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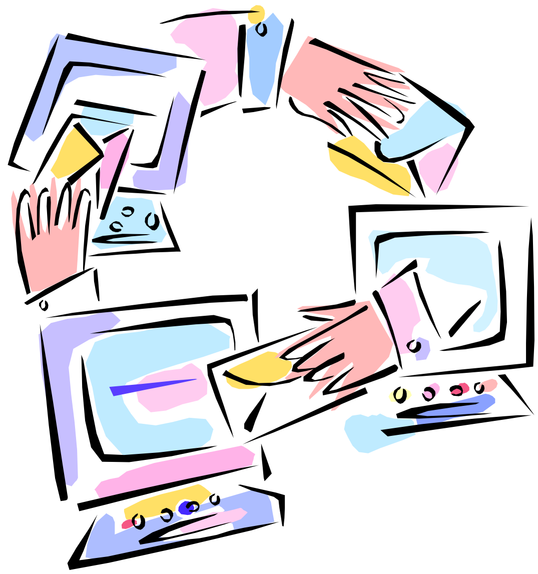


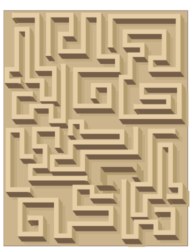
Reminiscence of tinkering with home networks

Amitava Dutta-Roy, Editor

To the best of my knowledge, X-10, a company based in Scotland developed the first commercially available “home control” network utilizing power lines. This was before the local area networks became the staples at offices and much before the Internet left the drawing boards of its developers. Distribution of audio, video signals and data in the home could be seen only in science fiction movies. The X-10 technology simply enabled the user remotely control lights and other basic home appliances — e.g. switch on and off lights and dim them, or switch on a fan — by pressing buttons on a small central console. Every remotely controllable light (incandescent only) was connected to the power line through a device that had a two-digit ID, e.g., A2, B4 and C9 etc. A couch potato had only to press the ID of the desired light and on/off/dim buttons to control it. Even with its limited capabilities the technology was a big deal those days; you could impress your visitors. Since (circa) 1978 these gizmos, the central console and the remote plug-in modules had been available at affordable prices from Radio Shack stores and some thirty six years ago I acquired a set of them. It worked and my friends were awed. I even tried to control neighbors’ lights but I succeeded only if the neighbor’s apartment was on the same phase of the power supply as that of ours. Stands to reason!

There was no standard for the proprietary technology patented by X-10. The manufacturers would not divulge what techniques they used to transmit the control signals; the company would not give out any of their secrets at all. We could have reverse engineered the devices but that needed a great deal of work and time. As a result, my friends and I did not go very far with our tinkering.

Many years later, in late 1999 to be more precise, I was commissioned by the IEEE Spectrum magazine to write a feature article on home networking (“Networks for homes,” IEEE Spectrum, December 1999, Vol. 36. No. 12). My search for manufacturers of home networking and similar equipment revealed that by that time X-10 had developed another product which extended their “home control” technology to the control of power supply by the utilities. The company also had moved its headquarters to Hong Kong. The new product was used to remotely control a two-tier — during peak and off-peak hours — system of supplying power to consumers. The off-peak power would be sold at a cheaper rate. The control signals from the utility’s substation traveled down the power lines to actuate two-way switching mechanisms installed near the customers’ premises. Those who opted for the program for cheaper power could not use many heavy appliances (e.g., washing machines and vacuum cleaners) during the peak hours. The processes of metering and reading the power were also simple, sort of a coffee-can approach but it worked. It was a simple solution. As it was expected, these customers of the two-tiered power generally belonged to lower-income groups. The affluent did not really care. If they wanted to start their washing machines they wanted the power “then and there.” This time around a little more of the X-10 technology was divulged to me. For example, the ones and zeros of the commands were sent in the form of 120-kHZ bursts within 1-ms envelopes. The transmissions of the signals were synchronized by sending them as close as possible — within 200µsec — of the zero crossing points of the 60Hz (or 50Hz) power line frequency. Since the data packets were short, communication between X-10 devices could achieve a high degree of reliability.



Companhia Energetica de Estado de Minas Gerais, Cemig for short, the state utility company in the state of Minas Gerais in Brazil successfully utilized this technology to lessen the effect of power scarcity. Mind you, all this happened before the concept of smart grid entered as an important factor in the planning rooms of the electric utility companies! This just goes to show how one technology developed for a specific purpose finds new applications.

Fast forward to home networking of today! Since writing my article in 1999 the concept of home networks has evolved in a manner that could not even be dreamed of some years ago. Now those who really need and can afford the latest technologies in homes would like far more amenities beyond controlling lights. They would like to access the Internet, cable TV, audio and video programs stored on servers in their homes, and make and receive phone calls without running from bedroom to the kitchen or from the TV den to the basement. The arrangement may not be good for one's physical health but there we are, keeping up with networking technologies. Owners of homes may also need closed circuit television for reasons of security and remotely watch their residences while they away. (Observe that now these security features are of a necessity especially in affluent suburban neighborhoods.) For whatever reason, the owners also may want to open a garage door from a remote location or switch on their ovens from their cars on their way back from office.

Twenty first-century technologies can offer all of the above. The present home networks are based on several types of media, the ubiquitous power lines, Ethernet cables that conform to, in the networking jargon, CAT5 and CAT6 ("CAT" meaning "category" explained in the sidebar), coaxial cable (of the cable TV variety) and also on Wi-Fi. Each of them uses a technology different from those of the others. There are advantages and disadvantages each.   For power line networking, the sources (modem, router, DVD player and VCR etc.) are connected to the power line. Thus, wherever power is available users can plug a module into the nearest outlet and access the sources. For networking with Ethernet and coaxial cables, the sources and destinations must be physically connected at either end. The wireless access, of course, does not need any physical connection at all though the reception will be poor or none at all if either the source and the destination (you!) happen to be in a blind spot. The electromagnetic waves obey the laws of physics and sometimes in case of broken links it is not even possible to identify the problem. The entire network gets finicky.

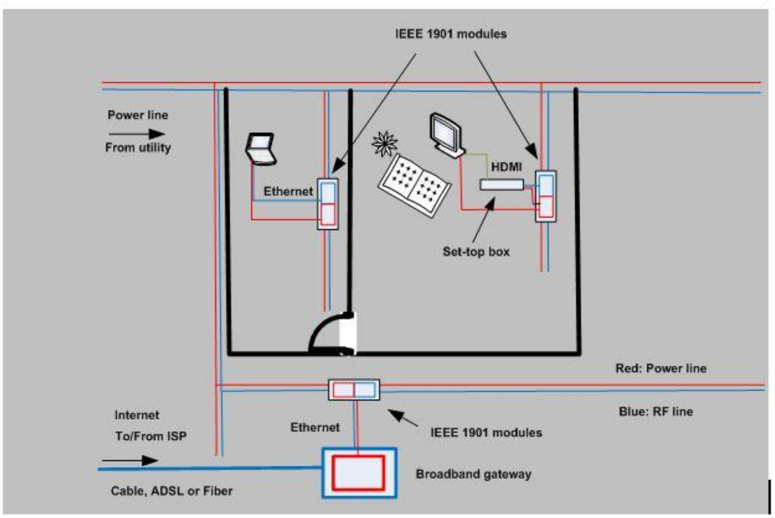
The specifications of CAT 5 and CAT 6 cables are both defined by the U.S. standard bodies. Both CAT 5 (and 5e) and CAT 6 type cable are composed of four twisted pairs of copper wires that end in Ethernet (RJ-45) connectors. The CAT 5 cable can transfer data at a rate of 10Gbps whereas the CAT 6 cable that must comply with more rigid specifications is capable of carrying data at 100GB/s.

Out of all these options, I guess, the least disseminated technologies are those that use the power line and the coaxial cable.

Data over power lines in homes

In plugged-in homes the power lines carry radio frequency signals at 2 to 10MHz corresponding to digital bit speeds of 4 to 10Mbps. It is envisaged that eventually such home networks will enable metering and optimization (with audible or visible alerts to the home owner). Some of the leading automobile manufacturers such as BMW and Audi of Germany are also interested in further development of power line home networks, since the batteries of electric vehicles will be usually charged at home and this charging process may be controlled through the network either locally or remotely. The utilities are keen on this technology because networked homes may be better served by smart grids. The plug-in modules comply with the IEEE 1901 standards. The work on the standardization of device specifications have been the responsibility of a trade group called HomePlug Alliance. Many firms — big and small — in the networking industry (chip manufacturers, system integrators and service providers etc.) are involved in this alliance. For more details please see https://www.homeplug.org.

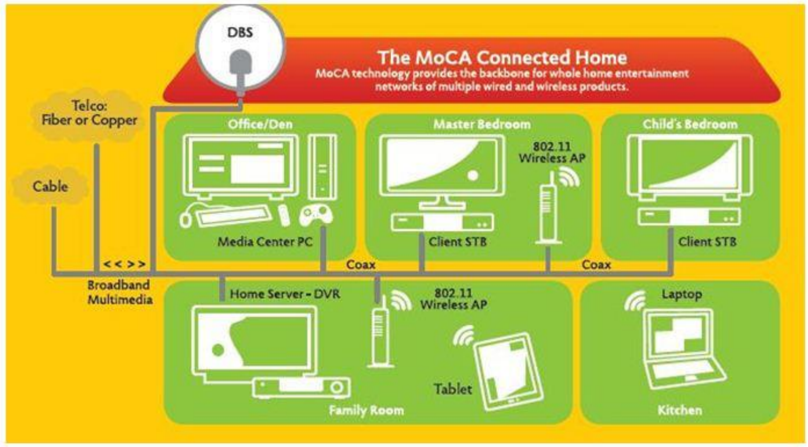
> In some countries power lines are also being used for connecting Internet service providers with homes. Though the technology is now approved by the U.S. Federal Communications Commission it has not made much headway in America. Much of the hurdles are caused by in-line power transformers. The technology is promising, since almost all homes in this country have power lines that supply the energy.



A general scheme of broadband network over power lines

Data over coaxial cables

It seems to me that the other technology not disseminated well in this area is the one that uses coaxial cables as media for carrying data. Most home users of the Internet know that there is a warfare going on between the telcos and the cable TV distributors. The latter are trying to attract more customers by offering triple-play (TV, telephone and access to the Internet) at a heavily discounted rates (remember that these rates are valid for one year only!). But after the cable brings into the Internet to the home then what? Many connect the output of the modem to a router that can feed several PCs and WiFi clients in that home. There is another way of distributing the multimedia Internet signals to some strategic points in the home.



This illustration taken from the MoCA brochure shows how data (data, audio and video can be distributed inside a home

That can be achieved by using coaxial cables (see the illustration, copyrighted by MoCA). Sure, it is necessary that install cables in a home unless it is already wired. Installation of coaxial cables is not all that difficult, especially in new homes under construction though much attention is required at the bends. While twisted pairs of Ethernet (10BASE-T or 100BASE-T) need one-to-one connection between a source and its destination, the signals traveling on the coaxial cables (just "coax" in the networking jargon) can be tapped from RF splitters. To accelerate the development of products and standards for home networking an alliance of chip makers, system integrators and service providers was formed and it is known as Multimedia over Coax Alliance (MoCA). The standardization of MoCA products is the responsibility of Society of Cable Telecommunications Engineers (SCTE), a non-profit body that works, like the IEEE, with the American National Standards Institute (ANSI). Mind you, the MoCA technology has nothing to do with the Data over Cable Systems Interface Specifications (DOCSIS) developed by another though allied trade consortium, the CableLabs that are geared to data transfer over cable TV lines from the Internet service providers to the homes. As the accompanying illustration shows the broadband connection to the outside world can be brought into a home by either telcos or cable TV providers. The coax home network is agnostic in this respect. The MoCA 1.1 equipment can deliver data at 175Mbps inside homes. The second generation of MoCA will raise the throughput to 400 or even up to a blazing 800Mbps.

The data over cable technology for inside of homes needs some advance planning before its deployment. Is the existing cable infrastructure adequate or do the user's perceived demands require that some new cables are installed? What are the costs? How many rooms need to be hooked to a computer, a wireless router, TV set-top boxes, analog TVs (yes, they still exist!) or high definition multimedia interface (HDMI – see the illustrations in the power-line technology section above) for watching videos streamed over the Internet? Many mix-and-match and interoperable products are available at affordable prices in the retail market to cater to the taste of an average home owner. The entire projects depend only on financial resources of the owners. More about MoCA is available at http://www.mocalliance.org/.

Wireless

Perhaps, the most known data communications technology after the Ethernet (invented at Xerox PARC in 1973 by Dr. Robert Metcalfe, born in New York city, Fellow and recipient of a medal of honor of the IEEE), the harbinger of networking, is the WiFi, since it is easy to install, easy to operate and many public spaces such as public libraries and airports offer free service to anybody with a laptop or tablet computer. The WiFi technology is standardized by (you guessed it right!) the IEEE. It keeps our standards department buzzing. WiFi stands for wireless fidelity and operates in either 2.4 or 5MHz band. These two are also known as the ISM (short for Industrial, Scientific and Medical) bands. Machines, laboratory apparatus or home appliances that use these bands do not need any license for their operation. This is true not only for the U.S.A. but it is true all over the world. Your laptop will work in other countries too. The latest incarnation of the WiFi protocol for networking is 802.11n that can deliver 54Mbps.

Unification of home networking technologies

A typical home owner is usually not an expert on networking technology. He or she may want to invest in “something” that is affordable, standard-compliant and thus interoperable, and robust. MoCA spearheaded the efforts to unify the home networking standards that would give incentives to equipment manufacturers to come up with an ideal solution. The next generation of home networks hopefully will unify the existing technologies so that there will always be a redundant network available. If the Wi-Fi fails, the cable will take up the slack. If the cables do not cooperate the power line will come to the rescue. Thus, a home owner whose work and leisure are woven around an “all connected” network will never be inconvenienced.

In this game of networking a crucial element is the central chip that will control operations of a device. Irvine, Calif.-based Broadcom Corporation has been a mega networking chip maker. We invited Dr. Stephen Palm, senior technical director and an IEEE member to write an article explaining the progress of the next generation of the technology that will unify all home networking technologies. His article is next in this issue. Keep reading!

Promenade on the Hudson, New York city [Photo: Amitava Dutta-Roy]

Designing the Next-Generation of Home Networks (Invited paper)

Stephen Palm*

The concept of sharing digital content throughout a home – be it a TV program, photos, Internet video, or music – continues to evolve. Faster broadband speeds and digital access technology gives consumers more choices in the selection of content along with the ability to download multimedia faster and on multiple screens. The ever-increasing variety of digital devices and data formats has made seamless connectivity between devices an essential facet of a "connected" home. The goal of home networking technology is to let the consumers access any content from any device in any room without having to know whether the content they are watching is being streamed from a hard drive on a PC upstairs, coming over the Internet, playing back from a handset, or pulled from a set-top box digital video recorder (DVR).

Home connectivity is entering its second generation and is evolving so as to provide the quality of service and transparent accessibility that both service providers and consumers desire. The underlying technology is ready. However, new deployments will need to support every type of digital device without the need for complex configuration or connection mechanisms. They will also have to support existing services as well as new services such as multi-room DVR capabilities. In addition, any next-generation home network technology must support ubiquitous connectivity throughout the home. Moreover, the manufacturers of devices must ensure that their devices interoperate with the accepted standards for ubiquitous connectivity. The home network infrastructure needs to be able to transport data quickly and reliably to ensure the delivery of multiple streams of high quality content, ushering in the fully interoperable home networking evolution.

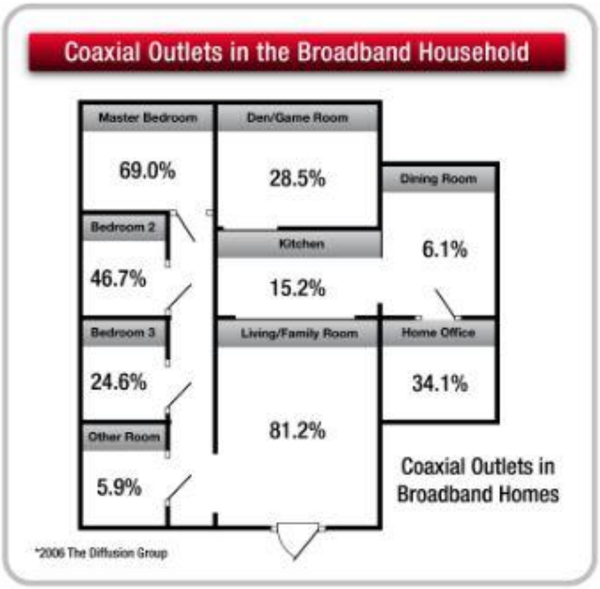
Ubiquitous Coverage with No New Wires

Most consumers already have a number of networks installed in their homes. For example, a satellite or cable link feeds one or more set-top boxes over coax, a PC connects to other PCs using power line communications (PLC), and Wi-Fi is used to distribute a shared Internet access connection among several laptops and handsets. While Ethernet networks provide very reliable connectivity, installation of CAT5 wiring — that connects two Ethernet end points — is expensive, so some users try to reuse existing “wiring” such as coax or power line or air:

Media	Protocols
CAT5/6	Ethernet
Coaxial cable	MoCA
Power line	HomePlug
Air	Wi-Fi

However, no single connectivity technology has 100 percent coverage in every room and in every region (e.g., basement and upper floors) of a home. Even as of recently, only 11 percent of homes had CAT5 wiring installed in them and most of that was not properly terminated for Ethernet. In some regions, coaxial outlets are installed in a variety of rooms, but perhaps not in all of them (see Figure 1). While nearly every room in a home has at least one power outlet, a part of a home may be on another phase of the power supply from the utility or be susceptible to interference. This reduces the performance and the effective throughput of PLC. Even wireless coverage is not guaranteed, as accessibility is dependent upon home layout, construction, and materials density.

For Engineers



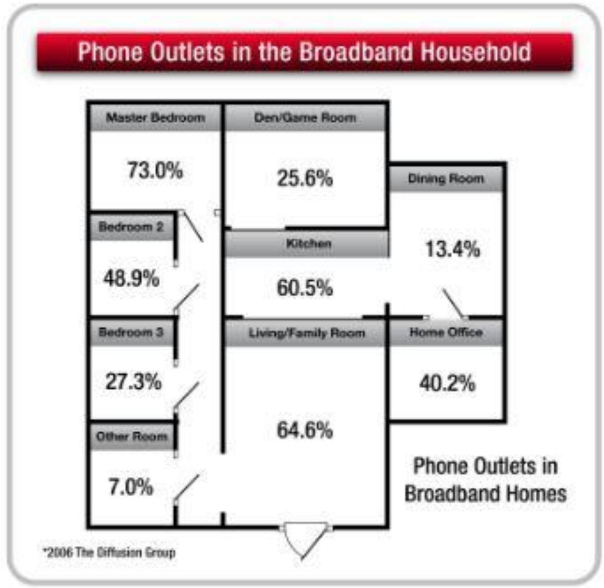


Fig. 1: No single connectivity technology has 100 percent coverage in every region in every home. For example, coax and telephone outlets are typically installed in a variety of rooms, but not universally

The next-generation of home networks will provide full coverage by building upon and combining the existing infrastructure available throughout a home – Ethernet, coax, power line, and wireless resources – and bridging them seamlessly. For example, while any one of these technologies may not provide whole-home coverage, a hybrid network comprising of multiple communications technologies dramatically improves the situation. Each room in a home can be serviced by at least one of these technologies and, in many cases, several of them.

The use of multiple technologies to create a hybrid network also provides redundant coverage in principal rooms of a home. Consider a couple watching a show streaming off the Internet. In this scenario, the data carrying the program would initially flow to the bedroom TV via a power line, coax, or wireless connection. At some point of time, that particular connection may get congested when some other occupants of the home decide to watch another program. Interference may also significantly reduce the throughput. In such cases, the "conduit" for the streaming can be shifted to another connection so that the reliability of the connection, as well as the quality of the content, are maintained regardless of the changing nature of the operating conditions within that home.

Since each connectivity technology addresses a different media and a different set of protocols, they have what, in networking jargon, are known as "orthogonal impairment mechanisms". For example, a noise source that causes interference over the power lines is likely to have little impact on wireless throughput. Thus, the probability that all connections into a room will fail at the same time is lower than just using a single connectivity technology.

The use of multiple connectivity technologies may also increase the quality of content that are capable of being delivered throughout a home. Load-sharing techniques can be used to distribute the contents over multiple channels. Instead of having one channel remain inactive while another channel operates at high capacity with a greater probability of congestion, two or more channels can share the data load. Each of them then would carry lower loads that would result in better reliability and lower latency (see Figure 2).

Fig. 2: The use of multiple connectivity technologies provides redundant coverage in key rooms in the home so that the quality of content can be maintained regardless of changing operating conditions. The numbers in magenta in the left half of the figure signify the data throughputs in different rooms if only one technology per room is used; the yellow figures indicate the throughputs only with a different technology. The green numbers on the right side of the figure show the effective throughput when both technologies are used simultaneously. The red ball is the location in the home where broadband entry point is located. All measurements are in Mbps

Another advantage of the next-generation home network is universal connectivity. Because of the reuse of existing infrastructure, devices that consumers own and operate today will be able to connect to a hybrid home network as well. Bridging capabilities built inside the network will support seamless data transport between the different connectivity technologies and, as a consequence, consumers will be able to access content from any device without having to know about its source, or where or how the content is actually stored. Furthermore, individual storage devices or a network attached storage (NAS), where the diverse contents may reside, need not know whether they are being streamed to a PC, TV, or a handset.

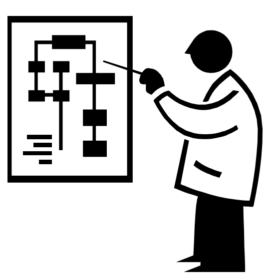
By leveraging the existing infrastructure and connectivity technologies deployed in homes, the next-generation home network will be able to provide complete coverage within a residence with redundant capacity and without the need for the installation of new wires. This is particularly important to both service providers, who want to be able to deliver new services throughout the home without expensive truck rolls, and consumers, who want connectivity without complexity and at the lowest price with no hassle.

Unifying the Home Network

Many service providers and equipment manufacturers understand the need for a hybrid network that seamlessly connects all types of devices in a home. The difficulty posed by first-generation home networks has been that, in the absence of a unifying standard that would allow transparent use of multiple networks, each device on the network must be configured, managed, and operated independently.

The new standard P1905.1 that is currently being developed by an IEEE Working Group provides the underlying mechanisms for unifying the diverse connectivity technologies that make up the home network. The P1905.1 standard defines a common data and control Service Access Point for hybrid networks based on Wi-Fi, HomePlug, MoCA, and Ethernet. Data can be exchanged over any interface, regardless of protocol and media in use.

The P1905.1 brings seamless bridging to the home network by introducing a software layer between layers 2 and 3 that abstracts the particular operational details of each interface in use (see Figure 3) and aggregates data across different interfaces. This layer also makes it possible to provide a feature for high-level management of the network. For example, users no longer need enter a different password for every media to which a device may connect; only a simple press on a button is needed. P1905.1 also specifies harmonized quality of service (QoS) mechanisms, handles device discovery and configuration, and establishes secure connections, among other advanced network management features.



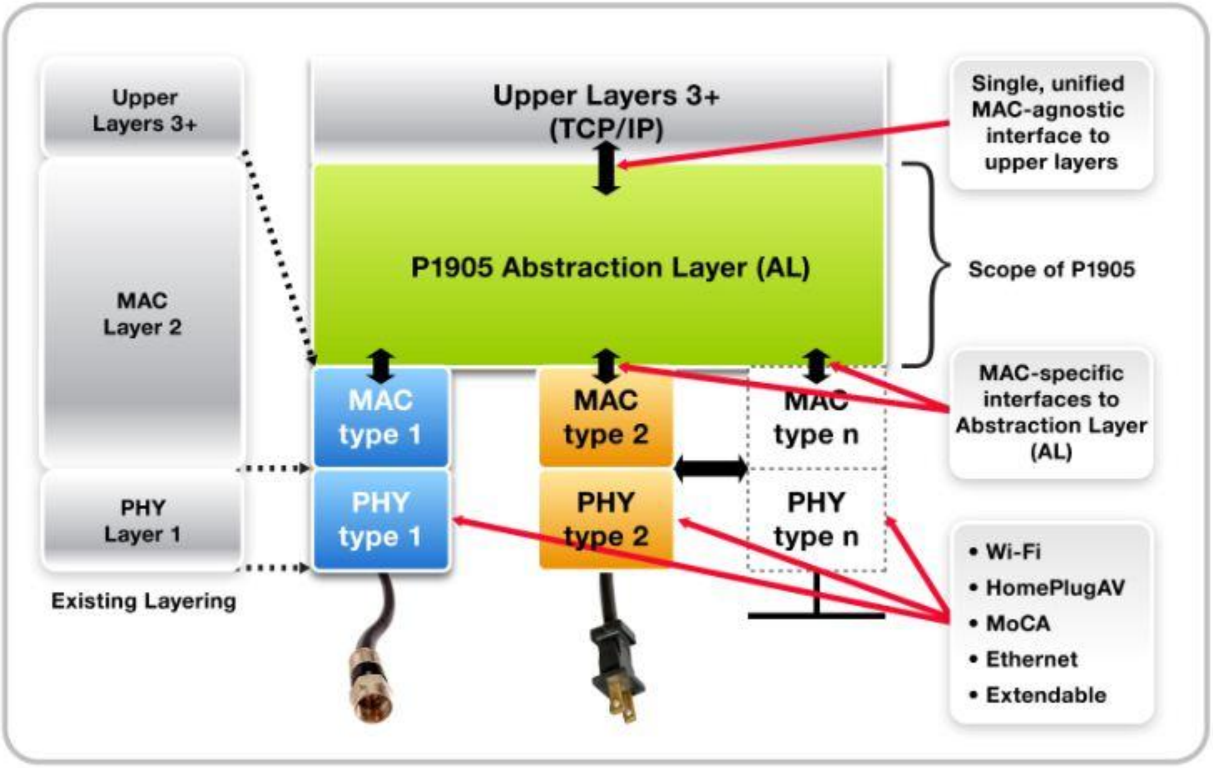


Fig.3: P1905.1 brings seamless bridging to the home network by introducing a software layer between layers 2 and 3 that abstracts the particular operating details of each interface in use. P1905.1 thus provides quality of service (QoS), device configuration, secure connections, among other advanced network management features

The standard enables the next-generation of home networks to provide many key functions and benefits. At this time, no other single technology is available for uniting the vast array of wired and wireless technologies, media, platforms, and devices. The P1905 features can be summarized as:

Ease of Use: As a consumer-oriented technology, it is critical that the procedures for setting up a home network be transparent to users. P1905.1 specifies common setup procedures for adding devices to the network, establishing secure links, implementing QoS, and intelligently managing network resources.

Reliable Service: Common network issues such as congestion or the temporary loss of connection can result in degradation of quality. By implementing path selection mechanisms (see Figure 4), devices can use alternative routes to lessen interruption of service, thereby ensuring a positive user experience and reducing the number of support calls service providers must manage.

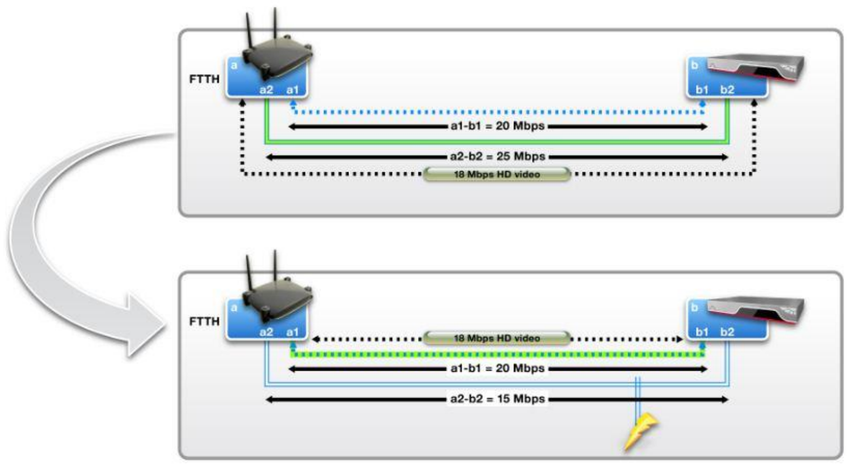


Fig. 4: P1905.1 maintains content quality and reliable service through the use of path selection to resolve common network issues such as congestion and interference.

Greater Network Capacity: Hybrid networks provide maximum throughput through the ability to aggregate bandwidth across all of their different interfaces.

Multiple Simultaneous Streams: With applications such as interactive TV where even a single user may watch multiple streams simultaneously, next-generation networks must have the capacity to handle several HD streams at the same time.

Congestion Management: P1905.1 enables features such as load sharing and QoS to limit network congestion to maintain network reliability and content quality.

Complete Interoperability: Next-generation home networks must support any existing infrastructure the service providers have already installed. P1905.1 is the only specification that supports full backward-interoperability with HomePlug, Wi-Fi, Ethernet, and MoCA.

Transparent Security: Service providers and content owners want robust security mechanisms for protecting their content. However, to avoid costly truck rolls and/or support calls, these mechanisms must be simple enough for consumers to perform. P1905.1 devices may be configured with a single button-press to avoid the complexity of password entry (see Figure 5). P1905.1 also enables consistent password and authentication procedures to support legacy devices.

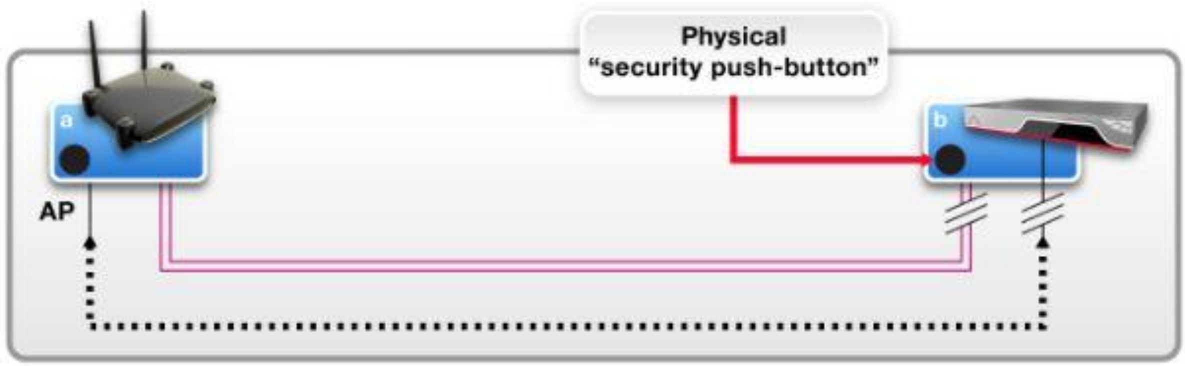


Fig. 5: P1905.1-compatible devices are configured with a single button-press to avoid the complexity of password entry. P1905.1 also enables consistent password and authentication procedures to support legacy devices.

Higher Reliability through Advanced Monitoring and Diagnostics: P1905.1-based networks are able to provide uniform diagnostics. In addition, service providers are able to remotely monitor networks and preemptively address potential impairments before they impact the user experience.

Self-Install: Avoiding service and installation calls is critical to controlling network deployment and operational costs. The next-generation home network must support simple installation, discovery, and self-configuration. For example, when a user connects a second P1905.1 Wi-Fi Access Point to the network, regardless of which interface is used, the primary access point will automatically configure the second access point with the network name and password.

Freedom through Mobility: Support for wireless devices is essential so that users can connect their smart phones, handsets, laptops, and tablets.

Universal Connectivity: For complete transparency, users need to be able to connect to the next-generation network from every room in a house without having to be aware of the interface they are communicating with. Furthermore, link handoff must be seamless when moving from one room (and the interface) to another.

Power Efficiency: P1905.1 supports more efficient and greener operation through power management capabilities that balance energy consumption with connection reliability and responsiveness. For example, routing can take into account the most power-friendly path through the network by considering which nodes are already awake and active.

In the past, attempts were made to connect devices within a home using a single connectivity technology. It was found in practice that none of the available standards for individual technologies provided reliable, whole-home coverage nor easily interfaced with every type of consumer device. To reach a higher level of ubiquitous connectivity, a hybrid network topology is recommended. The P1905.1 has been designed not to solve hypothetical problems but to provide a working technology for the real home networking issues that must be addressed so that service providers can deploy hybrid networks with confidence. By seamlessly bridging the existing connectivity technologies deployed today, the P1905.1 provides the final piece required for building a truly robust home network.

The work of the IEEE P1905.1 committee is on schedule to complete the draft standard by the end of 2011. Version 1.0 of the draft will provide the foundation of the next-generation home network and will serve as a platform for introducing advanced features and capabilities in the future. P1905.1 has broad industry support and companies like Broadcom are at the heart of delivering the key technologies and standards that will enable consumers to enjoy video, apps, photos, and any other content they desire in the room of and on the screen of their own choosing. For example, Broadcom's Xtendnet™ technology is an intelligent, decision-making software architecture that enables a hybrid homeplug-coax-Wi-Fi network to dynamically switch streams between the different media.

For service providers, the P1905 represents an opportunity to enhance profitability through new premium services that would attract new customers and the ability to deliver quality content in a reliable manner. For consumers, the P1905 will serve as the bridge between the wired and wireless technologies to connect homes and lead to a connected lifestyle.

For more information on the P1905.1, visit http://grouper.ieee.org/groups/1905/1/.

*Stephen Palm, member of the IEEE is Senior Technical Director at Broadcom Corporation. He is responsible for driving Broadcom's home networking strategy to enable multimedia and smart energy services for distribution via residential wired and wireless networks. Dr. Palm received his B.S. degree from University of California, Irvine, M.S. from Carnegie Mellon University and Ph.D. from the University of Tokyo.

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