HomeGrid FORUM

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GiGAWiRE

White Paper

Using G.hn in access networks

GiGAWiRE Technology

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Table of Contents

1 The role of copper in next-generation broadband access networks

Since at least the early 2000s, general consensus in the telecom industry has been that the long-term end-game for high-speed broadband services would be an extensive deployment of optical fiber reaching every single home. Proponents of this "Fiber-to-the-Home" (FTTH) deployment model assumed that existing copper networks (originally built for phone service or for cable TV) would not be able to deliver the high-speed data rates required for next-generation services and would need to be replaced with optical fiber.

Now we know that some the assumptions in the FTTH scenario had to be modified, mostly due to two factors:

- Installing fiber to every home is expensive (in terms of labor costs), disruptive to customers and often delayed due to slow process of getting permissions from building owners or local authorities.

- At the same time, advances in communications technology have allowed the industry to develop new telecom standards (such as ADSL, ADSL2, ADSL2+, VDSL, VDSL2) and new cable standards (DOCSIS 1.x, 2.x, 3.x) that provide higher data rates that are competitive with fiber while leveraging existing copper assets.

Each time a pundit says "copper is dead" a new technology has appeared enabling copper wires to provide up to ten times higher data rates than what was previously possible. This trend is ongoing, with new standards like G.hn providing broadband communication over copper (both coaxial cables and twisted pair) with data rates of between 1-2 Gbps, and with promises of even higher data rates in the near future.

This whitepaper discusses how service providers can leverage G.hn technology along with their copper assets to reduce the cost of deploying FTTx networks while delivering gigabit-class broadband services that are virtually indistinguishable from "traditional FTTH." A follow-on whitepaper will cover G.hn's innovative crosstalk mitigation techniques for addressing challenges created by the physical characteristics of copper wires. These techniques use statistical sampling and cloud-based technologies to provide a high-performing and cost-effective solution.

2 Leveraging G.hn technology for copper-based broadband access networks

2.1 An introduction to G.hn

G.hn is a networking standard developed by the International Telecommunications Union (ITU). The original design goal for G.hn was specifying a unified physical layer (PHY) and data link layer (DLL) capable of delivering 1Gbps data rates, while operating over any type of wiring available in residential environments (typically power lines, coaxial cables and twisted-pairs).

While the original application focus for G.hn was solving home-networking challenges, the industry quickly identified G.hn as a great solution for broadband access applications, especially in multi-dwelling units (MDU) that had legacy twisted-pair cabling for phone service, and where installing new optical fiber was prohibitively expensive.

G.hn was also shown to be a perfect fit for coaxial cable networks (which typically have a point to-multipoint topology), providing a solution capable of delivering gigabit services at a fraction of the cost of more traditional DOCSIS solutions that rely on expensive cable modem termination system (CMTS) equipment.

Table 1: G.hn Recommendations published by ITU

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 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

Table 2: G.hn technical parameters

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		

Note #1: 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, 2-200 MHz MIMO in twisted-pair mode. Commercially available products may not implement all the options. In particular, as of 2019, the highest performance product commercially available supports operation over twisted-pair at either 100 MHz MIMO or 200 MHz SISO.

Table 2 provides an overview of the most important technical parameters of the G.hn standard. The reader can see that most technical aspects are common across physical media, with differences only on aspects like Tone Spacing and frequency bands. This commonality is key to enable silicon vendors to develop a single chip that can implement all three media, ensuring economies of scales.

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.

The flexibility of G.hn technology is one of the main reasons why a large number of service providers rely on it to provide gigabit broadband services to millions of users around the globe.

2.2 Network deployment options for G.hn in broadband networks

Service providers can leverage G.hn technology in a wide range of scenarios, both inside and outside their subscribers' homes. In this whitepaper, we'll focus on the scenarios that deal with facilitating deployment of FTTx networks, not the ones that have to do with pure home networking use cases.

Figure 1 depicts the range of options available to service providers deploying services in neighborhoods with Single-Family Homes (SFU) between the two extremes of fiber-to-the-cabinet (FTTC) – shown as Scenario (a) – and Fiber-to-the-Home (FTTH) – shown as Scenario (f):

- Scenario (a) depicts a traditional FTTC model, where optical fiber is terminated at a street cabinet, providing backhaul for a DSLAM that serves a few hundreds of homes.

- Scenario (b) shows a Fiber-to-the-Distribution-Point (FTTdp) model, where the fiber is terminated at the distribution point, and a multi-port distribution point unit (DPU) provides service over copper to a small number (two to 16, typically) of homes.

- Scenario (c) is an evolution of (b), where the user density is low enough that the carrier decides to deploy single-port DPUs. But in this case, the fact that only one user is being served by the DPU means that from the point of view of the

OLT, we can consider it similar to FTTH in the sense that there is a one-to-one mapping between users and ONTs.

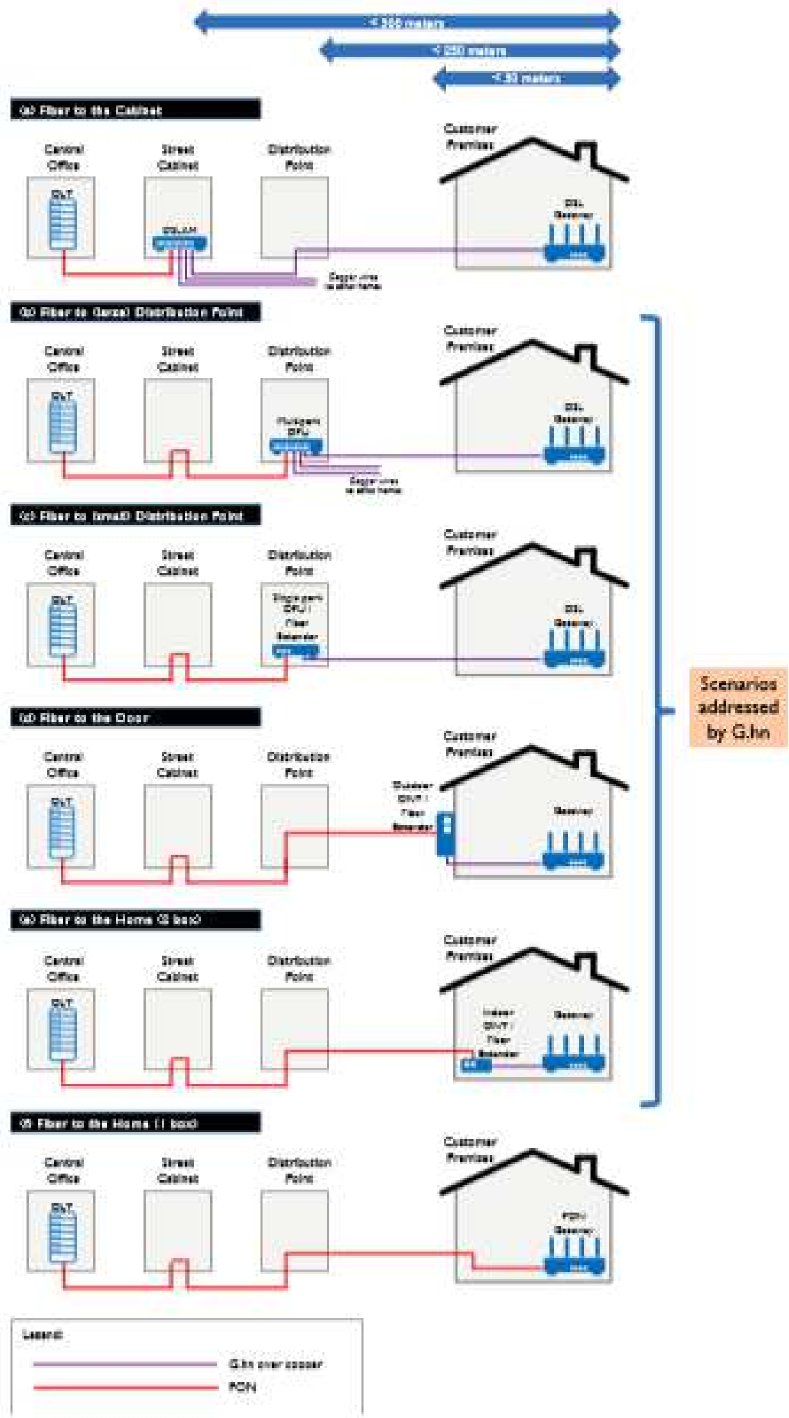
• Scenario (d), although probably considered as FTTH by most carriers, is not architecturally different from the single-port DPU used in Scenario (c). In this document we'll call it fiber to-the-door (FTTD), because the fiber ONT is installed outside the home, attached to a wall, pedestal or in a garage. The connection between the ONT/single-port DPU can be done using any wiring available in the home (twisted pair, coaxial cable, or even power lines).

• Scenario (e), is also one of the typical FTTH architectures, with ONT and gateway implemented as two separate appliances. From an architectural point of view, it's not different from scenarios (c) or (d). If the optimal location for the ONT (near the point of entry for the fiber) is different than the optimal location for the gateway (in the center of the home, for better Wi-Fi signal coverage), then the connectivity between ONT and gateway can be done using any wiring available in the home (twisted pair, coaxial cable, or even power lines).

• Scenario (f) is the most expensive model for FTTH, because the optical fiber is brought all the way to the location of the gateway, which typically requires spending a large amount of time rewiring the customer premises with fiber and dealing with user complaints about damaged walls and carpets or non-ideal Wi-Fi gateway location.

In this range of options for serving SFU customers, G.hn can be used in scenarios (b), (c), (d) and (e). G.hn is not optimal for scenario (a), because the distance involved is too long for the frequency range used by G.hn. In scenario (f) G.hn could be used on the LAN side of the residential gateway, but not on the WAN side. One of challenges in scenarios (b) and (c) is that potentially there are multiple users served through twisted pairs that are in the same bundle, creating potential for crosstalk between them. Crosstalk mitigation is one of the key features to consider when assessing the suitability of any broadband access solution and will be the focus of a follow-on whitepaper.

Figure 1: G.hn usage options in FTTx deployments for single-family home scenarios



2.3 The business case for using G.hn in broadband access networks

In addition to the technical parameters (such as data rate, reliability, robustness, latency) that need to be considered when selecting a copper-based technology (coax and twisted pair) to reduce the cost of FTTx deployment, there are a number of non-technical aspects to take into account:

• **Multivendor availability**: To ensure that hardware cost will be competitive, it's critical that service providers can choose from a number of system vendors that compete with each other. But having multiple system vendors is not enough, especially if all of them use the same underlying silicon supplier. It's important for service providers that any technology selected is supported by a large number of chipset vendors that will ensure a competitive ecosystem.

• **Multivendor interoperability**: Having multiple vendors is not very useful if their products are not guaranteed to be interoperable. If a carrier has a large installed base of products from vendor A, they'll never be able to adopt a lower cost product from vendor B if they are not interoperable. While both products may be based on the same technology, or even the same standard, there are often enough differences that interoperability cannot be guaranteed unless a third party certifies it by means of a thorough test. This has been a problem historically with products based on standards like GPON, VDSL2, etc.

• **Technology Maturity**: Although technology vendors have an incentive to push carriers to start deploying new technologies as soon as they become available, early adopters face the risk of finding the bugs that typically exist in any early implementation of a product. For large scale service providers, it's often better to wait until technology vendors have had time to iron out the bugs in their hardware and software. Being the first customer to use a new chip is not without risk.

• **Critical mass**: If a given technology is not used very widely, it does not generate enough revenue to allow vendors to invest resources in supporting it properly. When volumes are reduced, vendors are forced to keep unit prices high in order to recover their initial investment in R&D. Only when a technology is shipping in millions of units per year can vendors achieve the desired economies of scale.

How does G.hn score in these areas?

• As of 2018, **dozens of tier-1 and tier-2 system vendors offer G.hn products for the broadband industry**, addressing a wide range of form factors: from multi-port DPUs, to fiber extenders, customer premises equipment, home-networking products, Wi-Fi extenders, etc. These products also rely on chipsets sold by multiple silicon vendors.

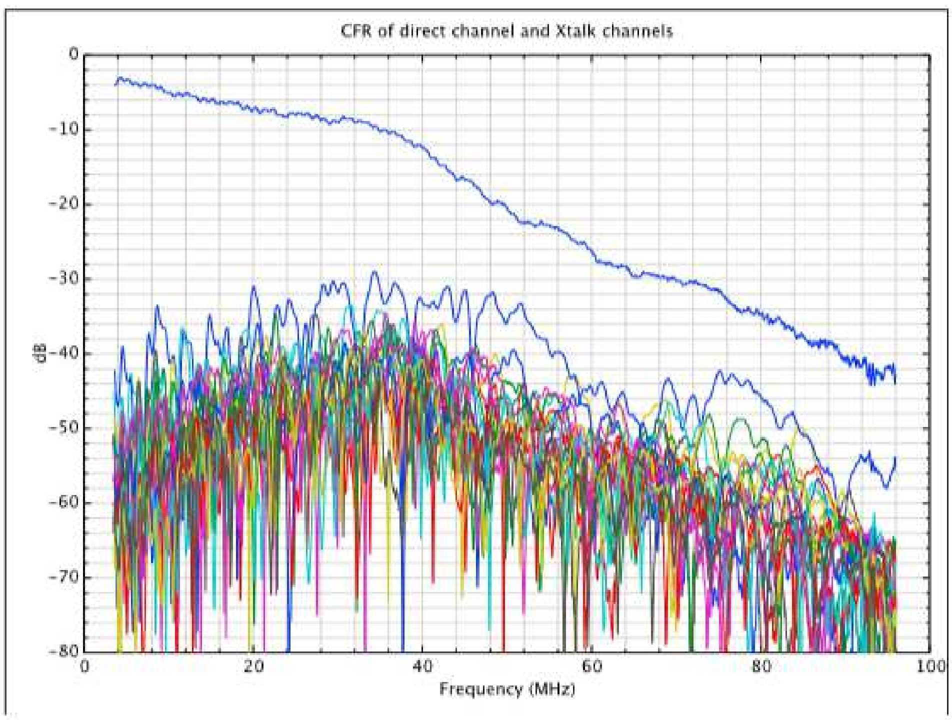
• Interoperability between G.hn products from different vendors is guaranteed by HomeGrid Forum, a non-profit organization dedicated to the promotion of the G.hn standard, including maintaining a complete compliance and interoperability program that issues certificates for G.hn products that pass their tests. **The HomeGrid Forum website includes a list of 38 interoperable G.hn products, manufactured by 14 different vendors, using G.hn chips**

from several different silicon suppliers. New vendors are constantly being added to list, available at this website: https://homegridforum.org/certified-systems/

• **The first release of the G.hn standard was approved in 2009, with multiple updates and improvements since then, making the standard very mature**. Silicon vendors have also had time to release multiple generations of their G.hn products. Millions of broadband users rely on products powered by G.hn chips.

• While some of the copper-based technologies competing for the gigabit broadband market have only shipped small quantities years after their arrival to the market, **G.hn technology has achieved a degree of critical mass that allows G.hn silicon vendors to ship millions of G.hn chips every year at very competitive prices**, in devices like multiport DPUs, fiber extenders, CPEs, Wi-Fi extenders, set-top boxes, etc. This high volume enables silicon and system vendors to invest tens of millions of dollars in R&D, ensuring a sustained development of the technology as it evolves to meet the demands of 10 Gbps networks.

Figure 2: CFR of direct channel and crosstalk channels

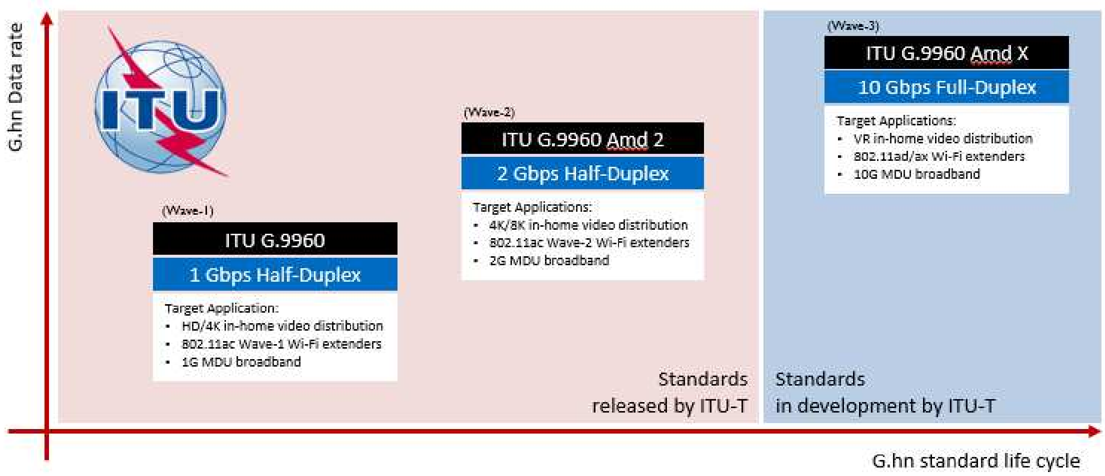


3 The evolution of G.hn

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.

This new amendment will represent the first major performance update to G.hn since 2015, when 2x performance improvement (when compared with the first version of G.hn, released in 2010) was introduced.

Figure 3: G.hn standard life cycle



The new amendment of G.hn is being developed with inputs from multiple industry participants, including silicon vendors and will address use cases such as 10Gbps MDU broadband access and next-generation 10Gbps Wi-Fi extenders.

Systems based on this amendment will be backwards compatible with existing G.hn systems.

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