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QUALITATIVE OVERVIEW FOR HIGH-SPEED DATA-OVER-CABLE COMMUNICATION TO INTRA-VEHICLE NETWORK APPLICATIONS

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ABSTRACT

Nowadays, vehicles are becoming smart in their interaction with passengers and the surrounding environment to support complex autonomous operations. These functionalities demand further capacities to connect massive sensors inside the vehicle to allow the processing of collected data. Besides, data-intensive applications such as cameras are also the main part of connected devices inside vehicles. The increasing total number of sensors as well as the data-intensive applications demand a novel use of the wired-bus system inside vehicles. Several approaches have been developed through LIN, CAN, FlexRay, MOST, LVDS and Automotive-Ethernet technologies to support the massive connection of sensors with the increase of available bandwidth. LIN, CAN and FlexRay sup-port communication with limited data-rate. On the other hand, MOST and LVDS and Automotive Ethernet-based solutions implement higher data-rate systems deploying additional infrastructure with increased costs. The current report discusses different approaches by considering OFDM (Orthogonal Frequency-Division Multiplexing) based systems for intra-vehicle communications taking into account the similarities with G.hn standard. This standard supporting home networking describes an OFDM based system over different mediums (PLC, coaxial, Phone Line and Cat-5 cables) whose network topology is nearly similar to intra-vehicle networks. This report provides a discussion on the possibility of using OFDM for intra-vehicle communications based on the G.hn standard. Functionalities regarding the defined topology as well as physical layer block diagram definition are illustrated.

KEY WORDS: IEEE 802.3, G.hn, DOCSIS, Network Topology, PHY layer, OFDM.

ANÁLISIS CUALTITATIVO SOBRE LAS COMUNICACIONES CABLEADAS DE ALTA VELOCIDAD PARA APLICACIONES EN REDES VEHICULARES

RESUMEN

Hoy en día, los vehículos están desarrollando funcionalidades interactivas con los pasajeros y el entorno para apoyar operaciones autónomas complejas. Estas funcionalidades exigen capacidades adicionales para conectar de forma masiva sensores dentro del vehículo y permitir el procesamiento de datos recopilados. Además, las aplicaciones de alto consumo de datos como la cámara también son parte principal de los dispositivos conectados dentro de los vehículos. El creciente número de sensores, así como las aplicaciones intensivas en datos, exigen un uso novedoso del sistema de bus cableado dentro de los vehículos. Se han desarrollado varios enfoques mediante las tecnologías LIN, CAN, FlexRay, MOST, LVDS y Automotive-Ethernet para admitir la conexión masiva de sensores con el aumento del ancho de banda disponible. Las tecnologías LIN, CAN y FlexRay ofrecen velocidad de datos limitada. Por otro lado, MOST y LVDS y Automotive-Ethernet implementan sistemas de mayor velocidad de datos, aunque implementan infraestructura adicional con mayores costos. El presente artículo analiza diferentes enfoques al considerar sistemas basados en OFDM para comunicaciones intra-vehiculares basados en las similitudes con el estándar G.hn. Este estándar de redes domésticas de soporte describe un sistema basado en OFDM a través de diferentes medios (PLC, coaxial, línea telefónica y cables Cat-5) cuya topología de red es casi similar a las redes dentro del vehículo. Se proporciona una discusión sobre la posibilidad de usar OFDM para las comunicaciones dentro del vehículo basadas en el estándar G.hn. Se ilustran las funcionalidades relacionadas con la topología definida, así como la definición del diagrama de bloques de la capa física.

PALABRAS CLAVES: IEEE 802.3, G.hn, DOCSIS, Topología de redes, Capa física, OFDM.

1. INTRODUCTION

The evolution of vehicles is pointing to the self-driving technology in almost every new car on the market [1]. In this direction, a variety of modules are deployed to support drivers on the road. For instance, adaptive cruise control, automated emergency braking or lane-keeping system are examples of already installed components to be part of a future self-driving application. The needs to support these intelligent technologies for driver assistant, the additional protection mechanisms and the increased comfort for vehicle passengers [2] demand to install proper capacities on communication systems for these data-intensive applications.

In this concern, communication systems for intra-vehicles applications are increasingly growing in the total number of sensors. To illustrate, Fig. 1 depicts onboard hardware components such as cameras, short- and long-range radars, ultrasonic and tier pressure sensors, LIght Detection and Ranging (LIDAR), all of them interconnected to conceive a decision-support system [3]. Typically, each of these applications conveys also the wired connection of stand-alone electronics, which in turn leads to a higher complex heterogeneous system. This implies to devise the means to connect by wires massive sensor networks inside the car with the proper resource allocation.

Technologies to support cable data transfer inside vehicles have been developed through several physical mediums: single wire, twisted-pair and coaxial cables [4]. These physical layer technologies have been standardized by LIN, CAN, FlexRay, MOST, LVDS and Automotive-Ethernet [5-10] to connect the variety of sensing nodes.

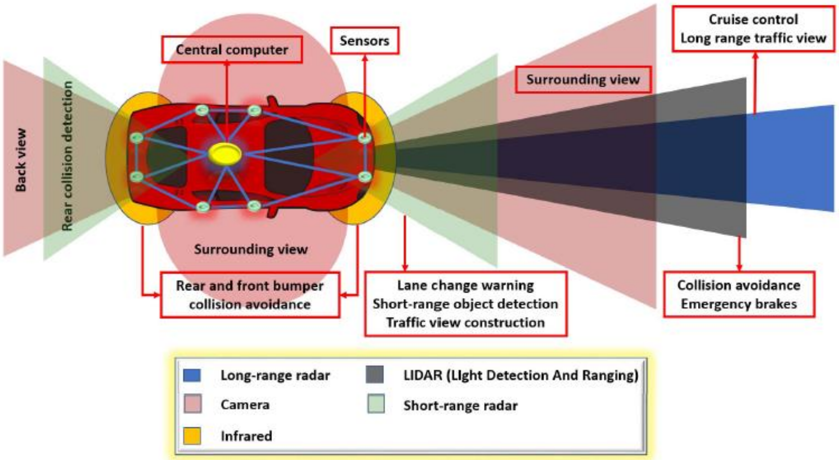

Figure 1: Sensor systems on vehicles [3].

Although a variety of standardized technologies support data-over-cable communications, some of them are still limited on data-rate transmission. For instance, LIN, CAN and FlexRay only support 19.2 Kbps, 1 Mbps, and 20 Mbps, respectively; while higher bandwidth operation is supported by MOST and LVDS with 150 Mbps and 655 Mbps; respectively. However, such data-rates are still insufficient for commercially available camera modules [4]. Further increase of the bandwidth parameter for intra-vehicle applications is still under development.

Automotive-Ethernet [10], based on Ethernet 802.3 standard, is a currently provided solution for commercial systems that offer increased data rates (up to 1Gps). However, on one hand, the implementation of Automotive-Ethernet is today incurring extra costs, provided the additional infrastructure it demands to implement, i.e. switches, additional cabling, and interfaces as depicted in Fig. 2. On the other hand, waveforms used to communicate nodes are based on three-levels PAM, which in turn limits the spectral efficiency of such communications.

From a different perspective, the use of spectral-efficient waveforms will benefit the transmission-rate over the same used bandwidth. For instance, OFDM waveforms information may be placed on different subcarriers and by using amplitude and phase modulation techniques such as M-QAM [11].

A similar approach is developed for home networking technologies from G.hn standard [12] [13], where the use of already installed wires at home are used to transmit higher data-rates based on OFDM waveforms. The use of OFDM-based systems may support such applications provided the allowed capacity to multiplex users and the robustness to undesirable channel effects.

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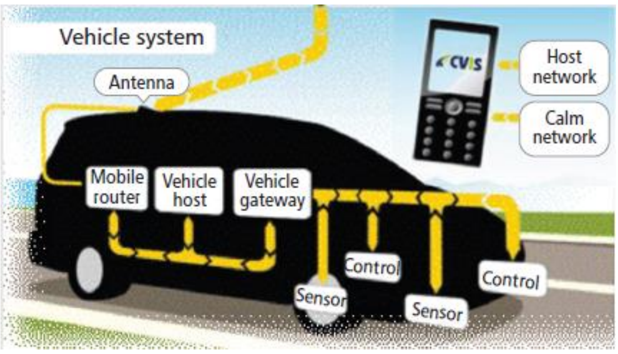

Figure 2: Onboard equipment communication system based on IEEE 802.3 approach [4].

The current report sketches a comparative summary of this standard and the network topology of bus CAN. Based on this study, points in common are established for future use on automotive-based applications to transmit high-speed data. Further details on bus CAN as well as G.hn standard are also provided.
The rest of the report is organized as follows. Section 2 summarizes the intra-vehicle network based on the bus CAN medium. Section 3 describes the G.hn standard for the network topology and the physical layer details, while Section 4 discusses the common points of both domain applications. Finally, concluding remarks are given in Section 5.

2. CAN BUS

CAN bus is implemented to support the communication between nodes inside vehicles. This bus is conceived to simplify the wired connections be-tween electronic devices to provide a low-cost, robust network, and multi-master communication system [14]. CAN bus backbone is physically implemented by a twisted-pair cable to connect up to 2032 electronic devices, although hardware limitations reduce this quantity to 110 nodes only [14].

Fig. 3 depicts a representation of the CAN bus. A variety of nodes (CAN Transceiver) are directly connected to the same line (twisted-pair cable) to have a fast serial bus. Each node follows the traditional OSI model by implementing 4-layers only: physical, transfer, object and application layers; with the functionalities described in Table I.

Applications supported by the CAN bus are not only related to vehicles; these are also extended to industrial automation (marine and aircraft electronics, factories, cars, trucks, etc) [14]. This expanded use of CAN bus is mainly given by its low cost, high performance, and scalability, which provides the needed flexibility to include further applications.

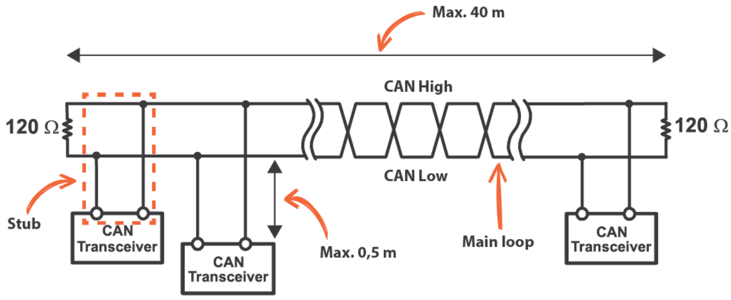

Figure 3: CAN bus representation [15].

3. G.HN STANDARD

G.hn standard offers a unified-speed wire-line based home networking description for a variety of mediums; telephone line, power line, and coaxial cable. By means of a family of standards specified on G.9960 to G.9964, Network architecture, PHY and Data Link layers, Management, MIMOa, and PSD (Power Spectral Density) specifications are described based on OFDM modulation.

Network architecture and topology is defined based on four different elements: nodes (transceivers), relays, inter-domain bridges, and physical medium. Domains are referred to as the connection of nodes over the same physical medium (telephone line, power line, coaxial cable), as depicted in Fig. 4. Architecture is defined by connecting these domains and by interconnecting elements inside each specific domain on three different modes: peer to peer, centralized and unified modes.

Table 1: Layer architecture of a CAN node [14].

Application Layer
Object Layer ▪ Message Filtering ▪ Message and Status Handing.
Transfer Layer ▪ Fault Confinement. ▪ Error Detection and Signaling. ▪ Message Validation ▪ Acknowledgment ▪ Arbitration ▪ Message Framing. ▪ Transfer Rate and Timing
Physical Layer ▪ Signal Level and Bit Representation. ▪ Transmission Medium.

On the other hand, the physical layer is specified by using OFDM modulation waveform and LDPC (low-density parity-check code). This standard also offers to avoid interference by notching specific frequency bands such as amateur radio bands and other licensed radio services. Each subcarrier from OFDM waveform is modulated using QAM of maximum order given by 4096-QAM (12-bit QAM). This waveform is transmitted over local wiring including inside telephone wiring, coaxial cables, and power-line cables, plastic optical fiber and any combination of these.

G.hn Network Architecture and Topology

G.hn network architecture is defined by domains, where each domain contains nodes only connected to the same medium (telephone line, power line, coaxial cable), as depicted in Fig. 4. Each domain should support at least 32 registered nodes up to 250. Each node shall be capable of supporting simultaneous communication sessions with at least eight other nodes using dedicated sets of transmission parameters.

Domains have three different modes of operations to establish a connection between constituting nodes as depicted in Fig. 5 a) to c):

- Peer-to-Peer mode: Direct signal traffic is established between two communicating nodes.
- Centralized mode: Each node most communicate by a Domain Access Point (DAP). The DAP receives signals from all nodes of the domain and further forwards them to the corresponding addressed nodes.
- Unified Mode: Two nodes within the same domain (node C and node H) that are hidden from each other have communication between them via the relay node (node A). Both nodes are managed by the domain master (node D) and can communicate directly with all other nodes.

Each mode shall support broadcast and multicast despite the mode of operation. Three different kinds of constituting element-nodes conform to the topology scheme in Fig. 4:

- Transceiver Node to implement the transceivers.
- Domain Master Node to support the control operations of nodes in the given domain.
- Inter-domain communication node: Implemented to connect nodes of different domains.

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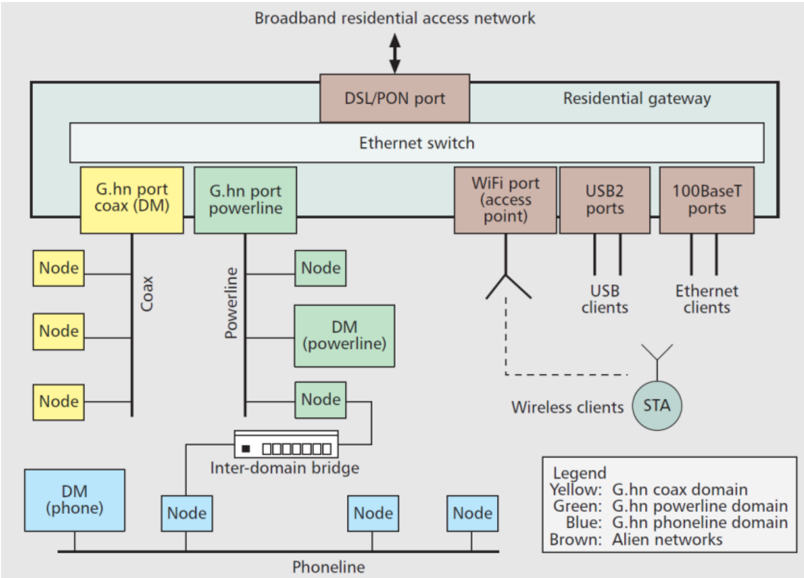

Figure 4: G.hn topology for home networking [13].

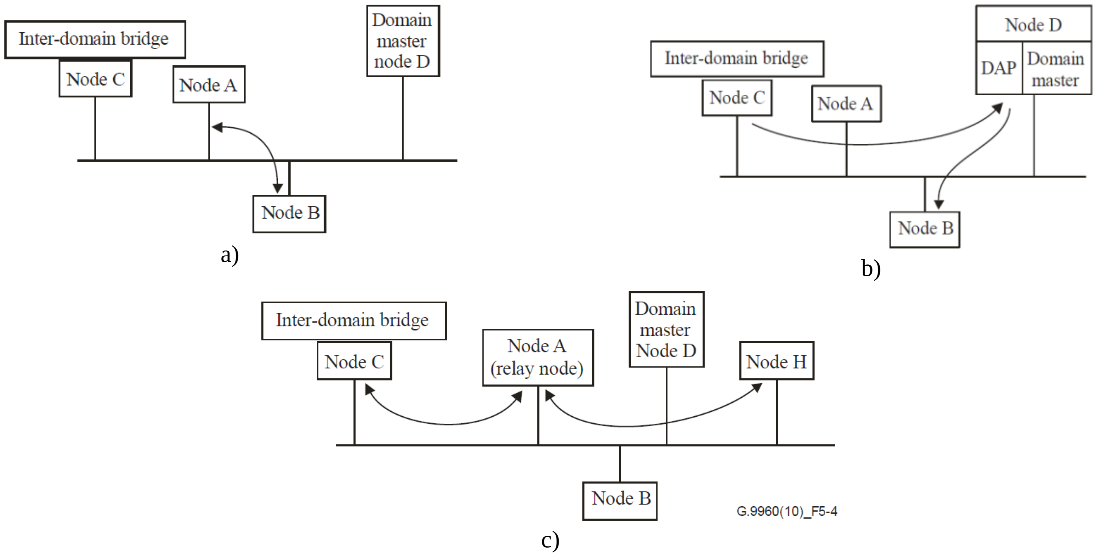

Figure 5: G.hn domain operating modes. a) Peer-to-peer mode. b) Centralized mode. c) Unified mode [12].

G.hn Physical Layer

PHY layer is comprised of three different sublayers as depicted in Fig. 6. Each sublayer communicates between each other utilizing synchronized frames and with the PHY management using control signals. These three different sublayers built the frame to transmit by the medium, see Fig. 7. This frame is comprised of a preamble (to synchronization and channel estimation), a header (to identify the frame type), additional symbols for channel estimation and the Payload with the useful information. Each sublayer performs the following specific operations to transmit this physical frame:

- PCS (Physical Coding Sublayer): To conform to the PHY frame by adding a PHY-frame header. PHY-frame header is detailed as explained in clause 7.1.2.3 in [12].

- PMA (Physical Medium Attachment): This sub-layer encodes header and payload bits from the RX PHY frame by different FEC options (clauses 7.1.3.4 and 7.1.3.3, respectively in [12]).
- PMD (Physical Medium Dependent): This sub-layer modulates the incoming frame from PMA into OFDM waveform and vice versa. Blocks to map the constellation points and modulate OFDM are implemented in this sublayer as depicted in Fig. 8.

Based on the functional model of Fig. 5, this section focuses on the PMD sublayer only where OFDM modulation takes place. Remain sublayers, as well as Data Link Layer, are described on the G-9960 document in [12].

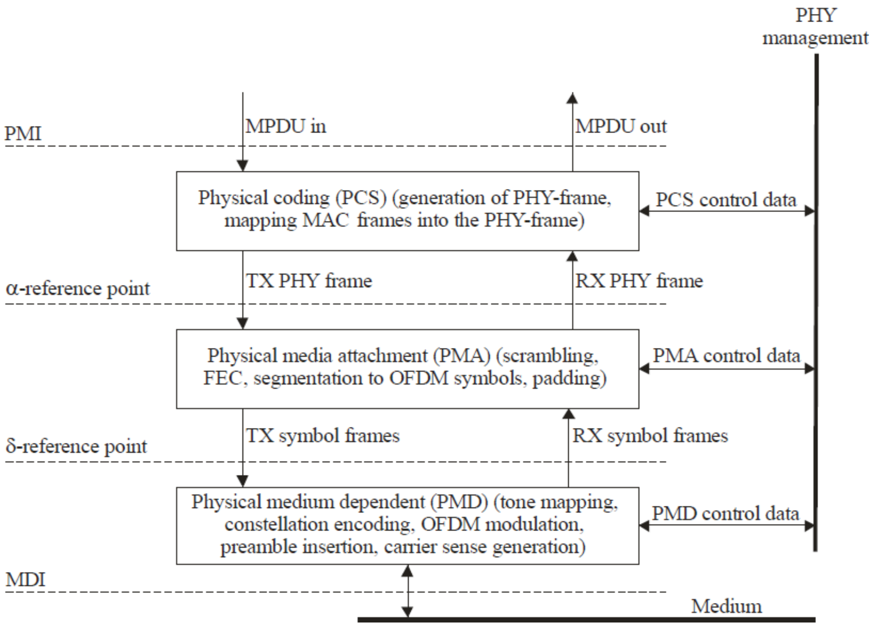

Figure 6: Functional model of the physical layer [12].

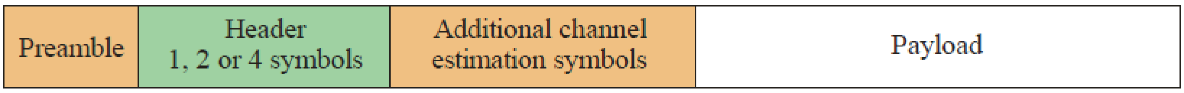

Figure 7: Format of the physical frame [10].

PMD Sublayer

PMD sublayer implements the generation and demodulation of OFDM waveform signaling. The functional block diagram is given in Fig. 8. This functional diagram implements a transmitter and a receiver. The transmitter confirms the constellations points and the OFDM modulator. The receiver retrieves frames from OFDM received waveform.

Constellation mapper block (clause 7.1.4.2 in [12]) converts a given group of bits into a complex number to modulate subcarriers from OFDM waveform. Besides, there are subcarriers only modulated by a pseudorandom bit sequence. Constellation encoders map a total number of bits ranged from 2 to 12. Additionally, constellation points are mapped cross-shaped for an even number of bits.

After the constellation mapper block in Fig. 8, a scramble operation is performed to reduce the effect of burst noise. Then, the OFDM modulator conforms to the signal to be transmitted through the medium. Subcarriers from OFDM are divided into two groups: Masked Subcarriers (MSCs) and Sup-ported Subcarriers (SSCs). MSCs are never allowed for transmissions given the channel characteristics. SSCs have active subcarriers for data transmission and inactive for measurement purposes.

OFDM modulator block comprises 5 different blocks as depicted in Fig. 9:

- IDFT (Inverse Discrete Fourier Transform): Performs conversion of a given complex number from constellation encoder ($Z_{i,l}$) into a time-domain sequence of complex numbers ($x_{n,l}$) following the relation

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$x_{n,l} = \sum_{i=0}^{N-1} Z_{i,l}\, e^{j2\pi \frac{n}{N} i}$, where i represents the subcarrier, l represents the given OFDM symbol and $Z_{i,l}$ the encoded data values. Values of $Z_{i,l}$ are set to 0 for MSCs.

- Cyclic prefix: Provides a guard interval to protect against ISI. The already obtained IDFT samples are preloaded by using last N_{CP} samples.
- Windowing, overlap and add: Windowing is comprised of a roll-off function depending on vendor developer. Windowing operation is performed on the first and last samples as well. This is used to reduce the out-of-band power spectral density of the signal of interest.
- Frequency up-shift: This operation offsets the spectrum of the computed signal by F_{US}, the value of which shall be a multiple of the subcarrier frequency F_{SC} as follows: $F_{US} = m \cdot F_{SC}$. Valid values of m are medium dependent and given in clause 7.2 in [12].

Table II summarizes the main parameters used by G.hn standard regarding OFDM waveform modulator.

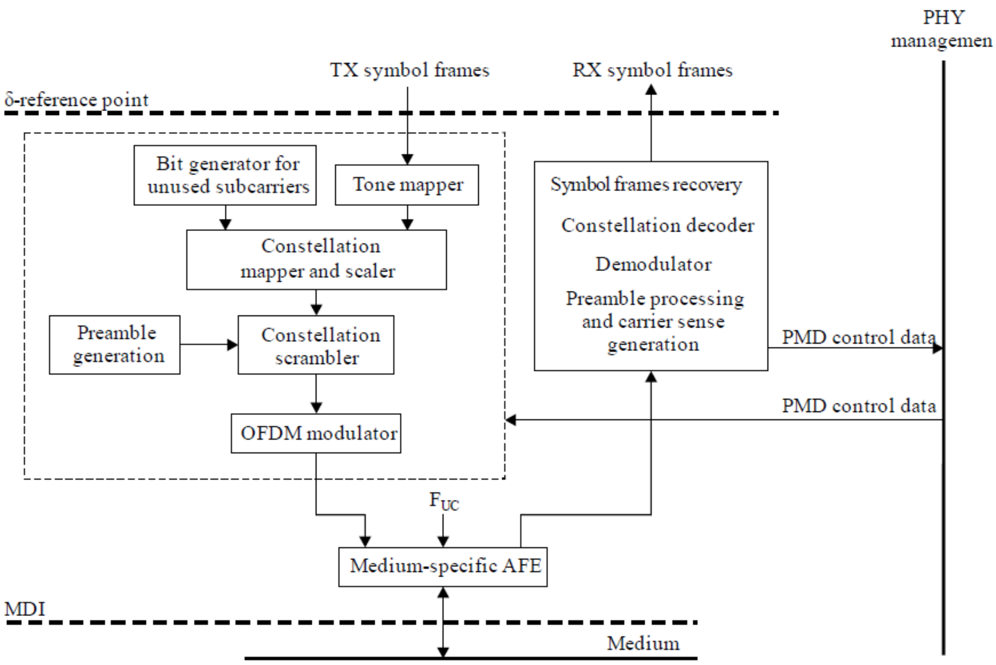

Figure 8: Functional model of the physical layer [12].

Table II: OFDM parameters for G.hn standard [12].

OFDM Blocks Parameter	**Range of values**
Constellation	▪ Even number of bits: QPSK, 64-QAM, 256-QAM, 1024-QAM, 4096-QAM ▪ Odd number of bits, Cross-shaped: BPSK, 8-QAM, 32-QAM, 128-QAM, 512-QAM, 2048-QAM
Total number of subcarriers	256, 512, 1024, 2048, 4096
Subcarrier spacing	$\mathbf{24.4140625 \cdot k}$ [kHz], $\mathbf{k = 1,\ 2,\ 4,\ 8,\ 16,\ 32,\ 64}$
Cyclic Prefix	$k \cdot \frac{N}{32}$, $k = 1,\ 2,\ 3, \cdots,\ 8$, N represents the total number of subcarriers
Windowing	Any even integer between 0 and $\frac{N}{4}$

4. DISCUSSION

G.hn offers a variety of potentialities through the use of OFDM-based systems on wired networks. Their topology exhibits the connection of massive connection of nodes similar to the needs of CAN networks inside vehicles. Based on the increased needs for automotive applications and the specifications from G.hn, an alternative intra-vehicle network may be designed to connect multiple nodes following a similar approach to G.hn standard. Through the use of UTP cables with higher bandwidth and implementing a similar topology G.hn a high-speed network may be achieved with lower costs of deployment.
Similar to the functionalities defined on the physical layer for the G.hn standard (PCS, PMA, and PMD), nodes on the car may perform the same operations with a similar structure. PCS, PMA, and PMD sublayers may be implemented on nodes, then to operate by transmitting OFDM waveforms. This may guaranty the use of the potentialities of OFDM signals to communicate nodes inside the vehicle (higher data-rate, better spectral efficiency, robustness to channel conditions) [11].

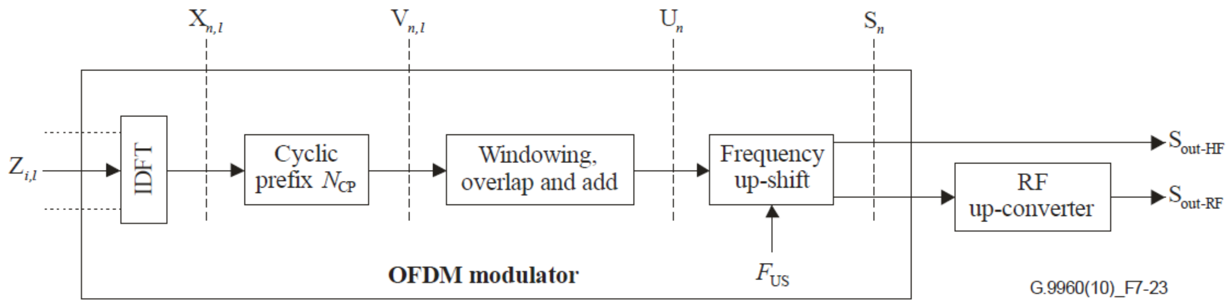

Figure 9: Functional model of the OFDM modulator [12].

The implementation of G.hn's physical layer functionalities into vehicle nodes will increase the complexity of each transceiver. The inclusion of digital signal processing techniques to support these operations and new network management policies based on the vehicle specifics will be needed to afford the implementation of high-speed connection on intra-vehicle networks.

5. CONCLUSIONS

Two different standards for two different applications have been discussed based on different application domains: intra-vehicle networks and home networking technologies. Intra-vehicle networks demand higher speed-rates to afford the increased demand for data-intensive applications and the increased total number of nodes. Besides, the successful smart-vehicles applications will depend on the increase of data rate transmission between the connected units. In this direction, G.hn offers a standard that may be followed as a first step to implement high-speed communication for automotive applications.

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