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GSTP-OVHN
Overview of ITU-T G.hn technology

Summary

The ITU-T G.hn family of Recommendations provides the framework and solution to implement in-premises communication systems that may work over multiple physical media (power lines, phone lines, coaxial and plastic optical fibre). This technical paper provides a high-level overview of the ITU-T G.hn system and a brief description of the relationships between the different Recommendations of the ITU-T G.hn family (including ITU-T G.9960, G.9961, G.9962, G.9963, G.9964, G.9972, G.9977, G.9978 and G.9979). In addition, Recommendation ITU-T G.9991 for in-premises transmission over visible light communication is also discussed, since it is largely based on ITU-T G.hn systems.

NOTE

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Keywords

In-premises communication, ITU-T G.hn technology, overview.

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1 Scope

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2 References

[ITU G.9960] Recommendation ITU-T G.9960 (2018), *Unified high-speed wireline-based home networking transceivers – System architecture and physical layer*.

[ITU G.9961] Recommendation ITU-T G.9961 (2018), *Unified high-speed wireline-based home networking transceivers – Data link layer specification*.

[ITU G.9962] Recommendation ITU-T G.9962 (2018), *Unified high-speed wireline-based home networking transceivers – Management specification*.

[ITU G.9963] Recommendation ITU-T G.9963 (2018), *Unified high-speed wireline-based home networking transceivers –Multiple input/multiple output specification*.

[ITU G.9964] Recommendation ITU-T G.9964 (2011), *Unified high-speed wireline-based home networking transceivers – Power spectral density specification*.

[ITU G.9972] Recommendation ITU-T G.9972 (2010), *Coexistence mechanism for wireline home networking transceivers*.

[ITU G.9977] Recommendation ITU-T G.9977 (2016), *Mitigation of interference between DSL and PLC.*

[ITU G.9978] Recommendation ITU-T G.9978 (2018), *Secure admission in G.hn network.*

[ITU G.9979] Recommendation ITU-T G.9979 (2018), *Implementation of the generic mechanism in the IEEE 1905.1a-2014 standard to include applicable ITU-T Recommendations*.

[ITU-T X.1035] Recommendation ITU-T X.1035 (2007), *Password-authenticated key exchange (PAK) protocol.*

[ITU GSTP-HNIA] Technical Paper ITU-T GSTP-HNIA (2020), *Use of G.hn in industrial applications*.

[ITU GSTP-HNSG] Technical Paper ITU-T GSTP-HNSG (2020), *Use of G.hn technology for smart grid*.

[ITU-T TPLS.G-HN] Technical Paper ITU-T TPLS.G-HN (2015), *Operation of G.hn technology over access and in-premises phone line medium*.

[BBF TR-069] Technical Report 069 (2018), *CPE WAN Management Protocol*.

[BBF TR-181] Technical Report 181 (2020), *Device Data Model for TR-069*.

[BBF TR-369] Technical Report 369 (2019), *User Services Platform*.

3 Abbreviations and acronyms

This Technical Paper uses the following abbreviations and acronyms:

ACE	Additional Channel Estimation
ADP	Application Data Primitives
AE	Application Entity
AKM	Authentication and Key Management
APC	Application Protocol Convergence
APDU	APC Protocol Data Units
BAT	Bit Allocation Table
BMSG	Bidirectional MSG
C&I	Compliance & Interoperability
CAT	Category
CBTS	Contention-Based Time Slot
CFTS	Contention Free Time Slot
CFTXOP	Contention Free TXOP
CP	Cyclic Prefix
CSP	Current Synchronization Point
DLL	Data Link Layer
DM	Domain Master
DOD	Domain ID
DSL	Digital Subscriber Line
EP	End Point
FDM	Frequency Domain Multiplexing
FEC	Forward Error Correction
FTTDp	Fibre-To-The-Distribution point
FTTep	Fibre-To-The-extension point
GM	Global Master
H-BMSG	Hierarchical BMSG
IDCC	Inter-Domain Communication Channel
IDFT	Inverse Discrete Fourier Transform
IDPS	Inter-Domain Presence Signal
IDSW	Inter-Domain Synchronization Window
IEEE	Institute of Electrical and Electronics Engineers

IH	In-Home
IoT	Internet of Things
ISP	Inter-System Protocol
LAN	Local Area Network
LCDU	Logical Link Control Data Unit
LCMP	Layer 2 Configuration and Management Protocol
LDPC	Low-Density Parity-Check
LLC	Logical Link Control
LPDU	Logical link control Protocol Data Unit
MAC	Medium Access Control
MAP	Medium Access Plan
MDI	Medium-Dependent Interface
MDU	Multi-dwelling Unit
MIMO	Multiple Input – Multiple Output
MITM	Man In the Middle
MPDU	Media access control Protocol Data Unit
MSG	Message
MV	Medium Voltage
OFB	Operating Frequency Band
OFDM	Orthogonal Frequency Division Multiplexing
PCS	Physical Coding Sub-layer
PHY	Physical
PMA	Physical Medium Attachment
PMD	Physical Medium Dependent
PMI	Physical Medium-independent Interface
POF	Plastic Optical Fibre
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
QC-LDPC-BC	Quasi-Cyclic Low-Density Parity-Check Block-Code
QoS	Quality of Service
RCM	Robust Communication Mode
RF	Radio Frequency
SISO	Single Input Single Output
SM	Smart Meter
SMG	Smart Meter Gateway
STB	Set Top Box
STXOP	Shared TXOP

TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TS	Time Slot
TV	Television
TXOP	Transmission Opportunity

4 Introduction

The ITU-T G.hn family of ITU-T Recommendations provides the framework for the description of a complete in-premises communication system that may work over multiple physical media (power lines, phone lines, coaxial and plastic optical fibre).

This paper provides a high-level overview of an ITU-T G.hn system and a brief description of the multiple Recommendations that are part of the ITU-T G.hn family of Recommendations:

- **[ITU-T G.9960]**: "Unified high-speed wireline-based home networking transceivers – System architecture and physical layer specification".
- **[ITU-T G.9961]**: "Unified high-speed wireline-based home networking transceivers – Data link layer specification".
- **[ITU-T G.9962]**: "Unified high-speed wire-line based home networking transceivers – Management specification".
- **[ITU-T G.9963]**: "Unified high-speed wireline-based home networking transceivers – Multiple input/multiple output specification".
- **[ITU-T G.9964]**: "Unified high-speed wireline-based home networking transceivers – Power spectral density specification".
- **[ITU-T G.9972]**: "Coexistence mechanism for wireline home networking transceivers".
- **[ITU-T G.9977]**: "Mitigation of interference between DSL and PLC".
- **[ITU-T G.9978]**: "Secure admission in G.hn network".
- **[ITU-T G.9979]**: "Implementation of the generic mechanism in the IEEE 1905.1a-2014 Standard to include applicable ITU-T Recommendations".

In addition, Recommendation ITU-T G.9991 for in-premises transmission over visible light communication is closely related to the ITU-T G.hn family of Recommendations since it is largely based on ITU-T G.hn systems.

5 What is ITU-T G.hn?

5.1 General

ITU-T G.hn is a technology defined by a family of international standards created by the ITU-T standardization body. ITU-T G.hn is defined to operate over any physical networking medium in the home, such as coaxial cables, telephone/CATx wires, power lines, and over plastic optical fibre. The "any wire" nature of ITU-T G.hn means that a single technology interconnects any device in the home over any type of wired infrastructure. ITU-T G.hn systems can pass data at very high speeds, up to at least 2 Gbit/s. Combining very high throughput with a very robust quality of service mechanism and complete security enables ITU-T G.hn networks to meet service provider requirements. ITU-T G.hn provides an in-home network that is secure from tampering or content theft while able to deliver any content anywhere throughout the home.

Prior to ITU-T G.hn, home networks were either Ethernet-based requiring new cables or they were based on proprietary technologies that did not enjoy widespread adoption, were expensive and were known to have service or throughput issues. ITU-T G.hn has consolidated the wired portion of the home network under a single technology. ITU-T G.hn eliminates the need for new wires, is very cost effective, and provides the high throughput and quality of service backbone for today's hybrid home network. Based on an ITU-T G.hn wired backbone network, the in-home network can deliver high bandwidth content anywhere for fixed or nomadic devices, and act as wireless backhaul for multi-access point wireless systems.

The covered mediums and associated main characteristics of the technology are summarized in Table 5-1.

Table 5-1 – Main characteristics of ITU-T G.hn technology

Medium	Maximum PHY (Note)	MIMO
Power lines	1.5 Gbit/s	YES
Phone lines	2 Gbit/s	YES
Coaxial	2 Gbit/s	NO
POF	2 Gbit/s	NO
NOTE – Maximum theoretical throughput at A-interface, maximum bandwidth and ideal transmission conditions.		

5.2 Applications of ITU-T G.hn

ITU-T G.hn provides the flexibility and robustness to address many different scenarios and applications:

- **In-home networking**: Consumers are fuelling the need for greater home network bandwidth requirements such as 4K/8K HD TV.

The consumer's desire to seamlessly share applications across a growing number of digital devices makes in-home networking critical, overall in terms of supporting a high bandwidth and reliable service.

Wireline networking consists of reusing existing power lines, coaxial cables, phone lines, and POF to support this application. It is one of the easiest and most reliable ways to meet this market demand, offering a comprehensive solution that optimizes networking.

Wireline can also help extend wireless networks by traversing the bandwidth requirements over existing consumer wiring without diminishing the integrity of the speeds needed to extend the wireless footprint.

The advantages of wireline's plug and play ease of use combined with the wireless' ability to roam freely within a home make the next generation digital experience essential for having the ability to handle high bandwidth in a ubiquitous way.

- **Ultra-broadband**: ITU-T G.hn extends broadband access from the fibre network termination in multi-dwelling units (MDUs), distribution points (DPs) or as Fibre extension (FTTep) to users' homes by taking advantage of the existing wiring. It offers significant end-to-end cost savings to operators around the world.

ITU-T G.hn solutions complement Fibre-To-The-Distribution-Point (FTTdp) and Fibre-To-The-Extension Point (FTTep) deployments to transfer all the capacity of optical backbones directly to each home reusing cables.

- **Industrial**: With the evolution of digitalization in industry, new requirements are coming out on monitoring and controlling the components/devices engaging in the industrial process. This requires communication technologies to satisfy the needs for each specific application. The challenge is that it may require additional features defined in the current technology to fulfil the very diverse requirements. These include, but are not limited to, a large number of nodes, robust transmission with very few bits, extremely long-distance reach, guaranteed latency, etc. ITU-T G.hn technology is promising to be the one to facilitate digital revolution in industry.

- **Smart grid**: The usage of power-line communications in a smart grid is getting traction in different markets. This growth is driven by a set of applications where the flexibility and versatility of ITU-T G.hn technology is an asset: Providing communication for smart meters (SM), smart meter gateways (SMG), narrowband smart meter concentrators and medium voltage (MV) backbone communication infrastructure.

The use of ITU-T G.hn technology in each of these different applications is explained in a series of Technical Papers published by ITU-T.

Table 5-2 – Application technical papers reference

Application	Technical Paper reference
In-home networking	In preparation
Ultra-Broadband	2015 - Operation of G.hn technology over access and in-premises phone line medium
Industrial	2020 - GSTP-HNIA: Use of G.hn in Industrial Applications
Smart grid	2020 - GSTP-HNSG - Technical paper on the use of G.hn technology for smart grid

5.3 Relationship between Recommendations of ITU-T G.hn

Figure 5-1 shows the relationship between the different documents of the ITU-T G.hn family of Recommendations.

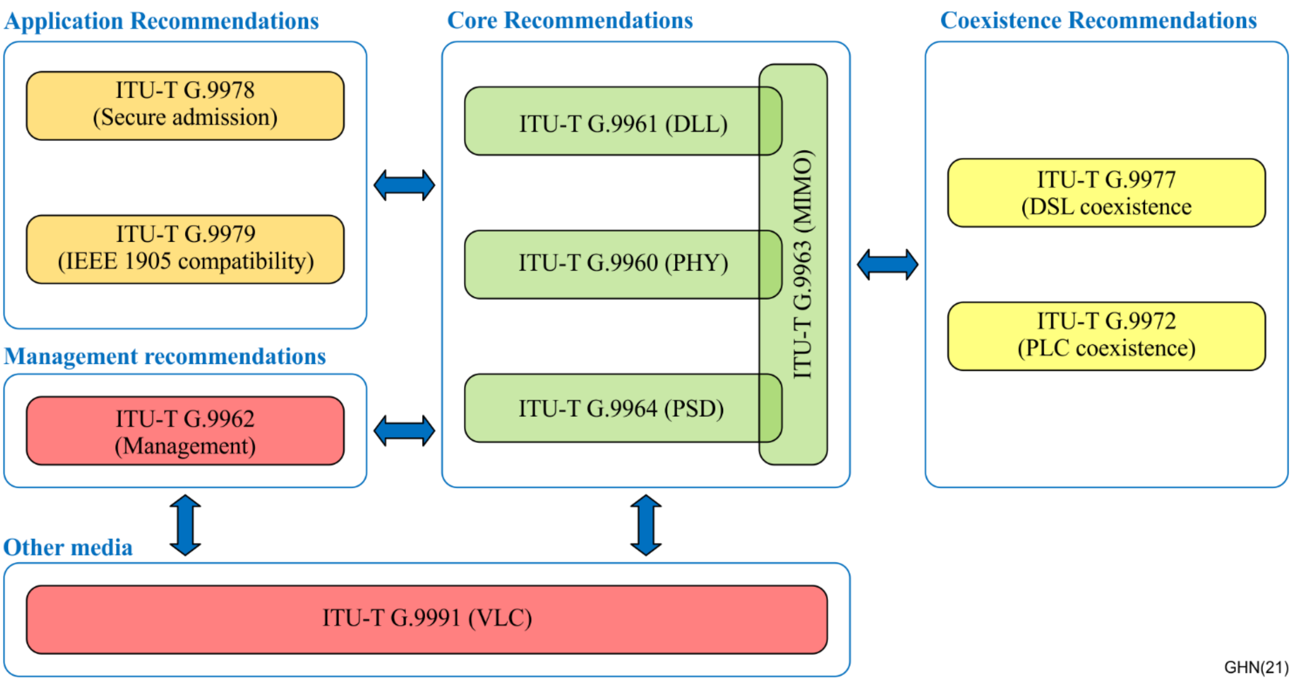

Figure 5-1 – Relationship between the different Recommendations of ITU-T G.hn family

These Recommendations are divided in four main groups:

- **ITU-T G.hn core Recommendations**, including the description of the physical and DLL layers, and describing the physical parameters to be used during the operation of an ITU-T G.hn transceiver both in SISO and MIMO modes.
- **ITU-T G.hn management Recommendations**, describing how the rest of the system interacts with the control plane of ITU-T G.hn systems.
- **Application Recommendations**, describing how to integrate ITU-T G.hn subsystems in larger networks.
- **Coexistence Recommendations**, specifying how ITU-T G.hn systems coexist and share resources with other systems operating over the same or a different physical medium.

In addition to the development of Recommendations, ITU-T is closely collaborating with other SDOs to guarantee the commercial exploitation of the technology. Among others, it is relevant to mention:

the collaboration with the **HomeGrid Forum (HGF)** industry alliance that supports the development and deployment of ITU-T G.hn technology. HomeGrid certification ensures compliance and interoperability (C&I) of silicon and systems through plugfests and rigorous C&I testing;

the collaboration with the **Broadband Forum (BBF)** industry alliance in the definition of possible access architectures where ITU-T G.hn is involved and in the management of ITU-T G.hn-based devices.

6 ITU-T G.hn Recommendations

6.1 Architecture

A set of several ITU-T G.hn nodes that operate over the same physical medium establish an ITU-T G.hn domain. This domain may be established over any type of wiring (power lines, coaxial cables, phone lines and plastic optical fibre).

Each ITU-T G.hn domain may include up to 250 ITU-T G.hn nodes, one of which is designated as domain master (DM), which coordinates operation of all nodes in the domain. All other nodes in the domain are called "end-point nodes" (EP) or simply "nodes". The DM is responsible for assigning a schedule that meets the traffic constraints of the EPs and uses in the most efficient way the available channel resources.

Each of the nodes of the ITU-T G.hn domain interfaces through an Ethernet interface "A-interface" to the external world. The frames entering through the A interface are processed and encapsulated into physical ITU-T G.hn frames that are sent through the ITU-T G.hn channel to the receiver ITU-T G.hn node.

When an ITU-T G.hn network is composed of multiple domains. The global master (GM) function provides coordination of resources, priorities, and operational characteristics between neighbour domains of an ITU-T G.hn network. The GM is a high-level management function that communicates with the management entities of the DMs and that may also convey the relevant inter-domain coordination functions.

Generic architecture of an ITU-T G.hn network is presented in Figure 6-1.

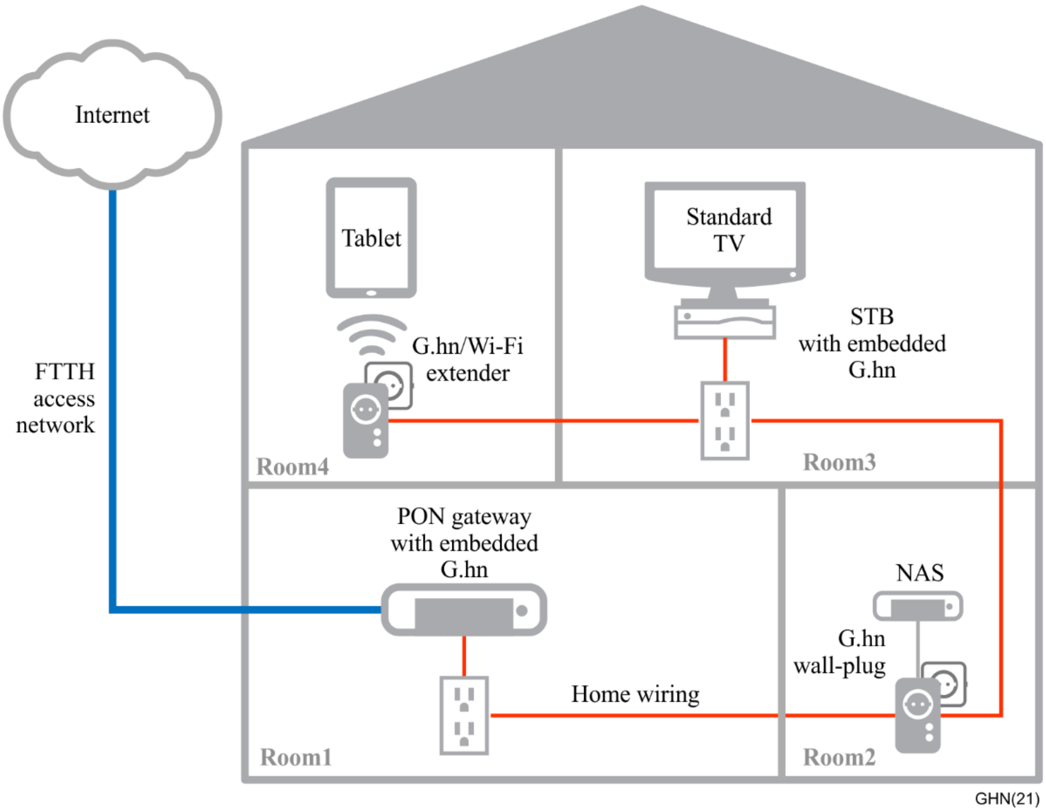

Figure 6-1 – Generic architecture of ITU-T G.hn network

In practice, a classical residential home network scenario using an ITU-T G.hn home network is shown in Figure 6-2.

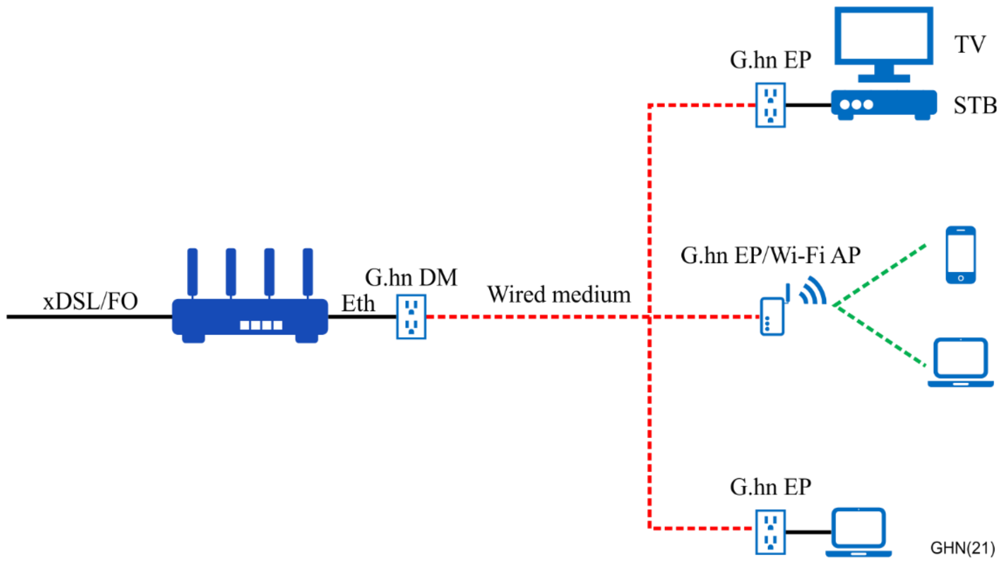

Figure 6-2 – Example of a typical ITU-T G.hn home network deployment

6.2 Reference model

The protocol reference model of a home network transceiver is presented in Figure 6-3.

	Layers and interfaces
A	A interface
APC	Application protocol convergence
LLC	Logical link control
MAC	Media access control
PMI	PHY MAC interface
PCS	Physical coding sub-layer
PMA	Physical medium attachment
PMD	Physical medium dependent
MDI	Medium dependent interface

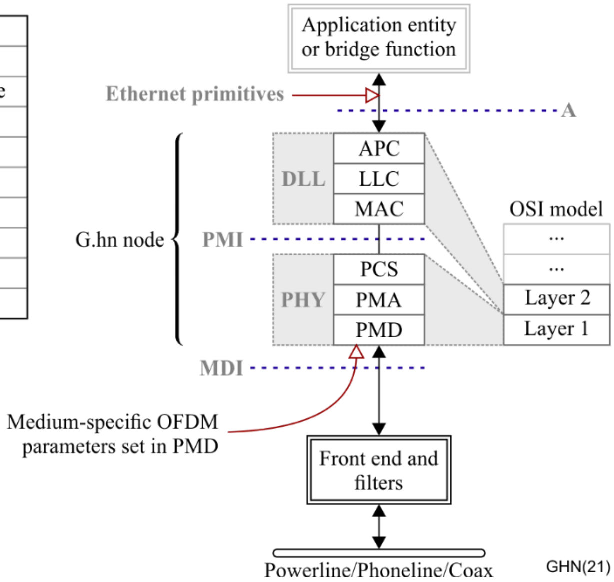

Figure 6-3 – ITU-T G.hn node reference model

The DLL is composed of the following functional sub-layers:

- The **application protocol convergence (APC) sub-layer** provides an interface with the application entity (AE), which operates with an application-specific protocol (for example, Ethernet). The APC also provides the data rate adaptation between the application entity and the ITU-T G.hn transceiver.
- The **logical link control (LLC) sub-layer** coordinates the transmission of nodes in accordance with requests from the DM. It is responsible for establishing, managing, resetting and terminating all connections of the node within the domain. The LLC also facilitates QoS constraints of the flow, defined for its various connections.
- The **MAC sub-layer** manages access of the node to the medium using various medium access protocols.

The PHY sub-layers are:

- The **physical coding (PCS) sub-layer** provides data rate adaptation (data flow control) between the MAC and PHY and encapsulates transmit MPDUs into the PHY frame while it also adds PHY-related control and management overhead.
- The p**hysical medium attachment (PMA)** sub-layer provides encoding of PHY frame content for transmission over the medium.
- The p**hysical medium dependent (PMD)** sub-layer modulates and demodulates PHY frames for transmission over the medium using Orthogonal Frequency Division Modulation (OFDM). By implementation, the PMD may include medium-dependent adaptors for different media (coaxial, power line, and phone line).

It includes three main reference points:

- **Application interface (A-interface)** that interfaces the ITU-T G.hn subsystem with the upper layers. So far, only an Ethernet-based A interface is described in the Recommendation but it may be extended in the future (e.g., for IoT applications);
- **Physical medium-independent interface (PMI)** that interfaces the DLL layer responsible for maintaining the links between ITU-T G.hn nodes and the physical layer, responsible for sending frames across the medium;
- **Medium-dependent interface (MDI)** that describes how to inject the ITU-T G.hn physical frames in one of the mediums defined by the Recommendation.

6.3 DLL layer

6.3.1 DLL layer overview

The DLL layer provides the mapping of incoming Ethernet frames into the ITU-T G.hn MAC protocol data units (MPDUs).

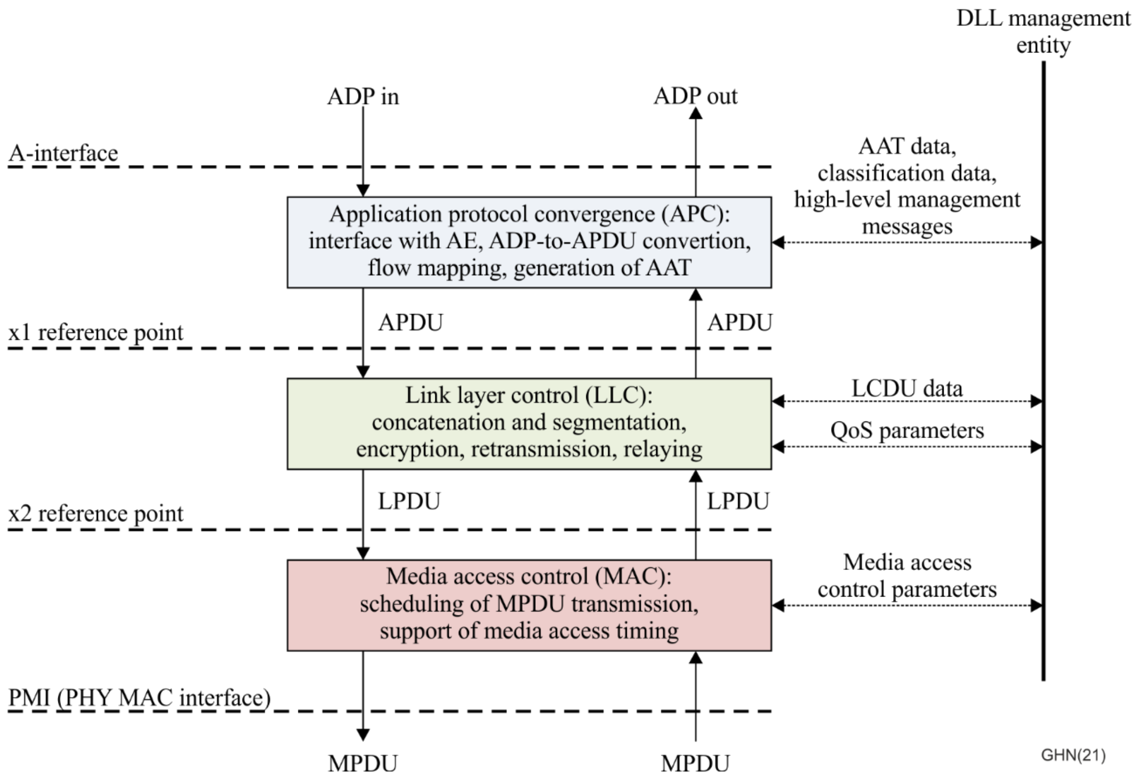

Figure 6-4 – Functional model of the DLL

In the transmit direction, the *Application Protocol Convergence* (APC) sub-layer is responsible for converting incoming Ethernet frames into APC protocol data units (APDUs) and to classify them into different transmission QoS queues depending on QoS rules that can be configured on the system and on the QoS information in the priority tags of the Ethernet frames.

Once the APDUs have been constructed, the *Logical Link Control* (LLC) sub-layer is responsible for establishing flows between ITU-T G.hn nodes and performs the aggregation, concatenation and segmentation of the incoming APDUs to maximize the use of the channel. This operation creates LLC protocol data units (LPDUs) that are passed to the MAC layer after encryption and that form the basic retransmission unit. The LLC is also responsible for relay operations and to inject/extract management information coming from the management entity into the ITU-T G.hn flow.

The *Medium Access Control* (MAC) sub-layer is responsible for concatenating LPDUs into MAC protocol data units (MPDUs) and then conveying these MPDUs to the PHY in the correct order and applying medium access rules established in the domain to guarantee the QoS parameters (e.g., throughput and/or latency).

In the receive direction, the opposite processes are implemented in order to retrieve Ethernet frames that are passed to the upper layers through the A interface and management frames to the management entity of the node.

A summary of the data plane encapsulations and how an Ethernet frame is conveyed along the ITU-T G.hn system is shown in Figure 6-5.

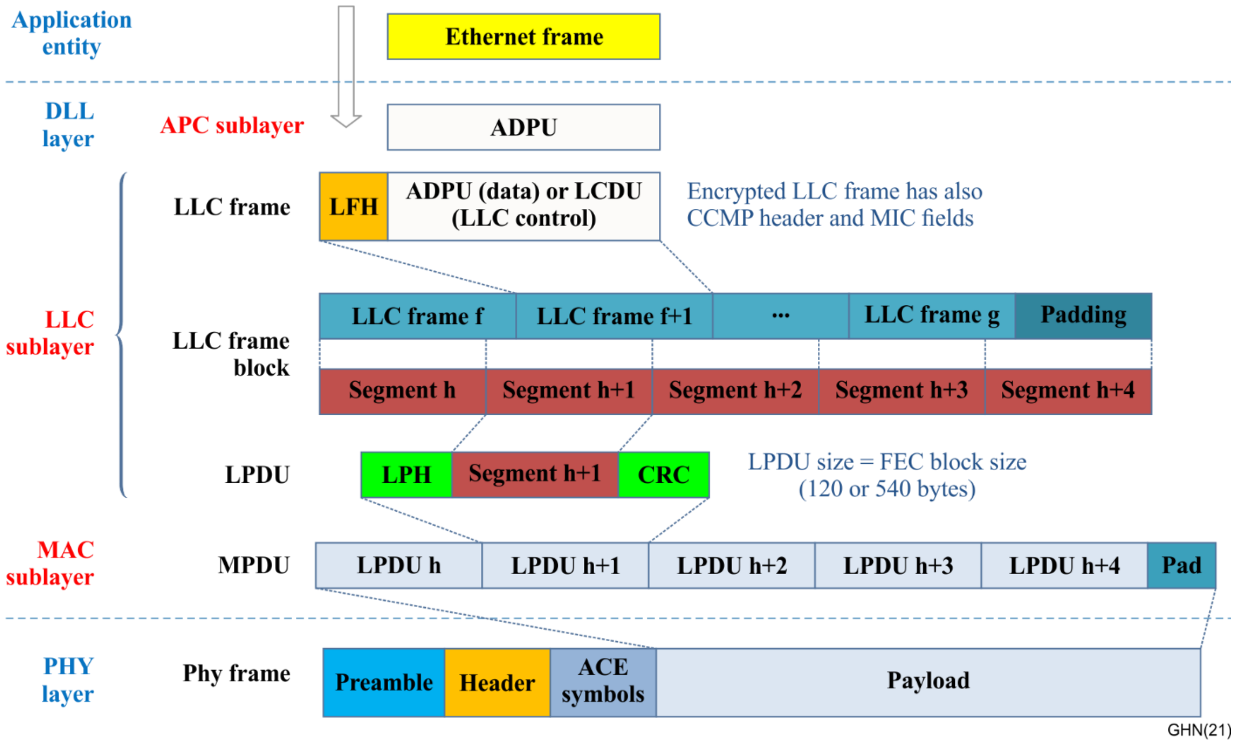

Figure 6-5 – Data plane in ITU-T G.hn

6.3.2 DLL layer main functions

6.3.2.1 QoS/Classifier

A classifier allows the mapping of incoming data traffic into flows, depending on their destination DEVICE_ID, class of service, and QoS support capabilities of the communicating nodes.

Flows are established in the APC by DLL management after receiving relevant data units from the AE, or during admission to the network, or by high-level management requests coming across the A-interface, or upon request from another node (by means of flow establishment protocol messages coming across the x1 reference point).

After mapping, data frames are classified into two types of flows and sent to lower layers:

- *Parameter-based QoS mechanism operates per flow*. Flows are set up, modified and terminated on a service basis. The characteristics of the service are used to select the QoS method used to deliver the traffic associated with the flow and to determine any relevant QoS parameters.
- *Priority-based QoS* refers to a mechanism that provides different priorities for medium access based on the priority of the incoming traffic as defined in Ethernet tagging.

These two approaches can coexist in order to set up the right QoS policy for each of the types of data exchanged between nodes.

6.3.2.2 Medium access scheme

ITU-T G.hn technology includes a very flexible synchronous medium access scheme called "MAP controlled medium access".

This MAP-based medium access mechanism has been specifically designed to allow QoS-aware operation of different topology models. Among others, we mention here the most popular:

- **Mesh operation**: When every node in the network may communicate with any other node of the network (either directly or through a repeater);

- **Point to Point operation**: When a node in a 2-node domain directly communicates with another node in the network;
- **Tree topologies (P2MP)**: When a node centralizes the communications in the domain.

For this, the MAP controlled medium access mechanism schedules MAC cycles continuously following one another. Each of the MAC cycles may be split in transmission opportunities (TXOPs) as shown in Figure 6-6.

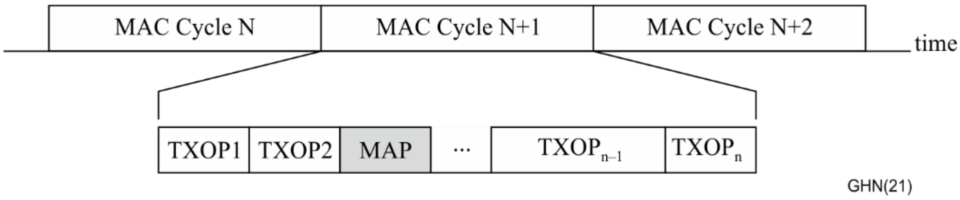

Figure 6-6 – Examples of MAC cycle

This synchronous MAC operation based on TXOP provides three different "tools" for accessing the medium. These different tools may be mixed in the same MAC cycle to create the appropriate scheduling for each type of topology and service.

- **Contention-based**: Where the nodes of the domain (or a subset of nodes) contend for the transmission opportunity. This approach is the more suitable one for non-QoS critical systems with low-traffic large number of nodes.
- **Contention-free**: Where the nodes of the domain (or a subset of nodes) have specific slots within the MAC cycle for QoS-guaranteed traffic that need allocated resources to guarantee latency and throughput.
- **Token-based**: When the nodes of the domain (or a subset of nodes) transmit one after the other following a predefined sequence. Whenever a node has nothing to transmit, the opportunity is passed to the following node in the list. This method provides the optimal QoS-aware channel utilization in a low-to-moderate number of nodes deployments but that necessitates full visibility between nodes. This mechanism is the most popular in-home network deployment.

In order to implement these three types of access, the following types of TXOPs are defined, and to address different applications, two main types of TXOP are defined.

- **Contention-free TXOP** (CFTXOP): Defines medium access based on time-division medium access (TDMA). Only one node can transmit during this TXOP. It targets services with fixed bandwidth and strict QoS (that is, video) needs.
- **Shared TXOP** (STXOP): A TXOP for which access is defined amongst a group of nodes. An STXOP is divided into a number of short time slots (TSs), representing an opportunity for one or more nodes to start transmitting. Each TS inside an STXOP is identified by its ordinal position within the STXOP. An STXOP may contain two types of TS:
    - **Contention-free time slot** (CFTS): Each CFTS is associated with a single node and a single flow/priority, identified by the node's DEVICE_ID and FLOW_ID/priority, which is exclusively allowed to transmit within that TS. If a node has nothing to transmit, it passes the opportunity to the next node.
    - **Contention-based time slot** (CBTS): A CBTS is not associated with a specific node and its associated priority. This TS can be used by all the nodes or by a group of nodes indicated by the DM node in the MAP. CSMA/CA is used during this TS for medium access with a priority resolution scheme for ensuring highest priority traffic contends for the medium before lower priority traffic.

An STXOP can be composed of only CFTSs, only CBTSs, or both CFTSs and CBTSs. An STXOP that is composed of CBTSs only is denoted as CBTXOP.

An example of MAC cycle structure and its division into TXOPs is shown in Figure 6-7.

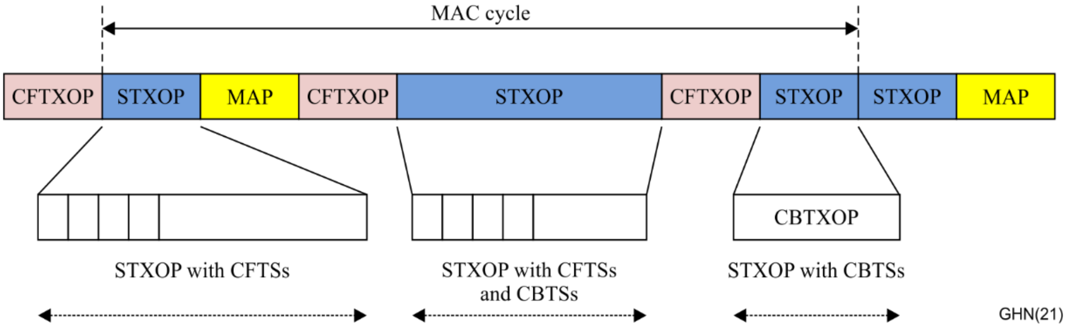

Figure 6-7 – Example of a MAC cycle structure

An example of a possible mechanism using a token-based approach is the use of STXOP transmission opportunities, which is the one typically used in home networking.

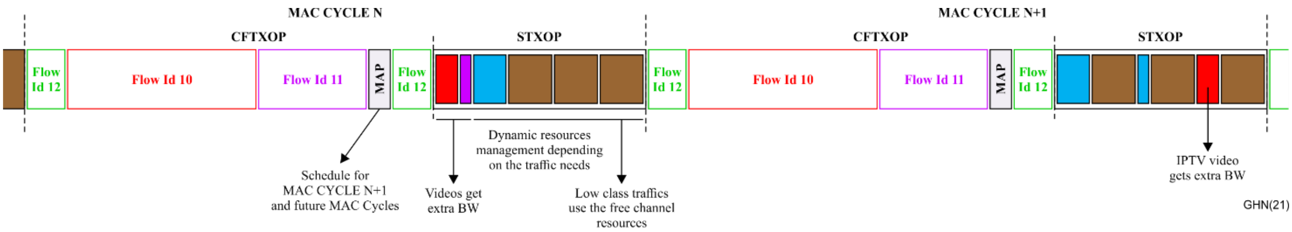

Figure 6-8 – MAC cycle distribution of ITU-T G.hn network use case example

In addition to the above-mentioned mechanism, the ITU-T G.hn standard provides other features that allow the optimization of the channel access for some given situations. As an example, the BMSG/H-BMSG mechanism proposes a master/slave transmission scheme that may be used in situations where a central coordinator has a full view of the network traffic and the traffic is bidirectional.

6.3.2.3 Relaying mechanism

When a node is not able to detect the presence of another node in the same domain, we refer to the non-detected node as a "hidden node" for that first node.

In these situations, in order to allow a communication between the nodes, a third node ("relay") is used. For this, two physical transmissions are done.

An ITU-T G.hn system allows a transparent relaying at the physical layer, not needing a full decoding of the frame for the relaying and preserving thus the confidentiality of the information and reducing the relaying processing power needs to a minimum.

6.3.2.4 Retransmission and acknowledgement scheme

ITU-T G.hn provides a robust retransmission mechanism to improve the robustness against the effects of impulse noises. The retransmission and acknowledgement protocol guarantees secure delivery of LPDUs under noisy mediums like power line by tagging the MPDUs with sequence numbers.

The acknowledgement protocol provides acknowledgement for the correct delivery of frames between two nodes. This acknowledgement can be done in two different ways:

- **Immediately after the reception of a PHY frame**, providing the validation feedback just after receiving a PHY frame;

- **in a delayed way**, providing the validation feedback in a separate PHY frame.

When an MPDU has been identified as being lost, it is retransmitted by the transmitter node following some scheduling rules that guarantee a prompt delivery with a minimal interference on the remaining traffic.

6.3.2.5 Power saving mechanism

ITU-T G.hn technology defines two mechanisms to limit the time a node may transmit traffic (active state) or not (inactive state):

- **Short inactivity scheduling**: A node may request the domain master for an inactivity scheduling for a fraction of the MAC cycle. This fraction of the MAC cycle may be negotiated between the node and the DM.
- **Long inactivity scheduling**: A node may request the domain master for inactivity scheduling for multiple MAC cycles.

By combining these two mechanisms, a domain master can implement power-saving strategies for the network based on adapting the scheduling generated to the requirements of power consumption and traffic of each of the nodes. This way, the DM can set the nodes of the network to different power states:

- **Normal mode (L0)**: This is the mode in which transmission up to the maximum data rate is possible.
- **Reduced-power mode (L1)**: In this mode, power consumption is reduced by limiting medium access for transmission and reception only to a portion of a MAC cycle (using the short inactivity schedule mechanism).
- **Low-power mode (L2)**: In this mode, power consumption is reduced by suppressing medium access over multiple MAC cycles. Only a limited data rate is supported (using the long inactivity schedule mechanism).
- **Standby mode (L3)**: In this mode, power consumption is reduced by suppressing medium access over an undetermined multiple MAC cycles. Only a limited data rate is supported (using the long inactivity schedule). In this mode, the node can be awakened by any node of the domain or by new transmissions through its A interface (wake on medium).
- **Idle mode (L4)**: In this mode, power consumption is minimized by suppressing any activity related to the domain. No data or control messages are transmitted or received. A node may request to quit this mode when there is traffic on its Ethernet port (Wake on LAN).

6.3.2.6 Channel estimation

The channel estimation protocol describes the procedure of measuring the characteristics of the channel between the transmitter and the receiver nodes. The procedure involves initiation of channel estimation, transmissions of PROBE frames, and selection of parameters.

Channel estimation can be done in two phases:

- Channel discovery – initial channel estimation
- Channel adaptation – subsequent channel estimation to adapt to a changing channel.

The protocols used for channel discovery and channel adaptation can be started either by the transmitter or by the receiver. The main part of the channel estimation protocol is always initiated by the receiver (receiver-initiated channel estimation). The transmitter can request the receiver to initiate channel estimation (transmitter-requested channel estimation).

During the initiation process, the transmitter and receiver jointly determine input parameters for channel estimation such as channel estimation window (a fraction of a MAC cycle over which channel estimation should be executed), and parameters for the PROBE frame.

The receiver selects the BAT_ID associated with the bit allocation table (BAT) to be updated. This BAT_ID is used for an identifier for a particular channel estimation process throughout the rest of the process.

Once the channel estimation process is started, the receiver may request the transmitter to send one or more PROBE frames. The receiver can change parameters of a PROBE frame at each request. In case the receiver requests a PROBE frame without specifying its parameters, the transmitter sends the PROBE frame using parameters previously selected by the receiver. The receiver is not required to request PROBE frames if it chooses other means such as MSG frames or PROBE frames transmitted to other nodes to estimate the channel. The protocol provides numerous options to speed up the channel estimation process for faster channel adaptation.

The receiver ends the channel estimation process by sending the outcome of channel estimation to the transmitter. This includes at least the following parameters:

- BAT
- FEC coding rate and block size
- Guard interval for payload
- PSD ceiling

The receiver may cancel the channel estimation process without generating new channel estimation parameters.

6.4 PHY layer

6.4.1 PHY layer overview

The PHY layer provides the adaptation of the data flow into physical frames that can optimally be transmitted over one of the physical media defined in ITU-T G.hn. In this step, the header of the PHY frame is also generated to include addressing and acknowledgement information.

The functional model of the PHY is presented in the following figure:

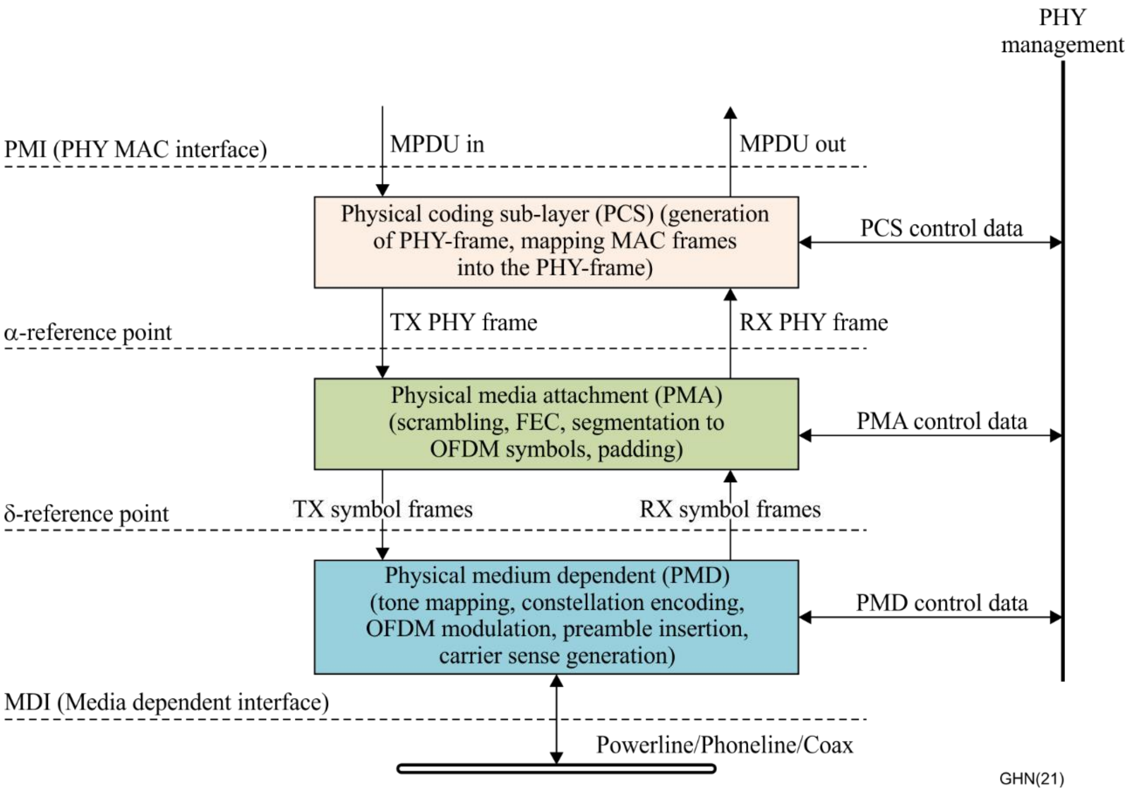

Figure 6-9 – Functional model of the PHY

The physical media attachment (PMA) sub-layer is responsible for line coding (using LDPC codes), scrambling and OFDM symbol segmentation to prepare the frames for a reliable transmission.

The physical medium dependent (PMD) sub-layer performs the insertion of the synchronization preamble and the adaptation of the PHY frames to the specific characteristics of one of the media defined in the Recommendation to optimize the usage of the channel under some given conditions of noise and attenuation by using the channel-specific OFDM parameters.

In the receive direction, the opposite processes are implemented in order to retrieve MPDU frames that are passed to the DLL layer.

6.4.2 PHY layer main functions

6.4.2.1 PHY frame format

A transmit frame (PHY frame) transmitted over the medium consists of a:

- Preamble
- header
- additional channel estimation (ACE) symbols (optional field, its presence is frame type dependent)
- payload

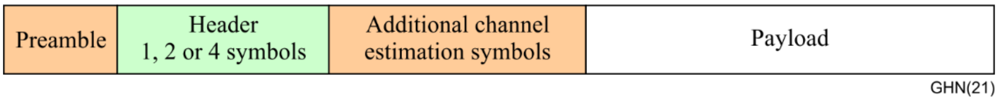

Figure 6-10 – Format of the PHY frame

The preamble and ACE symbols are added to the PHY frame in the PMD sub-layer.

The preamble does not transport any user or management data and is intended for synchronization and initial channel estimation. The preamble can be modulated using default seed or a domain specific orthogonal seed based on Domain ID (DOD). This mechanism is used to reduce the level of interference in case of neighbouring networks scenarios.

The header and payload each contain an integer number of OFDM symbols.

The PHY frame header carries settings of all programmable parameters related to the payload, such as guard interval, bit loading, and FEC parameters. The parameters of the PHY frame header are unified and specific per medium to ensure interoperability and selected to allow reliable detection of the header over noisy channels even without preliminary channel knowledge.

The length of the payload may vary from frame to frame; it may be of zero length.

The payload includes one MPDU composed of one or more LLC protocol data unit (LPDU). Each LPDU carries a segment of the transmitted data, a header identifying the carried segment, and the CRC to detect errored LPDU for selective retransmission. For the payload, different coding parameters and bit loading can be used in different frames, depending on the channel/noise characteristics and QoS requirements.

6.4.2.2 Robust communication mode

ITU-T G.hn technology allows the use of a robust communication mode (RCM) mechanism to transmit data over the medium when the characteristics of the medium are not known or when the medium does not provide the necessary quality (e.g., high-noise environments) and the communication has to be guaranteed.

The main characteristics of this RCM mode are:

- use of a payload repetition encoding that provides redundancy to the information sent over the line;
- use of predefined BAT to allow communication with new nodes and to operate under harsh conditions.

Some special frames like the MAP are always sent in RCM to guarantee the correct reception by all nodes.

6.4.2.3 Line coding

A quasi-cyclic low-density parity-check block-code (QC-LDPC-BC) encoding/decoding scheme is used in ITU-T as a FEC encoding/decoding scheme.

The FEC scheme consists of a systematic QC-LDPC-BC encoder and a puncturing mechanism with five code rates (1/2, 2/3, 5/6, 16/18, and 20/21) and three block sizes of 21 (header), 120 bytes and 540 bytes (payload). Three parity check matrices are used for code rates 1/2, 2/3, and 5/6, whereas the other two high code rates are obtained by puncturing the rate 5/6 code. The range of FEC parameters together with bit loading capabilities are designed to fit the retransmission scheme.

6.4.2.4 Modulation and adaptive OFDM engine

ITU-T G.hn adopted a windowed OFDM mechanism that adapts to the channel shape with the following programmable set of parameters to address different types of wiring:

- number of subcarriers, N = 2n, n = 8-12
- subcarrier spacing, Fsc = 2k × 24.4140625 kHz, k = 0 (power line), 1 (phone line) or 3 (coax)
- central frequency Fc
- window size.

For each particular medium and OFB, ITU-T G.hn defines only a single set of OFDM parameters so that overlapping OFBs use the same subcarrier spacing. This rule, plus a unified per medium default preamble structure and PHY frame header, facilitates interoperability. The number of subcarriers used in each OFB depends on the media and varies from 256 to 4096. There are also eight selectable values for the payload cyclic prefix (CP) length: k × N/32, k = 1, 2 …8.

ITU-T G.hn defines flexible per subcarrier bit loading in the range between 1 and 12 bits. Gray-mapping is used for all constellation points of even-bit loadings and for almost all constellation points of odd-bit loadings. The bit loading for each connection can be negotiated between the transmitter and receiver, providing sufficient flexibility to adopt channels with wide ranges of frequency responses and noise PSDs.

6.4.2.5 Operating frequency bands and profiles

ITU-T G.hn defines baseband operating frequency bands (OFBs) and RF OFBs as shown in Figure 6-11.

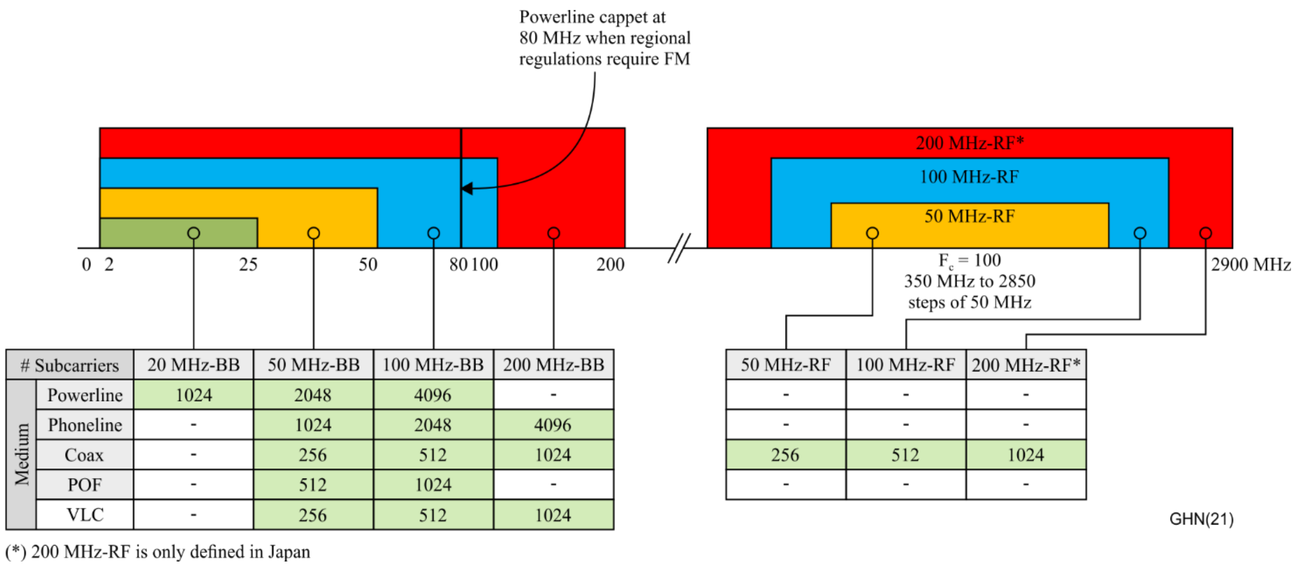

Figure 6−11 – Format of the PHY frame

For compliance with the ITU-T G.hn Recommendation, a node is required to support one profile, at a minimum. Profiles are summarized in Table 6-1.

Each profile allows the use of a given operating frequency band (OFB) that is related to the maximum achievable peak throughput.

Table 6-1 – Profiles

Profile name	Domain type	Valid operating frequency bands	
		Valid bandwidths when using normal frame format (PHY) – Profile 1 OFBs	Valid bandwidths when using high capacity header PHY frame format (HCH-PHY) – Profile 2 OFBs
Low-complexity profile	Power-line	25 MHz	Not defined
Standard profile	Power-line	50 MHz, 100 MHz (Note 2)	Not defined
	Telephone-line (Note 1)	50 MHz, 100 MHz, 200 MHz	500 MHz
	Coax	50 MHz, 100 MHz, 200 MHz	1 GHz
	Coax RF	50 MHz, 100 MHz, 200 MHz	Not defined
NOTE 1 – Telephone-line profiles are also applicable to any other pair-based copper cables (e.g., Cat5). NOTE 2 – Due to regulatory constraints, only frequencies up to 80 MHz are used for transmission.			

6.4.2.6 MIMO support

MIMO refers to a technology that has the ability to use more than one transmit path and more than one receiver path, in other words, multiple inputs to the path (or channel) referencing the transceiver's transmitters and multiple outputs from the path (or channel) referencing the transceiver's receivers.

Examples of commonly used MIMO technologies are typically found in the wireless space, with the IEEE 802.11 standard defining MIMO options for Wi-Fi transceivers. [ITU-T G.9963] (G.hn-MIMO) defines an enhancement to the operation of ITU-T G.hn in PLC mode to add MIMO functionality.

When used in a power-line scenario, the MIMO scheme is useful to boost the data rate while the hot line, natural line and ground line are available simultaneously in a power-line network.

In wireline, the use of multiple transmitters and/or receivers depends on the number of electrical paths between the two communicating devices. Each path requires two wires to function.

In the home, there is the use of 3-wire electrical sockets in many regions. These enable ITU-T G.hn-MIMO enhanced devices to send and receive signals over all three wires as two logical circuits.

In wireless, MIMO technologies enable better transmission/reception in crowded environments, while moving, and under increased noise conditions. Further, when conditions are favourable, MIMO transceivers are able to establish links at extended distances versus single input, single output (SISO) devices.

In power-line communications, the use of MIMO brings several improvements over standard SISO power-line transceivers.

- First, there is the ability to increase coverage in the building before the need for relays arises.
- Second, the ability of MIMO signals to cross over to other phases in the electrical wiring increases coverage and performance for many areas of the building.
- Third, there is the improved throughput as MIMO is based on a highly optimized communication scheme that sends spatially multiplexed signals over each port, with embedded self-noise cancellation techniques.

[ITU-T G.9963] specifies the basic characteristics of MIMO enhancement to ITU-T G.hn networking transceivers capable of operating over premises' power-line wiring. It provides a high-level introduction to the required technology and additions and modifications to [ITU-T G.9960] and [ITU-T G.9961] needed to define a MIMO enhanced ITU-T G.hn networking transceiver.

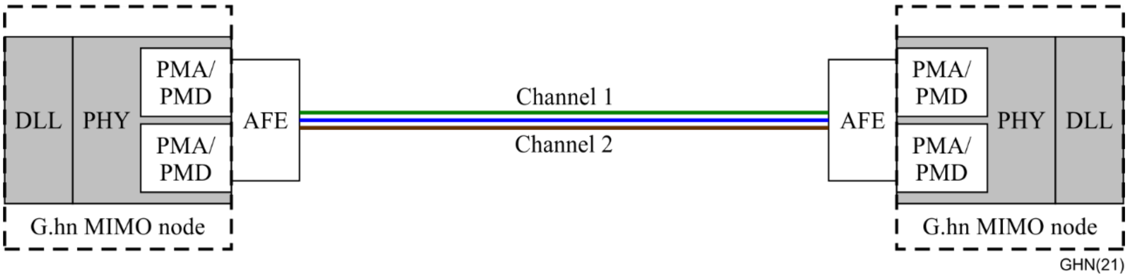

Figure 6-12 – ITU-T G.hn PLC nodes with MIMO linked by multiple channels

ITU-T G.hn-MIMO transceivers are able to transmit and/or receive over three power-line conductors (phase, neutral, and ground) using more than one Tx and/or Rx port. It provides a substantially increased data rate, greater noise immunity, and enhancing the connectivity (for example, service coverage) of the home network.

[ITU-T G.9963] includes:

- The PHY functional models of MIMO transceivers;
- descriptions of the modifications (changes and additions) needed in the PHY and DLL sections relative to [ITU-T G.9960] and [ITU-T G.9961] (for example, transmission and reception are mapped to multiple TX and RX ports in the PMD sub-layer);
- **t**he means by which both ITU-T G.9960/ITU-T G.9961 and ITU-T G.9963 transceivers interoperate when communicating on the same wires;
- **t**he means by which transmissions from ITU-T G.9963 transceivers do not degrade performance of ITU-T G.9960/ITU-T G.9961 transceivers when operating on the same wires.

An ITU-T G.9963 transceiver is defined to be fully compliant with [ITU-T G.9960] and [ITU-T G.9961], which ensures interoperability.

6.4.2.7 Frequency notching

In order to comply with the specific geographic regulatory constraints, each node of an ITU-T G.hn domain may be subject to a PSD reduction. This potential PSD reduction is defined by a transmit PSD mask that incorporates all the restrictions a node needs to comply with when transmitting. This transmit PSD mask is the composition of:

- **a subcarrier mask**, that eliminates transmission on one or more subcarriers;
- **a PSD shaping**, that allows transmit reduction of PSD in some parts of the spectrum, mainly for spectrum compatibility and coexistence with alien home network technologies;
- **notching of international radio bands**, suppressing transmission in the international amateur radio bands;
- **a limit PSD mask**, defined in the standard for each particular medium, specifically designed to minimize the interferences with other transmissions;
- **a PSD ceiling mechanism**, allowing to adapt the transmission level to the characteristics of the link.

6.5 Management layer

6.5.1 Management protocols / Data model

As part of the overall network of a service provider, ITU-T G.hn offers the possibility to the service providers to manage the behaviour of the network and of each of the individual nodes. For that, the DLL and PHY layers of the nodes may:

- interact with application layer entities that can control the behaviour of the system. This is particularly useful for service providers that need to control the ITU-T G.hn domain (e.g., through TR-069/TR-369 protocols);
- allow the exchange of management information (ITU-T G.hn protocols) between ITU-T G.hn nodes of the same domain, allowing to set up a unified point of management for management protocols like TR-069/TR-369);
- exchange information with a global master (GM) to coordinate several ITU-T G.hn domains.

For this, the ITU-T G.hn family of standards provides a data model in [ITU-T G.9962] including all the parameters that are accessible in all ITU-T G.hn-compliant devices. In addition to this data model, external organizations have defined additional data models more specific for some application scenarios like:

- **TR-181 G.hn data model** maintained by the Broadband Forum, including the parameters necessary to manage home network applications;
- **TR-374 G.hn data model** maintained by the Broadband Forum, including the parameters necessary to manage access applications;
- **Certification data model** maintained by the HomeGrid Forum, including the parameters necessary to manage certification operations.

The ITU-T G.hn data model can be accessed through:

- **a layer 2 management protocol** (LCMP) specifically defined in the ITU-T G.hn family of standards and that is include in all ITU-T G.hn implementations and that allows communication between external entities and ITU-T G.hn nodes and among ITU-T G.hn nodes;
- **any higher layer management protocol**, like TR-069/TR-369 or Netconf, widely used by service providers in home and access applications.

6.5.2 Coexistence mechanisms

Power-line communication devices may suffer interference from and create interference to alien power-line networks when operating over the same frequency range. Therefore, when there is a chance that multiple power-line networks are simultaneously using the same power-line cables in the same frequency range the technology has to offer mechanisms to cope with such a situation.

However, we need to differentiate two types of interference situation:

- **Coexistence with other ITU-T G.hn networks**: In the situation where the nodes of an ITU-T G.hn domain may interfere with nodes of another ITU-T G.hn node, ITU-T G.hn technology offers the use of the NDIM protocol to mitigate the interferences on a node-by-node basis.
- **Coexistence with alien protocols**: In the situation where the nodes of an ITU-T G.hn domain may interfere with nodes from a power-line network built using a different power-line technology, the coexistence protocol defined in [ITU-T G.9972] is used.

6.5.2.1 Coexistence with alien protocols: [ITU-T G.9972]

The ITU-T G.9972 coexistence protocol mitigates interference to ITU-T G.hn nodes from alien networks, thus enabling coexistence with other, non-interoperable, networks (alien networks).

This mechanism is based on the use of the inter-system protocol (ISP) that allows for the power-line medium to be shared between coexisting systems in the time domain, called time domain multiplex (TDM), the frequency domain, called frequency domain multiplex (FDM), or both. ISP supports coexistence between up to four non-interoperable coexisting systems.

Sharing of the power-line medium between coexisting systems is determined by the following:

- number of coexisting systems on the power line;
- type of coexisting system;
- access system capacity request.

Coexistence signalling is carried out by the use of periodically repeating ISP windows that are used to convey information on coexisting system presence, resource requirements and resynchronization request. Each coexisting system category is allocated a particular ISP window in a round robin fashion.

By monitoring the signals transmitted within the ISP windows allocated to other coexisting systems, a coexisting system is able to detect the number and type of other coexisting systems present on the line and the resource requirements of the access system (i.e., partial/full bandwidth).

Once the network status is known, the resource allocation algorithm defines the resource allocation between the different networks:

- **Frequency domain multiplex** (FDM): Within ISP, FDM may only be invoked by an access system. The overall FDM scheme consists of two frequency bands. The upper band is shared using TDM by in-home systems, the lower band reserved for access systems.
- **Time domain multiplex** (TDM): ISP allows TDM to be implemented between coexisting in-home systems or between coexisting in-home systems and an access system.

6.5.2.2 Coexistence with other ITU-T G.hn networks: NDIM protocol

This functionality is intended for power lines and maximizes overall performance of several neighbouring ITU-T G.hn PLC home networks in multi-dwelling units through coordination or isolation mechanisms.

An ITU-T G.hn node should be capable of detecting the presence of other neighbouring domains operating over the same medium (either directly or via information sent by other nodes in its own domain). Once a neighbouring domain is detected, a DM should take all needed actions to mitigate interference with the neighbouring domains' nodes including coordinating with them while guaranteeing that QoS requirements for existing service flows are maintained.

The NDIM procedure includes the following mechanisms:

- A signalling mechanism for detection of neighbouring domains based on synchronization points (CSP), synchronization signals (IDPS) and synchronization windows (IDSW).
- A mechanism (**MAC cycle alignment procedure)** to align the MAC cycles of all the domains that are present on the same medium and can detect each other, independent of the level of interference among their nodes, creating clusters of domains (NDIM cluster).
- A routine mechanism allowing nodes to update the information of the neighbouring domains that they can detect and to keep track of the status of the neighbouring nodes that interfere with it (**Routine Maintenance Procedure**).
- A mechanism that allows inter-domain management frames exchanges between two neighbouring domains by establishing an inter-domain Communication Channel (IDCC) (**Communication between Neighbouring Domains**).
- A mechanism specifying the usage of a near-orthogonal signal for generating and detecting the preamble, PR, INUSE and NACK signals in specific TXOPs. This mechanism may be applied in cases where the interference from neighbouring domains is low. Based on this mechanism the transmissions from other neighbouring domains are treated as noise.
- A distributed mechanism allowing coordination between domains of transmissions from and to nodes that can interfere with each other (**Neighbour Domain Coordination Mechanism**). Using this mechanism, neighbouring domains can independently infer a scheduling that avoids interference.

An NDIM cluster is defined as a group of domains that have their MAC cycles aligned. A cluster must be uniquely identified by its 48-bit cluster identification (ClusterID).

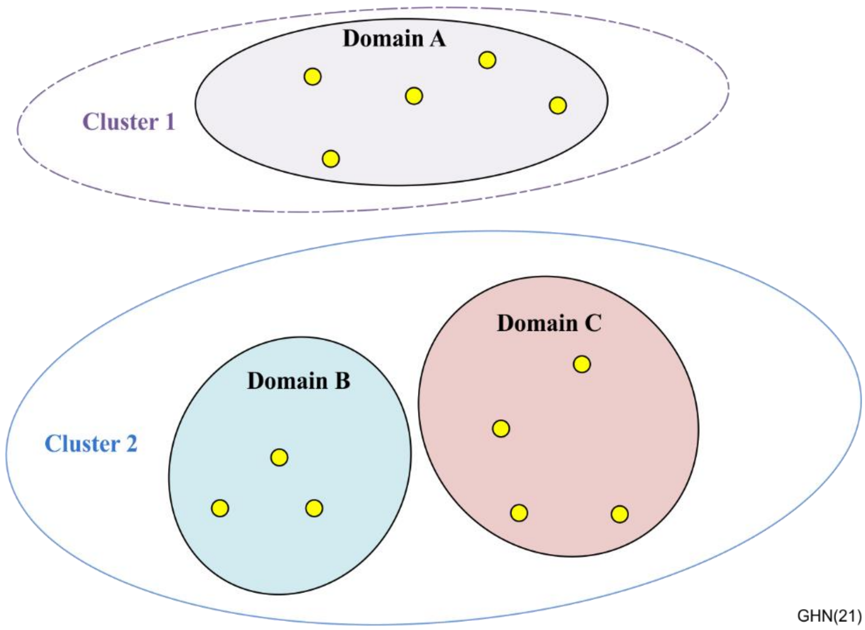

Figure 6-13 – NDIM clusters

To accelerate the processes of detection of neighbouring domains and MAC cycle alignment, the DM shall reserve some time of the MAC cycle for the inter-domain communication channel (IDCC) as depicted in the following figure.

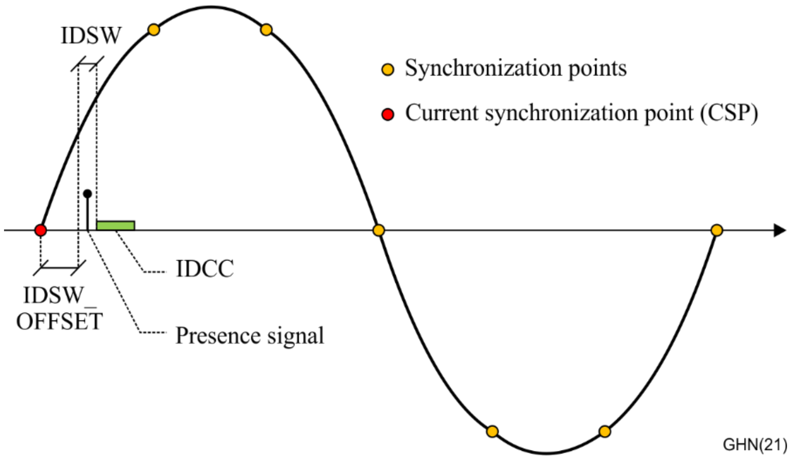

Figure 6-14 – Position signalling information in the MAC cycle

Each cluster shall use one of these synchronization points as a reference for the position of the inter-domain Signalling window (IDSW) and the inter-domain communication channel (IDCC). This selected synchronization point is called the Cluster Synchronization Point (CSP).

The IDSW defines a region of the MAC cycle that shall be used by all the nodes of a cluster for transmitting their inter-domain presence signal (IDPS). IDSW shall be present once every MAC cycle. The IDPS shall be generated within the IDSW by all nodes of the cluster domains to announce their presence to potential neighbouring domains. The IDCC is used by every DM of the cluster to exchange inter-domain messages with the others domains' DM.

6.6 Security mechanisms

6.6.1 Security overview

Since ITU-T G.hn is intended to operate over shared media, such as power lines and coax, its threat model includes two kinds of threats:

- **External threat** implies an attacker capable of eavesdropping on transmissions and sending frames within the network, but with out-of-network access credentials. ITU-T G.hn defines an authentication procedure based on the Diffie-Hellman algorithm and the counter with cipher block chaining-message authentication code algorithm (CCM), which uses AES-128.
- **Internal threat** is from a legitimate user of the network who has an illegitimate interest in the communications of another user or access to a specific network client. In case of hidden nodes, communications between two particular nodes may pass through a relay node, raising the potential for a man-in-the-middle threat. Internal threats typical for public installations, ITU-T G.hn defines pair-wise security: a unique encryption key is assigned to each pair of communicating nodes and is unknown to all other nodes. Pair-wise security maintains confidentiality between users within the network and builds another layer of protection against an intruder that has broken through the network admission control. Besides, end-to-end encryption avoids the man-in-the-middle in the relays, as ITU-T G.hn messages remain encrypted when relayed.

6.6.2 Security steps

ITU-T G.hn security functions are based on controlled entry of nodes into the domain, Security controller (SC) authentication of the nodes before communications is enabled, encrypted communications between nodes using peer-to-peer keys, and periodic re-establishment of authentication.

When a new node wants to join a domain, it must first register with the domain's DM. The DM verifies the node has a valid identity and is allowed to join the domain. Once this verification is done, the DM registers the node. This registration means that the node is a member of the domain; however, it is not allowed yet to communicate with any other node.

A newly registered node must then authenticate with the SC. The SC is a function that may be a separate function in the domain, co-resident with the DM function, or it may be distant from the domain. Once a node requests authentication from the SC, the SC validates the node's identity and, if the node is allowed into the domain according to the logic and records the SC may access, then it performs a series of steps with the node to establish a secure link with the node. This secure link enables the SC to pass encryption keys to the node for use when it communicates with other nodes. At this point, the node is allowed to communicate with other nodes.

When two nodes want to establish a communications flow between them, they query the SC for a set of keys that is unique to their specific flow. No other nodes have access to these keys, thus the flow between the two nodes is secure both from other nodes in the domain as well as external threats.

Periodically, the SC re-authenticates the nodes of the domain, authenticating the nodes and creating new keys for communicating between it and each node. Any node failing re- authentication is set as deregistered from the domain and unable to communicate with other nodes.

ITU-T G.hn's security architecture is composed of six major elements:

- **authentication**: Procedure to ensure that only authorized nodes/users can exchange data. The technology support two types of authentication depending on which entity provides authentication, generation, distribution of encryption keys between nodes, and periodic key and authentication update services;
    - ***native authentication***: Provided by a set of authentication and key management (AKM) procedures, described in G.hn Recommendations;
    - ***external authentication***: Provided by higher layers (external authentication). In this case, the node will use the AKM procedures only to distribute the computed keys.
- **key distribution**: Procedure to distribute secret keys to authenticated devices in the network;
- **data encryption**: Procedure to encrypt data with a secret key only able to be determined by the receiving node;
- **data integrity**: Procedure to ensure that messages are not altered after they have been transmitted.
- **message uniqueness**: Messages cannot be retransmitted by a third node in an effort to produce a "replay attack".
- **man-in-the-middle (MITM) protection**: A relaying node within a domain cannot decrypt messages.

6.6.3 Security main characteristics

ITU-T G.9961 security services have the following characteristics:

- encryption based on AES-128 and CCM/CCMP;
- advanced authentication and secure admission of nodes into a domain, based on [ITU-T X.1035];
- support of external authentication and secure admission of nodes into a domain, based on upper layer protocols (e.g., IEEE 802.1x);
- key management, including generation, secure communication, update, and termination of encryption keys;
- high confidentiality and integrity of all transactions, due to point-to-point authentication and unique encryption keys for unicast and multicast communications;

- support of secure (encrypted) operation over nodes that relay messages to other nodes: relay nodes do not possess encryption keys of the relayed frames and do not pass relayed messages above the LLC sub-layer;
- simultaneous operation of distinct, separately secured domains on the same medium;
- procedures for setting up a secure network that can be self-contained in its processes or open to secure communications with a security controlling entity that is remote from the domain;
- periodic and automatic re-registration, re-authentication and encryption key updates;
- replay protection.

7 Summary of key features of ITU-T G.hn

- Single technology for all wires = power line, coax, phone line, and plastic optical fibre (POF). Most optimum performance per medium:
  - support for ITU-T G.hn baseband band plans 25 (PLC), 50 MHz, 100 MHz and 200 MHz (coax and phone line);
  - specific OFDM parameter set per medium to maximize throughput while minimizing latency;
  - up to 1500 Mbps PHY rate over power line and up to 2Gbps PHY rate over coax and phone;
  - MIMO techniques for power lines (based on [ITU-T G.9963]) boosting PLC throughput;
  - robust communication mode (RCM) supported for high noise environments.
- Support for multiple network access MAC schemes (TDMA, CSMA, token-passing) to accommodate application-specific requirements.
- Reliability and robustness:
  - state-of-the-art LDPC forward error correction;
  - enhanced ACK-based selective retransmission of PHY blocks to maximize impulsive noise mitigation;
  - synchronization with the AC cycle for PLC medium;
  - relaying function and auto-mesh networking for increased coverage and network resilience.
- Power management: Up to five modes of operation allowing short-term and long-term inactivity periods and providing wake up mechanisms.
- Neighbouring networks (Multi-network/neighbouring domain interference mitigation) = G.hn standard mechanism achieves maximum aggregated performance in multi-dwelling units.
- Security:
  - AES 128 bits encryption algorithm using CCMP protocol to ensure confidentiality and message integrity:
  - native authentication and key exchange following [ITU-T X.1035] enabling end-to-end encryption even when packets are relayed;
  - external authentication and key exchange mechanisms support (e.g., IEEE 802.1X) to adapt the systems to all applications.
- QoS:
  - prioritized QoS with eight priority levels by selectable packet fields;
  - "Per-stream" parameterized QoS;

- ○ admission control, congestion control and bandwidth limitation.
- Power mask and notching allowing coexistence with radio systems.

8 Summary

This Technical Paper has briefly described the ITU-T G.hn technology described in ITU-T G.996x Recommendations and widely used for high-speed applications in the home, in access and industrial space. A more in-depth knowledge of the technology can be acquired by reading the related Recommendations available in ITU-T.

The work in ITU-T G.hn technology is continuously evolving in ITU-T Study Group 15 to address the new needs and requirements for in-premises communications and related applications through amendments to existing Recommendations and the creation of new ones. This work will lead to new versions of ITU-T G.hn technology addressing the different media (phone line, coaxial, power line and optical).