA ensures the error free transmission of data, between pairs of PLC 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.

3.5.1 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 12 shows how the mapping/encapsulation of an Ethernet 802.3 frame is performed in OPERA, 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.

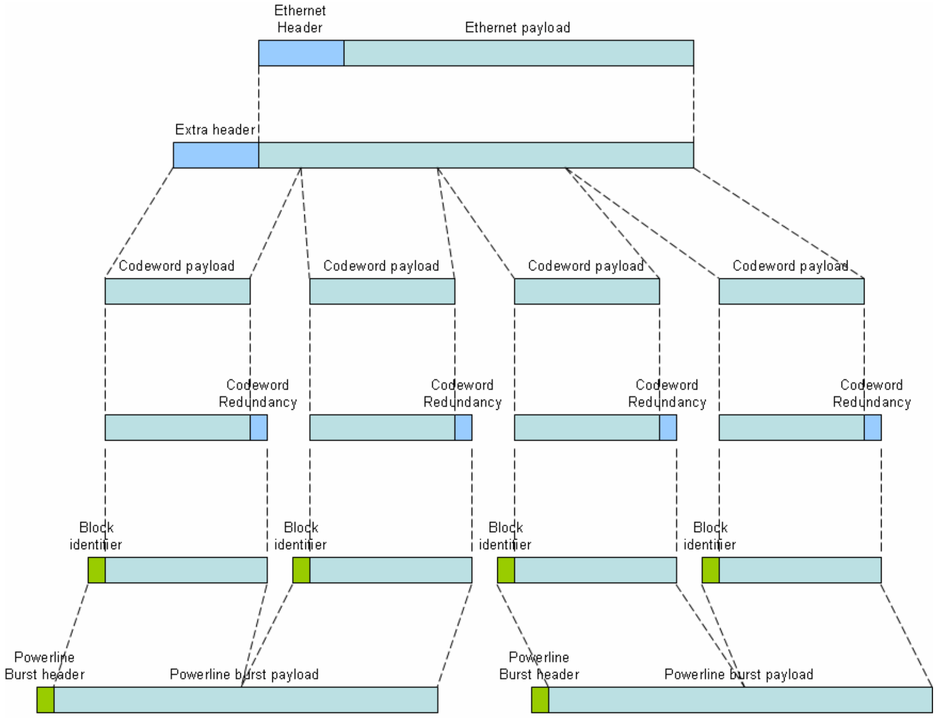


Figure 12 Generic Mapping of an Ethernet frame into PLC-level bursts

3.5.2 Burst Acknowledgement Scheme

OPERA 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.

Figure 13 shows how the ACK protocol works:

1. First, 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 that they need to be retransmitted.
2. Due to channel noise, burst #3 is corrupted. Only bursts 1 and 2 are correctly received.
3. Next, the “right node” sends a control message to the “left node”, acknowledging that the last successfully received burst was burst #2.
4. Next, the “left node” 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.

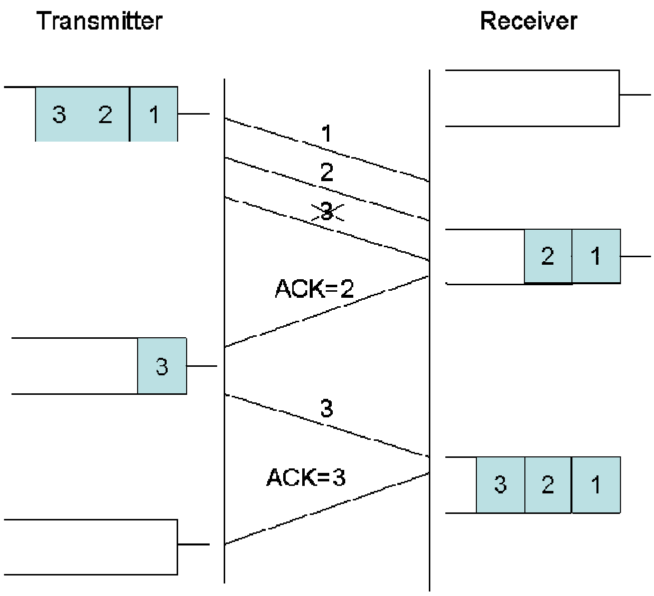


Figure 13 Burst Acknowledgement Scheme

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 powerline level are hidden from the application layer, which only perceives an “Ethernet-like” zero-loss channel.

3.6 Convergence Layer

The Function of the Convergence Layer is to encapsulate packets coming from external applications (typically 802.3 Ethernet frames) before passing them to the LLC for transmission.

The Ethernet frame is encapsulated into a powerline packet, which is basically formed by 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.

3.6.1 Virtual LAN Management

Virtual LAN (VLAN) management allows an OPERA 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 which can be used independently of the standard 802.1q VLAN tags.

3.7 Layer Management

3.7.1 Control protocols

OPERA 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 with each other, so that spatial reuse can be achieved.
- Connection admission protocol: to reserve resources for data flows.
- Protocol for automatic management of crosstalks between not synchronized systems: used when two independent networks interfere each other.

3.7.2 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 networks 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.

3.8 Quality of Service (QoS)

Many applications for the transmission of data, video, and audio have specific requirements in bandwidth, latency, jitter, and packet loss. The MAC layer with QoS support contains the required functionality to comply with the different services, and to conform to the Service Level Agreement(s) (SLA) of each customer.

The main objective of the QoS provided by the MAC layer is therefore to guarantee a given bandwidth and latency to different flows, depending on the how the available service classes are configured and on the type of traffic being transmitted.

There are eight service classes available (which will be referred to as SLA), which are mapped to three different types of resource reservation policies (Best effort, CBR and VBR) and four different maximum latencies. The incoming traffic goes through a module called the Traffic Classifier, whose job is to prioritize packets based on some simple rules. OPERA based systems provide up to eight different priorities, which are mapped to the already mentioned eight SLAs.

SLA	PRIORITY	RESOURCE RESERVATION	LATENCY (MS)
7	7	Best effort	80
6	6	CBR	10
5	5	VBR	20
4	4	VBR	40

SLA	PRIORITY	RESOURCE RESERVATION	LATENCY (MS)
3	3	VBR	40
2	2	VBR	40
1	1	Best effort	80
0	0	Best effort	80

Table 1 SLA Configuration table example

Upon acceptance of a new node, the QoS parameters that specify the services available to that user node are downloaded through the auto-configuration protocol. The set of parameters that can be configured in every user are:

- *Maximum Throughput:* Maximum throughput available to a user for the best effort traffic.
- *Allowed SLAs:* Set of SLAs allowed for that CPE.

The QoS of OPERA based systems provide the following features in order to guarantee the differentiated services to every connected user:

- Packet Classification
- Latency Management
- Call Admission Control
- Bandwidth Control
- Service Differentiation
- Excess Bandwidth Management
- User Profiles

3.8.1.1 Packet Classification

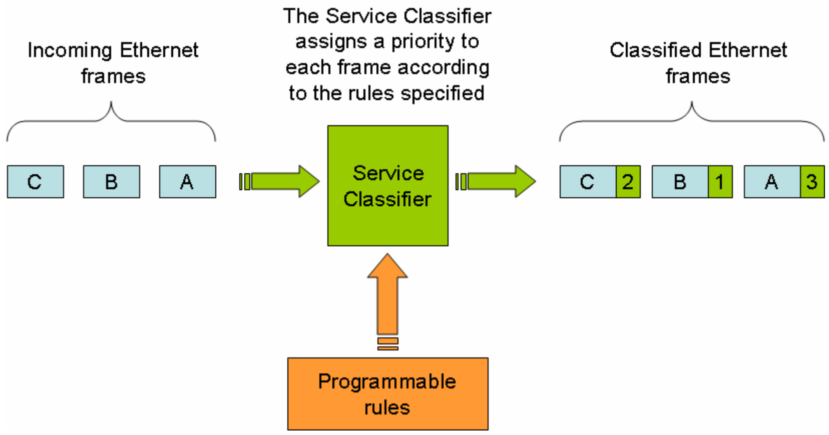


Figure 14 Service Classifier module

In order to handle different services and applications adequately, OPERA devices need to identify the class of service that each specific Ethernet frame belongs to. 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 SLA level of each frame according to a set of rules established by the device manufacturer, the service provider or the end-user.

Figure 14 shows how the Service Classifier entity works:

- Incoming frames are inspected, one by one, looking for patterns that the Service Classifier can use for determining SLAs.
- Once the SLA has been determined, a “tag” is added to the frame, so that it can later be identified by other entities of the OPERA specification (for example, for management of prioritized buffers).
- The set of programmable rules are typically of the following type: If the byte in offset AA of the Ethernet frame is BB, then the SLA of the packet is CC.

Typical default rules for the Service Classifier could be: decide SLAs according to bits in 802.1p or 802.1q field, or according to bits in IPv4 TOS field, etc. Incoming Ethernet data can be classified in eight different classes depending on some programmable rules based on the contents of the packet.

3.8.1.2 Latency Management

Infrastructure nodes detect the transmitted and received SLAs so that the scheduling mechanism is adapted to the type of traffic and to the specified SLAs. Thus, a node transmitting high priority traffic will receive better service than a node transmitting low priority traffic.

3.8.1.3 Bandwidth Control

Bandwidth control ensures that every node’s throughput is the specified value at all times. The scheduler also maintains the obtained throughput to the specified value, although sometimes it is not possible due to insufficient channel quality. Bandwidth control is performed on the transmitter side in order to maximize the efficiency of the system.

3.8.1.4 Service Differentiation

Any user may transmit several flows with different SLAs simultaneously. The scheduler ensures that the most demanding traffic will meet the SLA constraints. If there is unused bandwidth, lower priority traffic will be piggybacked in the same high-priority connection. Otherwise, excess traffic will be dropped.

3.8.1.5 Excess Bandwidth Management

Due to sudden changes in the channel conditions, it may happen that the agreed performance cannot be attained. OPERA based systems have the required embedded mechanisms to automatically degrade the lower priority services in order to maintain the quality of high priority services until the channel quality is enough to support all connections again.

3.8.1.6 User Profiles

To define the QoS profile of different connections in the PLC network, OPERA uses the concept of User Profiles, which are special files to specify the characteristics of the connections in terms of parameters such as maximum transmission and reception bandwidths, allowed types of SLAs and specification of the SLAs.

User Profiles are stored in a central server and are downloaded by the infrastructure equipment whenever a new user enters into the network through the auto-configuration process described in more detail later in this document.

3.9 Security Mechanisms

OPERA specification includes a powerful security structure based on 168-bit triple DES encryption that guarantees the privacy of each communication between nodes. In fact, a specific key can be selected for each communication link that a node can perform, increasing dramatically the data exchange protection. In addition to that, each data frame can be encrypted using time varying subkeys that change each few microseconds, making more difficult the action of possible unwanted observers.
The encryption key distribution uses the well-know asymmetric Diffie-Hellman key agreement, using a pair of public and private keys that are generated locally by each node using special method to assure the enough randomization of the seed. By means of this algorithm, common encryption key can be negotiated without compromising its knowledge.
Authentication of each node is performed by the use of a RADIUS server, that includes the MAC address list of allowed nodes to be connected in certain network, and that also tells if encryption in the links established in the network must be set.

3.10 Coexistence Mechanisms

The OPERA coexistence mechanism is based on the Coexistence Specification of the Universal Powerline Association.

It is based on the transmission/detection of two unmodulated OFDM signals. OPERA defines three sharing mechanisms among coexisting networks, based on pure FD, pure TD and hybrid FD/TD.

The basic coexistence mechanism between Access Systems (AS) and Inhome Systems (IHS) consists in FD sharing. AS work in the lower frequency band while IHS operate in the upper frequency band. If there are several in-home systems, these systems will share the upper frequency band using TD.

The way the channel is shared among contending networks is by using a common coexistence frame (see Figure 15).

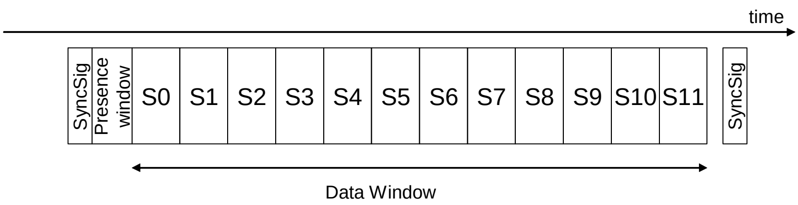


Figure 15 OPERA Coexistence Frame

The frame is divided in three different parts:

1. **Synchronization Signal.** Every node shall transmit a coexistence signal (SyncSig) at a fixed rate in such a way that all nodes transmit it simultaneously. The purpose of the SyncSig signal is to ensure that all nodes are synchronized in time, and are able to use the coexistence frame in the same way.
2. **Presence Window.** The presence window is used to signal the existence of different systems and to reserve the upcoming data slots.
3. **Data Window.** The data window is used in case of TD sharing. It is the time where individual networks transmit data. It is composed by 12 fixed size data slots. These

slots are assigned to different networks depending on the selected scheduling mechanism. Scheduling mechanisms can be devised in order to maximize different rules such as traffic priority, number of users or other different parameter.

3.11 Autoconfiguration and provisioning

Most important configurable features of the system can be easily configured through a unique and consistent configuration layer that provides the tools to match utility target network structure and expected performance.

This feature allows a complete automation of the deployment of the PLC network: medium voltage equipment, low voltage HE, repeaters and CPEs. All the parameters that need to be set to provision new equipment in a PLC network (QoS, VLAN, VoIP parameters…) can be configured remotely by means of configuration files and DHCP requests. Therefore, no pre-configuration of the modem is required prior to installation; only the MAC address of the node need to be known. The profile of every node is provisioned in a central server and different management VLANs can be present in different sections of the network. Besides, this configuration procedure allows as well the existence of multiple data and VoIP VLANs across the network, being able to support a wholesale model with multiple service operators.

If a node has permanent storage memory, the remote configuration can be downloaded and stored to be retrieved locally the next time the modem boots.

This autoconfiguration feature has a built-in authentication process to accept or reject nodes trying to connect to the Access network. If the node is accepted, a profile (QoS and VLAN settings) is assigned to it informing the master with the type of service the new node must receive. This authentication can be performed in three different ways:

- No authentication: All nodes will be accepted and a default profile is assigned.
- RADIUS authentication: The HE of the network queries the RADIUS server if the new detected node is allowed to connect to the network. If the node is accepted, the RADIUS server informs the HE the assigned profile.
- Authorization list authentication: In this configuration the RADIUS server is not used. The master holds a list of allowed nodes with their profiles.

Authentication allows the operators to control the access to the network.

The autoconfiguration allows policies to be set for each of the traffic types present in the network, as well as the dynamic control of the bandwidth and latency for each user.

In networks where Voice over IP (VoIP) is implemented, parameters like dial plan, gatekeeper configuration, regional specific configurations, activation of standard or specific codecs such G711, G729 and others can be fully configured.

In order to make easier the configuration, several user profiles that include sets of VLAN, OVLAN, QoS, VoIP, Spanning Tree parameters are possible. In this way, the network configuration becomes easy and at the same time with total control of each of the nodes in the managed network.

3.12 MIB / SNMP

OPERA equipment supports SNMP (Simple Network Management Protocol). The SNMP agent supports all the standard SNMP messages (*GetRequest*, *GetNextRequest*, *SetRequest*, *GetResponse* and *Trap*), providing a powerful management tool:

- *Get* operations allow monitoring the status of the network nodes, retrieving the current node configuration, and collecting statistics.
- *Set* operations allow a wide range of management actions including the full configuration of the node by an SNMP manager.
- *Traps* are sent by the agent to inform the manager about relevant events, so it can act consequently.

Supporting all these operations allows reaching a trade-off between a pure active management (where SNMP managers are in charge of contacting periodically the agents to control their state) and a pure trap-directed polling (where each agent is responsible of notifying the management station any unusual event).

OPERA SNMP agents maintain up to three MIBs (Management Information Bases) that are compliant with RFC 1155, which specifies the general framework in which a MIB can be defined and constructed:

- MIB-II: The standard management information base approved by the IAB and defined in RFC 1213. This MIB defines all the managed objects that should be present in the nodes of any communication system.
- OPERA MIB: Provides status, configuration and statistics that are particular to PLC systems and the OPERA technology.
- OPERA VoIP MIB: Provides the VoIP status, configuration and statistics for the VoIP-enabled nodes.

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