HomeGrid FORUM
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White Paper G.hn Industrial IoT Use Cases

Version 8.0

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1 Next-generation Industrial networks

1.1 Introduction

Since the arrival of the 4th Industrial Revolution (4IR), the industrial communications market is predicted to grow to US$26.8 billion by 2027, as companies increasingly turn to technology to deliver significant business improvements.

During the last years of digitalization and 4IR, almost every new product is required to be connected to the Internet or network to boost efficiency, and productivity in the industry as well as to improve the user experience in home networks.

These demands bring the following challenges together:

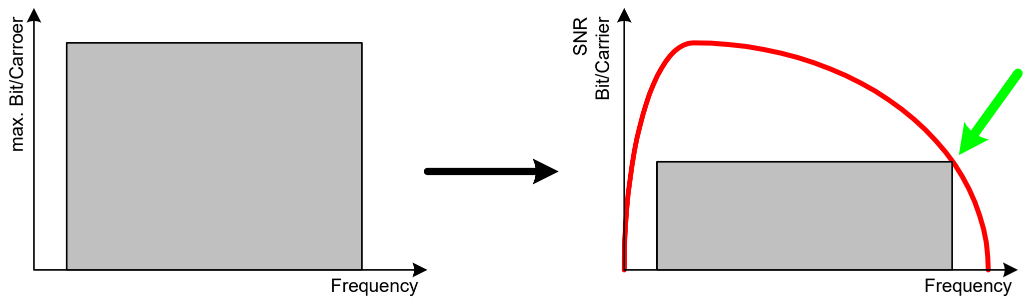
- Integrity to existing technologies, protocols, and different networks (interoperability)
- IT and OT integration
- Low-cost deployment
- Wide range of connectivity
- Manageability
- Security
- Easy installation, troubleshooting, and configuration.
- High speed, low latency, high reliability, to support real-time and bounded-latency communication.
- Deterministic behavior and higher bandwidth.
- More data to access and robust transmission under harsh environments.

G.hn offers not only a solution to overcome these challenges but also eases and accelerates the digital transition by filling the gap between old and new technologies. G.hn delivers robust, reliable performance for large-scale industrial IoT applications, hybrid, and multi-hop networks.

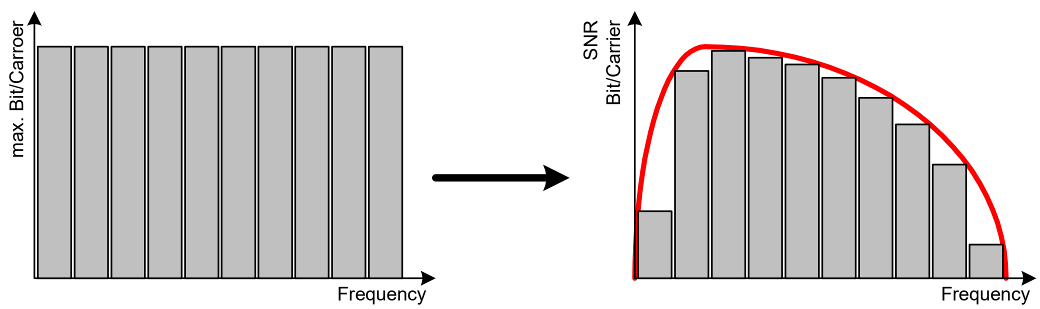
2 Technology and Industrial IoT

2.1 Overview of G.hn

G.hn operates OFDM to reach up to 2 Gbps and the subcarriers are modulated using QAM. This modulation scheme allows the best possible utilization of real-world-transmission-channels under all possible influences like attenuation, frequency-response, bridged-tabs, impedance, noise, and interferers. Compared to single-carrier modulation, where the maximum channel capacity is limited by the worst-case signal-to-noise-ratio (SNR) of the entire transmission-band as shown in the following figure:



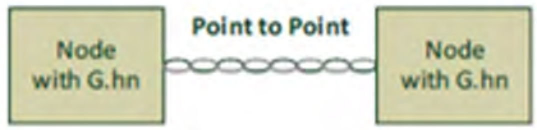
Multi-carrier-modulation like OFDM as used in G.hn allows the flexible and automatic adaptation to the channel while maximizing the capacity (e.g., bitrate):



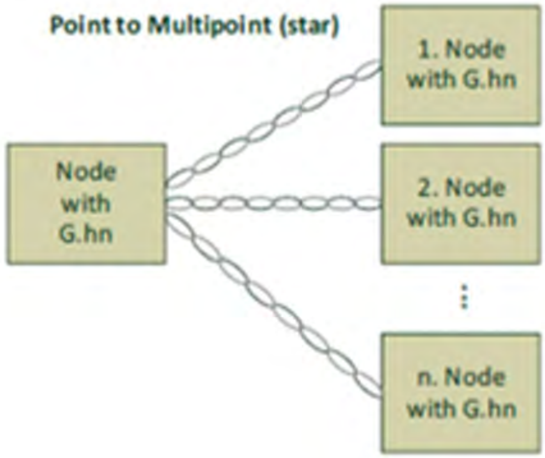
The number and width of the used carriers are media dependent in a form that more carriers are used in poorly shielded media or noisier environment to minimize interference and loss of available spectrum. In this way, optimum efficiency of transmission is provided. It directly supports different media like telephone wiring, coaxial cables, power lines or plastic optical fibers with optimized parameter-sets (e.g., OFDM carrier-spacing and FEC). According to the media-access G.hn utilizes a TDMA-scheme, where the transmission-medium is utilized exclusively by one endpoint at a time with a domain-controller (so called domain-master) controlling the access to the timeslots. This also offers the possibility to enable modern schemes like data and power over a single line for bidirectional traffic and maximum flexibility.

A network based on G.hn is self-organizing – this means it includes automatic configuration, a fast setup time, an optimal path selection and network self-healing – providing the best possible performance according to the utilized physical transmission medium. Using the TDM-scheme, different networking-topologies are possible. Besides classical point-to-point (P2P) there are point-to-multipoint (P2MP) and even ring structures are possible without the need for multiple transceivers at one endpoint and even with increased operational safety, as the transmission media can be one closed galvanic connection where the endpoints are only tapped to. The following pictures show these topologies:

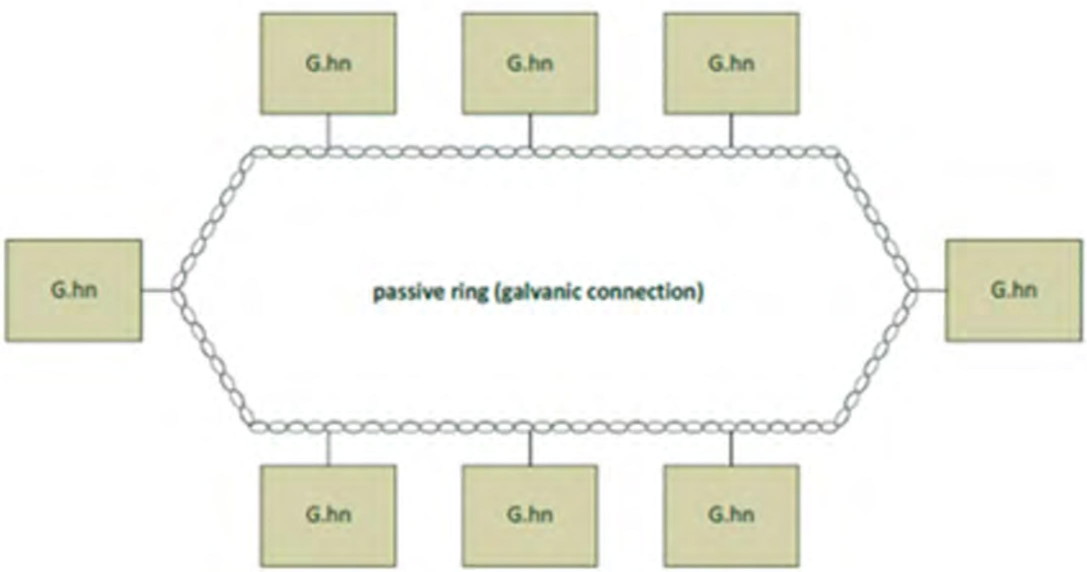
- **P2P**



- **P2MP**



- **Ring Application (passive!)**



Besides applications for in-home-networks (with PLC/Coax profile of G.hn), the access network (GiGAWire™ with Twisted Pair/Coax), and optical networks (POF or VLC), the industrial field offers a wide range of possibilities for G.hn. The technology is internationally standardized and available from multiple vendors.

The total number of nodes in the same G.hn domain can be from 2 up to 250 depending on the media used and the profile (topology) used. Basically, G.hn is designed to offer a transparent channel for Ethernet-based networks e.g., as a backbone to extend the reach of wireless networks, providing easy to use and low-cost installations and simplifying wiring architectures, but above all, G.hn is designed to enhance network resilience, protect its performance, and offer the most reliable networking backhaul for Industry 4.0 applications.

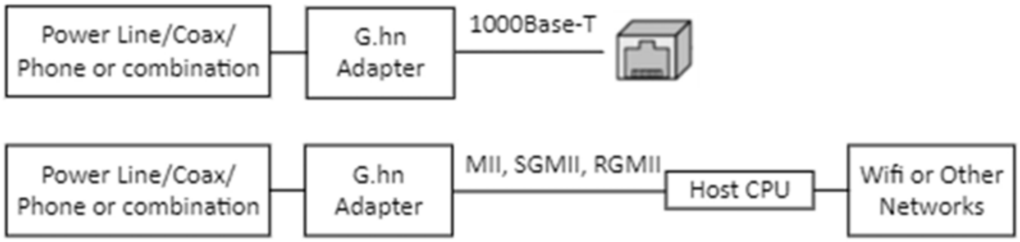
2.2 Industrial IoT

In the growing market of industrial IoT, companies are looking for affordable, robust, efficient, flexible, and easy-to-install solutions for the harsh environment. Nowadays industrial applications are composed of Distributed Control Systems (DCS), where the communication architecture and solution play an important role for its correct operation. For this purpose, many industrial network protocols have been used over the past decade to perform specific tasks. Although Fieldbus communication was widely used before, industrial ethernet (e.g., PROFINET, EtherCAT, TTEthernet) is becoming more prevalent as a leading technology with new interfaces such as wireless extension being adopted. Each technology has its own advantages and disadvantages according to the following factors and requirements such as:

Wiring, application range, operation conditions, safety and mixed-criticality operation, power management, QoS, initial cost, noise immunity, latency, security, scalability, integrability/co-existence, extensibility, and performance.

The convergence of information technology (IT) systems with operational technology (OT) systems is another important topic in current and future industrial applications, which means the integration of such networks within the same network technology, having different functional requirements. That is, the integration of IoT and IIoT systems.

G.hn stands out from other technologies by providing secure, bounded latency, high speed, real-time connection including environmental sensors and video surveillance as well as high quality of service, especially on control and information level industrial applications where new cables and infrastructure are challenging due to budget limitations and safety regulations. Since it operates efficiently with any wire, it is not only a good alternative but also a good backbone for other technologies and networks.



On the diagram, a typical application is shown. G.hn adapter allows high-speed data transmission over existing medium like Power Line/Coaxial Cable/Phone as well as Plastic Optical Fiber and interconnects any device through Ethernet PHY or MII, SGMII, RGMII interfaces.

2.3 An introduction to ITU-T G.hn Standards Family

G.hn Recommendations were approved and published by the Telecommunication Standardization Sector of the International Telecommunication Union (ITU). The family of standards (see: Table 1) consists of:

ITU Recommendation	Scope	First Approved	Latest Update
G.9960	System architecture & physical layer specification	2009	2016
G.9961	Data link layer specification	2010	2016
G.9962	Management specification	2013	2016
G.9963	Multiple Input Multiple Output specification	2011	2016
G.9964	Power spectral density specification	2011	2016
G.9972	Coexistence mechanism for wireline home networking transceivers	2010	2014
G.9977	Mitigation of interference between xDSL and PLC (G.DPM)	2016	2017
G.9978	Secure admission mechanisms in a G.hn network	2018	2018
G.9979	Implementation of IEEE 1905.1a for ITU Recommendations	2014	2016

Table 1: G.hn Recommendations published by ITU

Table 1 provides an overview of the most relevant Recommendations (see Note#1) published by ITU specifying different elements of the G.hn standard. While the first G.hn Recommendation was approved in 2009, multiple parts of the standard have been updated and improved since then (through "amendments" and "corrigenda"), incorporating feedback from users and vendors, as the range of applications for G.hn technology was increased.

The full list of G.hn Recommendations published by ITU is available at this link:
https://www.itu.int/ITU-T/recommendations/index.aspx?ser=G

Area	Sub-area	Power Lines	Coaxial Cable	Twisted Pair
Physical Layer	Line code	DMT (Discrete Multi-Tone)		
	Maximum modulation	4096-QAM (12 bits/tone/symbol)		
	Spectrum used	2-80 MHz	5-200 MHz	2-200 MHz
	Tone spacing	24.4 kHz	195.3 kHz	48.8 kHz
	MIMO support	Yes	No	Yes
	Forward Error Correction	LDPC (Low Density Parity Check)		
	PHY layer max rate[2]	1500 Mbit/s	2000 Mbit/s	4000 Mbps
Data Link Layer	MAC layer max rate[3]	1000 Mbit/s	1700 Mbit/s	3400 Mbps
	Automatic Retransmission (ARQ)	Yes		
	Medium Access	TDMA, coordinated by a Domain Master (DM)		
	Encryption	AES-128		
	Quality of Service (QoS)	8 levels		

Table 2: G.hn technical parameters

Note #1: Standards published by ITU are traditionally called "Recommendations". Readers not familiar with ITU terminology may think that the name "Recommendation" suggests that complying with them is optional. This is not the case. Complying with the ITU Recommendation is critical to ensure compatibility between vendors.

Note #2 and #3: This has been calculated assuming the maximum options specified by the standard: 2-80 MHz MIMO in powerline mode, 2-200 MHz SISO in coax mode, and 2-200 MHz MIMO in twisted-pair mode. Commercially available products implement one or all the options identified as relevant for the specific applications targeted.

Table 2 provides an overview of the most important technical parameters of the G.hn standard. Most technical aspects are common across physical media, with differences only in aspects like Tone Spacing and frequency bands. This commonality is key to enabling silicon vendors to develop a single chip that can implement all three media, ensuring economies of scale. Today, G.hn chipsets support all three media, enabling system vendors to build products that can adapt to any available wiring by just changing a software setting in the device.

With a track record of deployments using 4 forms of media (any wire): powerline (PLC), coaxial cable (COAX), telephone cable (TP), and plastic optical fiber (POF), G.hn allows for fast installation and works seamlessly through existing wiring to provide low latency connectivity upon which industrial applications rely. The technology is naturally well-suited as a backhaul for smart sensors, video surveillance, and safety panels, thanks to its real-time two-way traffic handling and high bandwidth.

2.4 Benefits of using G.hn technology for Industrial IoT networks

Industrial installations benefit from G.hn in both brownfield and greenfield scenarios. The functionality of existing installations can easily be extended, as G.hn facilitates the addition of high-speed data communication without the need to add or change existing infrastructure:

- No defined termination required - opposed to many field bus technologies, G.hn does not require a specific topology or well-defined termination of wires.
- Free wire topologies for the PLC profile.
- Simplify installation, works on AC and DC lines, powered and unpowered.
- Easy addition of add-on services, such as:
    - Video surveillance
    - Audio Transmission
    - Bulk data transfer
    - Build an Industrial IoT backbone network.
- Dynamic master allocation prevents a single point of failure.
- Reverse power feed (RPF) option.
- Extend Ethernet distance at application layer speeds of typically 100 Mbit/s and above.
- Superior noise immunity to other connectivity technologies.

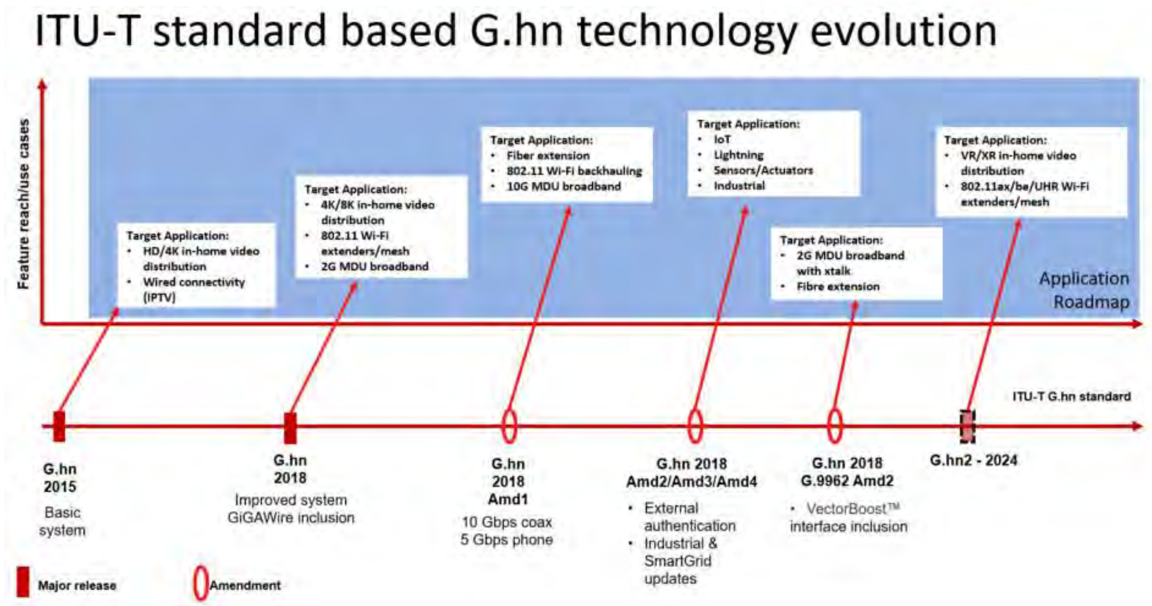
G.hn-based implementations benefit from data and power on a single wire, simplify wiring architecture, and enable significant cost savings on installation, maintenance, and wiring materials, by reusing existing wires. G.hn is not a deterministic communication system, but because of its high throughput, the requirements of a vast number of real-time applications can be satisfied if certain properties can be tolerated by the application. Section 3.5 below details the possible settings based on use cases and technical requirements.

Using G.hn for Industrial IoT, customers can build on:

- Proven Technology Maturity of G.hn, with components and devices being available for the coming years,
- Multivendor availability of both hardware and software, and finally
- Multivendor Interoperability, ensured by the G.hn certification program of the HomeGrid Forum

2.5 Evolution of G.hn and Roadmap to Interoperability

The G.hn standard is constantly being maintained by ITU, with periodic updates and clarifications to address feedback from the industry. ITU is currently working on a new amendment of the G.hn standard that is designed to deliver data rates up to 10 Gbps, including full-duplex support. The new amendment of G.hn is being developed with inputs from multiple industry participants, including silicon vendors. Systems based on this amendment will be backward compatible with existing G.hn systems.



3 Industrial IoT Use Cases

3.1 Buildings and Cities Automation

- Smart Buildings Entry-Door Access Control
- Fire Alarms
- Smart parking systems control
- Smart Lighting Control
- Smart sensors
- Smart Elevators

3.2 Factory Automation

- Sensor and actuator deployment in the factory facility
- Robot controlling
- Machinery communication
- Subsea telemetry
- Autonomous Mobile Robots
- Smart Lifting
- Oil exploration with semi-autonomous systems
- AR/VR
- Extending reach of existing RS232/485 bus

3.3 Transportation

- Railway industry
- Aerospace industry
- Automotive industry
- Maritime industry

3.4 Energy

- Substation automation
- Wind turbine automation

3.5 Settings well-suited to G.hn solutions

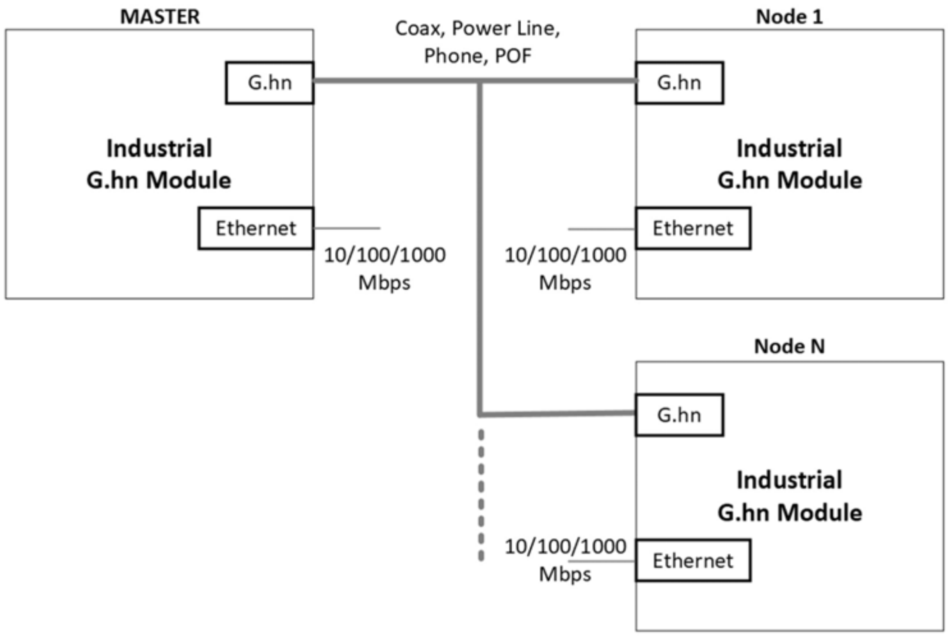
- **Setting 1**
  - Adding sensors / cameras / voice to a system)
  - Moderate number of nodes (8, max 14)
  - Required bitrate per remote node 1-100Mbit / node (not concurrent)
  - Data can be sent in chunks of 1-10 kBytes

- **Setting 2**
  - Smart grid-like applications
  - High number of nodes (up to 250)
  - Moderate latency and bandwidth requirements
  - Mesh topology
  - Logical star communication
  - No big consumers in the network

- **Setting 3**
  - Control applications
  - Moderate number of nodes (8, max 14)
  - Usually small packets, the system can handle additional file transfer
  - Application can tolerate outliers (late delivery) of 20 ms or more
  - Number of user packets in the system below 1`300/s

3.6 Use Case Examples

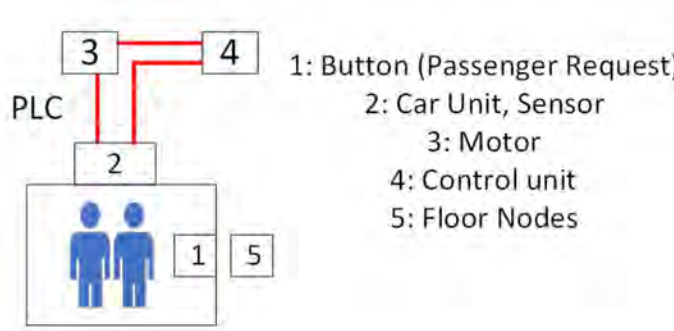
G.hn technology makes it possible to connect devices with multiple types of networks over any wire such as coax, phone lines, power lines, and optical fiber. Although it was first used for the home network, today it has a wide range of applications for industrial use cases.



The use of Powerline Communication in industrial applications enables end-to-end IP communication with simultaneous power distribution on cost-effective cabling without strict topologies. It can also have advantages with mixed data traffic including control data, log files, and FW updates. The OFDM technology used in powerline carrier modems supports packing large data packets into a short frame. This is also a clear advantage of the technology compared to field buses with a static maximum data rate.

Smart Lifts

As an example, a modern elevator contains many sensors and actuators that are ideally connected via IP. The communication between these distributed devices (IP nodes)



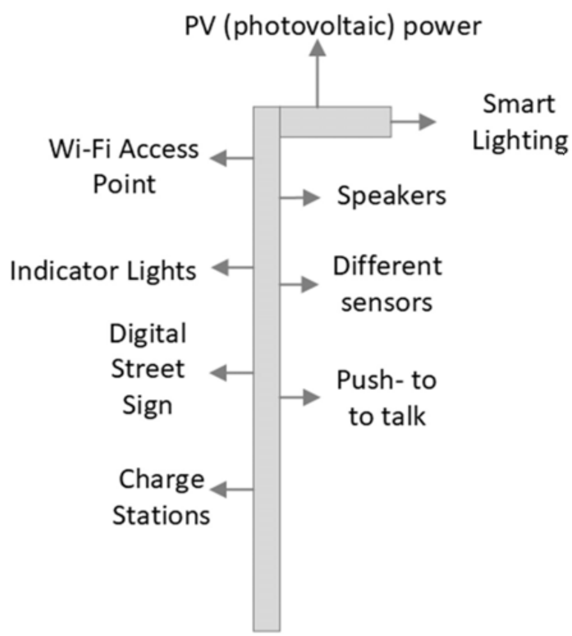
PLC Usage of Smart Lifting

with G.hn can significantly save wiring in the installation.

Whereas the migration from CAN buses to Ethernet is quite expensive or time taking for lift manufacturers, the PLC profile of G.hn is a fast and reliable solution. Communication within the elevator system consists of Control, Monitoring, Human Interaction, and Emergency Phone. All these groups accept certain latency for the operation, and not all functions are active at the same time. In normal operation, passengers can request elevator trips by pressing the call button close to the elevator door. The IP node on the respective floor sends a message to the main controller. The controller receives the request, checks that all safety conditions are fulfilled (all doors closed, brakes operable) and sends the command to the motor for the required travel. During this trip, the speed is controlled, and the end position is approached with millimeter precision using a position sensor.

Smart Lights

Digitalization creates an opportunity for different technologies and solutions. Smart lighting systems are also part of the digitalization process in buildings, shops, factories as well as streetlights. It aims to have an efficient operation by adjusting the light intensity, monitoring power consumption, controlling the lighting schedule, on/off, and setting failure alarms. In smart cities, lighting systems are turning into interactive system which communicates with the environment. That may include a variety of nodes with street signs, light control, water level, humidity/temperature sensors, pedestrian push-talk system, vehicle charging, image sensing units, speakers, Wi-Fi access points, monitoring of containers for smart waste collection, and other cameras and sensors. To achieve this, the application requires broadband communication and a high data rate, sufficient reach, and a self-adaptive network with plug-and-play functionality. Currently, there are 60-90 million lampposts in the EU zone, and %75 of them are older than 25 years. [*] Therefore, G.hn



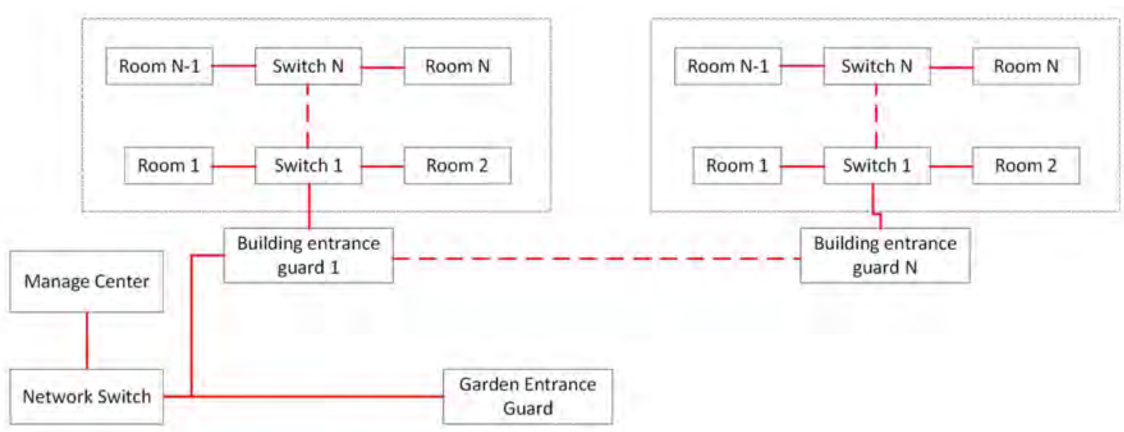
Smart Lamppost

provides a good solution to use existing infrastructure and cut the cost of adapting technology as well as it can serve as a backbone for other protocols and technologies.

” Use of G.hn in Industrial Applications “, the Technical Paper by ITU-T, illustrates other use cases such as the Entrance Guard System of Building, Smart Lifting, Smart traffic light, and navigation lighting aid in the airport.

Entrance Guard System

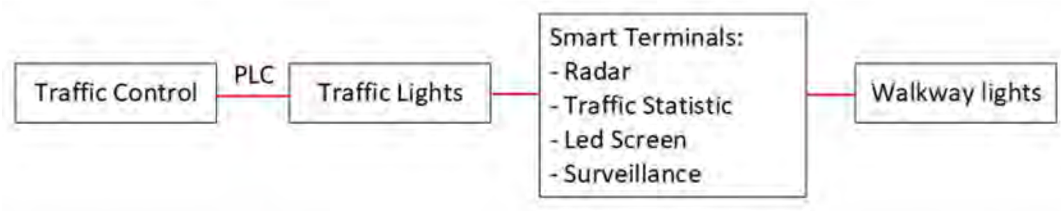
It is a system that permits access to visitors or residents through voice or video identification. Permission is approved if the visitor is identified by the owner of the room. The system can also be coordinated with smart building features like switching on lights for the guest and automatically calling the elevator for the visitor.



Building entrance guard

To provide this service, basic communication including voice, video, IoT commands, etc. is needed. Implementing this connection requires support for real-time speech, face-to-face video streaming, a sufficient length of loops, extra cabling, and floor switchers. Especially, video identification makes the design more complex with the use of ethernet and coax cables. The connection between sensors and the gate requires other private protocols, which also causes additional wires. In this case, using the existing power line infrastructure can save a significant amount of effort and cost. For this use case, the PLC profile of G.hn technology offers a good potential and less complex alternative.

Smart traffic light

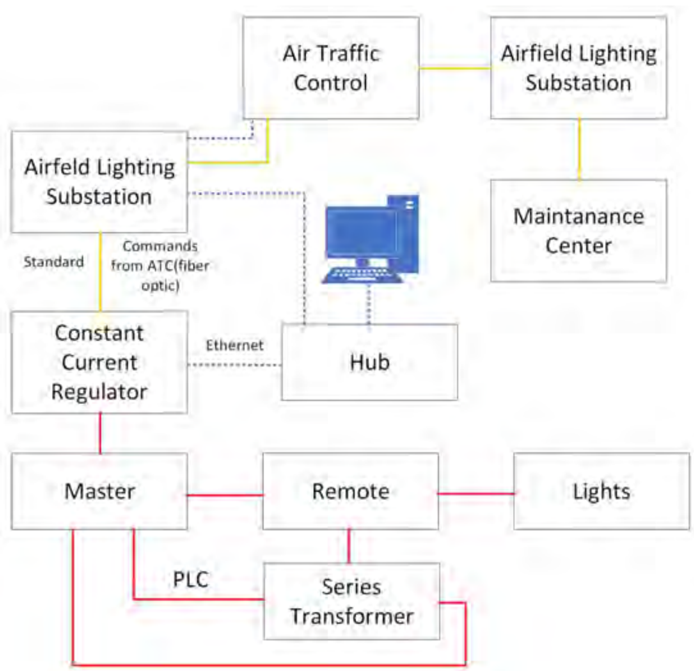


Smart Traffic Light

Smart traffic consists of smart terminals including traffic lights, count-down devices, radar, etc. to provide central control of the traffic flow. The existing solution uses CAN BUS which requires additional wiring. It also causes headend size and relatively complex design. Besides, a powering system is embedded in a smart traffic light system to supply power for all active terminals. Therefore, G.hn PLC technology might be a good alternative to collect information, power transfer, and control by using existing wiring and avoiding additional deployment costs.

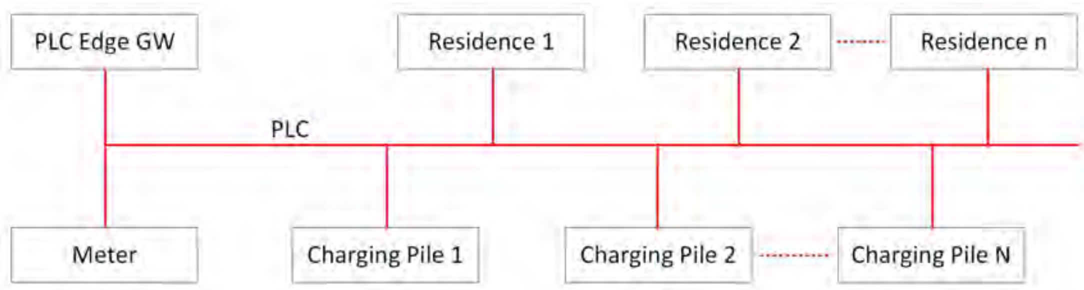
Navigation lighting aid in airport

The lighting system is used to help pilots to locate and define the airport environment and the runway. It typically consists of hundreds of lights in a long loop for several km, relay hops. Lights are cascaded with power cables buried underground and shielded to protect from radiation leakage. During the operation, real-time control with limited reaction time is needed. Furthermore, attenuation during this long path should be kept minimum. By using an appropriate signal coupler, existing infrastructure can be re-used by the G.hn PLC profile so that easier establishment of the communication system can be provided accordingly.



PLC usage of smart navigation lights in airport

Charging Station



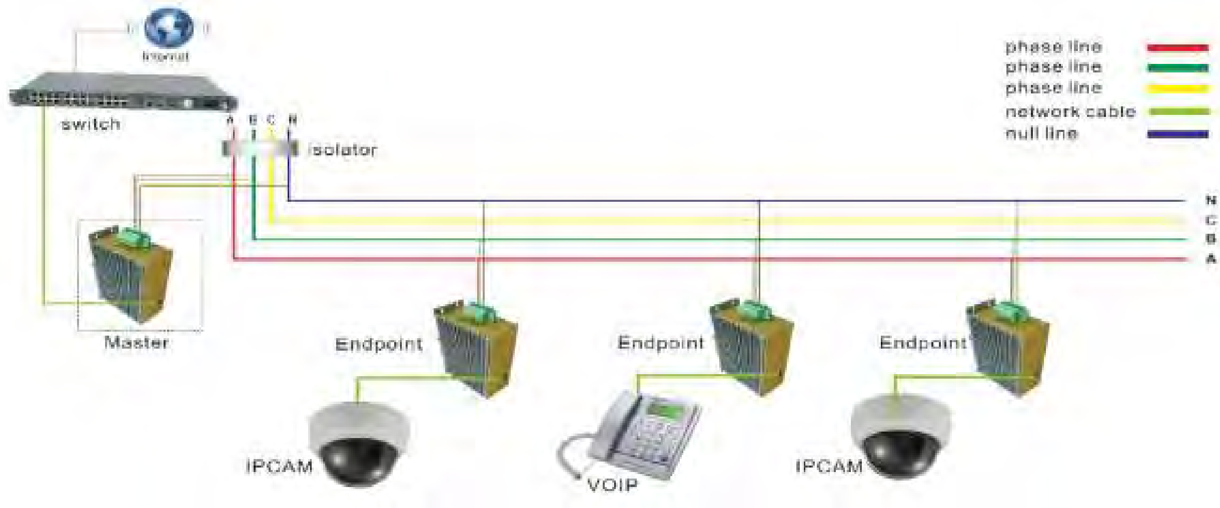
Charging Station G.hn PLC Application

Another example given in Technical Paper is the use of G.hn for charging stations. The electrical vehicle industry has grown significantly in the last few years. Consequently, the number of charging stations is significantly increasing to meet the demand. The network of the charging station includes fast payment, easy query, operation, station management, and a cloud control center. For local communication, different wired and wireless technologies such as PLC, Ethernet, RS485, ZigBee, Wi-Fi, and LTE can be used. Especially, in the underground garage scenario, where an additional, backhaul facility is needed, re-using the existing infrastructure of the powerline for data transmission is a good alternative.

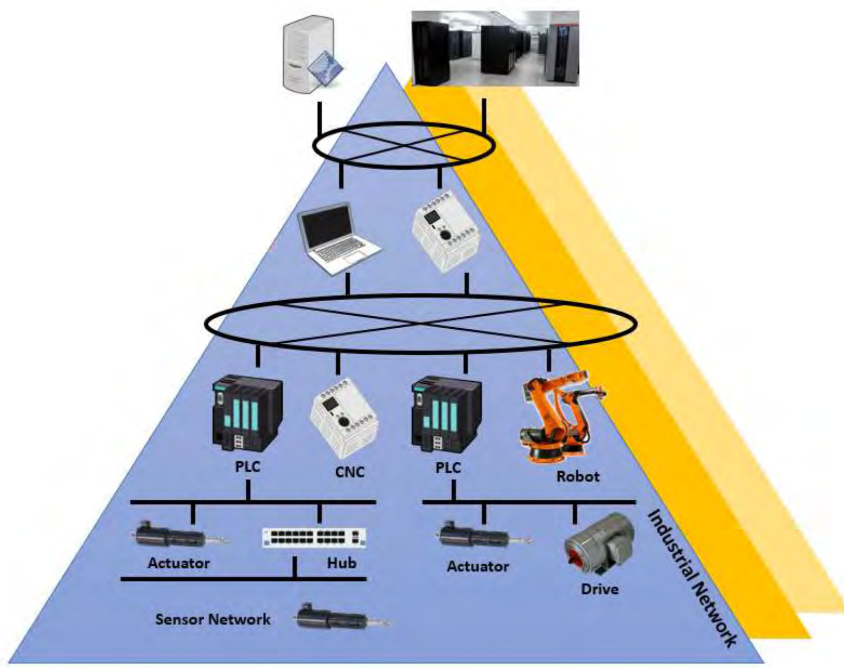
Industrial Plant

G.hn based components can be installed for operating with industrial control solutions via the power bus. The use of coax cabling is considered an advantage since it reduces the need for conduit because of its survivability in harsh environments (EMC immunity). G.hn runs on the power bus of a Programmable Logic Controller (PLC) and DIN Rail equipment is an extremely unique aspect for G.hn. These *three-phase industrial G.hn solutions* include immunity to Electro-Static Discharge (ESD), immunity to fast transient impulse groups, surge protection, and anti-vibration; all key requirements for use in industrial environments.

Figure below is an example of a DIN rail G.hn solution for an industrial plant environment.



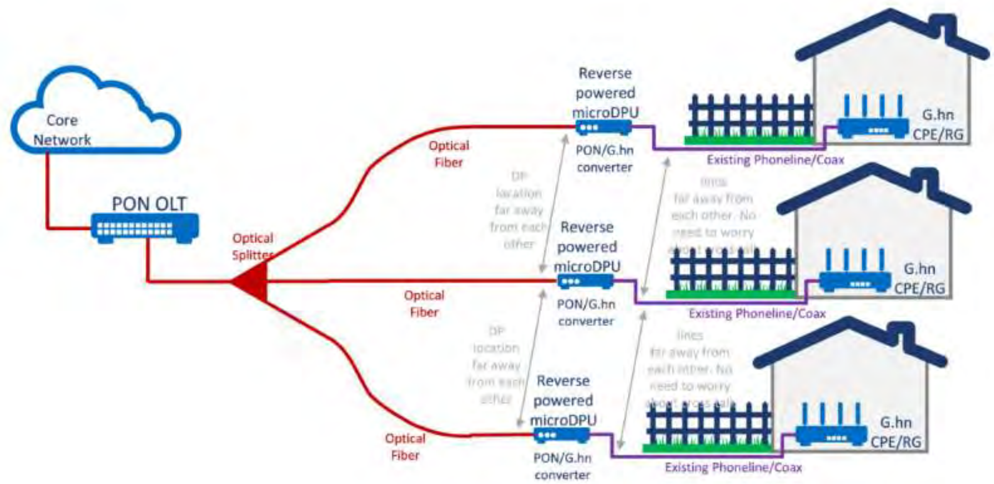
Use of G.hn for Industrial Control Networks
via Power Bus (multiple phases to improve speed ~400Mbps)



Use of G.hn for Industrial Robots

Fiber Extension for Extreme Environment

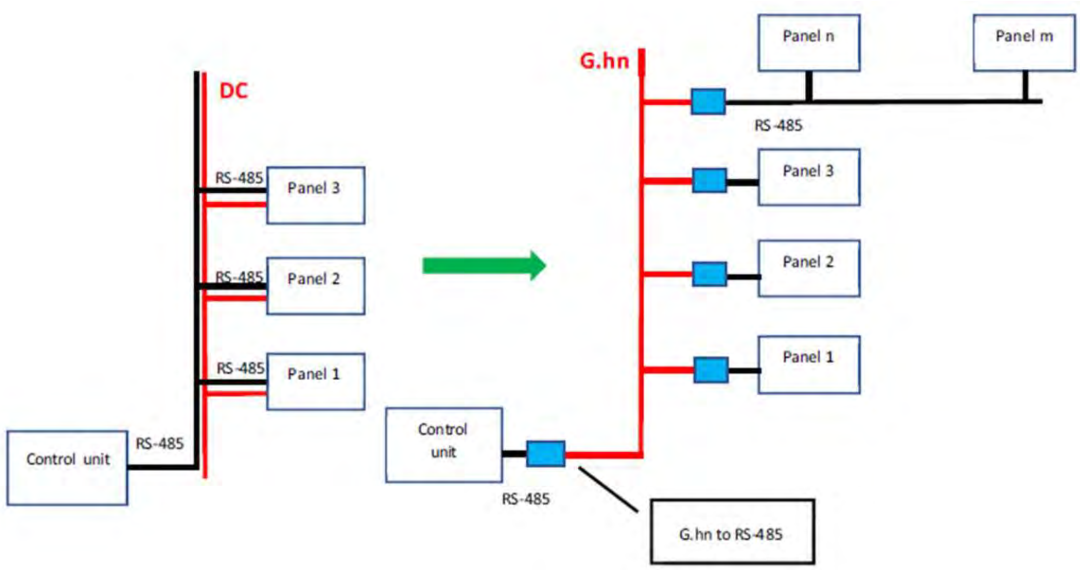
Hardened G.hn Access devices can be installed to upgrade existing Fiber to The Curb (FTTC) to 1Gb speeds, using the existing fiber connections and copper drops as well as the existing DC power. These G.hn Access systems have industrial profile and can operate under difficult environmental situations such as flooding and extreme temperatures.



SFU P2P topology, no crosstalk, fiber extension with G.hn

Multi-Medium Multi-Platform

This is a typical scenario where the industrial multi-medium multi-interface can replace the RS-485 + DC by a single cable to reduce wiring and increase the connection distance. In the following image G.hn means either powerline, coaxial line or phoneline.



Industrial Multi-Medium Multi-Platform Scenario

The ITU-T standards-based G.hn technology is the most versatile and reliable network backhaul available today for multi-gig connectivity and access solutions ranging from enterprise and residential to industrial and smart grid use cases. G.hn is continuously evolving over multi-media, including coax, copper pairs, powerline, and plastic optical fiber as well as LiFi communication systems over visible light, ultraviolet and infrared spectrums, to support the digital transformation of the industry. HomeGrid Forum members promote the global adoption of G.hn, a single unified, multi-sourced networking technology.

4 References to Industrial G.hn

PREVIOUS REFERENCES TO G.HN INDUSTRIAL PROFILE

SOURCE	DATE	FRAMEWORK
*European Commission	October 2022	Lampposts are one quick fix for smart success | Smart Cities Marketplace (europa.eu): https://smart-cities-marketplace.ec.europa.eu/news-and-events/news/2018/lampposts-are-one-quick-fix-smart-success
ITU-T	September 2022	ITU-T Technical Paper: GSTP-OPHN Operation of G.hn technology over access and in-premises phone line medium: https://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-HOME-2022-PDF-E.pdf
ZHAW Zurich University of Applied Sciences	July 2022	White Paper: Industrial Ethernet with Powerline https://www.zhaw.ch/storage/engineering/institute-zentren/ines/forschung-und-entwicklung/communication-network/white-paper-industrial-ethernet-over-powerline-en.pdf
Shengyang Electronics & HomeGrid Forum	June 2022	Shengyang Electronics joins HomeGrid Forum bringing exciting G.hn knowledge of Industrial M2M and IoT use cases: https://homegridforum.org/2022/06/20/shengyang-electronics-joins-homegrid-forum-bringing-exciting-g-hn-knowledge-of-industrial-m2m-and-iot-use-cases/
Teleconnect & HomeGrid Forum	March 2022	HomeGrid Forum Certifies First G.hn Embedded Module for Industrial IoT with Teleconnect: https://homegridforum.org/2022/03/29/homegrid-forum-certifies-first-g-hn-embedded-module-for-industrial-iot-with-teleconnect/

ITU-T	December 2021	ITU-T Technical Paper: GSTP-OVHN Overview of ITU-T G.hn technology: https://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-HOME-2021-3-PDF-E.pdf
MaxLinear	August 2021	MaxLinear Industrial IoT Evaluation Platform DMI920 Combines G.hn Gigabit Capability with Common Industrial Interfaces: https://investors.maxlinear.com/press-releases/detail/443/maxlinear-industrial-iot-evaluation-platform-combines-g-hn
Mouser Electronics	July 2021	MaxLinear DMI920 Demo and G.hn Industrial Evaluation Kit available from Mouser Electronics: https://www.mouser.com/new/maxlinear/maxlinear-dmi920-evaluation-kit/
ITU-T	February 2020	ITU-T White Paper: GSTP-HNIA Use of G.hn in Industrial Applications: http://handle.itu.int/11.1002/pub/81590347-en https://www.itu.int/pub/T-TUT-HOME-2020-1

5 White Paper Authors and Versioning

AUTHORED BY IIOT TASK FORCE MEMBERS OF THE HOMEGRID FORUM

NAME OF AUTHOR	MEMBER COMPANY
Philipp Rietzsch	Teleconnect
Livia Rosu	MaxLinear
Martin Ostertag	ZHAW – Zurich University of Applied Science
Bahadirhan Cicek	Teleconnect
Tobias Frauenrath	devolo / FH Aachen University of Applied Sciences Fachbereich Elektrotechnik und Informationstechnik
Andy Baird	Shengyang Electronics
Tom Barnett	LUMEN
Iñaki Val Beitia	MaxLinear
Jose Maria Verdu	MaxLinear

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3.0	October 10, 2022	Bahadirhan Cicek	Review
4.0	October 25, 2022	Andy Baird	Review
5.0	December 16, 2022	Livia Rosu	Contributions from HGF Members
6.0	January 3, 2023	Livia Rosu	Contributions from HGF Members
7.0	January 25, 2023	Iñaki Val Beitia	More use cases added
8.0	March 8, 2023	Livia Rosu	More use cases added. Final review

6 About HomeGrid Forum

HomeGrid Forum (HGF) is an industry alliance that brings together the world's best in technology innovators, silicon vendors, system manufacturers, and service providers to promote G.hn, a globally recognized networking technology based on ITU-T standards providing multi-gig access and in-building solutions for enterprise, industrial, smart grid, and residential use cases. G.hn is the most reliable and versatile network backhaul available today over coax, copper pairs, powerline, and plastic optical fiber as well as LiFi communication systems over visible light, ultraviolet and infrared spectrums. Our members promote the global adoption of G.hn, a single unified, multi-sourced networking technology.

HomeGrid Forum provides G.hn silicon and system certification programs through Compliance and Interoperability testing and collaborates with other standards organizations for deeper performance testing.

For more information on HomeGrid Forum, please visit our website at www.homegridforum.org.

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