

CABLEHOME™: A HOME NETWORK ARCHITECTURE

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Abstract

Home networking is emerging as a highly competitive key strategic market for cable operators. CableHome is a CableLabs initiative focused on enabling cable operators to differentiate by guaranteeing convenient operation of the home network in concert with the delivery of quality services. Creating a supporting infrastructure requires the accommodation of a diversity of networking technologies and protocols, insulation from and integration with non-compliant devices, and a non-restrictive design environment. The CableHome architecture addresses these concerns by facilitating the separation of compliant and non-compliant networks via technology independent logical network elements. These logical elements are correlated with physical devices, non-restrictively, to provide a concrete reference frame. Supplying robust network management and quality of service capabilities in the home is key and these concerns are specifically explored.

INTRODUCTION

Over the next five years, home networking equipment and services have the potential to emerge as perhaps the most strategic market of interest for cable operators since this segment may control how cable operators and consumers can manage the delivery of Internet-based services in the home. Success for cable operators in this market will require a cooperative environment between content producers, service providers, and device manufacturers so that consumers can obtain one-stop shopping and customer care solutions. Indeed, consumers will strongly equate convenience with consumption. In this view, whoever can assemble a home networking system that is easy to deploy and utilize will likely win a large share of this emerging market.

It follows that the cable industry would benefit by offering consumers the following proposition: *If you choose to use home networking equipment approved by your cable operator, the operator will guarantee it will work seamlessly with your broadband cable services delivered over cable.*

Through the CableHome project, the cable industry will establish the technical infrastructure for home networking equipment that will allow individual cable operators to fulfill this promise since today's off-the-shelf products fall short. In particular, with CableHome products consumers will have a guarantee that service quality for their IP telephony, streaming media, or other packet-based services would be maintained over their compliant home networks, and that cable operators would assist them in diagnosing and formulating a response if they encounter problems.

To execute this strategy requires the industry to specify how home networking equipment will interact with the cable operator's "IP cloud". This requires creating specifications that define the minimum set of industry requirements for network management, quality of service, service provisioning, and security functions. Other benefits to cable operators from these specifications should be: 1) lower installation costs by simplifying the home networking installation process; 2) lower equipment costs to consumers through the multiple suppliers enabled by CableHome's open specifications; and 3) lower operating costs by providing cable operators with tools that facilitate remote troubleshooting of consumer problems.

This general set of capabilities allow CableLabs' member companies significant flexibility to develop their own path of

businesses designed to generate revenues from home networking services.

Within this context, several other strategic observations are relevant:

- *Window of Opportunity.* As the broadband data market starts to mature, there still remains a significant window of opportunity for the cable industry to develop a path for customers to obtain convenient home networking products and subscription-based services tied-in with its high-speed data deployments.
- *Threat of Inaction: Cable's a "Bit-Pipe".* Because home networking and the Internet lets any service provider be the "last microprocessor" reaching the customer, thus establishing a dominion that conveniently provisions and manages Internet-based services over home networks, the cable operator's role could be reduced to one of a "bit pipe" or supplying an Ethernet jack.
- *Competition Moving Forward.* Cable's competition is active in formulating their own strategies for providing convenient home networking services and technologies.
- *Open Specification Process.* The CableHome specification process mimics those established by DOCSIS, PacketCable, and OpenCable. This open process allows for any vendors with an interest in developing innovative products for this arena to participate in the development of the specifications, with an eye towards building upon the substantial development already available in the market.

CABLEHOME CHALLENGES AND SOLUTIONS

The home network presents a complex, diverse, and rapidly evolving service delivery environment. Myriad transport technologies, a

variety of device discovery and management protocols, and several structured service delivery platforms all are jockeying for consumer favor in the nascent home-networking marketplace.

The challenge of the CableHome project is to bring some degree of order to this uncertain environment. The end game is to enable the delivery of high-quality cable services to the home, and to design a system to do so requires the consideration of a number of thorny issues.

ARCHITECTURAL CHALLENGES

Choosing a Transport Technology

The first question likely to enter the mind of a network architect when considering the home networking space is: "Which transport technology should be used?" There are many choices: phone line, power-line, new line, and wireless. Each of these choices has strengths and weaknesses, and selecting any particular technology will involve making tradeoffs and concessions.

A tool that has served well in the past in analyzing these types of tradeoffs is the identification of "typical usage scenarios". This turns out to be an elusive exercise because the types and combinations of services consumed on a home network will vary widely across the consumer spectrum. The optimal technology choice is going to vary among cable operators and from consumer to consumer. In the long run, the consumer panacea may well turn out to be a combination of technologies in a single home network. And of course, neither the cable operator nor the consumer wants to get locked long term into a dead-end technology solution.

For these reasons the CableHome project is developing a technical approach that is independent of any particular transport technology. We are able to realize this objective by choosing protocols that operate at the IP layer and above. Insulating quality of service (QoS) mechanisms from the Layer 1/Layer 2 specifics of the various home networking technologies is a particularly challenging task, and is discussed in more detail in a section to follow.

Providing Managed Service Delivery

Two of the primary tenets of the CableHome project are:

- *Operation of the home network and provisioning of services and devices must be extremely simple.*
- *A wide variety of service types with quality guarantees must be enabled.*

In meeting these requirements, a number of complications become apparent. First, “*easy to use*” is relative to technical knowledge, and it is safe to assume that the typical mass-market customer will not possess the expertise nor have the desire to manage the complicated home network environment. With this in mind, a major focus of the CableHome project is the extension of the robust provisioning and network management capabilities of the existing DOCSIS and PacketCable platforms across the home-networking environment.

The second challenge has already been mentioned: there will be many different services with a variety of resource demands used in many different combinations. In order to ensure the quality delivery of these services in numerous and unpredictable usage scenarios, the second major focus of the CableHome project is to extend DOCSIS and PacketCable quality of service mechanisms into the home, providing an end to end QoS solution.

With these two areas of focus in mind, CableHome is drafting network management and QoS specifications (among others) that will define the capabilities needed to ensure the high-quality delivery of a variety of cable services.

We must now consider how to structure the complex home environment such that participating devices can be managed to the

degree necessary to provide quality guarantees. The CableHome approach is to create a clear separation between cable operator-managed networks and non-managed networks in the home. Devices that provide CableHome management and CableHome QoS capabilities are said to reside in the CableHome domain. As shown in Figure 1, CableHome domains are diagrammatically represented as shaded regions and are meant to serve as a visual tool to identify compliant devices that are manageable by cable operators and that are able to take advantage of cable-based service offerings.

CableHome QoS characteristics can be established dynamically. CableHome networks must be insulated from possible performance corruption by non-QoS-capable devices (i.e., devices that reside outside of the CableHome domain). The CableHome architectural element that allows CableHome domains to be established and insulated is known as the **Boundary Point (BP)**, also shown in Figure 1.

The BP is a functional entity (agent) that resides within a device, and it performs the following tasks:

- Supplies the functionality needed to support CableHome QoS and Management;
- May connect non-compliant networks to the CableHome network;
- Insulates CableHome networks from performance corruption that might otherwise be caused by non-compliant devices;
- May serve as a proxy for connected non-compliant devices, enabling indirect management and service delivery to these devices.

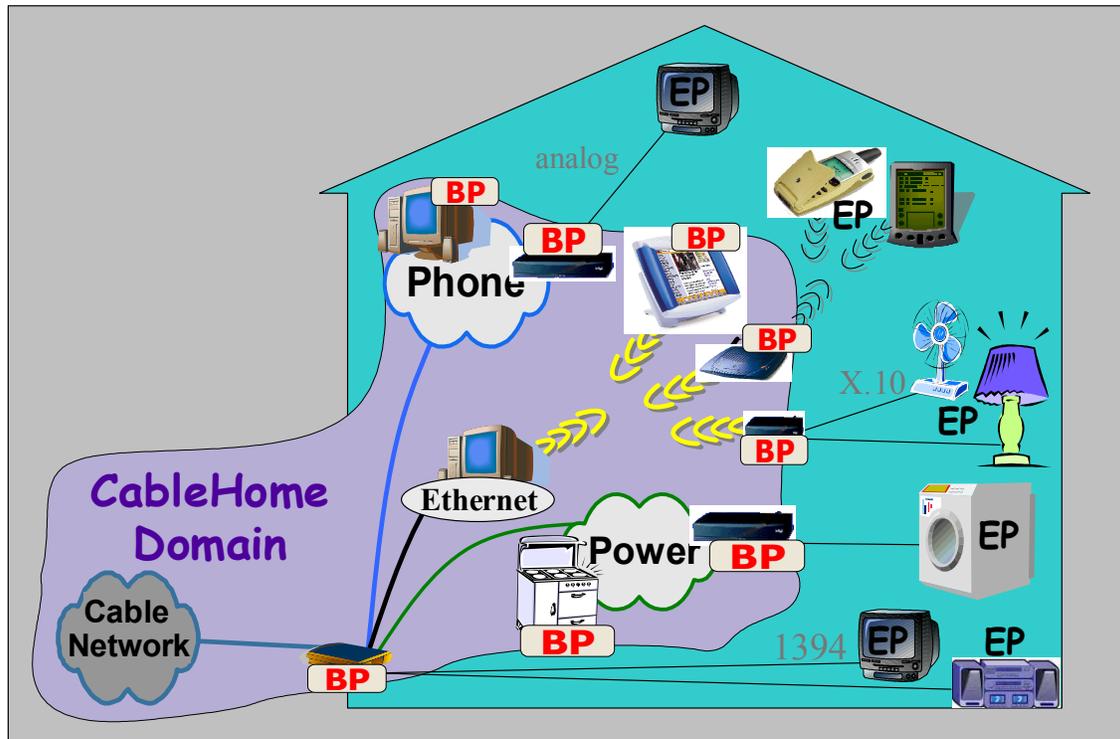


Figure 1: Isolating the CableHome Network

Boundary points generate and consume CableHome messaging and will take the appropriate actions based upon the messages received. BPs always lie on the boundary of the CableHome domain.

The CableHome environment will clearly have to integrate legacy and non-CableHome compliant devices and networks. The ability to deliver services to non-compliant devices may present attractive opportunities to cable operators. But how can these non-compliant devices deliver services when CableHome capabilities are required to do so? CableHome provides this capability through the BP element.

In the CableHome architecture, non-compliant devices that are connected to BPs are known as **Endpoints (EP)**. Endpoints may source or sink data content, but they reside outside of the CableHome domain. These non-compliant entities may range from simple analog audio and video presentation devices to complex non-

compliant networked devices. A BP might connect CableHome networks to the following example types of EPs:

- embedded EP;
- external EP;
- EPs residing on non-compliant networks;
- EP-like applications.

A CableHome boundary point can be thought of as an agent acting on behalf of one or more EPs, enabling them to consume cable services. In the case of a simple embedded analog EP, a BP may do nothing more than convert IP streams to the appropriate format and pass the data on to the EP for consumer presentation. In contrast, a BP may be connected to a functionality-rich EP, in which case the BP and EP might engage heavily in bi-directional communications.

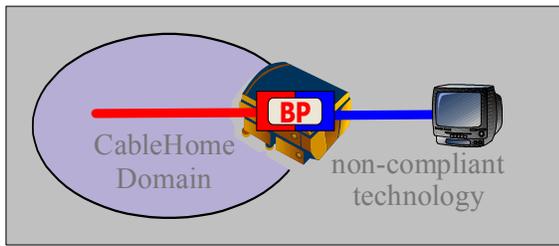


Figure 2: BP Protocol Proxy/Translation

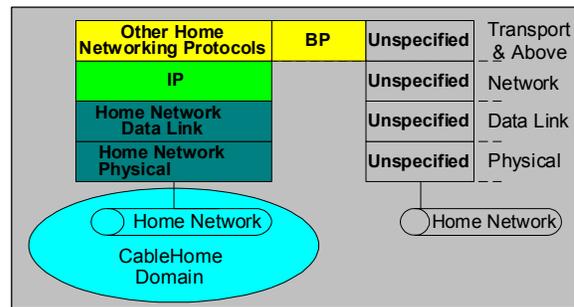


Figure 3: BP Protocol Translation Stack

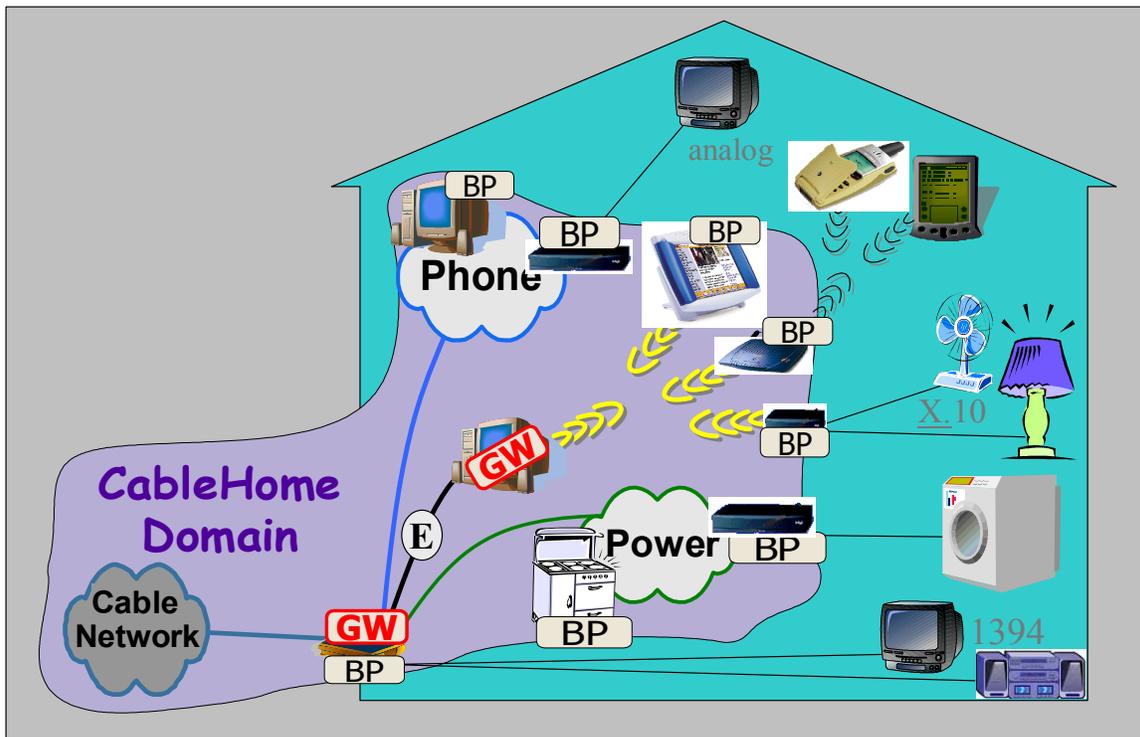


Figure 4: Extending the CableHome Network

BPs may act as a proxy function or as a translation function for the EPs, as shown in Figure 2. The proxy function allows the BP to act on behalf of one or more EPs, while the translation function translates the CableHome-compliant protocols to non-CableHome-compliant protocols. Figure 3 suggests a stack representation for a BP taking on a protocol translation role.

CableHome Traffic Handling

Speculation abounds when it comes to predicting which networking technology will

dominate the home market. Home networking presents a dynamic environment that is ideal for creativity and innovation, and the possible configurations are endless. A reasonable scenario that is occasionally mentioned is a wired “backbone” (for example phone line or power line) with wireless “islands” scattered throughout the house. It clearly is undesirable for a home network architecture to place restrictions on the number, type, or combinations of networking technologies possible in the home.

With all of this in mind, flexibly extending the CableHome domain to multiple home networks becomes an important consideration. The CableHome architectural element that provides this capability is known as the **Gateway (GW)**, shown in red in Figure 4.

Like the BP, the GW is a functional entity (agent) that resides within devices. The GW connects CableHome compliant networks and provides the following capabilities:

- Supplies the functionality needed to extend CableHome QoS and Management capabilities to multiple home networks;
- Insulates the HFC network from in-home traffic;
- Provides routing capabilities required to support unique packet handling needs, such as support for multiple ISP addressing schemes.

Figure 5 demonstrates the placement of a GW propagating CableHome messaging from a wired network onto a wireless network. Figure 6 suggests a stack representation for a GW taking on a such a protocol propagation role.



Figure 5: GW CableHome Message Propagation

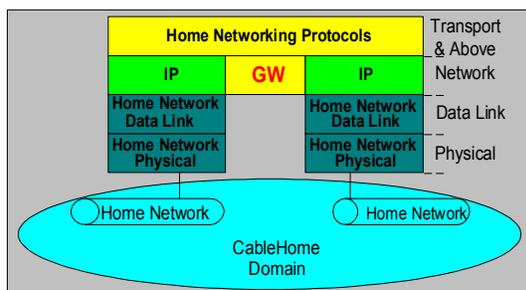


Figure 6: GW Protocol Propagation Stack

Refining the GW and BP Elements

Because the CableHome project is focused both on network management and QoS, specialized versions of the CableHome BP and GW functional elements are identified in the CableHome architecture as follows:

- **MBP: Management Boundary Point**
Provides the previously described BP capabilities for management concerns.
- **QBP: QoS Boundary Point**
Provides the previously described BP capabilities for QoS concerns.
- **MGW: Management Gateway**
Provides the previously described GW capabilities for management concerns.
- **QGW: QoS Gateway**
Provides the previously described GW capabilities for QoS concerns.

In addition, the CableHome domain is further partitioned into separate QoS and Management domains (Q-domain and M-domain respectively). The Q-domain consists of the set of CableHome QoS compliant elements that are able to deliver guaranteed cable-based services. Similarly, the M-domain consists of the set of CableHome management compliant elements that the cable operator can provision and manage.

The Q-domain is defined to be a subset of the M-domain, ensuring that cable operators can manage devices delivering QoS-based services to the degree needed to fulfill service quality guarantees. In addition, the M-domain is defined to extend beyond the Q-domain, allowing CableHome management of products that are not CableHome QoS compliant.

Logical vs. Physical Views

Although not explicitly stated, all of the CableHome architectural elements identified thus far have been **logical** in nature. BPs and GWs are logically bound functional entities that

reside in devices, and do not necessarily imply or specify any specific device or hardware configuration.

The BP and GW logical elements fully define a CableHome network within the home, and they supply all of the in-home functionality defined by the CableHome specifications. Each BP and GW logical element is assigned a unique IP address, and it is the CableHome logical elements that are provisioned and managed. A CableHome network can be conceptualized as a set of BPs and GWs that are discovered and managed, and that interact with each other and with the CableHome support infrastructure, as needed in a flexible manner, to deliver cable-based services.

That said, the CableHome team has found it useful to identify device classes in the home to lend tangible context to the CableHome BP and GW logical elements and combinations of these logical elements. The CableHome concept of device classes places no restrictions on physical devices or combinations of logical elements within physical devices.

There are three classes of CableHome devices, referred to as HA (Home Access), HB (Home Bridge) and HC (Home Client), as shown in Figure 7. The HA, HB, and HC devices are loosely distinguished by their placement in a CableHome network. These device classes provide a strictly informative tool for depicting collections of logical elements but are not considered restrictive. HA, HB, and HC are not addressable entities within the CableHome architecture.

The HA device extends CableHome capabilities from the DOCSIS™ network into the home network. The HA device has a single DOCSIS RF-compliant interface and may have zero or more CableHome compliant interfaces. The HB device extends CableHome capabilities to additional CableHome compliant networks and has at least two CableHome compliant interfaces. The HC device originates and terminates CableHome messaging and has one or more CableHome-compliant network interfaces.

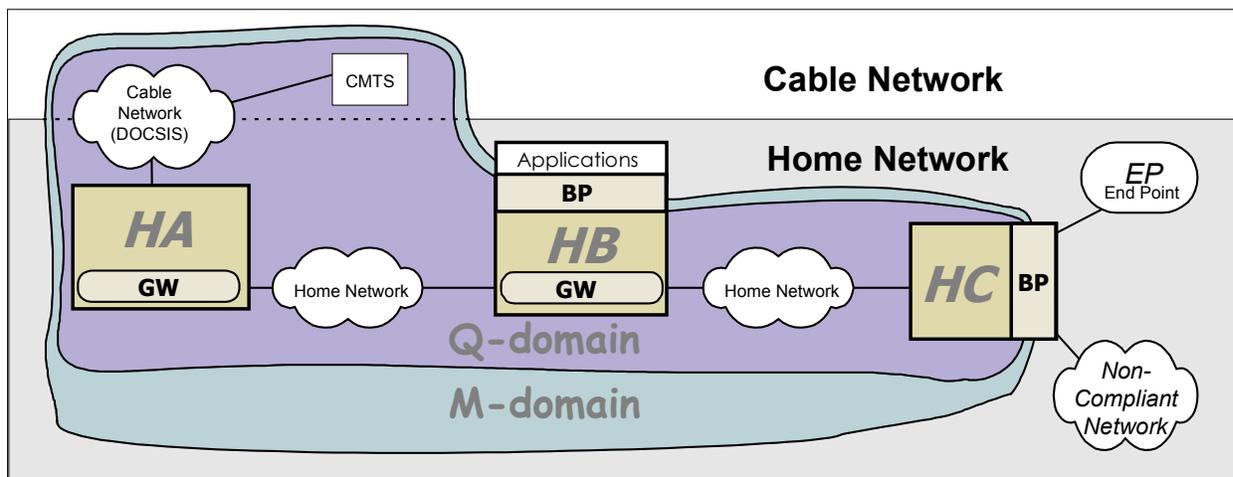


Figure 7: CableHome Device Classes HA, HB, and HC

A CableHome device of a particular type may contain functionality typically associated with other device classes. For example, an HA device, in addition to containing a DOCSIS-compliant interface, may contain HB-like GW

functionality that connects two compliant home networks.

Flexible Solution space

As home networking continues to grow in popularity, consumers may demand many different types of services. To accommodate this demand spectrum, an architecture that allows the design of devices with a broad range of resources and capabilities is critical. As we

have described above, the CableHome architecture provides just such a flexible and non-restrictive design space. Figure 8 demonstrates the flexibility of this approach, showing various example combinations of CableHome elements laid out in various topologies.

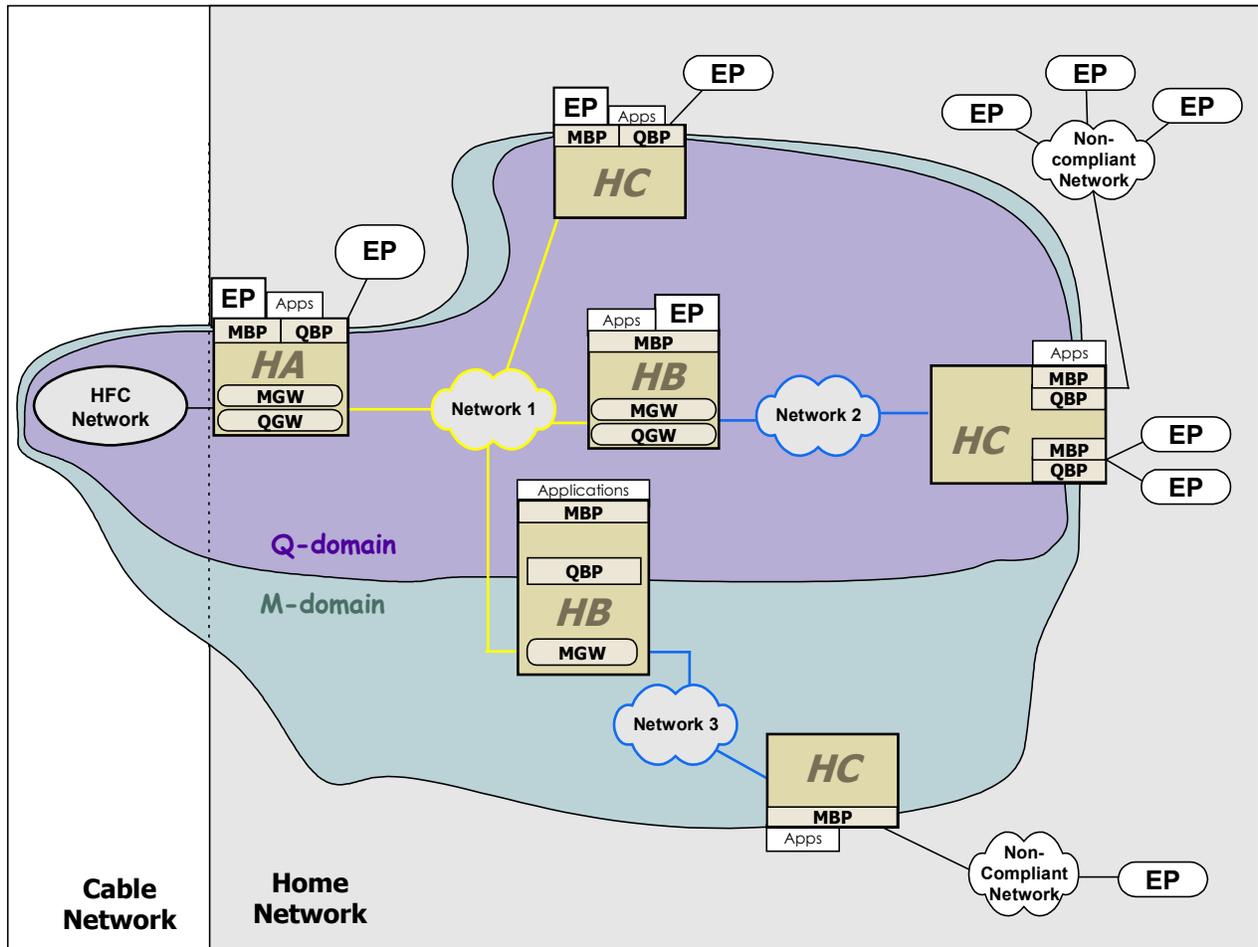


Figure 8: CableHome Architecture, Putting it all Together

CableHome Architecture Summary

The CableHome architecture was developed via a cooperative effort with contributions provided by a large number of service and equipment vendors, in concert with the requirements communicated by cable operators. In summary, the benefits provided are many, including:

- Clearly identified CableHome domain that enables cable operators to manage networks to the degree necessary to deliver quality-guaranteed services.
- A logical element focus that places minimal restrictions on device capability configurations.
- The ability to interface with non-compliant technologies. This enables

service delivery to existing and future proprietary technologies, to non-IP-based network technologies, to thin client devices, etc.

- Interoperable products within the CableHome domains.
- Transport technology independence, leaving a broad set of choices for cable operators and for consumers
- Transport technology independence, allowing cable operators to leverage the existing and rapidly progressing home networking technology base, to deploy new services.
- Flexible implementation space both fosters vendor innovation and permits graceful evolution to include new technologies and services.

MANAGEMENT AND PROVISIONING CHALLENGES

The ability to manage network elements in the home is a critical component of the CableHome vision of guaranteeing reliable delivery of cable-based services in subscribers' homes. The extent to which network elements can be initialized and configured for operation without user intervention is expected to have significant influence on how well CableHome-compliant networks are accepted by consumers. These issues are among those to be addressed by CableHome network management and provisioning systems. This section considers important challenges to the development of CableHome network management and provisioning systems, and how these challenges might be met.

Scope of the Provisioning Task

There may be a great number and type of networked devices in the home that will need to be initialized and configured for operation. Many will likely require unique initialization parameters and configuration processes. The number and type of networked devices in the

home that will need to be initialized and configured for operation is potentially very large. Many will likely require unique initialization parameters and configuration processes. CableHome cannot begin to identify, much less specify, the provisioning needs of all current and future home networking devices and functions.

CableHome is addressing this challenge by limiting consideration of provisioning only to CableHome-compliant devices, and by taking a phased approach to specifying provisioning and management of CableHome-compliant functions. The initial phase will focus on applying the DOCSIS provisioning process to CableHome-compliant devices in order to enable delivery of basic data transport service to these elements connected to the home network. Later phases will explore more complex issues such as service and device capability discovery, and ways to provide basic support specific to a service type such as video distribution.

Management Capabilities

The wide array of devices potentially connected to the home network makes it difficult if not impossible to predict the set of management capabilities needed. "Thin" network devices may have little or no management capability. Some types of devices, such as white goods and other appliances, may have very specialized management needs.

In order to bound the task and limit the scope, the CableHome management system will focus on the management of CableHome GW and BP functions only. The initial set of management functions will be similar to some of the management functions specified in the DOCSIS specifications' suite.

Other network management and provisioning challenges to be addressed during the initial specification phase are listed below:

- Should device and capabilities discovery be supported as part of the CableHome provisioning process?

What protocol(s) should be used and how does it integrate with the existing management protocol framework?

- What do the details of an end-to-end provisioning process for any new service need to be? How are services requested, granted, delivered, billed for, and terminated?
- How will devices on different sub-nets in the home (assigned IP addresses from different service providers) exchange data with one another?
- How will addressing be accomplished as devices are added to the home network, or as leases expire, during periods of isolation from server functions in the cable network (headend or NOC)?
- How will service-level diagnosis be accomplished? How will problems with service establishment, delivery, and termination be detected, reported, and corrected?
- How will CableHome management systems integrate with DOCSIS™, PacketCable™, and OpenCable™ management systems in the cable operator's network?

QUALITY OF SERVICE CHALLENGES

Extending quality of service capabilities from the cable network to the home network presents its own set of unique challenges in order to ensure consistent, reliable service delivery to consumers. Some of these challenges are listed below:

- Maintaining HFC service quality levels as they are delivered over different home networking technologies.
- Developing a common QoS signaling method. This for home network devices and applications to establish prioritized service levels across different, lower-

layer home network transport technologies that interface to DOCSIS 1.1 and PacketCable QoS mechanisms.

- Delivering QoS levels to non-compliant devices and network technologies.
- Establishing a method for mapping DOCSIS 1.1 QoS levels to the QoS levels of different home networking technologies.
- Developing an architecture that is independent of all the different home networking topologies and configurations that are expected.
- Classifying performance characteristics of home networking devices/technologies on their ability to deliver different types of services.

LOOKING FORWARD

This paper offers a description of the vision and challenges incumbent upon establishing a technical infrastructure in the home-networking environment capable of delivering cable-based services in seamless fashion to customers. CableLabs, in cooperation with its member companies, is now working with a large community of vendors to create the technical specifications to implement this vision.

Looking forward, we anticipate new developments in a number of key respects:

- *Entertainment video.* The unique transport requirements for entertainment video applications will likely require modification to existing home networking management and transport protocols. For example, one such immediate requirement is the establishment of a copy protection system for digital media in the home-networking environment.
- *Higher bandwidths.* The increasing bandwidth capabilities of emerging home networking protocols offers cable

operators new opportunities to exploit the broadband capabilities of their networks. Through the CableHome project, the cable industry will work to develop these technologies in a way that will enable the delivery of cable services to consumers.

- *Security.* CableHome will also work to extend onto home networks comparable security mechanisms now provided over cable networks by the DOCSIS and PacketCable specifications.