Volume 06 Issue 04 Published, November 15, 2002 ISSN 1535-766X

Intel® Technology Journal

Interoperable Home Infrastructure

Home Interoperability Framework for the Digital Home

A compiled version of all papers from this issue of the Intel Technology Journal can be found at:
http://developer.intel.com/technology/itj/index.htm

Home Interoperability Framework for the Digital Home

Yasser Rasheed, Corporate Technology Group, Intel Corporation
Jim Edwards, Desktop Platform Group, Intel Corporation
Charlie Tai, Corporate Technology Group, Intel Corporation

Index words: UPnP Technology, Home Interoperability, Digital Home, PC/CE Collaboration

ABSTRACT

The transition from analog to digital media, coupled with recent advancements in broadband and home networking technologies, is fostering a Digital Home environment where rich multimedia content can be delivered to and distributed throughout the home seamlessly. This promises mutually beneficial opportunities for collaboration between the Personal Computer (PC) and Consumer Electronics (CE) industries, and it paves the way for new usage scenarios and significantly improved consumer experiences.

A key element for a successful PC/CE collaboration in the Digital Home is interoperability between devices operating on a common home network. We define interoperability as the ability for devices in the home to discover, configure, and control the capabilities of peer devices and to negotiate common protocols and media formats for proper multimedia content distribution.

This paper presents a number of typical usage scenarios in the Digital Home and then uses these scenarios to extract interoperability requirements. A standards-based Home Interoperability Framework is then described that enables vendor interoperability. Finally, a case study is used to illustrate the Home Interoperability Framework along with its building blocks in action.

We believe that the interoperability of PC and CE devices will (1) reinforce consumers' expectations about anytime, anywhere access to their content; (2) create new device categories; (3) add functionality to existing devices; and (4) offer numerous opportunities for content providers, manufacturers, retailers, and service providers to profit from advances in technology. To achieve the necessary interoperability and provide the consumer with the ultimate digital entertainment experience, it is imperative for both the PC and CE industries to embrace a common framework.

INTRODUCTION

In recent years, the world has witnessed tremendous advancements in computer platforms, consumer electronics, and communication networks. The phenomenal growth of the Internet and the insatiable demand for bandwidth have resulted in a growing demand by consumers for broadband access. Meanwhile, the explosion of mobile devices has conditioned consumers to expect access to their information and content *anytime* and *anywhere*. The deployment of home networks promises to help fulfill this consumer need in the Digital Home and be the catalyst for a new wave of digital devices. Technological advancements will enable high-speed Internet services and rich multimedia content delivery to the home, paving the way for significant enhancements to consumers' entertainment experiences.

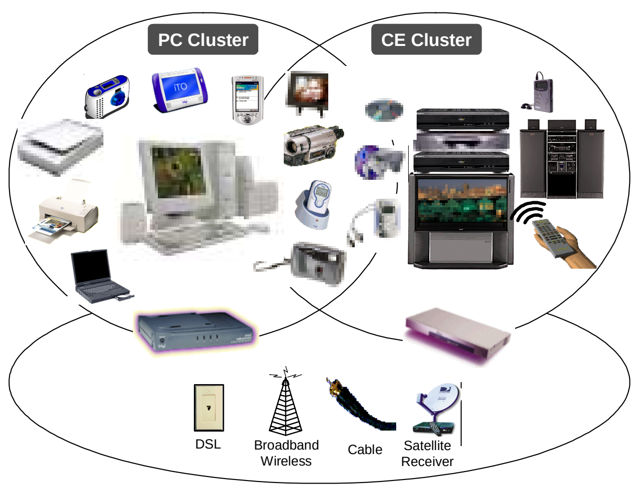

Figure 1: Clustered home entertainment environment

As illustrated in Figure 1, the typical home has two clusters of equipment used for entertainment purposes: the Consumer Electronics (CE) cluster and the Personal Computer (PC) cluster.

The CE cluster has traditionally been considered the main entertainment environment for home users. It normally consists of TVs, stereos, video cassette recorders (VCRs), DVD players, and personal video recorders (PVRs). Its content comes from terrestrial broadcast, cable, or satellite programming received through dedicated set-top boxes (STBs), and from removable media such as video tapes, CDs, and DVDs.

The PC cluster, consisting of one or more PCs and a number of attached peripheral devices, is emerging as an alternative, complementary entertainment environment. The content for the PC cluster is typically rich multimedia content acquired from the Internet over a broadband access pipe, or from removable media such as CD-ROMs and DVD-ROMs.

In the future, these two clusters will increasingly communicate with each other and form the basis for what we refer to as the Digital Home. This trend is exemplified by PC and CE manufacturers' integration of new digital features and functions into their products. For example, more and more CE devices are capable of communicating with the PC using Ethernet and IEEE 1394 connectivity. As a result, a 'network effect' is being unleashed in the home, resulting in a multitude of new devices and appliances that share content and resources, expanded revenue opportunities, and increased consumer satisfaction.

The new home devices that emerge will combine the power of the PC, especially with respect to management, storage, and processing capabilities, with the convenience and ease-of-use of CE devices. The rich multimedia content available in PC and CE clusters will be easily exchanged between a large number of devices, allowing the consumer to experience it *anytime* and *anywhere* in the home. This will result in a number of innovative usage scenarios that can greatly enhance consumers' entertainment experiences.

USAGE SCENARIOS

The following scenarios highlight the key drivers for the home network and the associated impact on device interoperability requirements.

Watching TV and Movies

On a Friday evening after a long day at work, Jim and his wife Pam sit on the living room couch and start to watch a movie on their TV. While they are watching, Jim is able to pause the live TV to accommodate an interruption by his kids, rewind to catch up on missed segments, and resume watching. After the movie is over, Pam remembers the preview she saw earlier and, pushing a few buttons on the remote control, sets the PVR to record the show.

On Saturday afternoon, Jim's kids take over the living room to watch their favorite shows recorded over the course of the week. When Jim sees his favorite chair occupied by his 11-year-old, he decides to watch TV in the kitchen. After glancing at the program guide and not finding anything he wants to watch on live TV, he pushes a button on the remote control to see what programs are stored on all the devices on his home network. A guide pops up and shows all the movies, TV shows, and music stored on his two PVRs and three PCs. He finds an old war movie (Jim loves the new service he signed up for that downloads movies based on his preferences over his broadband connection), makes himself a sandwich, and sits at the counter to watch the movie. After Jim finishes his sandwich, he realizes he prefers to watch the movie in a more comfortable position. He pauses the movie with the kitchen remote, turns off the TV, and heads up to his bedroom. Grabbing the bedroom remote, he lays down on his bed, locates the movie in the program guide, hits Play, and the movie resumes from where he paused it.

At the same time, Pam is doing the family finances on a PC in the den while listening to songs on the PC's jukebox application. She decides she needs a break and clicks on an icon on the desktop. A screen pops up (the same screen Jim saw on the kitchen TV) showing all the programs recorded on the home network. Pam sits back and starts watching her favorite documentary.

Benefits for Consumers

The entire family can easily and conveniently watch TV and movies on any display, whether it is a TV or a PC, anywhere in the home, all at the same time. The program guide shows a common integrated listing of all movies, TV programs, pictures, music, and other content from all the devices on the home network—at the touch of a button.

Listening to Music

Waking up late on Saturday morning, Jane reaches over to her bedside table for the remote control. She pushes the play button and the bedroom clock radio resumes playing her "weekend mix" playlist stored on her PC. Jane decides to stop the "weekend mix" and instead play all her songs from the U2 music group in shuffle mode. She grabs her wireless tablet, re-orders the songs by artist, and saves the resulting playlist to the PC. After a few more minutes of lying in bed, Jane goes to the kitchen to eat breakfast. She pushes a button on a remote control in the kitchen and the music starts playing on the kitchen speakers, without missing a beat.

Benefits for Consumers

Music can be conveniently stored on a PC for personalized access from anywhere on a home network and can be easily controlled by multiple devices like remote controls, tablets, and other PCs.

Capturing and Sharing Life's Moments in Pictures

Returning from their honeymoon in Hawaii, Bob and Alice are excited about sharing their pictures with friends and family. At the touch of a button, Bob wirelessly downloads the photos and video clips from his new digital camera to a home PC. Then Alice, feeling inspired while everything is still fresh in her mind, edits the photos and video clips into one file, adding captions and music to create a multimedia slideshow of their honeymoon.

At their party the next weekend, Bob and Alice invite their guests to join them in the living room to watch their honeymoon pictures. Bob pushes a button on the remote control and a display of available pictures and personal videos stored on the PC appears on the TV. Bob quickly locates the honeymoon slideshow and selects it. Everyone loves the pictures and clips, and compliments Alice on the captions she added.

After lunch the following Monday, Bob meets his friend Paul at a coffee shop and decides to show him his honeymoon slideshow. From his personal digital assistant (PDA), Bob connects to the 802.11 hotspot, logs on to his home network, and brings up the slideshow to show his friend.

Benefits for Consumers

Wireless technologies like Bluetooth* can be used to conveniently download pictures from a mobile device like a digital camera to a PC. 802.11 wireless home networks can be used to access content stored in one place (in this example, a PC) to view on a display elsewhere in the home. Broadband-enabled homes allow consumers to easily and securely access content stored in the home and from other locations outside the home.

Turning the Usage Scenarios into Reality

These scenarios demonstrate the range of new and innovative usage models that can be supported by a Digital Home network, where devices collaborate to provide the best user experience. Clearly, these represent only a few of the many possible usage models.

*Other brands and names are the property of their respective owners.

Interoperability between PCs and CE devices provided by different manufacturers is critical for these usage models to work seamlessly and without explicit user intervention. Interoperability must be realized at different levels for these devices to communicate with each other and exchange useful information. For example, interoperability must address networking and connectivity technologies, media formats, streaming protocols, and configuration and control mechanisms.

It is imperative that device manufacturers and application developers address interoperability as a design-level requirement, rather than as an optional feature.

HOME INTEROPERABILITY REQUIREMENTS

Vendor interoperability is accomplished between devices when they are capable of collaborating on a particular desired service that they provide to the consumer. Typically, this includes the capability for these devices to communicate with each other and exchange relevant information.

The list below identifies requirements at various layers of functionality to achieve vendor interoperability:

- *End-to-end connectivity between devices inside and outside the home*. This includes networking compatibility at the link layer (layer 2) and network layer (layer 3), such that devices are able to establish communication with each other.
- *Unified framework for device discovery, configuration, and control.* This refers to the ability of a device on the home network to discover the presence of other devices and services on the network, and identify their functionality and associated capabilities. It also includes the ability to configure these devices and services, and control their operation with the appropriate ease-of-use.
- *Common media formats and streaming protocols.* Once devices can communicate with each other, they need to agree on a common streaming protocol in order to establish a media streaming session. These devices also need to agree on a common media format to ensure that the media can be shared and consumed.
- *Common media management and control framework.* Media management and control refer to the ability to organize, package, browse, search, and select media items to be processed and the ability to control the operation of media streaming sessions. A media management and control framework must be established across all devices in the home to enable the proper exchange of information between devices provided by different vendors.

- *Flexible Quality of Service and policy management mechanisms.* Quality of Service (QoS) networking is essential for transporting multiple high-bitrate media streams in the home. In addition, users may want to apply certain usage rules that govern how their home network is used by household members. The key for both QoS and policy-based network management mechanisms is flexibility and ease-of-use. For this to work, all devices must agree on a common framework and associated mechanisms to implement these functions.
- *Compatible authentication and authorization mechanisms for users and devices.* A number of authentication and authorization mechanisms are being considered by device manufacturers and application developers to provide appropriate security for access and control. It is imperative to settle on a compatible framework to enable devices to request and/or grant access to particular devices and services in the home.
- *Common commercial content protection and Digital Rights Management framework.* A flexible and extensible content protection framework must be adopted by the industry that enables the chaining of content protection solutions to provide comprehensive, end-to-end protection of commercial entertainment content as it is delivered, managed, stored, and consumed on a wide range of devices within the Digital Home. A consistent set of technical and licensing mechanisms must be agreed upon to ensure that content is protected in an effective and efficient manner throughout the home.
- *Standard mechanisms for user interfaces at a distance.* In the future, devices will be created to specifically handle user interaction tasks. Applications running on other devices in the home can drive these "I/O devices" to deliver the desired end-user experiences. As a result, users will be free to interact with home networking applications from anywhere in the home, rather than being restricted by the location of the resources. The traditional fixed location, fixed user interaction style, such as a "PC-in-the-den" will be augmented with new kinds of user interaction, where a range of activities in the home will be supported by user interfaces tailored to the needs of the user.

HOME INTEROPERABILITY FRAMEWORK

This section defines a Home Interoperability Framework—one based on industry-wide standards and building blocks—that enables vendor interoperability. The functionality that results can be built upon, and enables the creation of compelling, interoperable devices and applications for today's market and future markets.

The Home Interoperability Framework (HIF) consists of a number of building blocks that work in harmony to ensure vendor interoperability between various types of devices in the home.

The HIF allows flexible interconnection between these devices, each with potentially different networking media technologies, using an internetworking layer based on Internet protocols.

The framework is divided into four layers, as shown in Figure 2.

- Device Connectivity Layer: The various connectivity options for home devices.
- Internetworking Layer: The routing and internetworking components based on the Internet Protocol (IP).
- Platform Middleware Layer: The collection of platform middleware building blocks used by various home devices.
- Applications and Services Layer: The applications and services running on a particular device. This layer includes the Content Protection and Digital Rights Management (DRM) building blocks for the management and distribution of premium content.

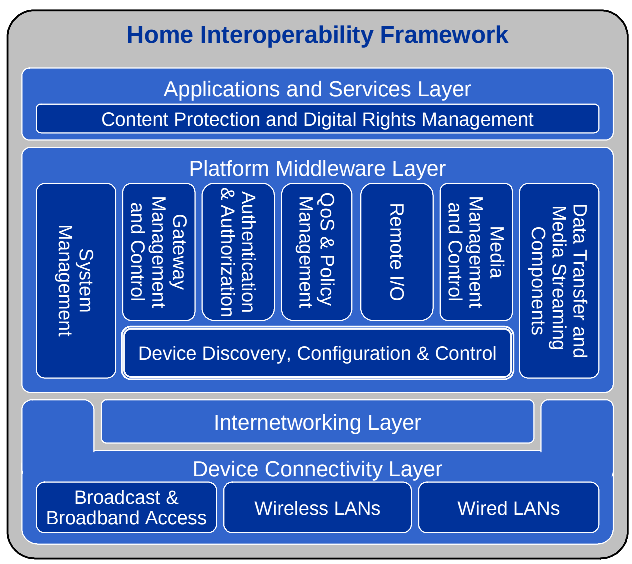

Figure 2: Home Interoperability Framework

The following sections explore the detail for each of the four layers of the Home Interoperability Framework.

DEVICE CONNECTIVITY LAYER

A fundamental requirement for devices to participate in a networked Digital Home is connectivity. Devices may include one or more connectivity options depending on their functionality, as illustrated at the bottom layer of the

Home Interoperability Framework (HIF) in Figure 2. The device connectivity options can be classified as follows:

- Connectivity to the outside world. This includes both broadcast and broadband access. Broadband access represents Internet connectivity to the Wide Area Network (WAN) through Cable, Digital Subscriber Line (DSL), Cable, or Wireless Local Loop (WLL). Broadcast access represents connectivity to content sources such as Terrestrial broadcast, Cable TV, and Satellite programming, all of which are typically non-IP based, in contrast to content received through broadband access connections.
- Connectivity to the home network. This includes both wireless Local Area Network (WLAN) options such as 802.11 technologies and wired LAN options such as Ethernet. In cases where 1394[1] is used as an entertainment cluster connect, further protocol translation may be needed at higher layers to make 1394 content and devices available for access on the Digital Home network.

INTERNETWORKING LAYER

The Internet Protocol (IP) is a family of protocols that provide the underlying network communications for devices on the Internet. IP also provides a suitable internetworking technology to facilitate pervasive connectivity for devices inside and outside the home, regardless of their physical connectivity technology. IP is based on industry-standard specifications implemented and supported in a wide range of devices with more than two decades of deployment in government, academic, and commercial environments.

IP encapsulates data from upper-layer protocols with address information. The address information is used to route the data traversing the network. Demand for IPv4 addresses for the burgeoning personal computer, consumer electronics, and mobile handheld markets is predicted to exhaust the supply of available IPv4 addresses, particularly in rapidly expanding market segments in the Asia-Pacific region. To conserve the limited supply of routable IPv4 addresses, many residential gateway vendors support “private” IPv4 addresses through Network Address Translation (NAT) technology.

Many interactive multimedia person-to-person communication applications, such as video conferencing and online interactive games, make use of upper-layer protocols that may break with NAT. This forces residential gateway vendors to add workarounds to NAT to repair the communications channel. Since each workaround is specific to an upper-layer protocol, many such fixes are necessary over time, and they limit the design of new upper-layer protocols. While NAT is a reasonable short-term answer for a limited supply of IPv4 addresses, a better solution is the new version of IP known as IPv6.

IPv6 is essentially IPv4 with built-in auto-configuration, enhanced support for mobility and security, and a much larger network address space that allows more devices to be transparently interconnected. The Internet Engineering Task Force (IETF) is actively pursuing a range of transition techniques for a smooth migration from IPv4 to IPv6, many of which are applicable to home devices and residential gateways. IPv6 is gaining traction in the PC, CE, and mobile industries as the long-term solution to the shortage of IPv4 addresses while maintaining end-to-end transparency.

The HIF supports both IPv4 and IPv6, with an emphasis on IPv4 in the short term and IPv6 in the longer term.

PLATFORM MIDDLEWARE LAYER

The Platform Middleware Layer in the Home Interoperability Framework (HIF) provides the basic platform building blocks that may be needed on various home devices. The cornerstone of this layer is the Device Discovery, Configuration, and Control building block, which are based on UPnP* technology.

The Platform Middleware Layer also includes platform building blocks such as Data Transfer and Media Streaming Components, Media Management and Control, Remote I/O, Quality of Service (QoS) and Policy Management, Authentication and Authorization, Gateway Management and Control, and System Management.

Discovery, Configuration and Control

The UPnP device architecture enables peer-to-peer network connectivity of PCs and CE devices of different form factors, intelligent appliances, and wireless devices. It is a distributed, open networking architecture that leverages Internet and Web technologies, such as Hyper-Text Transport Protocol (HTTP), Simple Object Access Protocol (SOAP), and eXtended Mark-up Language (XML), to set up flexible data communication between any two devices under the command of any controlling device on the network. UPnP specifications are defined

[1] This refers to the physical and link layers of the 1394 specifications

* Other brands and names are the property of their respective owners.

by the UPnP Forum [1], an industry consortium with more than 500 member companies including various PC and CE manufacturers.

The UPnP Forum working committees are responsible for establishing standard Device Control Protocols (DCPs). UPnP DCPs define the syntax and semantics for devices and services that implement a specific class of functions. The term *device* is used in the UPnP architecture specification to define a logical container of other devices and services, where *services* are logical entities providing a specific service to the UPnP device network. Services are controlled by control points, which are in turn defined as logical entities that can control specific services. A physical UPnP device may combine multiple services and/or control points. Several examples of UPnP services are discussed in the following sections.

The operation of UPnP devices is divided into the following phases:

- *Addressing:* In the addressing phase, devices obtain an IP address through Auto-IP or Dynamic Host Configuration Protocol (DHCP) mechanisms.
- *Discovery:* In this phase, control points search for devices and services, and devices advertise their services.
- *Description:* Once a control point finds a device or service of interest, it requests a description document. Devices and services respond by sending XML description documents that define the actions and attributes they support.
- *Control*: In this phase, control points invoke the actions described in the XML description documents associated with the services they control. These actions are executed by the services and typically cause changes in the service states and attributes. The syntax and semantics of these control actions are defined in the UPnP DCPs associated with the device class.
- *Eventing*: Control points subscribe to event servers hosted by the services, which allows them to receive events from a specific service they are interested in. Similar to control actions, events are defined in the corresponding DCPs.
- *Presentation*: Finally, devices may choose to host an HTML document that provides a user interface for the device.

UPnP technology forms the basis for the device discovery, configuration, and control building block in HIF. It defines a horizontal abstraction for distributed networking across PCs and CE devices in the home, independent of any particular operating system, programming language, or physical medium.

Data Transfer and Media Streaming

Media streaming refers to the ability to transfer real-time content between multiple, networked devices and between different software modules on a device (see Figure 3). Since these software modules usually perform media processing functions on the data being transferred, such as encoding and decoding, compression and decompression, and packetization and de-packetization, they are referred to as media streaming components.

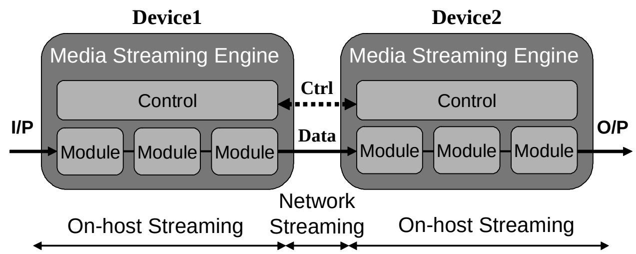

Figure 3: High-level architecture of media streaming

A media streaming engine is responsible for providing a connection (a virtual data channel) between the software modules to enable efficient data transfer between them. The media streaming engine is responsible for the setup, configuration, and maintenance of a network connection for streaming between devices.

A media streaming engine may provide the following features:

- dynamic (run-time) support for multiple media formats, streaming, and stream control protocols
- support for multiple, simultaneous streams
- audio/video synchronization and buffer management

A number of media streaming engines exist today. DirectShow*, which is available on Microsoft Windows* operating systems, is arguably the most prominent. Regardless of the diversity of the streaming engines on various devices in the Digital Home, it is necessary for all of the devices to agree on compatible components to allow the exchange of media content.

Media Management and Control

UPnP AV specifications define the interaction model between UPnP AV devices and associated control points. UPnP AV devices include TVs, VCRs, CD/DVD players, set-top boxes, stereo systems, still-image cameras, electronic picture frames, and PCs. The UPnP AV architecture allows devices to support various types of entertainment content such as MPEG2 and MPEG4 for

* Other brands and names are the property of their respective owners.

video, JPEG for pictures, and MP3 for audio. It also allows various types of transfer protocols such as HTTP and Real-time Transport Protocol (RTP).

UPnP AV specifications define two types of logical devices on the home network: Media Servers and Media Renderers (see Figure 4). They also define four "services" hosted by servers and renderers:

- The *Content Directory Service* enumerates the available "content" (videos, music, pictures, and so forth).
- The *Connection Manager Service* determines how the content can be transferred from the Media Server to the Media Renderer devices.
- The *AV Transport Service* controls the flow of the content (play, stop, pause, seek, etc.).
- The *Rendering Control Service* controls how the content is played (volume/mute, brightness, etc.).

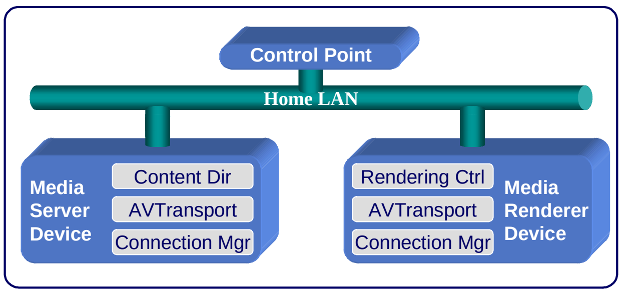

Figure 4: UPnP AV device architecture

The UPnP AV specifications are defined by the UPnP AV Working Committee (WC) as chartered by the UPnP Forum* steering committee. UPnP AV version 1.0 specifications have been defined with active support from many CE vendors and have been recently approved and published by the UPnP Forum.

The HIF uses UPnP AV technology for media management and control, allowing various PCs and CE devices to discover content on the home network and control media streaming sessions between these devices.

Remote I/O

Remote I/O is a technology under development based on the UPnP device architecture. It moves the point of user interaction away from an application running on a specific device, such as a PC or a CE device, to one or more remote I/O devices. The remote I/O device supplies input and output services such as mouse, keyboard, and display, that together comprise the user interface. Applications run on a host elsewhere on the home network and are matched with compatible I/O devices. Applications may take on different user interface characteristics depending on the I/O devices being used. Furthermore, the application user interface can migrate across I/O devices as the user moves about the home.

Remote I/O supports PC/CE collaboration by introducing *location independence* and *tailored I/O devices* to the home network. Applications can connect to wireless I/O devices anywhere in the home, freeing the user interaction from the location of the application. For example, a user might prefer to read the news in a comfortable chair in the family room instead of using the desktop PC in the den. In addition, I/O devices can be tailored to user activity. For example, a display for reading the news should be handheld, comfortable to hold, and allow the user to adjust visual settings such as colors and contrast. These two properties of remote I/O devices will improve the quality of user experiences in the home.

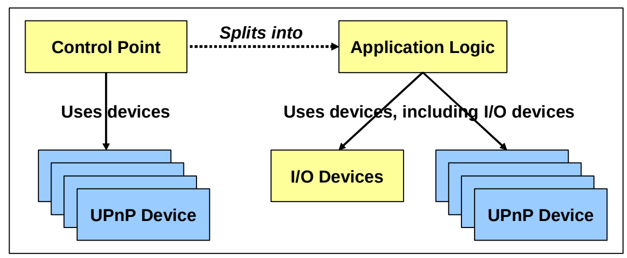

Figure 5: Control point splits into application logic and I/O device(s)

Remote I/O separates user interaction from application logic. In effect, a UPnP control point is being split in two. One part retains the controlling application logic, while the other part consists of the user interaction components and their related hardware. The I/O part becomes a standard UPnP device that is controlled along with other devices required by the application (see Figure 5).

Quality of Service and Policy Management

Streaming of rich multimedia content in the home typically requires using QoS networking and policy-based network management techniques to ensure the best consumer viewing experience possible. The QoS and Policy Management building block provides the necessary mechanisms for application developers to add support for QoS and policy management to their media streaming applications. The overall architecture of the QoS and policy management building block is shown in Figure 6.

The capabilities supported by the QoS and policy management building block may be divided into two categories:

---

* Other brands and names are the property of their respective owners.

- *Traffic Control:* Traffic Control (TC) refers to the ability of a device to perform functions such as packet classification, policing, shaping, queuing, and scheduling. We define two types of TC functions: 1) Traffic Shaping for end-systems such as a media source/sink device; and 2) Traffic Enforcement for network infrastructure devices such as residential gateways and wireless access points.
- *Policy Management:* Policy management refers to the ability to create, modify, and delete usage policies. A policy manager application residing on a device in the home would typically be able to evaluate policy requests against the policies it maintains, and provide decisions to a policy client upon request.

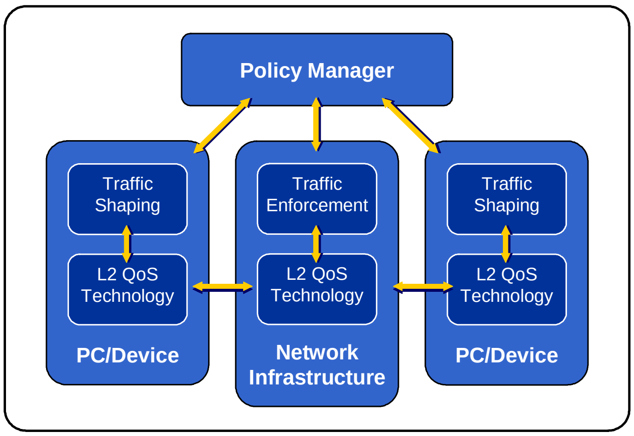

Figure 6: System architecture for QoS networking

Authentication and Authorization

An implicit assumption in the Digital Home is that devices and control points on the network can be trusted. It is possible, however, for unknown and potentially hostile entities to connect to a UPnP device network and listen to messages or control and query UPnP devices. It is important in such cases that devices and control points employ security mechanisms to verify the identities of each other and provide basic levels of access control for resources on the network. The solution for these devices is to use UPnP Security. UPnP Security protects UPnP messages from tampering and/or disclosure to untrusted parties, and it protects UPnP devices from unauthorized control operations. The primary focus of UPnP Security is access control, which is the ability to specify which control points can perform secured operations or receive sensitive information from specific devices. UPnP Security also permits fine-grained access control so that some control points can be granted limited access.

UPnP Security uses public-key cryptography to identify principals (entities to whom access is granted). However, unlike secure Web server public-key certificates, the public keys used in UPnP Security do not need to be issued or certified by a centralized authority. The decision to trust a public key is made by the device owner during device and/or control point installation.

Another important aspect of UPnP access control is the set of permissions that can be granted. The approach taken by UPnP Security is to define access control in terms of device-specific sets of abstract permissions. Each permission potentially enables one or more actions to be performed by a control point authorized by an entry in the device's Access Control List (ACL). Device manufacturers are free to define their own permissions and use whatever mechanism they want to map incoming control requests onto required permissions.

Gateway Management and Control

The term "Gateway" refers to an Internet access device that provides Wide Area Network (WAN) connectivity to the home LAN. In addition to addressing and naming services, it typically provides Network Address Translation (NAT) and firewall support. Ease-of-use for home networks can be greatly enhanced if applications can programmatically manage and query the gateway properties.

The gateway management and control building block enable applications on a home LAN to select and configure available WAN connections. It provides users with diagnostic information by maintaining the connection state and sending event notifications when appropriate. A LAN client can also configure LAN interface parameters, such as 802.11-related configurations. Although having a NAT on the gateway is commonplace and convenient, it breaks some important peer-to-peer applications. The Gateway Management building block provides a service for applications to dynamically configure automatic NAT traversal through port mapping for both inside-out and outside-in access. Applications can also query the gateway for the effective bandwidth on the WAN and LAN link and adjust their behavior dynamically.

It is important that a common management mechanism be used across gateway vendors and applications. Most of these capabilities are currently supported through the Internet Gateway Device (IGD) v1.0 specification defined recently in the UPnP Forum. This specification has been adopted by major gateway vendors including Linksys, Microsoft, and D-Link. Additional functionality, such as security bootstrapping for 802.11 access points, is being addressed by the IGDv2 working committee.

System Management

System management refers to the ability to manage the operational state of devices across the home network. To enable this capability, all networked devices must support a common set of operational services. These system management services can be classified into the following categories:

- *Development, Test, and Manufacturing* services that assist device vendors during the design, test, and manufacturing stages of development.
- *Administration and Management* services that exist to ensure the correct run-time operation of a device, allowing for run-time diagnosis and correction of problems. This category also includes firmware and software upgrade operations.

APPLICATIONS AND SERVICES LAYER

The Applications and Services layer provides a number of functions that mostly deal with the applications and services running on a Digital Home device. This includes coordination between the underlying platform middleware building blocks and interaction with the user through a User Interface (UI). Most importantly, the applications and services layer is responsible for performing content protection and digital rights management for multimedia content on a device.

Content Protection and Digital Rights Management

Commercial content providers require technical and legal protection for their digital content to prevent unauthorized access and copying. PC and CE manufacturers are working with the content industry to develop content protection solutions, which typically consist of a combination of technical and legal mechanisms.

Technical protection mechanisms are effective at preventing unsophisticated attempts to circumvent a particular content protection solution. Licensing and other legal mechanisms are much more effective against business entities with assets, employees, and distribution channels than they are with individuals. Accordingly, technical mechanisms provide the basis for content protection, and an effective licensing structure provides for enforcement.

BENEFITS OF THE HOME INTEROPERABILITY FRAMEWORK

The Home Interoperability Framework (HIF) provides a set of building blocks that allow devices to perform desired functions in an interoperable fashion. Clearly, not all devices need to implement all HIF building blocks. For example, a gateway device may need to support both a LAN and a WAN connection. In contrast, an audio player device need only support a LAN connection. Similarly, selection of other HIF building blocks depends on the overall functionality of a particular device in the home, whether it be a PC, a gateway, or an embedded device that performs a limited set of functions.

The HIF provides various benefits for the constituents of the Digital Home entertainment value chain, including consumers, content providers, service providers, CE device manufacturers, and application developers.

- *Benefits for Consumers*: The HIF allows devices in the home to collaborate and provide consumers with compelling and innovative entertainment experiences. The vendor interoperability features of HIF provide consumers with greater flexibility in selecting their entertainment equipment. This is a clear benefit for consumers, and has the potential to drive consumer demand for more content, devices, and services.
- *Benefits for Content Providers:* For content providers, HIF provides support for content protection mechanisms that help protect their high-value assets. The vendor interoperability features of HIF also provide content providers with assurances that their content can be delivered to various devices in the home in a protected fashion.
- *Benefits for Service Providers:* The HIF building blocks provide interoperable technical solutions that eliminate barriers for secure end-to-end connectivity and high-quality media streaming. Therefore, the HIF allows content and services to be delivered to more end-points in the home, increasing revenue opportunities for service providers.
- *Benefits for CE Device Manufacturers and Application Developers:* The HIF allows CE device manufacturers and application developers to build interoperability into their devices and applications. The resulting interoperability features will fuel more demand for devices and applications in the home. Clearly, this has the potential to create numerous business opportunities for both PC and CE vendors. The framework enables device vendors to provide new product features and customized interfaces for market differentiation.

CASE STUDY

The following case study uses one of the usage scenarios described earlier. It examines the scenario in which Jim decides to watch a movie on the TV and at the same time Pam decides to watch a documentary on the PC in the den. It is assumed that Jim's movie is stored on the Personal Video Recorder (PVR) in the living room and Pam's documentary is stored on another PC in the bedroom. The overall theory of operation is reviewed to better illustrate the effectiveness of the Home Interoperability Framework (HIF) in providing vendor interoperability.

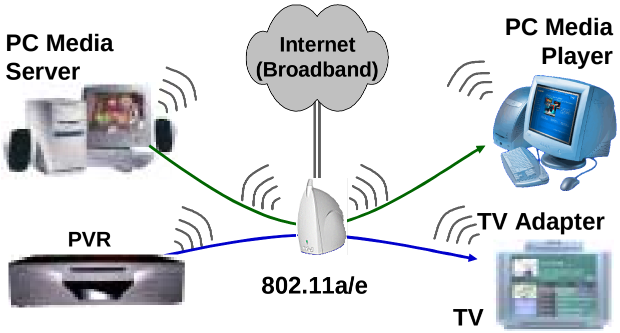

Figure 7: Equipment configuration for the case study

This case study involves a PVR acting as the media server for Jim's movie and a TV adapter that connects the legacy TV to the home network. It also involves the bedroom PC acting as a media server for Pam's documentary and the PC in the den acting as the media player. The scenario, as illustrated in Figure 7, also includes a wireless gateway acting as the access device to the Internet and as an 802.11a wireless access point with 802.11e Quality of Service (QoS) support.

From a functionality point of view, the PVR and the TV adapter perform similar functions for Jim as the PC server and the PC media player do for Pam. To avoid redundancy, we focus on Jim's movie session and describe the interaction between the PVR, the wireless gateway, and the TV adapter.

The Scenario

Jim finds his favorite chair in the living room occupied by his 11-year-old. He heads to the kitchen, browses the movie collection stored on all the devices in the home and decides to watch a war movie, *Gladiator*. He makes himself a sandwich and pushes the Play button on the kitchen remote.

Jim and Pam subscribe to a premium video-on-demand service that allows them to watch three movies per week for a flat rate, and any additional movies for an extra charge. The service allows movies to be downloaded overnight over the broadband Internet connection and stored on either the PVR or one of the PCs in encrypted format with appropriate Digital Rights Management

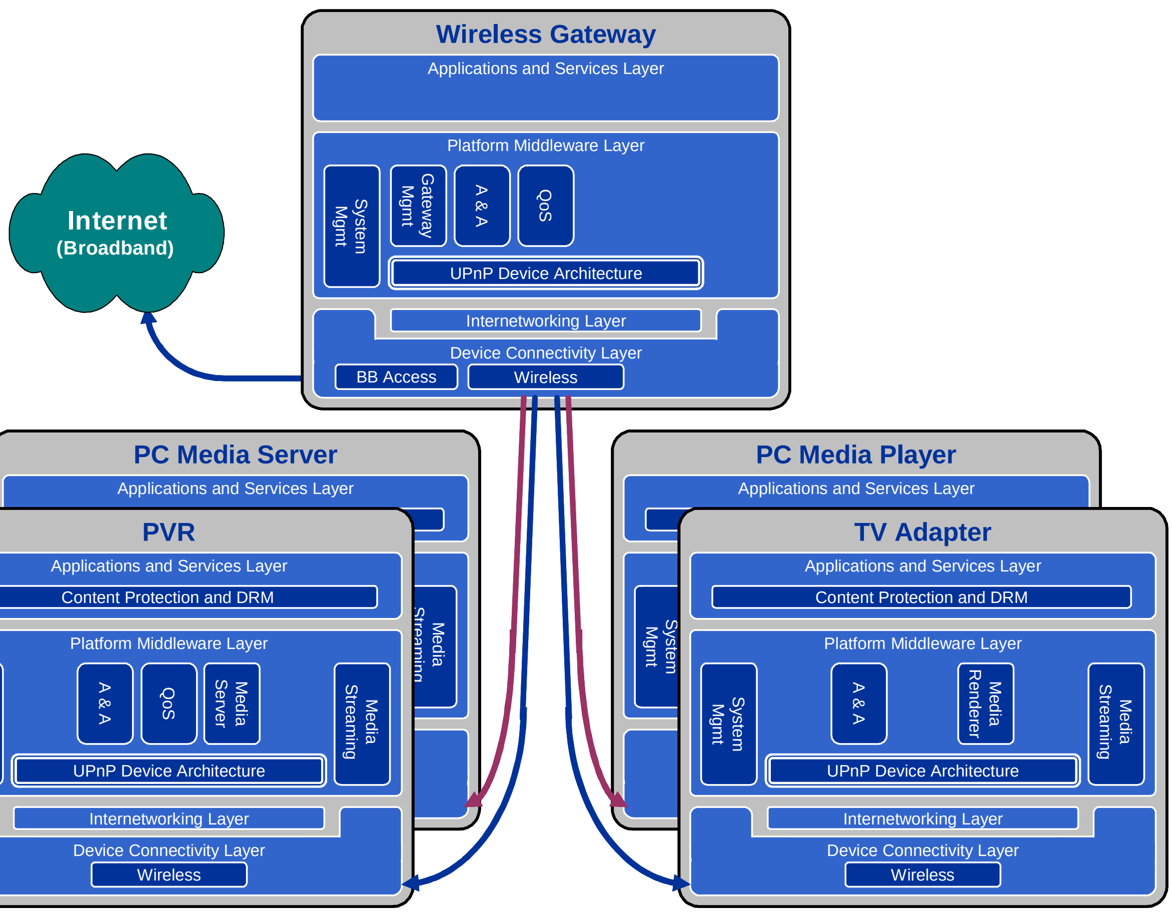

Figure 8: HIF Device Configurations

DRM) credentials. Billing is not activated until a movie is decrypted at playback time.

Figure 8 shows the HIF tailored to the desired functionality. The PVR, shown in the bottom left corner of the figure, acts as a UPnP* AV media server, with 802.11e QoS support over the wireless 802.11a connection; the QoS server is responsible for tagging all outgoing packets with appropriate priorities.

The wireless gateway, shown at the top of Figure 8 is an 802.11a access point with 802.11e QoS support and an additional DSL WAN interface supplying the connection to the broadband Internet. The wireless gateway serves as a UPnP Internet Gateway Device (IGD) for management and control of gateway services (NAT, DNS, Firewall, and so forth) to allow secure and transparent end-to-end connectivity to the WAN. The wireless gateway also supports the policy management service for the home LAN.

The TV adapter shown in the bottom right corner of Figure 8 has several functions. It connects the legacy TV to the wireless home LAN and is responsible for receiving, decoding, and playing back the movie over its video output connected to the TV. It acts as an UPnP AV media renderer, performing other functions such as content protection (DRM and media decryption), and it provides the user (Jim) with an electronic program guide for browsing content on all devices in the home. All three devices participating in this service support UPnP Security for device authentication and authorization.

Finally, in this usage scenario it is assumed that the TV adapter application includes a UPnP control point that is used to both browse the content on the home network and to control streaming sessions.

Theory of Operation

This section describes in detail the sequence of steps the UPnP control point implements and how the user interacts with it. The operation is divided into three phases: discovery, browsing and selecting content, and playback.

Discovery Phase

When the TV adapter is activated, its control point searches and discovers all UPnP devices and services on the home network. As a result, it discovers the PVR media server with support for QoS and security. It also discovers the wireless gateway as a UPnP IGD device with support for UPnP Security and policy management services.

Browsing and Selecting Phase

As soon as Jim points the kitchen remote at the TV and starts interacting with it, the TV adapter queries the UPnP AV content directory service running on all media servers in the home—including the living room PVR—and requests a list of movies that are available for viewing. The TV adapter presents an electronic program guide on the TV that allows Jim to select one of the movies to watch. As Jim navigates through the list of interesting titles, he finds the movie *Gladiator* and selects it for viewing. Jim may want to learn more about the movie by pressing the Info button on his remote, which then triggers the TV adapter to display a synopsis of the movie plot, the number of chapters, and languages supported by the soundtrack. Jim can also see if the movie is available for free viewing or whether he will be charged an extra fee for watching it.

During the process of finding movie content on the PVR, the TV adapter also determines certain technical details about the movie, such as information about the digital format used to encode the movie. Jim never sees this information, but it is used later by the TV adapter and the PVR media server to set up the correct network connection and playback configuration when the movie actually starts streaming.

Jim, unaware of the extra work being done by the TV adapter on his behalf, decides to start watching *Gladiator* from chapter 15 and settles back in his chair. The navigation and title information are not encrypted, so Jim is able to browse through his movie list without interacting with the DRM even though *Gladiator* is commercial content.

Playback Phase

When Jim presses the Play button on the remote to begin playing the movie on his TV, a number of activities are triggered. On the server, the Content Protection/DRM module makes an entry in a billing log to identify the movie being watched. Later, this billing log will be sent to a central server where Jim's credit card will be charged for the appropriate amount. The control point invokes the connection manager services on both the TV adapter and the PVR to set up the connection. It requests a list of streaming protocols and the supported media formats. After processing the response, the control point selects HTTP streaming and the MPEG2 format.

On the media server, the DRM retrieves the key used to unlock *Gladiator* from its database and securely sends that key to the TV adapter. Now the application can begin to stream the encrypted movie to the TV adapter. When the TV adapter receives the encrypted buffers, they can be decrypted and then processed. The control point also

* Other brands and names are the property of their respective owners.

invokes the AV Transport service on the TV adapter and sends it a "play" command, which triggers the media streaming engine to start decoding and playback.

Variation of the Above Scenario

Instead of the TV adapter acting as a control point, it is possible for the PVR Media Server to perform this role and provide the user interface that is rendered by the TV adapter. Remote I/O supports this capability. Using Remote I/O, user input is collected from the remote control by the TV adapter and forwarded to the PVR. The PVR provides appropriate user interface screens for display by the TV adapter.

CONCLUSION

Personal Computer (PC) and Consumer Electronic (CE) collaboration creates significant new business opportunities for both the PC and CE industries. Both industries are actively working to capitalize on these opportunities. An important key to success for these new opportunities is vendor interoperability.

This paper covered the basic interoperability requirements for the Digital Home and proposed a Home Interoperability Framework (HIF) for creating innovative and interoperable solutions that can greatly enhance the consumer's digital entertainment experience. The HIF is based on well-established standards for home networking such as 802.11 wireless LANs, IP-based internetworking, and the UPnP* architecture.

ACKNOWLEDGMENTS

This paper is the product of the collective thinking of many architects inside Intel Labs and Product divisions, too many to list here. These individuals deserve much credit for continuing to push the Digital Home vision for Intel and for the industry at large.

REFERENCES

[1] UPnP Forum, http://www.upnp.org

[2] UPnP Technology, Intel Research and Development, http://www.intel.com/labs/connectivity/upnp/

AUTHORS' BIOGRAPHIES

Yasser Rasheed is a Network Architect in the Corporate Technology Group, Intel Corporation. He has been with Intel for two years, and has been involved in a number of projects related to home networking and advanced media streaming over wired and wireless networks. His interests include UPnP technology, Quality of Service, and policy-based networking for real-time applications. Yasser holds a B.Sc. degree in Electrical Engineering from Cairo University, Egypt, and M.Sc. and Ph.D. degrees in Electrical and Computer Engineering from the University of Toronto, Canada. Yasser's e-mail is yasser.rasheed@intel.com

Jim Edwards is a lead architect and a technology development manager with Intel Corporation's Solutions Architecture lab in Hillsboro, Oregon, working on the architecture and technologies for the Digital Home. Solutions Architecture is a part of Desktop Platform Architecture, which is an architecture organization within the Desktop Platform Group responsible for defining and developing platforms of the future. His interests include home networking, digital media, and sports cars. Jim holds a B.S. and M.S. degree in Electrical Engineering from Cornell University. His e-mail is jim.edwards@intel.com

Charlie Tai is a Principal Engineer in the Corporate Technology Group, Intel Corporation, and has focused on communications and networking technologies and strategies. His interests include home networking, ad-hoc networking, broadband network, Quality of Service and traffic management. Charlie has represented Intel in standards and industry organizations such as the Winsock 2 Forum, ATM Forum, UAWG, DSL Forum, USB Forum, IETF, and the UPnP Forum. He has been on the UPnP Forum Steering Committee and on the Board of Directors of the UPnP Implementers Corporation. He was instrumental in the establishment of the Internet Gateway, Audio-Video, and Security working committees in the UPnP Forum. Charlie received his B.S. degree in Computer Science from National Taiwan University and an M.S. and Ph.D. degree in Computer Science from UCLA. His e-mail is charlie.tai@intel.com.

* Other brands and names are the property of their respective owners.

For further information visit:

developer.intel.com/technology/itj/index.htm