Audio/Video Inter-Device Power Control

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ABSTRACT

A large amount of energy is used by audio/video devices in homes and elsewhere that are fully on but don't need to be. Today, most powering up and down of these devices is done manually (including with remote controls). This is becoming increasingly problematic as the number of devices connected or networked to each other rises, with many in other rooms, or elsewhere on the Internet. Neither the manual approach nor a centralized command and control approach are likely to be satisfactory, either for users or for energy use. This paper describes a system for managing A/V device power state by the principle that they should "wake up when they need to, and go to sleep when they can." This system would require devices to communicate and coordinate for functional and power state purposes and could provide greater usability to people as well as save energy. This paper reviews key concepts underlying present and future A/V systems, and explains the architecture and the usage models the system is designed to support. This paper also summarizes how current communications technologies and device usage models already contain or lack the features necessary to support the general model. Finally, the paper reviews the steps needed to make this vision of integrated audio/video inter-device power control a reality.

Introduction

Audio and video devices in U.S. homes are estimated to consume about 140 TWh/year (Urban, 2011). The portion of this from devices on but not in use is not known, but even if it is only 10% of this, that is well over $1 billion/year in wasted energy. As the mechanisms described in this paper generally do not increase the manufacturing cost of products, attention to this topic is clearly merited.

Audio/video (A/V) systems today are of great variety in vintage, technologies, and size. While this paper primarily considers what power control of these devices should be like in the future, with new devices, the current devices and context greatly shape that future in many ways.

A/V systems provide people with entertainment from traditional television broadcasts, subscription TV services, pre-recorded content, and, increasingly, from the Internet. These systems enable many different usage scenarios requiring different sets of devices to be on and active. With many devices, multiple users, and evolving technology, it is easy for devices to remain on long after the time they are needed, wasting energy. This paper proposes an architecture for managing A/V device power state with the key principle for each device to "wake up when it needs to, and go to sleep when it can". This should enable power control to be more automatic and reliable, and provide greater usability to people as well as saving energy. The rest of this paper is organized as follows. First, key concepts for A/V systems are defined and explained. Then, the candidate architecture is proposed and detailed operational issues considered. Finally, there is consideration of the transition period with many legacy devices and a summary of next steps.

Audio/Video Systems

This section reviews key concepts that underlie the complex structures of A/V systems. An A/V system is a collection of devices that provides video content (usually on a television), and/or audio content (usually on loudspeakers). Systems that provide video almost always also produce audio, and the great majority do both. Most A/V systems are found in residences, but they are present in all building types, including vehicles. Most A/V systems interact with devices in other locations **via** the Internet or in subscription television (cable/satellite) infrastructure. These remote devices are not part of the local A/V system, though they can affect local power control.

It is becoming more common to connect traditional Information Technology (*IT*) devices like computers to A/V systems, and to be compatible, including for power control, the IT devices should implement needed A/V protocols and behaviors, such as those described here.

Useful metaphors for A/V systems include "ecosystems," "collections," and networks. These systems evolve over time, as devices are added or removed, fail, and upgrade software. The usage models that individuals bring to their A/V systems also evolve over time, as device capabilities, and the interests and needs of users change. As an example, mobile devices bring a new dynamic to A/V systems, both in function, as a source of content for TVs or an additional display, and in technology, as in the wireless protocols used.

Example Systems and Devices

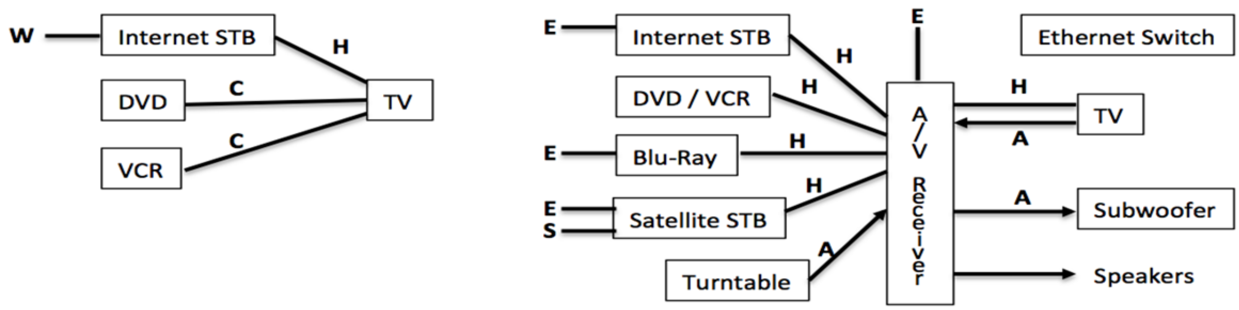
Figure 1 shows two typical example residential A/V systems found in the field. In the simple system, there is no separate A/V receiver, so that all audio comes from the TV itself. The complex system has a receiver which is used to select among the various sources (and can be a source itself) and provides five-channel sound. The links are labeled as **E**thernet, **W**i-Fi, **H**DMI, **A**udio, **C**omposite video, and **S**atellite. Most devices have more interfaces than indicated by the links shown – often many more. The simple system has four powered devices (plus three remote controls); the right one has nine powered devices (and five remotes). All of the Ethernet links are used to access the Internet, not for communication between the devices in the system (links to the Ethernet switch not drawn for graphical clarity). The main speakers are powered through the receiver, so not independent devices in this context.

The devices in these systems already have some power management capabilities. For example, the subwoofer will go to sleep automatically if the audio input is silent for an extended period of time, and then wake when the audio reappears. The Internet set-top boxes also have an auto power-down feature after an extended time in the navigation menu with no input.

Concepts

The basic unit of an *A/V system* is a *device*, which has its own *power state*. Each device has a set of *interfaces* for communication. Connected interfaces on two devices form a *link*. The primary data transmitted across these links are *streams* of audio or video content. Devices can be the *source* (e.g. DVD player) or *sink* (e.g. TV or speaker) of a stream, or an *intermediate device* through which the stream passes that is not its source or sink. A component often ignored in consideration of A/V systems is the *users* who actually consume the content and interact with the devices. Data communicated other than the content streams include *control signals*. Details of each of these concepts are covered below.

Figure 1. Two example A/V systems (Left: Simple; Right: Complex)



Devices. Each device is individually powered, and has one or many communications interfaces, usually employing a variety of technologies.

Power states. The overall *power state* of a device determines the types of functionality the device is capable of, responsiveness to the various supported interfaces, the front panel user interface, and power consumption. While the power levels of a device within a basic power state do vary somewhat, the basic power state is the primary determinant of overall energy use, and consequently is the key consideration for saving energy in A/V devices.

Originally, A/V devices had only two basic power states: on and off. Decades later, two factors emerged to change this. First, the label "standby" was applied to any low-power state in which power consumption was non-zero[1], and as devices increasingly had off modes with non-zero power, standby became a synonym for off. Second, remote controls (usually with one-way infrared communication) were introduced which included the ability to turn a device on and off. When such devices were functionally off, they still required power to detect a power command from the remote control, creating a difference from the traditional off state. Such devices still had only two widely used power states, with disconnection from their power source used only rarely, and the "standby" state exited with a power command and so still an off mode.

Some newer devices have three basic power states. An active mode, an off mode (which can only be exited with a power command), and an intermediate mode in which it is also responsive to communication from other devices. With Information Technology (IT) devices, these are usually called sleep states, but in A/V devices, no consistent terminology has been applied.

Interfaces and links. An interface is hardware that enables a possible communications connection (link) to another device. Interfaces can be of many different wired technologies (e.g. composite video, line level audio, HDMI, or Ethernet) or, more recently, wireless. Some interfaces are deployed in groups, to enable multiple parallel links as for individual audio channels, for separate colors in component video, or for audio and video separately.

A data link is a point-to-point connection between two devices. There are many types: analog or digital, one-way or two-way, etc. A link is defined by the interfaces at each end, which

[1] The standard symbol for "on/off" is ⏼ which implies zero power when off; the "power" symbol is ⏻ and allows non-zero off and has the name "standby". This name dates back to at least 1973.

must match. Originally, all A/V communication occurred in discrete links between two devices. HDMI introduced sequences of links of up to seven devices.

Network technologies enable arbitrary communication among any number of devices. Networks are not traditional in A/V systems, though as Internet Protocol technologies make inroads, they are beginning to be a factor.

Streams. A stream is an ongoing flow of data that transports audio and/or video content. It flows from a source to a sink, across one or more links, of the same or different technologies. A stream is an association between the source and sink devices, and the source context (e.g. channel, time in media, or playlist name).

Some A/V systems can have multiple streams operating at the same time. Examples are when one source is being recorded and a second source is displayed on a TV, and "picture-in-picture" features that show two streams on the same screen. Stream topologies are becoming more complicated with ability to replicate video content to a second TV, and split off audio from a video stream to a separate device.

A stream may contain typical TV or movie content, or a content navigation screen. Streams can also be static (e.g. when content is paused), audio-only, or audio with peripheral video content (e.g. artist and song title).

Sources. A source is the initial appearance of a stream within an A/V system. Examples include local static media (e.g. DVDs), recorded media (on DVRs), remote content (e.g. from broadcast or service providers), or locally created content (from security cameras, PCs, or game consoles).

Sinks. A sink is the final destination of a stream, with the most common sink being a television display with integrated speakers. A "display" communicates media to a user. A TV's main component is its visual display; speakers are "audio displays."

Intermediate device. Some devices are sometimes or always only a "pass-through" of content and neither a source nor a sink. An A/V receiver is the most common example of this. Some devices can be sources, intermediates, or sinks at different times or for different purposes.

Control signals. Control signals are data that are not part of a media stream itself, but which actively determine or describe the content being displayed. Examples include infrared data from remote controls, and control paths on digital links such as HDMI. High-end A/V components sometimes include interfaces for control signals, some of which use RS-232 interfaces; these enable a central controller to direct the detailed operation of other devices.

Power Control in Current Systems

Today's A/V systems are generally very good at accomplishing their primary function of displaying media content for people to enjoy. However, control of power states on these devices is frequently cumbersome and/or confusing. For a variety of reasons, devices are often left fully on when not needed, wasting energy. Users are annoyed and distracted by manually powering up devices when needed.

The core issue of this paper is the matching of content wanted (and actually consumed) by people, with devices being active as necessary to deliver that content. Energy efficiency is best served by doing this as precisely as possible, with the least burden imposed on users.

An Improved A/V Architecture

This section describes principles for a new A/V power control architecture, which builds on existing technologies, but makes key changes and additions. The concept only addresses how devices should behave in an optimal future with all new devices; how we manage the transition is considered later. Power control is primarily about transitions – how a device knows when its state should change. This section covers principles fundamental to the new approach, issues encountered in changing power state, what this means for how devices behave, and user interface concerns.

Starting Principles

A/V devices are beginning to adopt many conventions and technologies from computers in how they communicate and behave. Examples include the change from using only data links, to increasingly making use of network connections (that are digital and bidirectional), and the ability of some A/V devices to perform multiple tasks simultaneously. Thus, lessons from how PCs are power managed are likely to apply to A/V devices. Key among these are:

- Use a three-state power state model (not two) and make it clear in the user interface.
- Maintain network connectivity in sleep.
- Ensure that power management is as automatic as possible.
- Keep delays on device wakeup short (a few seconds at most).

These lead to several conclusions about devices; they should:

- Be aware of the *power state* of other A/V devices in the local network.
- Be aware of the *functional state* of other A/V devices in the local network.
- Mostly toggle between on and sleep.
- Be quick to wake, and (relatively) slow to go to sleep.

Streams

Media content streams are the core of A/V system functionality and need to evolve to create new capabilities and to optimally support power control.

Computers have three basic power states, and since applications are contained within a single device, they go to sleep with the device, and the operating system informs applications when the sleep and wake events happen. In A/V devices, streams are the analog of applications, being the basic unit of activity. Since streams inherently involve multiple devices, power management of them can be considered separately from the power state of the involved devices. In general, the three-state model has advantages over its two-state counterpart.

This paper proposes that devices also support “sleeping” streams, that have representation within devices and networks, but in which no content is being communicated. This would enable new functionality. A sleeping stream should be more available than a stream which does not exist (new streams must go through a series of link and inter-device negotiation steps, requiring both time, and user effort). A sleeping stream would be distinct from one which is active but just paused, since a paused stream needs to be able to resume with no delay at all and should contain a static image of the pause point.

As with sleeping devices, people will need to be aware of the sleep state of a stream to understand differences in its functionality from a fully active one, and as it may be useful in how devices are used functionally. For example, the video stream from a security camera could be set as a sleeping stream and so have authority/capability to wake up a television when it becomes active. By contrast, a mobile phone entering a space that does not have a relationship with the TV might need to have the TV powered up first before it can negotiate access to the display.

Another relevant analogy for streams in a network context is the Transmission Control Protocol (TCP), widely used in Internet communications (Postel, 1981). It enables reliable bidirectional data transfer between two end points. Before any data can be transferred, a negotiation takes place between the two end points to agree to open the data connections, and the device that gets the request from the other can refuse it. Either side can close the connection at any time. TCP connections do not have the concept of a sleep state (although they probably should), but if an extended period of time passes with no data being sent, then either device can send a "keep-alive" packet with no stream data to assure the other side that it is still there. Since TCP includes acknowledgment packets, presence of both devices on the network is confirmed any time data or keep-alives are exchanged. The energy burden of occasional packets is minor, as long as doing this does not require a higher device power state.

The combination of sleeping devices and sleeping streams should provide needed flexibility for a variety of current and emerging usage scenarios while keeping the complexity of the system manageable for both devices and the people that use them.

Powering Up Considerations

Users care most that devices are on and available when they are wanted. It is important to minimize or avoid forcing people to power up devices manually (e.g. with its remote control, its power switch, or with a different remote programmed to do so).

Consider a simple example with three source devices (DVD player, set-top box (STB), and camera), an A/V receiver they all connect to (intermediate device), and a television (sink). Today, powering up the TV results in display of the content source that was active when it was powered down (a receiver, internal tuner, or directly attached source device). When a receiver powers up, it does the same. Thus, when all necessary devices are powered on, the last stream in use is revived, but the powering up is usually not automatic today. Formalizing this, waking the stream should cause all involved devices to wake up. A corollary is that on device power down, the last stream being displayed should commonly be put to sleep rather than terminating it entirely, so that it can be woken at a later time.

In this example, powering up the TV and then selecting a source as needed is likely the most common usage model. Apart from possibly defaulting to the last known source, the TV will want to know what devices and streams can be selected. This is a reason that devices should be present on the network even while asleep, so the TV can correctly represent what source devices are available (including visual representation of the power state of each device).

The other common usage would be to power up the source device through interacting with it, which should cause the TV to then wake if a stream is activated. For example, a user may insert a DVD into the player in which case watching the DVD is the most likely next step (by contrast, removing the DVD should not cause a TV wake event). If the TV is woken, it should then switch to the DVD player as the source. If the TV is already on, the user may be watching a different stream (e.g. broadcast TV) so switching streams is not necessarily the right choice. This is an example where the TV itself needs to be the arbiter of its state and functionality – the other devices should not command it, but rather provide good information for that decision. Similarly, if a TV powers down, that fact should be relayed to the source device, but an explicit power command should not be sent. For example, a set-top box may be providing streams independently to several different TVs at the same time, or to a recording device, so when the first stream goes away, the other streams may still be active.

Intermediate devices usually are less interesting and important in a networked world than in one dominated by data links. Internet Protocol (IP) switches and routers commonly have no involvement in the content of the data they pass. The main action that intermediates need to take is always wake up any time a stream is created or woken. In the A/V context, intermediate devices may have active functions. These could include splitting off the audio part of a stream to other devices (e.g. speakers), duplicating the whole stream to secondary TVs, or combining several streams into one.

Most devices will wake any time a sleeping stream they are part of is woken. A request for a new stream involving the device will often wake it, particularly if the requesting device is well-known. Intermediate devices will always wake as needed as it is the end points that will make the decision about the state of the stream.

In sum, devices need to always wake if they need to (or even just might need to), to maximize user convenience and match expectations. If they fail to do this, users will likely disable power saving features, leading to much energy waste.

Powering Down Considerations

The other part of power control is for devices to know when they should go to sleep (turning off will usually be something actively done by a user). As a TV does not have a network connection to the people watching it (or listening to it) it has to make assumptions about when its services are still wanted. In most usage cases, there are rarely periods of no user interaction with an A/V system longer than a few hours, and usually much less. Signal examples include changing volume, changing channels, and pausing media; these indicate that someone is present and active. If a long enough time passes with no activity, then it is likely that no one is present.

In future, there will be an increasing number of ways for devices to glean information about occupancy, from direct sensors, from sensing mobile phone location, and communicating with other devices in the room or building. Today, many people commonly experience TVs for extended periods of time as audio-only from a nearby room, so this behavior needs to be accounted for in decision-making. When TVs automatically power themselves down as the occupant leaves, people may take advantage of that on a routine basis, and so entirely abandon actively powering them down (an increasing number of TV models incorporate occupancy sensors which facilitate this). Already, many people rely on a PC monitor powering down automatically based on PC activity as their primary or only monitor power management method.

Another power-down scenario is when a stream is paused for an extended period of time. For example, a DVD may be being watched, and in the middle of it, the TV is switched to broadcast content (the DVD should then automatically pause). After some suitable time (perhaps 15 or 30 minutes) the source could consider that the delay may be very long and so put the stream to sleep and then go to sleep itself. Waking the stream would wake the player at the location of the pause.

Streams that are finite, such as a movie, may be followed by a navigation menu. This should have some time-out (e.g. 15 minutes) until the stream goes to sleep so that the menu is not displayed indefinitely.

A/V devices are commonly used for sequences of activities rather than only isolated ones, so that it is appropriate for them to wait some period of time after a stream powers down before putting itself to sleep. How long to wait is likely dependent on the context and should be adjustable by users, but consistent default settings would help the user experience.

A final case is when a source or sink disappears from the network entirely. Turning a device off will usually accomplish this, as could disconnecting a communications cable. Similar to the previous case, a short delay is appropriate as the cut in the network connection may not have been intended and will be quickly restored.

In general, if devices power down immediately, it will annoy many people and lead to disabling of power management features. Modest delay times after use will be a good "investment" to avoid disabling, and will represent a small portion of overall time in the on state.

Standard Device Behaviors

From considering the above and other such scenarios, a set of standard behaviors can be defined for streams and for different device types, including standard default delay times. These behaviors could then be adjusted by users, much as power management settings on PCs and printers can be adjusted today. Some current behaviors are context-dependent (e.g. delay times on a PC can be set differently depending on whether it is mains-powered or on battery). A/V device behavior decisions could also be informed by context (e.g. that a long sporting event is on or by the time of day). Devices should provide for temporary overrides to behaviors in addition to making permanent alterations (otherwise it is easy for "temporary" disabling of power management to inadvertently become permanent).

A general principle here is that possibly-relevant information needs to be distributed among A/V devices on an ongoing basis, whether they are on or asleep. This requires that devices retain network connectivity throughout, and in most cases data links should also be kept open whether the device is on or asleep. Protocols need to support implementing these behaviors. A summary of the requirements for devices specified above is presented in Table 1. These are not complete; consideration of further use cases will add to the list.

User Interface Needs

Past experience with power control of electronics has shown that unclear or inconsistent user interfaces are a barrier to saving energy. In addition, standardizing user interfaces has a very low to no manufacturing cost, and improves the overall user experience. One need is to clearly embody the 3-state power model into A/V devices, in hardware (including indicator lights), and software control panels (Nordman, 2003. IEEE, 2004). Another need is to put device power state into navigation user interfaces, so that when devices available are presented, there are subtle distinctions made between those that are fully on and those that are asleep (off devices will generally not be visible at all). This distinction can help alert users when there are functionality differences between sleeping and on devices. It can also help a user to diagnose problems, e.g. to see when devices are fully on that don't need to be (many users do not commonly look at most devices, locating them in cabinets, closets, or elsewhere).

Inertia is a powerful force in user interface design, and power control is not a feature that is likely to be a driver of purchase decisions, so manufacturers have little incentive to focus on it. However, it is clear that the energy savings benefits from improved user interfaces is orders of magnitude larger than the costs required to deploy them.

A further user interface challenge is how to represent content streams other than those actively being viewed. It remains to be seen what overall principles and approaches manufacturers will bring to this so it is premature to comment on it from the energy perspective.

Table 1. Device behavior requirements

Basic Behavior	Details / Examples
Communicate device and stream state to network	
Selective device wake on stream wake or stream request	wake on all stream wakes; wake on all stream requests for certain devices
Stream termination or putting to sleep	delay time after stream is paused
Device powering down	delay time after no user interaction with A/V system
	delay time after no indication of occupancy (more than just interaction)
	delay time after wake with no subsequent use of device
	delay time after content entity (e.g. movie) has ended
	delay time after stream suspended by loss of network connectivity

The Road Ahead / Transition Considerations

Even when a well-functioning system is implemented in all new devices, we will still have a huge stock of existing "legacy" devices that they will need to interoperate with new A/V components. Systems with legacy devices will use more energy and lack usability advantages; effort will be needed to assure that problems in both areas are minimized. New devices will need to detect when they are interacting with legacy devices and be able to adjust their behaviors accordingly.

Interfaces

While future devices should have broader visibility into networks and streams, legacy device information is usually limited to what is apparent from individual interfaces and at best only to directly-connected devices. To understand the depth of the problem, it is important to first review existing interfaces and existing devices. Existing interfaces can be divided into two major categories: analog and digital. Analog are almost always one-way and wired. Digital interfaces can be data or network links, can be one-way or two-way, and can be wired or wireless.

For two-way digital interfaces, it is usually possible to determine if a powered device is present at the other end of a data cable (and similarly for wireless), in addition to whether a data stream is actively being exchanged. This is a great advantage over analog for which it is usually not possible for a sending device to know if there is a device receiving the information. An analog receiving device can detect when there is no video signal, and can identify when there is no audio signal by observing silence for an extended period of time.

In one-way wireless links, the transmitter can't know the status of the device at the other end of the link, and the receiver needs to be always listening in case the transmitter wakes up.

The other aspect of interface behavior is wake events. While a device that is off pays no attention to content interfaces (only to those interfaces that may contain a power command such as an IR signal from a remote), sleeping devices may want to wake on some or all content interfaces. For analog and basic data links, a signal could appear where there had previously been none; there is no need to understand anything about the signal, just that it exists. It is desirable for a networked device to remain present on the network while the device is asleep, which may involve generating some routine traffic, and understanding incoming traffic sufficiently to detect when data on the network is of a nature to warrant waking up.

Existing Device Behaviors

An early example of power management on A/V devices is the "sleep timer" which powers down the device after a defined time period (e.g. one hour) so that it will occur after the user has gone to sleep (or is otherwise no longer expected to be consuming the content). Many subwoofers have auto power-down and wake up features.

In the ENERGY STAR program, the (now expired) requirements for Digital Television Adapters (that enable use of analog TVs after the conversion to digital broadcasting) included an auto-power-down (APD) of four hours or less after the last user input detected (EPA, 2007). The feature had to be enabled by default. The requirements for Audio/Video devices are presently being revised for a third version (EPA, 2012a). In the newest draft, the default timer setting for APD must be no more than two hours. Stated examples of coverage are a DVD player to power down after a movie has finished, and an audio amplifier to power down when sound ceases to be supplied to the selected input. The draft notes the possibility that a device could wake when signals reappear, but there is no requirement and no test associated with this possibility.

Many devices sold today lack key features for automatic power management, or when they are present, they are often disabled as shipped.

Remote Controls

Remote controls present a variety of difficulties in how they can be used for power control, though in an optimal situation, they can be very effective. One issue is physically transmitting the signal to a device, since Infrared requires a line-of-sight view between the remote and the device in question. Second, a user of the remote may not understand the capabilities of the remote, and what sequence of button presses is required at any particular point in time. Third, a remote control may not have the needed features and/or capabilities. For example, someone may be finished watching a television program (and want to power down the display), but still want to listen to music (and not power down the audio amplifier). Fourth, many remote control power commands toggle the power state of a device rather than deterministically set it. Thus, if the device is not in the state that the remote control expects, it will end up accomplishing the opposite of what was intended. As new devices begin to do automatically what older ones had to be commanded to do, they will need to selectively ignore remote control commands.

Next Steps

The architecture described here has not yet been vetted with the consumer electronics industry or subjected to the full range of use cases needed, but serves as an example of what could be specified. It will require extensions to protocol standards; in particular, adopting the three-state power model for devices and streams, and always exposing power and functional state to other devices on the local network.

A next step is to refine the architecture, and then create a reference document that could be forwarded to an appropriate standards organization for consideration. This document should enable product designers to understand what to do and why, how to present this to users, and how to adapt the system to new circumstances.

A subsequent task is to review communication technologies to determine gaps between what they do today and what the architecture describes. Assuming there is agreement with industry on the general approach, the standards gaps can be addressed and the principles put into new products. Some features can be put into products even before the standards development is finished. A final need is a detailed summary of recommendations for how to deal with legacy products.

Essential to the harmonization process will be to get critical review from manufacturers of A/V devices, and the standards committees for relevant interface technologies. If a critical mass of these individuals and organizations do not support the system, it will not succeed. Manufacturers need to be assured that user amenity is the top priority.

The principal communications standard needed to accomplish this architecture in use today is HDMI. Apart from providing the needed data path to send video data, HDMI also has features for content protection, addressing piracy concerns for many companies. HDMI is most commonly understood as a point-to-point mechanism, but it does facilitate a tree of devices with a single display at its root. It is possible to directly embed the notion of a sleeping stream within the core HDMI protocol, or implement it at a "higher layer" over the Ethernet channel present in newer versions of the standard. Regardless of the mechanism, the HDMI organization (HDMI Forum, hdmi.org) could host such a standard.

It is also likely that one or more standards will get wide use for transporting A/V streams over Ethernet and Wi-Fi. These standards will also need the features described in this paper.

Conclusions

A/V device control is a complex topic with diverse devices, interfaces, technologies, system construction, usage models, and users. As power control has not been a high priority for the industries involved, it is not surprising that it is not well articulated in current technologies and devices. Digital technologies not only bring functionalities, but also offer the possibility of a more robust system for power control. A new power control architecture seems possible to construct and implement in technologies and products. In the interim, improving products with legacy analog interfaces will inherently complicate power control, and present a great challenge.

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