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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Applications of ITU-T G.9960, ITU-T G.9961 transceivers for Smart Grid applications: Advanced metering infrastructure, energy management in the home and electric vehicles

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Summary

This technical paper describes typical network architectures, parameters, and implementation issues regarding Smart Grid (SG) applications that use G.9960/G.9961 transceivers (called here *"G.9960 transceivers"*). The main Smart Grid applications in which these transceivers are used are Advanced Metering Infrastructure (AMI), plug-in electrical vehicles (PEV), and various home energy management applications. G.9960/G.9961 devices are designed to be extremely flexible, capable of operating over different types of media, using different bandplans (frequency ranges), and different sets of PHY and MAC parameters. Each of these applications has a number of specifics that require corresponding settings (configuration options) to be used. Additionally, implementations themselves must consider various aspects of the applications, which are described in detail in this document.

This document is not an ITU-T Recommendation, but a tutorial that provides a guidance for the user and describes typical applications of SG devices based on Recommendations ITU-T G.9960, G.9961. The document does not imply any requirements in addition to those specified in G.9960, G.9961.

Change log

This document contains Version 1 of the ITU-T Technical Paper "Applications of ITU-T G.9960, ITU-T G.9961 transceivers for Smart Grid applications: Advanced metering infrastructure, energy management in the home and electric vehicles" approved at the ITU-T Study Group 15 meeting held in Geneva, May/June 2010.

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ITU-T Technical Paper

Applications of ITU-T G.9960, ITU-T G.9961 transceivers for Smart Grid applications: Advanced metering infrastructure, energy management in the home and electric vehicles

1 Scope

The scope of this document is the use of G.9960 transceivers in Smart Grid applications, and is intended to promote possibilities to define, configure, deploy, and network various devices using G.9960 transceivers in Smart Grid applications.

The G.9960 family of Recommendations includes G.9960, G.9961, G.9970, and G.9972 (optional), and is referred to as G.9960 here.

G.hnem (G.996x) is considered a part of this family; its technology definition and capabilities will be included in future revisions of this document.

2 References

[1] Recommendation ITU-T G.9960 (2010), *Next generation home networking transceivers*.

[2] Recommendation ITU-T G.9961 (2010), *Data link layer (DLL) for unified high-speed wire-line based home networking transceivers*.

[3] Recommendation ITU-T G.9970 (2009), *Generic home network transport architecture*.

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

3 Definitions and acronyms

3.1 Definitions

Term	Definition
AMI domain	A G.9960 domain deployed over Powerline Access lines to provide AMI services to and from the utility to the residence.
AMI Network	A network consisting of at least one AMI domain used for delivering AMI services to and from residences.
AMI Network Branch	A part of an AMI network that includes one or more G.9960 AMI domains, up to 16 domains in total, under control of a Global Master.
Device	Any type of system used for an application using a networking transceiver.
G.9960 device	A device using a G.9960 transceiver.
G.9960 domain	A G.9960 network comprised of a domain master and its registered nodes.
G.9960 network	One or more domains used to provide communications services for a single residence or utility under the control of a single Global Master.
G.9960 transceiver	A node in a G.9960 domain that conforms with G.9960 and G.9961.
G.hn family transceiver	Includes transceivers defined by G.9960/G.9961 and G.hnem.
Node	A network element or member; specifically, in the context of this paper, a G.hn family transceiver.
Utility Back Office (BO) systems	Information Systems within the utility or related third parties that provide management, customer support, and information processing functions.

3.2 Acronyms

Abbreviation	Definition
AKM	Authentication and Key Management
AM	AMI Meter (node)
AMI	Advanced Metering Infrastructure

AMM	Automated Meter Management
AMR	Automated Meter Reading
ASM	AMI Sub-Meter (node)
BB	Broadband
BO	Back Office (IT systems)
BPL	Broadband Over Power Line
DLL	Data Link Layer
DM	Domain Master
EM	Energy Management
ESC	Energy Services Channel (secure)
ESI	Energy Service Interface
EV	Electric Vehicle
EVCF	Electric Vehicle Charging Facility
EVSE	Electric Vehicle Supply Equipment
GM	Global Master
HAN	Home Area Network, a communications network in the residence
HE	Head End
HN	Home Network
HV	High Voltage
IDB	Inter-Domain Bridge
IH	In-Home (regarding location of a domain)
IHD	In-Home Display
LV	Low Voltage
MV	Medium Voltage
NB	Narrow-band
OSI	Open Systems Interconnection (network communications reference model)
PBC	Public Broadcast Channel (unsecure)
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PLC	Power Line Communications
SAE	Society of Automotive Engineers
SC	Security controller
SG	Smart Grid
SGA	Smart Grid Access (node or device)
SGH	Smart Grid in-Home (node or device)
UAN	Utility Access Network
VDSL/VDSL2	Very High-speed Digital Subscriber Line (DSL)

4 Introduction

This Technical Paper describes how Smart Grid (SG) applications are accommodated through the use of G.9960 transceivers and the standard G.9960 network architecture. The G.9960 network architecture incorporates nodes that operate as part of the Smart Grid Home Area Network (HAN) within the home, or operate as part of a Smart Grid Utility Access Network (UAN) outside the home. Further, the HAN may be interconnected to a UAN as a part of an SG deployment.

To meet complexity and energy consumption requirements for Smart Grid applications, G.9960 SG nodes may be implemented using G.9960 low-complexity profiles. Low-complexity profile nodes are fully interoperable with other G.9960 nodes operating in the same domain.

G.9960 is a world-class networking technology which can be used for a robust in-home broadband network, or for the "last leg" link in a Smart Grid access network as it attaches to the home. Further, G.9960 supports requisite Smart Grid applications inside the home. G.9960 provides all necessary functions required for a Smart Grid networking technology inside the home as well as connection of Smart Grid services to the home.

Until the advent of G.9960 technologies, in-home Smart Grid services delivery was typically assumed to occur over either via power lines or wireless. With G.9960's ability to use any wire in the home as a possible Smart Grid connection, every device in the home can have its energy consumption monitored and managed, as well as interconnecting any wired device into a smart network where data accessibility is as valuable as energy efficiency.

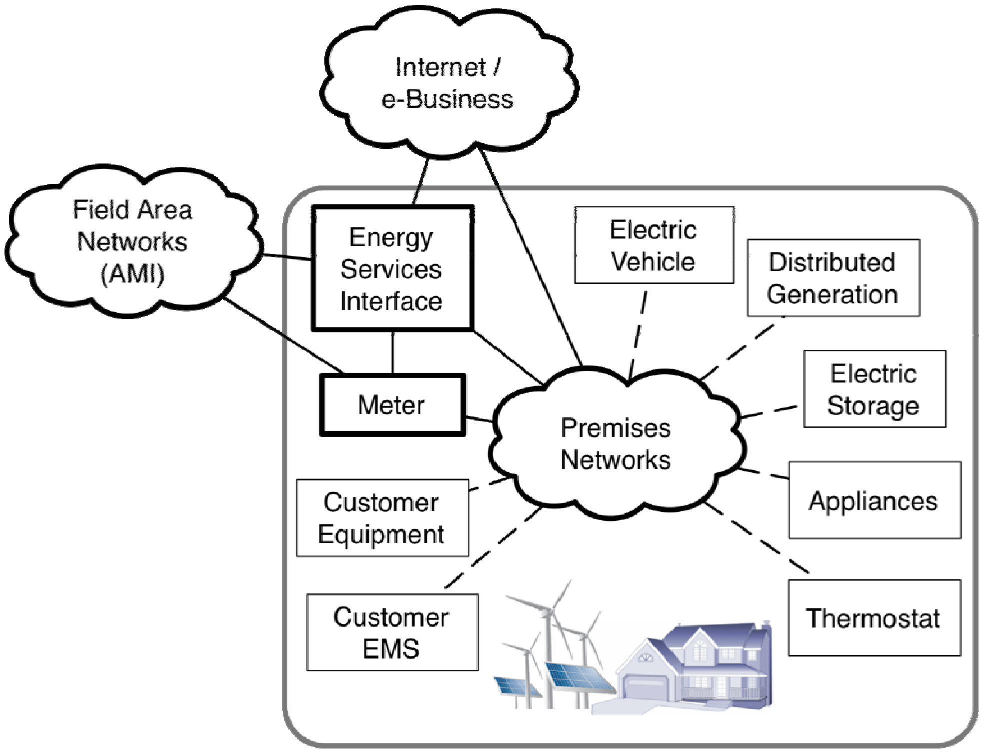


Figure based on NIST Smart Grid Framework 1.0

Figure 1 - Smart Grid communications across all HAN links (Field Area Network represents UAN)

This technical paper is divided into three parts:

- **Part 1**: Background on Smart Grid and Smart Grid services in the home
- **Part 2**: Brief introduction to G.9960 network architecture
- **Part 3**: Use of G.9960 for AMI and for in-home Smart Grid applications

Part 1

5 Background on Smart Grid and Smart Grid services in the home

Smart Grid is a term used for an advanced electricity delivery system comprised of the power grid from generation to consumption points, related management and back office systems, and an integrated modern digital information technology to provide improved reliability, security, and efficiency, resulting in ultimately lower costs for providing utility services to the user. With its overlay of information technologies, a Smart Grid has the ability to be predictive and self-healing, so that problems are automatically avoided.

Smart Grid services outside the home include Advanced Metering Infrastructure (AMI), Automated Meter Management (AMM), and Automated Meter reading (AMR). Inside the home, Smart Grid applications can provide communication between Plug-in Electric Vehicles (PEV) and their charging station, as well as communications between smart appliances such as heaters, air conditioners, washers, and other appliances.

SG services in the home include granular control of smart appliances, the ability to remotely manage of electrical devices, and the display of consumption data and associated costs to better inform consumers, and thus motivate them to conserve power. The architecture of G.9960 not only enables these services, but promotes ubiquity throughout the home.

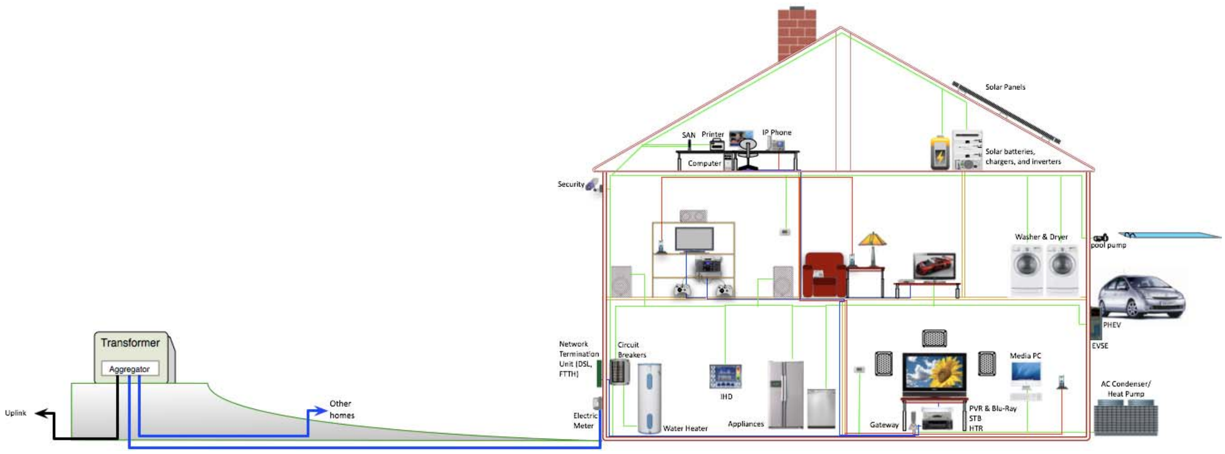


Figure 2 - The Smart Grid home

5.1 How the Smart Grid reaches the home

The Smart Grid outside the home touches the whole power grid and related infrastructure, from back office (BO) IT systems used for billing and managing the grid to power generation, transmission and distribution, and eventually the connection to the home (see Figure 3). Smart Grid services over power lines transit access lines (Medium Voltage and Low Voltage power lines) to the home.

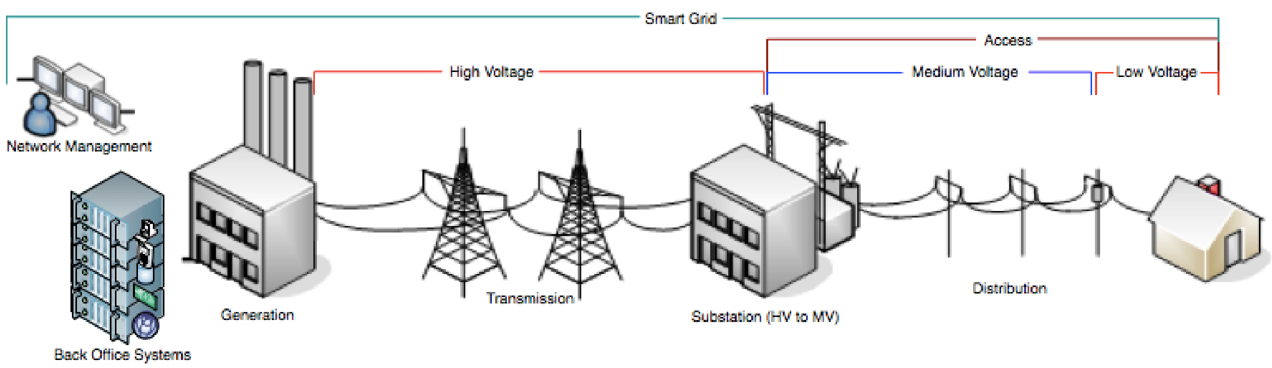


Figure 3 - General model of Smart Grid including Utility Back Office Systems, Power Generation, Transmission, and Distribution (Access is part of Distribution)

The final path for Smart Grid communications services to reach the home may be provided by a power line technology, by a wireless technology, or by a traditional broadband technology. G.9960 devices can be used to provide AMI services to the home over the Utility Access Network as shown in Figure 4.

The following subclauses discuss Smart Grid services provided over Powerline Access.

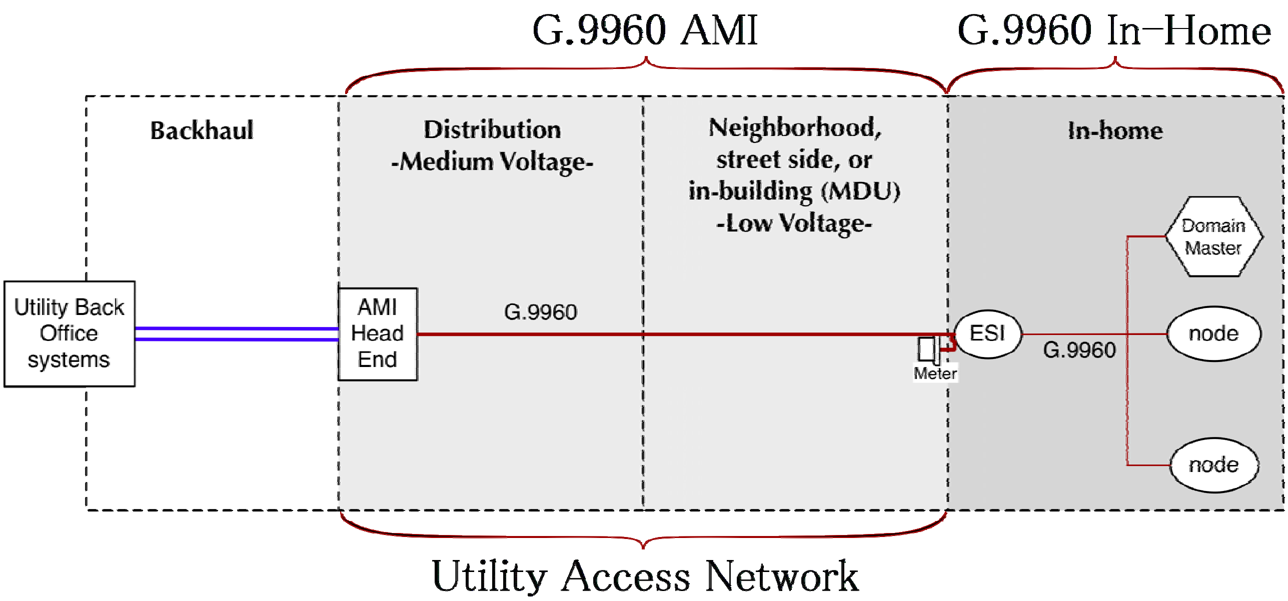


Figure 4 - Utility Smart Grid communications options to reach the meter and HAN

5.1.1 Powerline Access Services

Powerline Access Services are defined as data communications services provided over exterior power lines in the distribution part of the electric grid, over either aerial or buried wires that connect the business or residence to the utility. Distribution lines carry Medium or Low Voltage electricity.

Numerous types of services can be provided as part of Powerline Access, including Broadband over Powerline, AMI, AMR, and AMM.

As Figure 3 shows, the Smart Grid covers all aspects of electric flow, from generation, delivery, management, to consumption. The Smart Grid is the overlay of a digital data communications network for monitoring performance, gathering data, and controlling each component in a manner to make the grid (and in-home systems) more efficient.

5.1.2 Powerline in home

Power lines in the home were designed for delivering electricity safely and efficiently to power sockets (outlets) and appliances; they were not designed for communications purposes. The unshielded and untwisted wires used for power transmission are subject to many types of strong interference; many electrical devices are also sources of noise on the wire. However, with the advent of the advanced communications and noise mitigation technologies within G.9960; power lines, with their ubiquitous sockets, have become the most desirable wired communications path in the home. *"Wherever there's a power socket there's a data communications connection"* is a compelling statement, as most modern devices in the home require an electrical connection, while the services they provide can likely benefit from networking with other systems.

With the arrival of G.9960 technologies, power line communications (PLC), which has traditionally been a "best effort, moderate speed" communications option, is now a very high speed, high quality communications path.

5.2 Advanced metering

5.2.1 Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) is defined as the communications hardware and software and associated system and data management software that creates a network between advanced (or "smart") electricity meters, gas meters, and/or water meters, and utility back office systems, allowing pre-defined meter data collection schedules and on-demand distribution of information to customers and other parties such as competitive retail providers, in addition to providing information to the utility itself. Deployment of AMI is one of the primary goals of consumer-focused Smart Grid initiatives.

Unique characteristics of AMI implementations that set them apart from other typical utility projects include the following:

- AMI has millions of nodes and touches every consumer
- AMI must be a two-way communications system
- AMI must be a highly secure communication system, used to securely deliver meter data to the utility

Besides data delivery, AMI provides service management (disconnect/reconnect), monitoring of the meter for tampering, and delivery of rate and other information to the customer for energy management purposes.

Many AMI deployments currently use low bit rate communication solutions; however, in multiple instances utilities are experiencing difficulties in downstream data flow, real time data delivery, and certain maintenance functions that require higher throughput. Thanks to its high throughput and quality of service characteristics, G.9960 provides an ideal and cost-effective solution to these issues.

Automated Meter Reading (AMR) is a predecessor technology to AMI, and is currently considered a subset of AMI. Advanced Meter Management (AMM) sits on top of AMI to manage meters and their data, and therefore is in support of and a client to AMI.

Sub-meters are also supported within the AMI architecture. Sub-meters are meters that provide usage information on a particular part of the load in the residence. To prevent confusion, the AMI meter serving the whole load for the home is referred to as the "main" meter. One or more sub-meters may be installed behind the house's main meter. An example of a sub-meter would be one found in electrical vehicle supply equipment (EVSE) for charging a plug-in electric vehicle (PEV). The electricity passing through the EVSE (usually installed in a residence's garage) is tracked by the main meter as part of recording the residential consumption. However, the EVSE's sub-meter allows tracking that subset of the usage related to PEV charging which may be provided at a special rate, while the main meter shows the net usage. AMI improves sub-meter communications with the main meter with which they are associated, as well as with the utility and the billing entity.

The communication protocol between the meter or sub-meter and the utility or billing entity is at layers above the PHY/DLL, and is thus outside the scope of G.9960. In this sense, G.9960 is transparent and can accommodate any of the existing layer three and above protocols, including IPv6.

When a HAN is established at the residence, an Energy Service Interface (ESI) is installed to bridge the HAN to the meter and the AMI network. ESI functionality may be within a meter, although it is anticipated that the ESI will generally be a separate device from the AMI meter. The separate ESI contains an AMI node allowing it to communicate with the AMI network, meaning this ESI AMI node must register and be authenticated just as any other AMI node.

Part 2

6 Brief introduction to G.9960

6.1 Generic network architecture

A G.9960 network may include up to 16 separate domains, which may be established over any type of in-home wiring (power line, coax, phoneline, category 5 cable); for Smart Grid applications, power line is the typical medium. Each domain may include up to 250 G.9960 nodes, one of which is designated a domain master that coordinates operation of all nodes in the domain. All other nodes in the domain are called “end-point nodes” or simply “nodes”.

G.9960 devices of different domains communicate with each other via Inter-Domain Bridges (IDB). IDBs are simple data communications bridges that link multiple domains, enabling a node in one domain to pass data to a node in another domain. One popular example of IDB services is provided by the Energy Service Interface (ESI), which enables connection between the AMI Network and HAN.

In addition to G.9960 domain-to-domain bridging, G.9960 domains can be bridged to alien (non-G.9960) domains, which can be established over wireline media or wireless. Alien domains can be bridged to G.9960 domains using L3 bridges. The specification of bridges to alien domains is beyond the scope of G.9960.

The Global Master (GM) provides coordination of resources, priorities, and operational characteristics between domains of a G.9960 network. The GM is a high-level management function that may also convey the relevant domain coordination functions initiated by a remote management system.

Generic architecture of a G.9960 HAN containing both G.9960 domains and alien domains is presented in Figure 5.

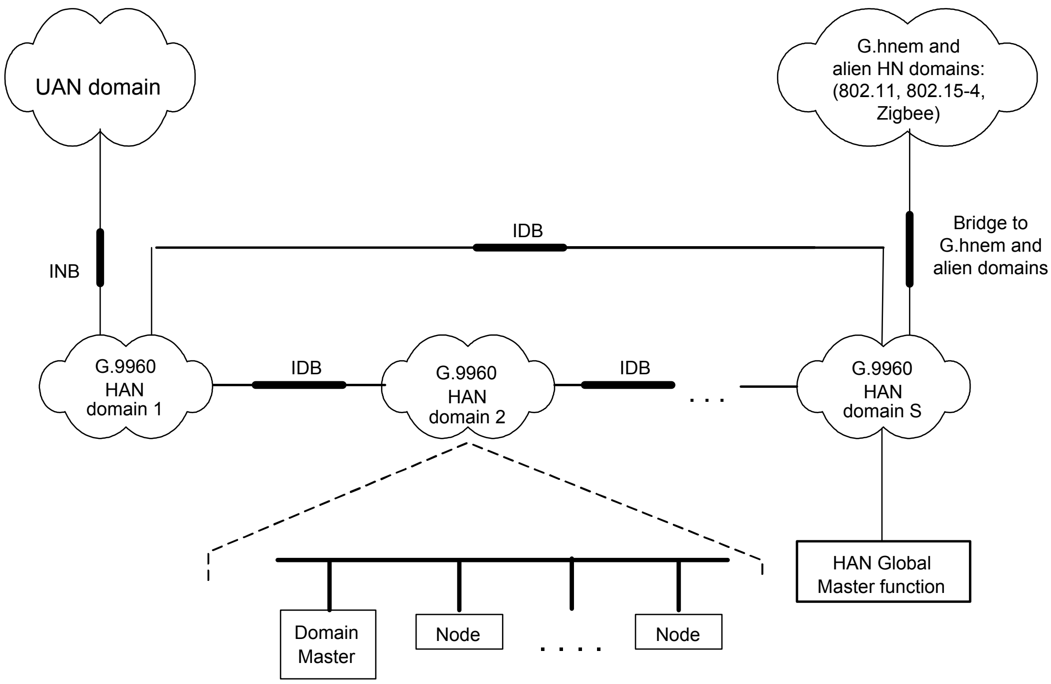


Figure 5 - Generic architecture of G.9960 HAN

G.9960 domains have no limitation on topology; the fact that one is connected to another domain via an IDB does not dictate the topology of either domain. Depending on the application, G.9960 domains may be daisy-chained, star-connected, or may use another connection topology.

6.2 G.9960 low-complexity devices

The G.9960/G.9961 Recommendations define different profiles of G.9960 nodes that allow reduced implementation complexity for lower bit rate implementations. The standard Low Complexity profile is for use in Smart Grid implementations, providing communications with PHY bit rates up to 20 Mbit/s and highly robust communications with PHY bit rates up to 5 Mbit/s (using x4 repetition encoding).

The concept of relative complexity versus throughput of different G.9960 applications related to Smart Grid is presented in Figure 6. The complexity of PEV implementations can be further reduced due to specifics of the PEV communication architecture (see clause 9).

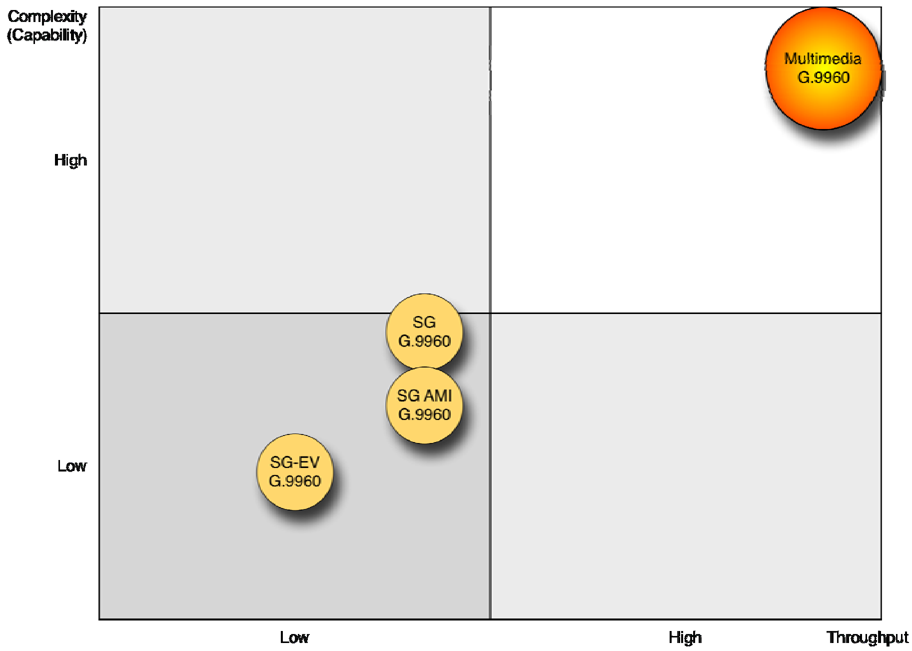


Figure 6 - Chart comparing relative complexity versus throughput of G.9960 nodes

Part 3

7 Use of G.9960 in AMI

7.1 G.9960-based AMI network

AMI is the most typical Smart Grid application which will come to the home. The G.9960-based AMI network referred to in this paper consists of AMI domains, possibly connected to HAN domains. AMI domains provide access between the HAN and utility services (see Figures 3 and 4). The qualities of G.9960 devices used for AMI are similar to those for G.9960 Smart Grid HAN use. The G.9960 devices for this application provide the necessary communications for data sharing; Smart Grid monitoring and management functions between utility back office systems; the meter; and AMI sub-meters. Via the ESI, G.9960 devices provide necessary communications between the utility back office systems and other Smart Grid-related devices in the residence, including other meter(s), PEV applications in the garage or the yard, and energy management functions.

7.2 Basic G.9960 AMI network architecture

The G.9960 AMI network architecture conforms to the established G.9960 architecture shown in Figure 5; the AMI network may include one or more AMI domains. Each domain contains a domain master and up to 250 G.9960 nodes used in meters, sub-meters (if in the AMI domain) and in ESI devices (see Figure 7). In a large utility area, thousands of meters may be deployed in an AMI network. G.9960 accommodates this through the use of multiple AMI domains, with up to 16 in a single AMI Network Branch under a Global Master (up to 4,000 nodes), with an unlimited number of network branches possible.

The G.9960 nodes used in meters are labelled AMI Meter (AM) nodes while nodes used in sub-meters and ESIs are labelled AMI sub-meter (ASM) nodes. AM and ASM nodes may be identical to each other.

The domain master of an AMI domain is located at the Head End (HE) device and is labelled the Head End node. The HE device has all domain master capabilities, which differs from AM and ASM nodes, which are not required to be domain master capable. The HE device of the AMI network is also known as an Aggregator, Hub, or Collector. In Figure 2, the HE device is labelled as "Aggregator."

The AMI example presented in Figure 7 shows the case in which two AMI domains are deployed, each with their own backhaul connection to the utility BO systems.

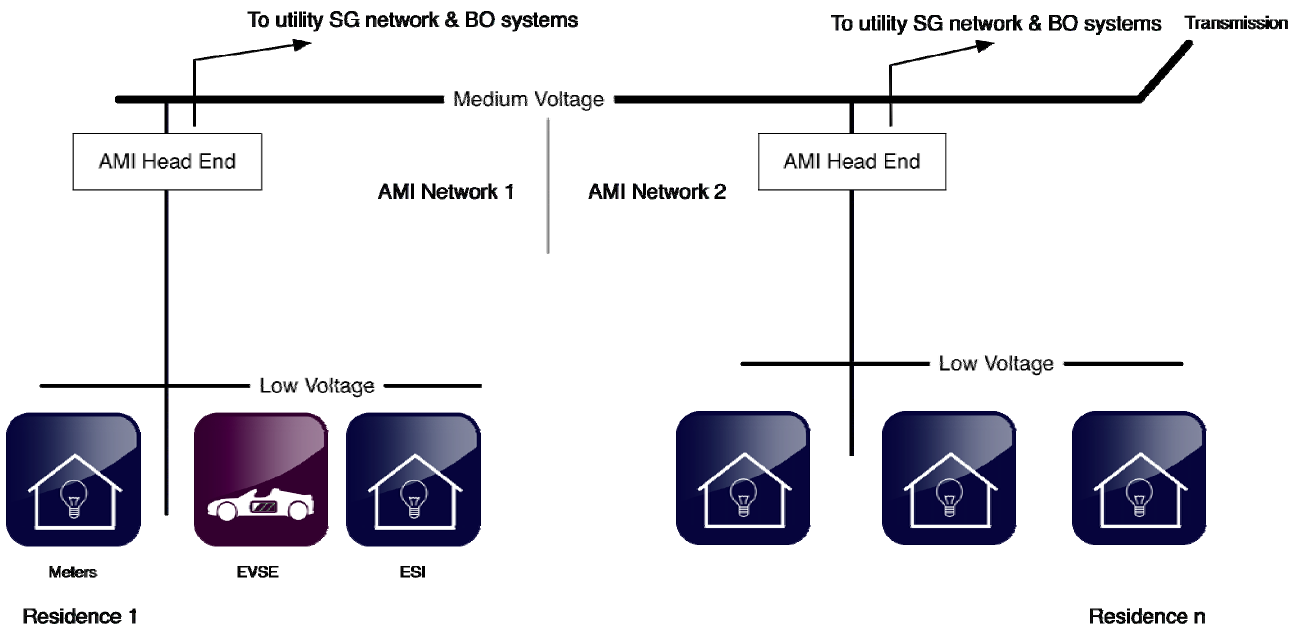


Figure 7 - Example AMI domains with separate connections to the utility via medium voltage line

7.2.1 A sub-meter in an AMI network

As defined previously, a sub-meter tracks a specific load's consumption downstream from a residence's main meter.

The sub-meter node may be a node of the AMI network or a node on the utility-secured part of the HAN. If the sub-meter is on the HAN it communicates with the meter and with the utility BO systems via the ESI, and is not considered an AMI device. The same meter node can function in either AMI network and in the HAN, since AMI nodes and IH nodes have the same basic G.9960 capabilities.

The sub-meter may periodically report to the meter either automatically or in response to a command from the meter or from the utility back office systems. Further, the sub-meter sends on-demand responses to the meter or to the utility BO systems.

7.2.2 Presence of an ESI with an AMI network

The Energy Service Interface (ESI) connects the AMI domain to the HAN, serving the role of a gateway. The ESI supports multiple communications channels coming into the HAN; both secure and public channels are supported, with the public channel providing utility information to the customer. More details on ESI operation are provided in clause 8.1.2. The ESI secure channel function enables interactions of the Smart Grid HAN devices over an AMI domain/network with utility back office systems. ESI functions can be either inside the meter or separate from the meter in a standalone ESI device. Current industry thinking is that the ESI will typically be separate from the meter. Examples of both cases are presented in Figures 8 and 9.

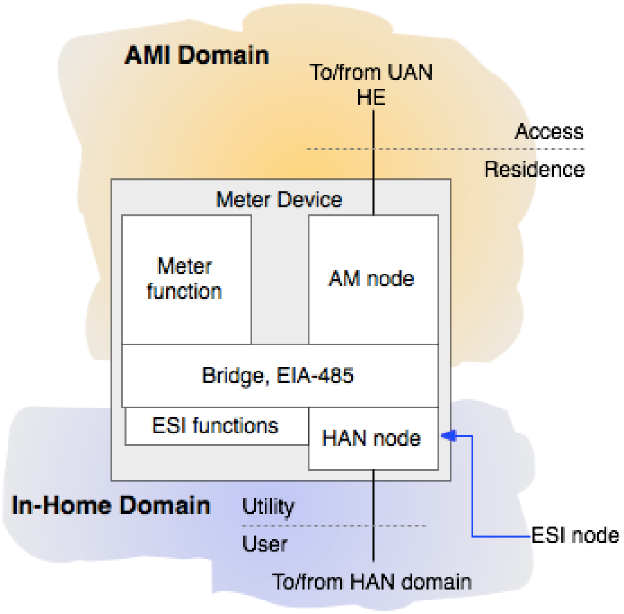


Figure 8 - Example of ESI function, AM node, and HAN node incorporated within a meter and connected using an Ethernet bridge or a EIA-485 bus

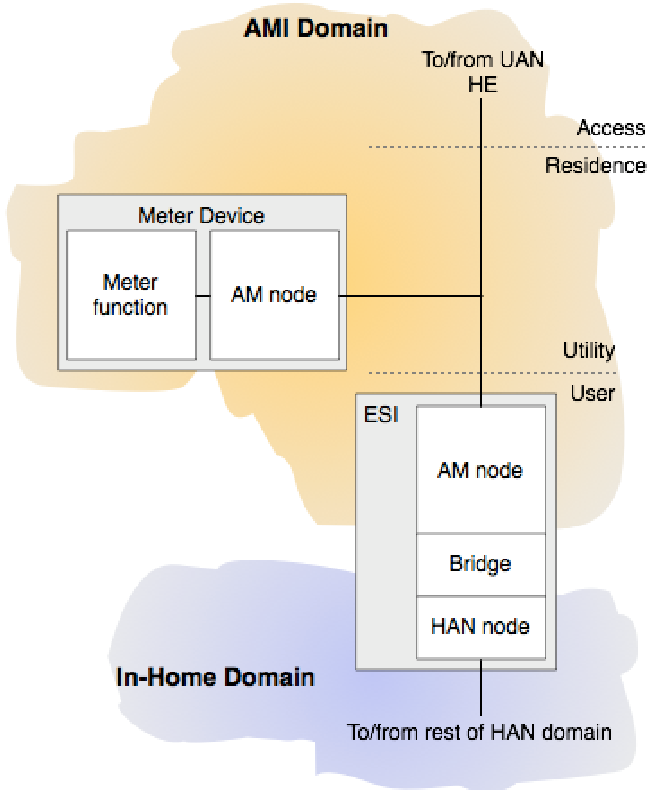
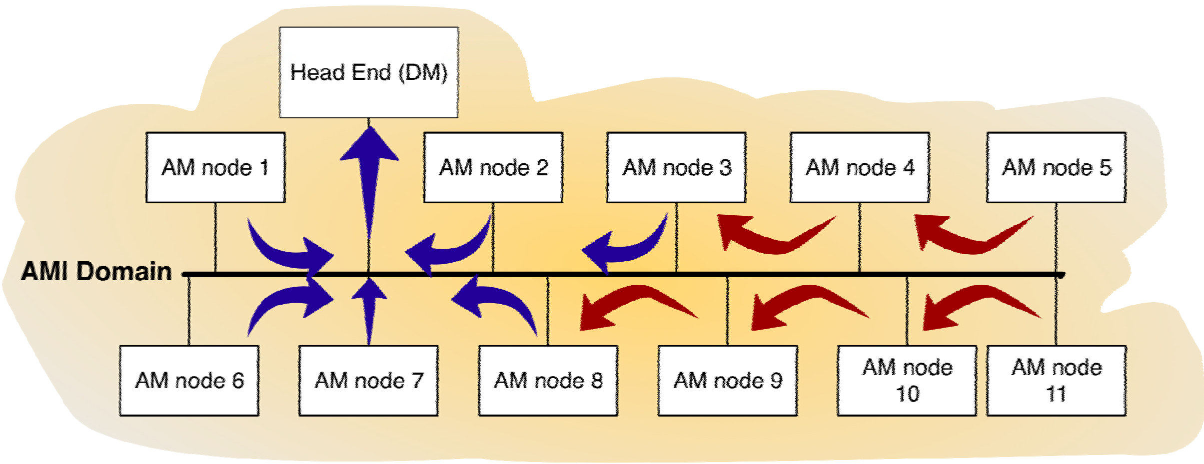


Figure 9 - Example of ESI separate from a meter

7.3 G.9960 AMI Domain

Typically, a G.9960 AMI domain includes a greater number of nodes than a HAN domain. As the AMI domain may span a large geographic area, the use of relays is crucial for passing information between distant meters and the HE. Figure 10 shows an AMI domain (Domain A) that makes extensive use of relays to deliver messages from distant AM nodes (meter nodes) to and from the HE.

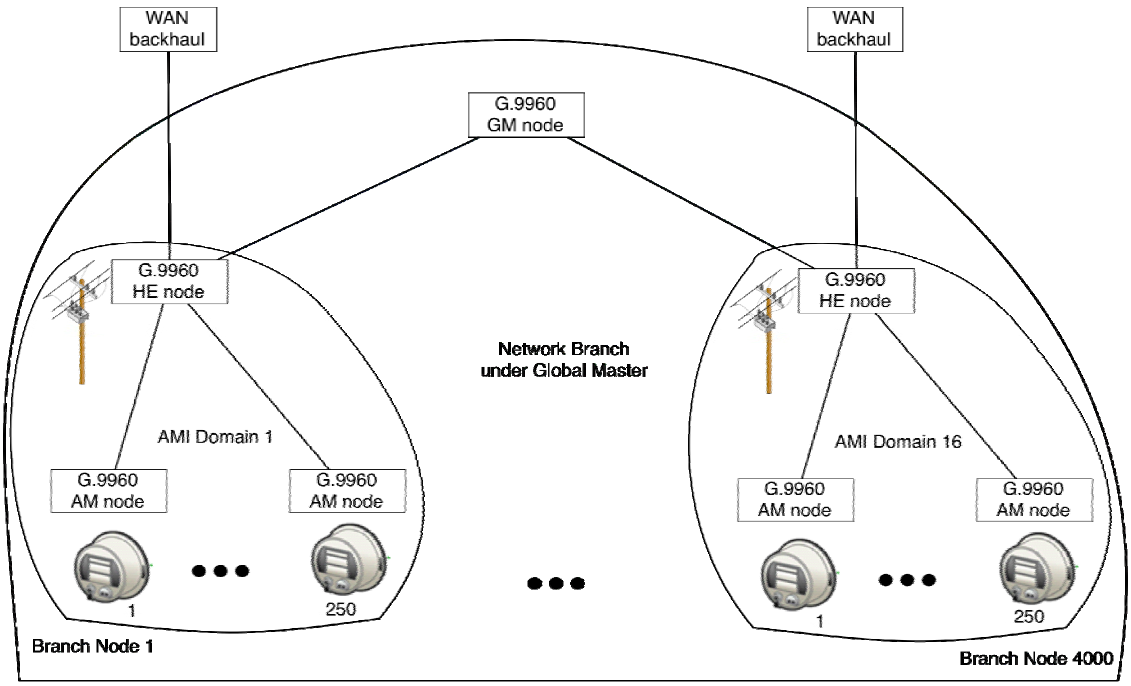


NOTE - Red errors show nodes that need their frames to be relayed by other nodes to reach the HE.

Figure 10 - Example of AMI domain using G.9960 nodes

AM nodes can relay packets from the HE to other AM nodes within a building or neighbourhood. AM nodes can also communicate with the HE directly or via another AM node that passes their messages on to the HE. Thanks to automatic setup and reconfiguration, this inter-AM node relaying enables G.9960 AMI domains to act as self-healing mesh networks.

A G.9960 domain supports up to 250 nodes associated with various AMI devices (meters, sub-meters, etc.). Up to 4000 nodes may addressed by a G.9960 AMI network (16 domains of 250 nodes each). A Global Master (GM) manages coordination between the AMI domains in an AMI Network (see Figure 11); each AMI network or network branch is controlled by its own GM.



NOTE - The GM is shown here as a separate function.

Figure 11 - Example of an AMI network with a Global Master managing up to 16 AMI domains

The GM in an AMI network branch can act as a coordinator of the AMI domains it controls and any neighbouring G.9960 HAN domains, including coordinating transmit power levels, used sub-carriers, and media access time spaces. This function of the GM in an AMI application enables reduced interference to the point that the coexisting AMI and IH domains lose as little throughput as possible.

As stated above, the G.9960 AMI architecture provides a mesh, self-healing network by definition, ensuring with a high degree of confidence the delivery of information from the AM nodes to the HE and from the HE to the AM nodes, regardless of intermittent node operation or connectivity. If a node which was acting as a relay for other nodes loses its link to these nodes or the HE, the transmitted messages will be automatically routed around the loss of connectivity and still delivered.

7.3.1 G.9960 AMI Abilities

The concept of a G.9960-based AMI network can be summarized as follows:

1. The G.9960 Low Complexity profile fits the AMI node application requirements, for both AM and ASM nodes.
2. The frequency range of G.9960 AMI devices is 2-25 MHz.
3. Limited electromagnetic emissions, for example VDSL2 over drop wires in close proximity to an AMI link will be protected by reduced transmit PSD of G.9960 over the relevant VDSL2 frequencies.
4. AM and ASM nodes only transmit to the HE node or to utility-approved HAN devices behind the associated ESI. However, AM and ASM nodes may act as relays/proxies for other AM and ASM nodes, thus extending the domain's coverage.
5. The HE node transmits to one, many, or all AM nodes.
6. Each HE node supports up to 250 AM and/or ASM nodes, forming an AMI domain.
7. As shown in Figure 11, the network supports up to 16 AMI domains in an AMI Network branch for up to 4,000 AMI devices per branch.
8. The routing tables maintained in the nodes may be centrally or locally managed. The HE selects which methodology should be used, G.9960 supports both methods.
9. The potential for interference between an AMI domain and the HAN can be reduced by the standard coexistence mechanism defined in G.9972. More efficient mechanisms, including those based on coordination between neighbouring networks and specific AMI traffic patterns, are also available. In particular, the meter nodes may transmit on an automated periodic basis or as polled from the HE (query/response interaction).
   A mechanism for coexistence with neighbouring networks mitigates interference between AMI devices that belong to different domains (controlled by a different HE) if a GM is not used or the AMI domains belong to different branches, and also between AMI and HAN devices. When a neighbouring G.9960 domain is detected and it shares the MAC cycle with the AMI domain, the AMI domain restricts the use of the MAC cycle to a maximum of 10% of the time in any MAC cycle, with an average usage less than 5% of MAC cycle time. This mechanism is currently under study.

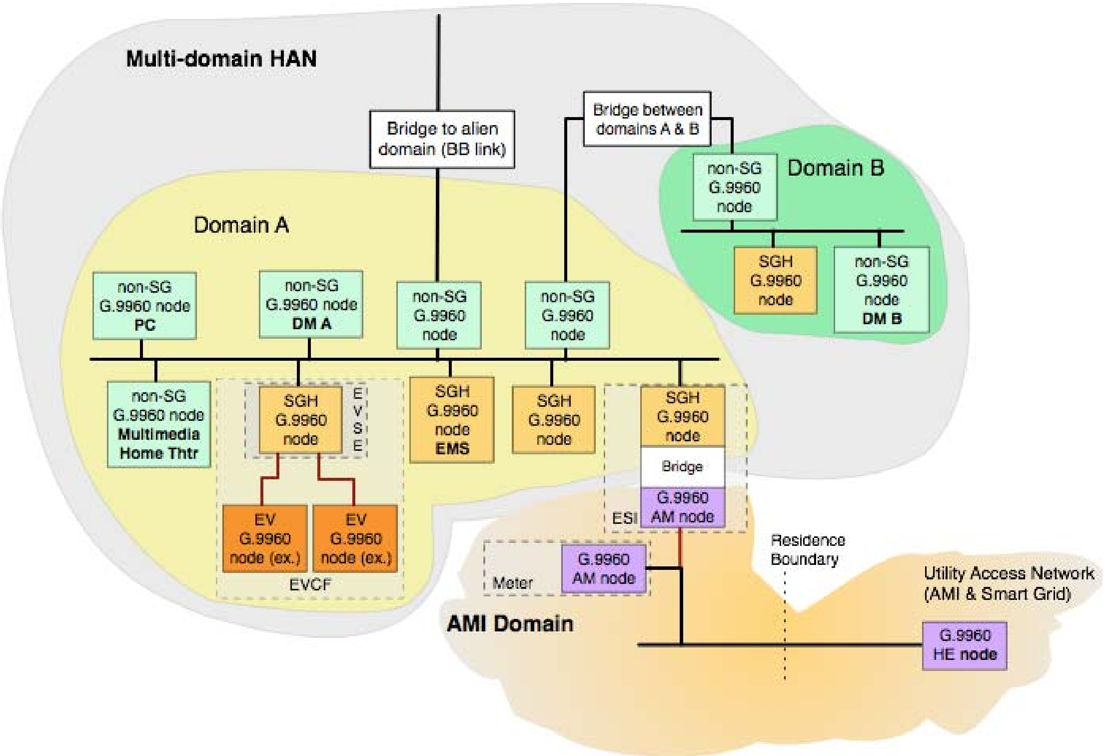


Figure 12 - The AMI application viewed with the G.9960 broadband, Smart Grid, and Electric Vehicle applications

In many instances, AMI is deployed, but no HAN exists in the residence, making AMI the sole domain at the home; Figure 13 depicts such a scenario. Figure 14 shows what would be needed to establish a HAN over powerline after the AMI deployment with the addition of an ESI to link the HAN and AMI Network.

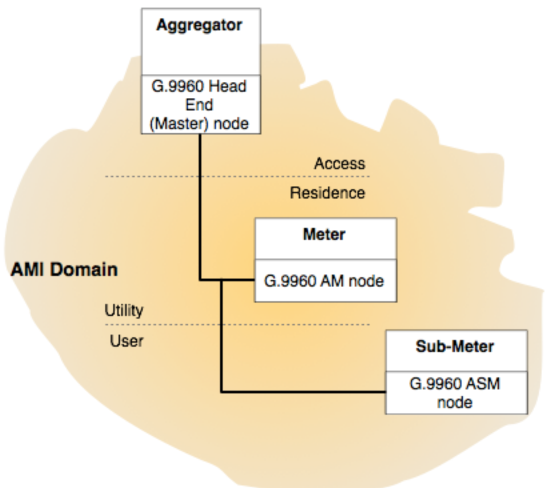


Figure 13 - Example AMI deployment to a residence with a meter and a sub-meter, no HAN present

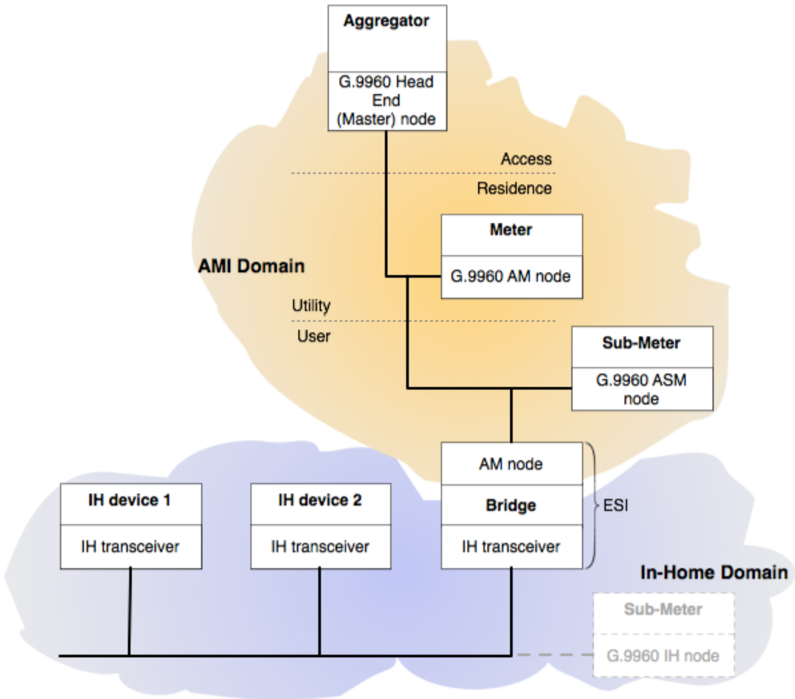


Figure 14 - HAN installed after AMI deployment requiring an ESI (IDB with an AM node); option: the sub-meter node could be moved into the IH domain (HAN)

7.3.2 Mesh networking in AMI

Mesh networking techniques defined in G.9960 greatly help to establish a robust, self-healing G.9960-based AMI network. In the example in Figure 15, the black lines designate connections that are established and defined in routing tables as the first choice for routing packets between AM nodes and the HE. In the event one of these connections fails for whatever reason (e.g., node outage), the standard G.9960 routing procedure will reroute the connections (red dashed lines) to ensure packets pass to their destination. Routing algorithms provide delay minimization.

For example, if link "f" fails between the HE node and AM node 8, the upstream path of packets would go over link "n", "o", or "p" to go from node 8 toward the HE. Once the packets have transited one of these links, they are treated as any other packet and passed along upstream toward the HE. Algorithms and processes are in place to ensure no looped packets occur and the best new route is used (based on numerous parameters, including traffic, delay, bandwidth, number of relay hops, and "cost").

Sub-meters, if part of an AMI domain, will mainly use their associated meter to communicate with the HE if direct communication is not available. In star topologies, when each meter is logically connected directly to the HE (no relays), loss of the associated meter could result in no link for the sub-meter to the HE.

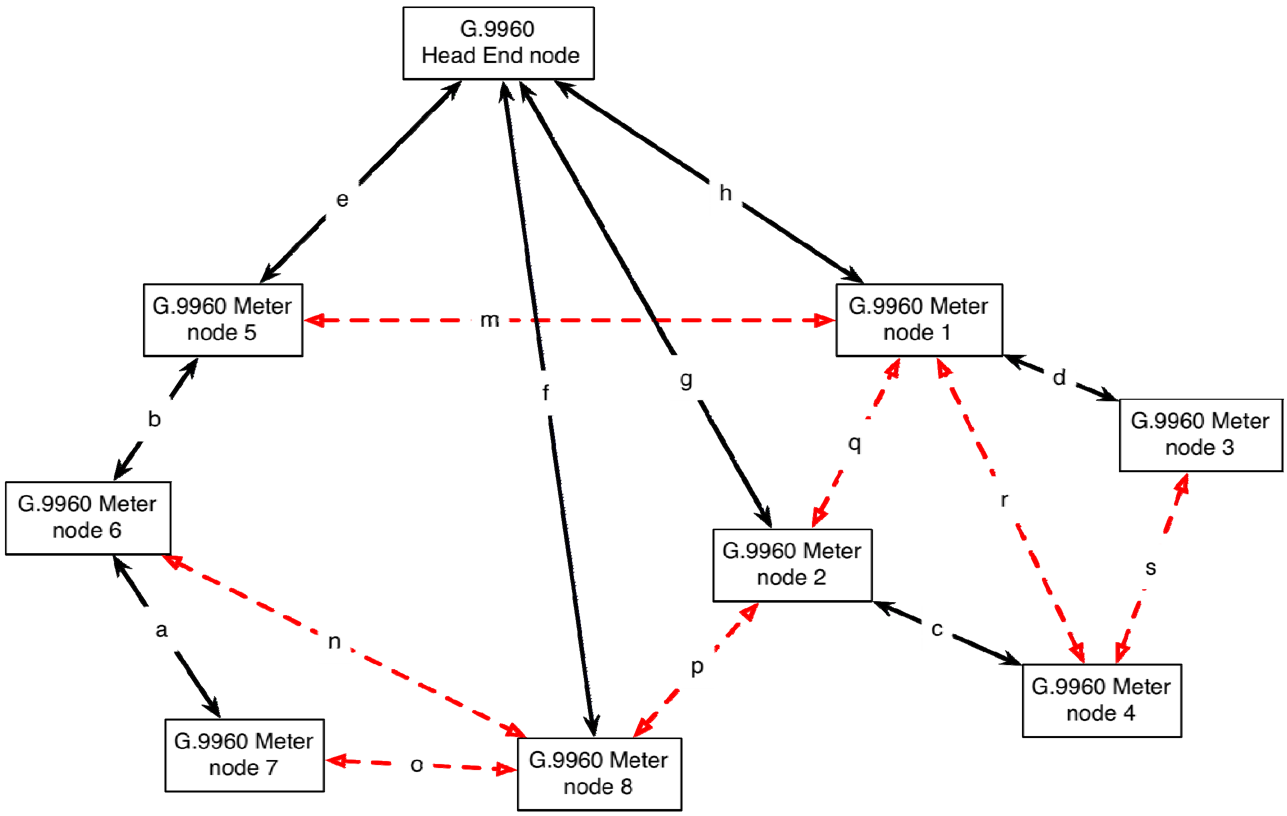


Figure 15 - Original connections (solid black lines) and reroutes (dashed red lines)

7.4 AMI specifications

The following specifications have been listed as requirement or important criteria for the AMI application.

Table 1 - AMI Specifications

No.	Title	Description	Note
1	Embedded Module	G.9960 module should be small enough to be embedded into meters	Meters, sub-meters, ESIs, and EVSEs
2	Capable of operation over both LV lines and MV lines		
4	No provisioning at installation is required for AM/ASM nodes		
5	AM and ASM nodes can be added to/removed from an AMI domain without re-programming of the HE		With continued support for automated utility BO system authentication step
6	Flexible network topology with HE at root		Structure of nodes can be daisy-chain, star, or hybrid
7	Every AM node can behave as a repeater, extending the network		This is an automated function
8	Maximum number of nodes in	250	

Table 1 - AMI Specifications

No.	Title	Description	Note
	an AMI domain		
9	Maximum number of domains in an AMI network branch	16	
10	Maximum number of nodes in an AMI network branch	4,000	16 domains @ 250 nodes each
11	Flexible application layer interface		Ethernet interface supported as standard and able to support other interfaces
12	Supports at least 6 levels of repeaters		
13	Self-healing mesh network	If any node acting as a repeater fails the remaining nodes shall automatically reconfigure the network topology tables to route around the outage	Automatic repeater fail-over
14	Time to join the network	<2 s	
15	Criteria for selecting a node to act as a repeater	May include throughput, hops to HE, "cost", traffic load, noise, and other criteria	
17	Minimum throughput available per node	1 Mbit/s	
18	HE functions as a repeater or bridge to other AMI domains		
19	Frequency notches enabled by default		
20	Maximum allowed power consumption of meter side module	<2w peak, <1w average	This is industry stated target that G.9960 outperforms
21	Minimum temperature range for all AMI nodes	-40° to +85° C	

7.5 G.9960 AMI Networks interaction with other systems in the local loop

To reduce potential impact on non-G.9960 systems, G.9960 AMI systems should reduce its maximum PSD by 10 dB with respect to the limit PSD defined for G.9960 using the standard PSD shaping mechanism. This reduction does not significantly affect the ability of G.9960 AMI to provide the expected service and coverage since the required throughput of AMI is rather low and mesh networking capabilities of G.9960 will maintain the coverage. The robust communication mode (RCM) will be used to increase robustness of communications.

To further reduce interference into the deployed VDSL2 systems, Annex E of G.9960 offers special PSD configuration for VDSL2 band-plans, referenced in Annex E of G.9960 as tables for PSD settings to be used in the presence of VDSL2 service. There is an ongoing study for defining a standard control messaging (which will then be configurable via TR-069 ACS) that instruct the domain master (be it in-home powerline or AMI) to set the effected nodes in the domain to work in a mode compatible with Annex E.

Regardless of the means of signalling the presence of VDSL2, the nodes shall work in a mode that either notches or reduces PSD in downstream VDSL2 bands to reduce impact on the VTU-R reception. The impact on upstream VDSL2 bands by an AMI service is for further study, as it is different than an in-home powerline domain.

8 Smart Grid in the Home

8.1 G.9960 transceivers for IH Smart Grid applications

This clause is solely focused on in-home G.9960 applications. In this clause, G.9960-compliant Smart Grid devices that operate in the HAN are called G.9960 Smart Grid HAN (SGH) nodes. Other devices (G.9960-compliant or not) that operate in the utility access network are called Smart Grid Access (SGA) devices.

8.1.1 G.9960 SGH devices

Nodes may be embedded into devices that participate in the Smart Grid HAN (SGH devices). Typically, these are consumer-owned appliances that may require external control or devices that control the use of energy by other devices. Examples of devices in this category are:

- In-home smart sub-meters
- Energy System Interface (ESI) devices and gateways to the SG Access network
- In-home displays (IHD) and thermostats
- Heating or air-conditioning appliances
- Plug-in Electric Vehicles (PEV) and Electric Vehicle Supply Equipment (EVSE)
- Washing machines, dryers, and dishwashers

  NOTE - Some of these devices can also be located outside the home; a pool pump would be one example.

Such SGH devices are able to provide a variety of Smart Grid applications related to data processing and data exchange. Examples include:

- Collection of information on energy consumption, and distribution of this information to consumers and service providers
- Adaptation of energy consumption to time-of-day fluctuations in energy billing rules and rates
- Support for automated Demand Response/Demand Management programs
- Flexible control of appliances to reduce power consumption when not in use, and when used

8.1.2 G.9960 Home Area Network Architecture

SGH nodes are connected to the G.9960 network based on the standard G.9960 architecture, which is multi-medium, multi-domain by definition. SGH nodes can be connected to any wireline media types available at the customer premises (power line, phoneline, coax, or CAT 5 cables). Interconnection between SGH nodes connected to different domains is through the corresponding inter-domain bridges (IDBs), which are typically standard Ethernet L2/L3 bridges.

The bit rate and QoS settings for communications between SGH nodes are set to meet the individual Smart Grid application's requirements.

SGH nodes are typically Low Complexity profile nodes, with reduced power consumption levels. The standard G.9960 "scheduled inactivity" mechanism allows further reduction of SGH node power consumption. In addition to the SG architecture described in this paper, the home may also have a separate broadband network access connecting to a residential gateway (RG) separate from the ESI, but then also utilize G.9960 home networking via the same in-home power wires used for SG communications within the home.

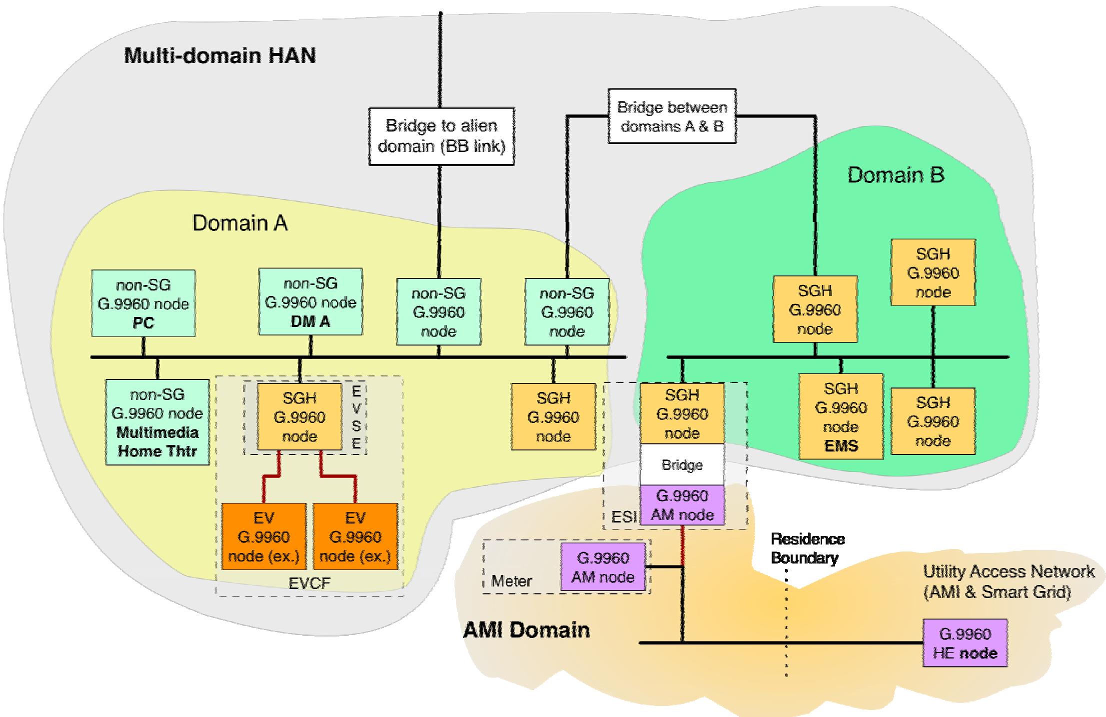


Figure 16 - Smart Grid HAN implementation based on G.9960

In different implementations, the ESI functionality may be or may not be located inside the meter.

Referencing Figure 16, the HAN (comprised of domains A and B, consisting of SGH nodes as well as regular non-SG nodes) interfaces with the utility SG access network via the Energy Services Interface in order to implement end-to-end Smart Grid applications between the SGH devices and the SG access network devices external to the home. The HAN can be connected to a broadband Service Provider via any generic broadband access network using various access technologies, which might be a powerline communication network, wireline network (e.g., DSL), wireless network, or other type of access technology. If Smart Grid applications are delivered over power lines, SGA devices will coexist with HAN devices on the same powerline wires using generic coexistence mechanisms and communicate with HAN devices via the ESI.

The ESI provides a network connection to the in-home medium (via SGH node), a physical or logical connection to the UAN (SGA node), and a logical interface (i.e., a bridge, gateway, or proxy) between the utility and SG devices of the HAN. The ESI is expected to facilitate at least two service channels (on OSI layer L3 and higher) between the UAN and the HAN:

- Energy Services Channel (ESC)
- Public Broadcast Channel (PBC)

The ESC is required to be two-way secure: the SGH devices registered with the utility or the appropriate service provider communicate with each other and with the service provider (via the ESI) over the ESC that operates on OSI layers L3 and higher. The PBC is used to supply the customer with public data of a general nature related to SG applications (e.g., per-hour pricing, instant discounts, events, etc.). The PBC may be insecure. Besides these two channels, other channels may also be established via ESI. A broadband connection to the home allows the user to remotely access its SGH devices (utilities) and the meter (via ESI), so long as the appropriate security is in place (at layers above G.9960).

For security purposes, the SGH nodes within a HAN are logically separated from non-SG HAN nodes by secure upper-layer protocols running over the ESC, both for registration of SGH devices with the utility, and for communications between SGH devices and with the utility or designated service providers. These ESC protocols sit atop the upper-layer security mechanisms, and hence allow secure SG communications between SGH nodes and utility BO systems independent of the HAN topology and the specifics of any particular customer installation. If all SGH devices are connected to the same medium, separation of all registered SGH nodes into a domain whose security settings are controlled by the utility via ESI can further enhance security (such as domain B in Figure 16).

8.1.3 Interconnection of G.9960 and narrow-band technologies

Narrow-band (NB) Smart Grid networking technologies such as G.hnem or certain wireless technologies can operate with G.9960 SGH in the same residence. NB PLC technologies operate in the frequency spectrum below 500 KHz, and do not overlap with the spectrum used by G.9960 nodes (above 2 MHz). Thus, both technologies can coexist on the same medium with insignificant impact on each other.

Interconnection between G.9960 SGH devices and narrow-band network devices is based on the generic G.9960 network architecture and performed through L3 (network layer) bridging.

The SGH gateway device in Figure 17 includes a G.9960 port towards the G.9960 domain and a narrow-band network port (PLC or wireless) towards the narrow-band network. In some applications, it is convenient that the gateway between the narrow-band technology and G.9960 is the “access point” of the narrow-band network.

A G.9960 SGH node bridged to the narrow-band network will consider it architecturally as an alien network; see Figure 17.

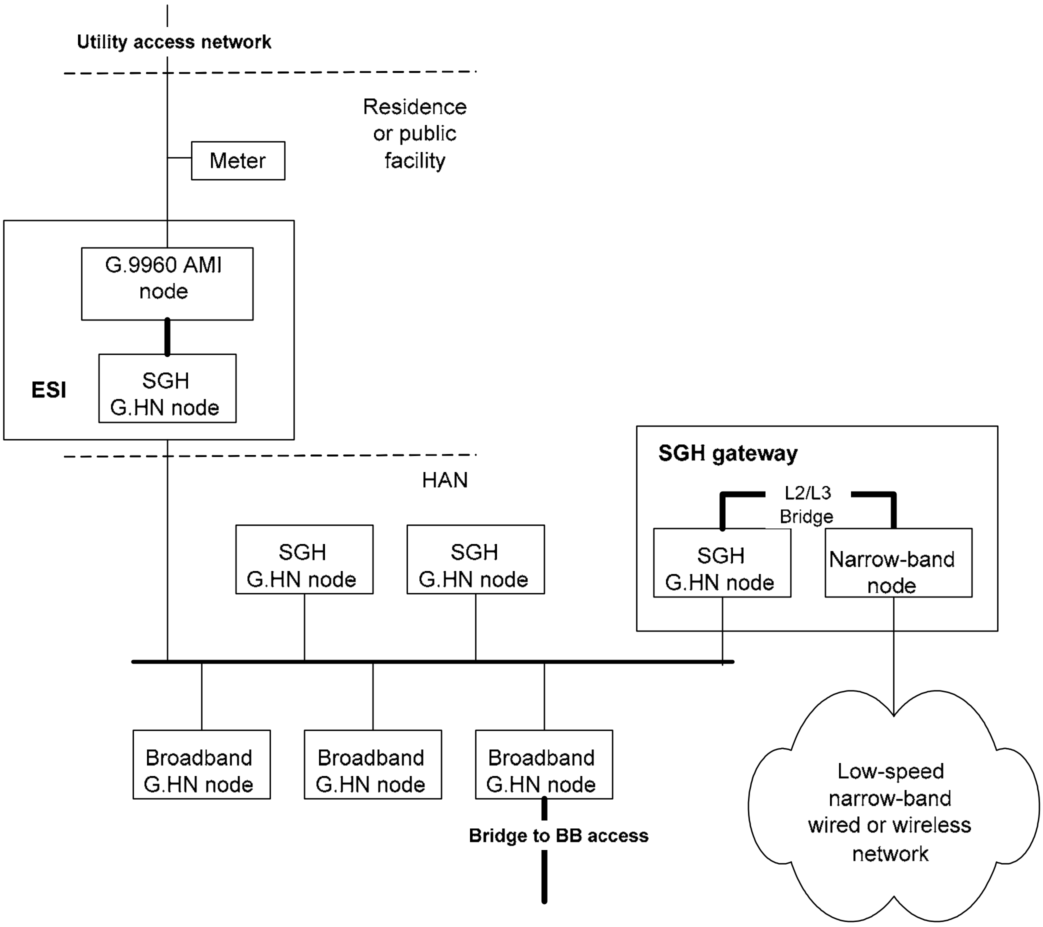


Figure 17 - Interconnection between G.9960 SGH and a SG narrow-band network, in particular G.hnem

9 Plug-in Electric Vehicles

9.1 G.9960 transceivers in PEV applications

9.1.1 Introduction

This clause describes how G.9960 nodes can be used for applications related to Plug-in Electric Vehicles (PEVs), including nodes installed into the Electric Vehicle Supply Equipment (EVSE) and nodes installed into the PEV, designated here as “EV nodes.” These nodes, both in the EVSE and attached EV(s), form an Electric Vehicle Charging Facility (EVCF).

To reduce the complexity and energy consumption of G.9960 nodes in an EVCF, these nodes are expected to use G.9960 low complexity profiles. Low complexity profile nodes are fully interoperable with other G.9960 nodes operating in the same domain. Further, the complexity of PEV devices may be reduced due to less required functionality than the low complexity profile defines. Requirements and specifications for EVs are listed in clause 9.2.

A simplified diagram of an EVCF including EVSE and an attached PEV showing primary external connections is presented in the figure below.

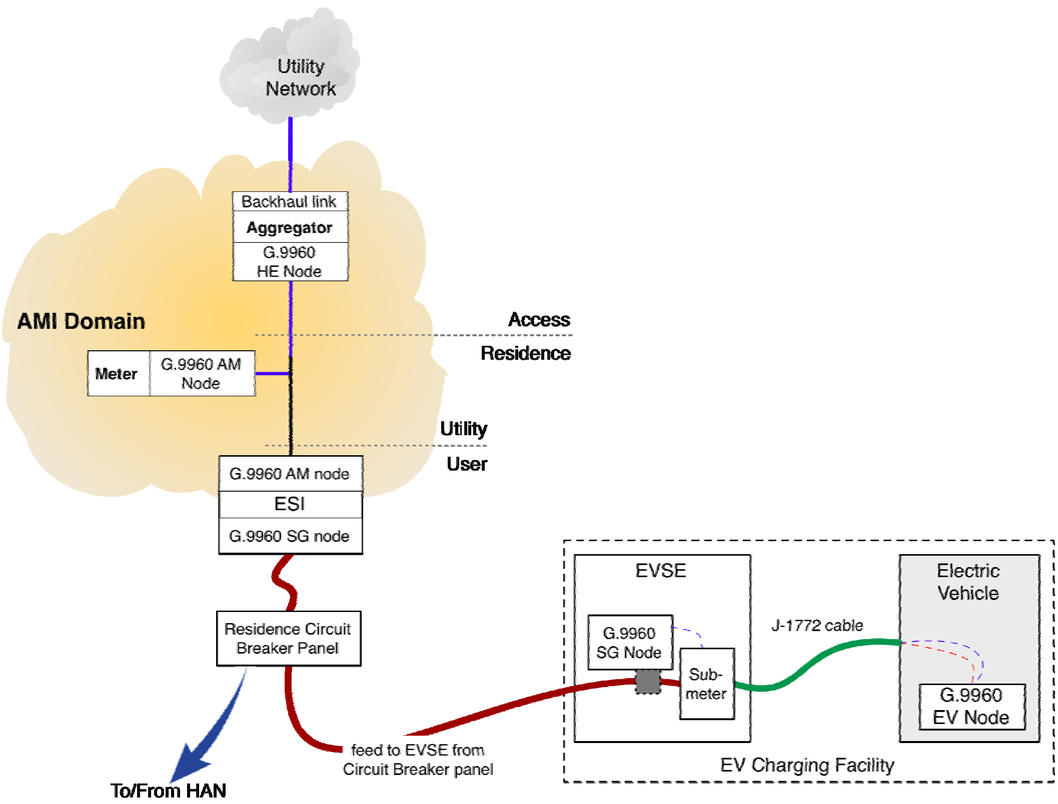


Figure 18 - EVCF with EVSE and one attached EV showing external links

9.1.2 EVSE and EV Devices

G.9960 nodes embedded into EVs and EVSEs perform the following common functions.

- Establish a link between EVSE and EV nodes in a period that does not exceed 5 seconds. NOTE - Establishing a link includes at least registration and authentication of the EVSE node, registration and authentication of the EV node by using the EVSE node as a proxy, and receiving authorization from the service provider for charging activity.
- Operate in a mode where the EVSE node operates as a proxy for the EV node of the connected PEV, i.e., all communications between the EV node and the outside world are exclusively through the EVSE node.

The data exchanged between EVSE and EV nodes can be of three types: recharging/discharging management, EV maintenance, and multimedia data. The first type may only require low throughput, while the second and third types may require relatively high data throughout (with a predominant amount downstream to the EV). Some EVs may only require the first two types of data.

The EVSE device provides the following communications:

- Between the HAN domain master (or ESI, if ESI is the domain master in the residence) and the associated HAN Security Controller (SC).
- Between HAN nodes, directly or via an IDB (if the HAN uses non-G.9960 technology). The EVSE node should coexist with the HAN if it is unable to communicate directly with the HAN.
- With the ESI of the residence, directly or via an IDB (if the ESI uses non-G.9960 technology). The EVSE node should coexist with the ESI if it is unable to communicate with the ESI directly.

- With the Utility, via the ESI, or over the HAN's broadband link (if present and allowed by the service provider), or via the AMI Network if no HAN and ESI is installed. These communications provide the EVSE with information such as billing rates, maximum amount of current flow allowed, allowed time for charging, and authorization of the specific vehicle to charge at this specific EVSE; the EVSE would provide the utility back office systems with the meter readings related to the charge.
- With the EV manufacturer and associated third parties for vehicle maintenance and management, via the HAN's broadband link.
- With an EV node of any PEV attached to the EVSE's J-1772 charging cable(s). This link is used for exchanging command, control, and management information between EV and EVSE, and may include consumer-specified data (e.g., GPS maps, multimedia content). If required, the EVSE node acts as a proxy for the EV node into the HAN and the ESI.

An example depicting a connection between an EVSE and an EV node is presented in Figure 19. The G.9960 nodes may each be connected to the control and power lines, allowing for consecutive communications links for added security and ensuring accurate pairing of EV and EVSE link. The EVSE controller detects the J-1772 connection to an EV and triggers EVSE node connection to the EV, and also triggers electricity to flow over the cable once all authorization is completed. The EV controller manages the charging of the batteries in the EV; turns the EV node on and off depending on sense lead status; and determines that the EV is going to charge through a regular power outlet. The EVSE may charge the EV using AC or DC voltage.

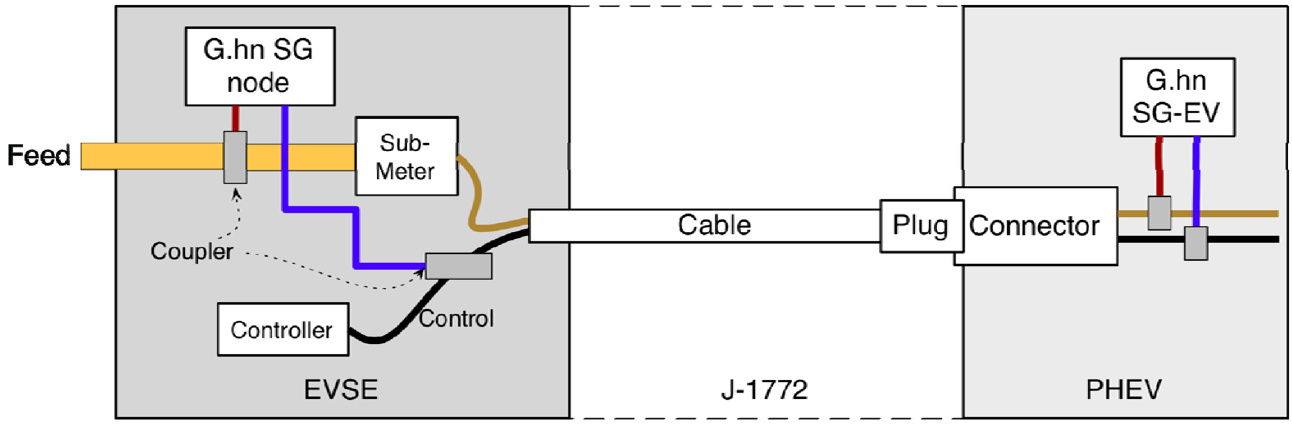


Figure 19 - Simple EVSE to EV link using a J-1772 cable

For residential garages, the EVSE will likely communicate with two vehicles simultaneously over individual J-1772 cables from the EVSE. For deployment in public parking areas, the EVSE will typically have the ability to handle up to four EVs concurrently, as the following figure illustrates. In either case, the EVSE controller, with assistance of the EVSE node, will identify which EV is associated with which meter and J-1772 cable. The G.9960 node's ability to handle communications over multiple mediums allows for this linkage of EV and cable; this capability is unique to G.9960.

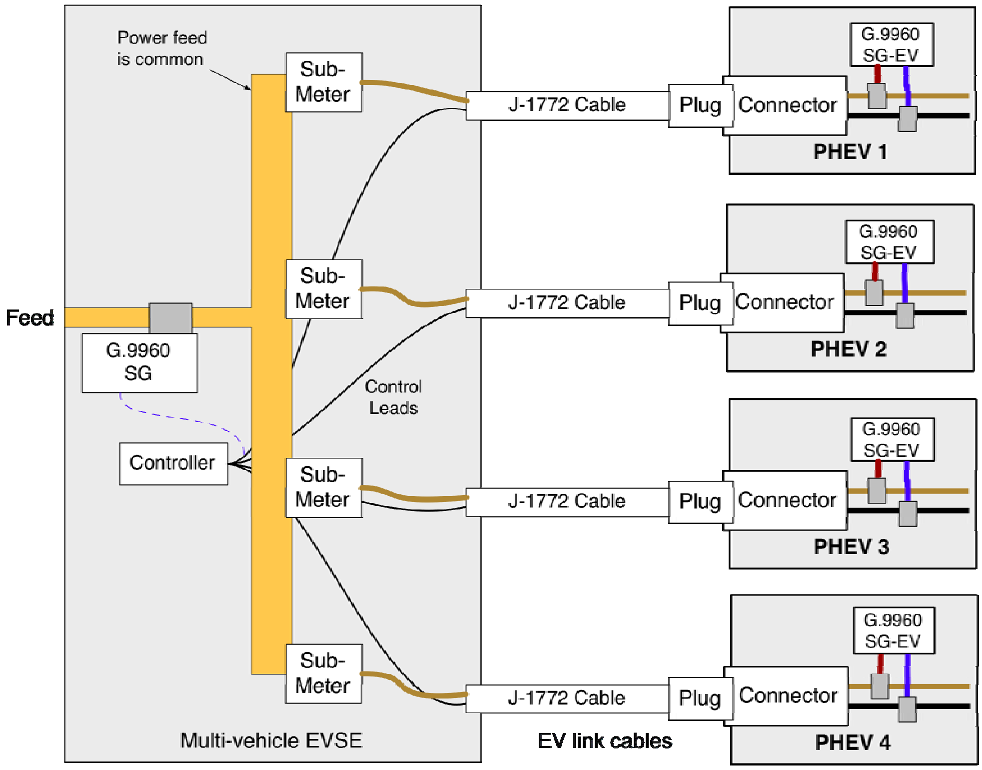


Figure 20 - EVSE attached to 4 EVs

Typically, the vehicle and EVSE need to communicate with far-end systems (e.g., utility BO systems) for charging authorization and with other services. For this, the EV may use the EVSE as a proxy. The link between the EV and corresponding EVSE in the EVCF is secure, with a point-to-point key established using standard G.9960 authentication and key management (AKM) procedure.

The EV node may have these characteristics:

- The EV nodes communicate to the HAN or to ESI through the EVSE node, which may serve as a proxy for the EV node, if required.
- The EV nodes limit their transmission power levels to prevent unnecessary EMI and unintended association between the EVs of different J-1772 cables, using the standard G.9960 power spectral density ceiling setup procedure that ensures the lowest available power levels are established and maintained between each pair of communicating nodes.
- The EV nodes are not expected to act as proxies, as relays, or as domain masters, and are not expected to maintain large topology tables.
- The EV node transmission data rate is not expected to exceed 5 Mbit/s.
- The EV node receive data rate is not expected to exceed 20 Mbit/s.

Using one or more EV nodes within a vehicle is for further study, although fully supported by the standard G.9960 architecture. In the example presented in the figure below, the EV nodes may be standard low complexity G.9960 SG nodes and able to communicate with one another.

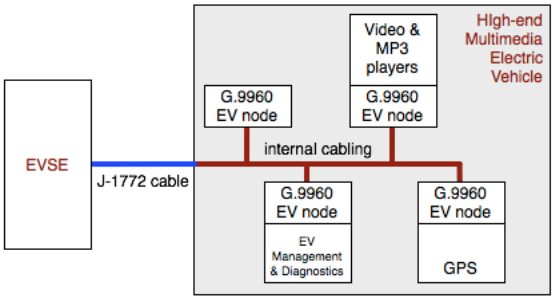


Figure 21 - Example of multiple nodes within an EV

A typical distance between EV node and EVSE node is 10 metres, although this distance could be longer in a public parking area or in a multi-car garage.

9.1.3 Connection to the Home Network

EVSE nodes are connected to the HAN and the ESI based on the standard G.9960 network architecture. As shown in the figure below, the usual application uses power line as a communication medium, although any in-home wired medium is possible with G.9960.

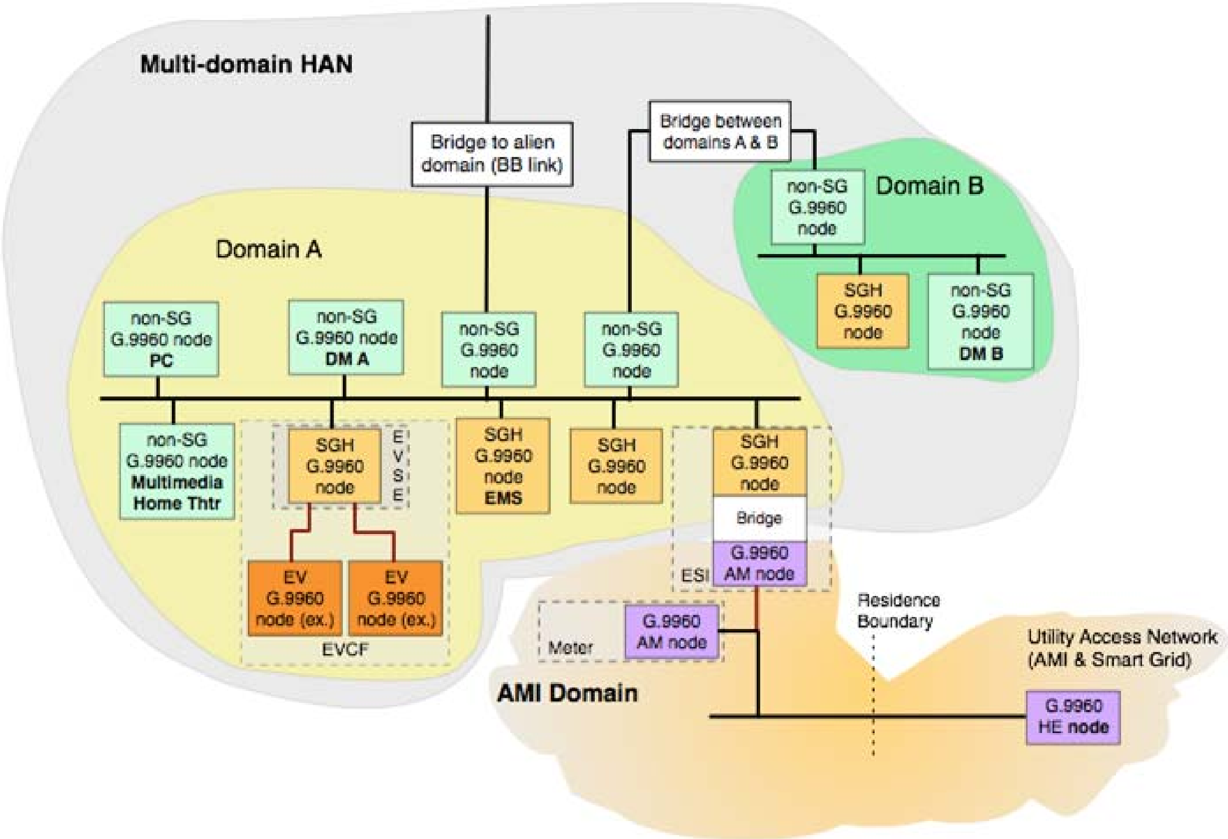


Figure 22 - Illustration of Smart Grid HAN with EVCF implementation based on G.9960

The EVSE contains an SGH node that may interface with the HAN (directly, or via an IDB if the HAN is a non-G.9960 network) and with the utility network via the ESI or via a broadband service through a HAN broadband gateway.

9.1.4 Authorization of an EV

The EV node, upon being notified of the active J-1772 link, seeks to establish connection to the nearest domain master or proxy node, possibly the EVSE. After establishing communication with the EVSE node, the EV node uses the normal G.9960 registration and authentication procedures through the EVSE node as a proxy. Remote authorization is supported by G.9960 through a trusted channel with the service provider established from EVSE via the ESI and UAN. Through this trusted channel service provider validates the EV's identity credentials, and authorizes its access in the EVCF, and authorizes the EVSE to charge the EV at a given charge rate, for how long, and at what time. The service provider authorization protocol is outside the scope of G.9960.

9.1.5 Charging an EV without an EVSE

In the event the EV is to be charged and no EVSE is available, the EV may have an option to be plugged into a standard mains outlet using a cable other than a J-1772 cable; this option is for further study. However, using standard G.9960 network architecture, the ability of the HAN and/or ESI to establish connectivity to the EV is possible, and through the HAN or ESI the utility and third parties can communicate with the EV for management of charging and other necessary functions.

9.2 EV specifications

The following specifications have been listed as either requirements or important criteria for the EV application.

Table 2 - EV and EVSE Specifications

No.	Title	Description	Note
1	Extended temperature range	-40 to +105° C	For EV & EVSE
2	Low transmission capabilities	5 Mbit/s maximum under noise conditions	EV implementation dependent
3	Higher receive capabilities	20 Mbit/s	EV implementation dependent
4	EV node will not be a relay node		G.9960 function, needs further study in EVs with multiple EV nodes
5	EV node will not be a proxy node		G.9960 function, needs further study in EVs with multiple EV nodes
6	Very limited network topology maintenance needed		G.9960 function, may be implementation specific
7	No Domain Master Capability		G.9960 function, may be required on EVSE
9	Option to only communicate directly to EVSE node or some other proxy	EV node is a point to point node, however can handle more than one concurrent session with EVSE, limit on number of sessions for further study	This is open for further discussion
10	Minimal number of FEC rates	1/2	
11	Reduced processing requirements, optimized for EV functions		More delay comparing to general G.9960, less options
12	QoS requirement: support a number of traffic classes (priorities)	At least 2	For further study, however more than best effort
13	Optimized distance requirement	10 m to 50 m	25 m may be acceptable
15	Extended sleep mode support		EV node only active when J-1772 cable connected, EVSE node only active when EVs attached to J-1772 cable(s) or EVSE is powered on, otherwise in extended sleep mode or off
17	Lower transmit power level		Just to achieve required low error rate for required distance, regardless of noisy powerline environment
18	Managed power level at start		Start at estimated low power level to reduce crosstalk
19	Limited number of bits per carrier	2	

Table 2 - EV and EVSE Specifications

No.	Title	Description	Note
20	Limited EVM	G.9960 Low-profile specification	
22	Signal crossing open relay contacts and how to prevent concurrent EV links form being confused at the EVSE node.		Test (somehow) the ability of G.9960 spectrum to cross open relay contacts and what attenuation this adds, and could this be how vehicles are identified as the command to close the relay could be staggered so that only one vehicle out of several simultaneously attached would have a good link to the EVSE and as the relay identity would be known and associated with a specific J-1772 cable, this would enable the EVSE controller to know what EV was on what J-1772 cable and what meter

10 Summary

The G.9960-family Recommendations includes G.9960, G.9961, G.9970, and G.9972. G.hnem is considered a part of this family; its technology definition and abilities will be included in future revisions of this document to address AMI, AMR, PEV, and other SG applications.