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IMPROVED AUDIO-VIDEO EFFICIENCY THROUGH INTER-DEVICE POWER CONTROL

National Lab Buildings Energy Efficiency Research Projects

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PREFACE

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ABSTRACT

Audio/Video (A/V) systems provide people with entertainment from traditional television (TV) 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 after they are needed, wasting energy. The goal of the project is to save substantial electricity by creating a technology standard on managing power states of interconnected A/V devices. This standard can then be incorporated into future products and communication standards.

Initial phases of research included assessing features and capabilities of relevant products for sale today, and evaluating communication technologies used in A/V systems to understand inter-device coordination. The team created a new technology concept of persistent, or "sleeping," content streams for inter-device communication, and tested the concept against use cases. The Consumer Electronics Association (CEA) ultimately created a working group to write an umbrella standard to implement persistent streams. Individual technology standards will add necessary features identified in the CEA standard. Device manufacturers can then include behaviors specified by the standard. Users will find the added convenience attractive, with energy savings an added benefit

Audio and video devices in U.S. homes are estimated to consume about 140 TWh/year (Urban et al., 2010]. Some unknown portion of these devices is on, but not in use. Assuming that only 10 percent of A/V energy use is due to when they are unintentionally on, over 1 TWh/year wasted enegy and well over $1 billion per year in energy cost. Costs to consumers to add power management to A/V devices should be negligible or low, making these strategies highly cost-effective.

Keywords: audio video, A/V, A/V stream, A/V power control, sleeping stream

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EXECUTIVE SUMMARY

Introduction

Audio/Video (A/V) systems today vary widely in vintage, technology, and size. New technologies evolve from the current generation of devices, thus current scenarios for device-usage directly impact future technological development. 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 after they are needed, wasting energy. This report primarily explores the power control of these devices in the future. The Authors propose an underlying principle for managing A/V device power state based on the key principle that each device should:

"wake up when it needs to, and go to sleep when it can."

This principle will enable power control to be more automatic and reliable, provide greater usability, and save energy.

This report summarizes research on "Improved Audio Efficiency through Inter-Device Control," as part of the National Lab Buildings Energy Efficiency Research Projects sponsored by the California Energy Commission. This project aims to save substantial electricity by creating a technology standard on managing power states of interconnected A/V devices. This standard can then be incorporated into future products and communication standards.

Initial phases of research included assessing the features and capabilities of relevant products for sale today, and evaluating communication technologies currently used in A/V systems. This baseline provided an understanding of inter-device coordination among products today. The team developed a set of use cases to cover usage scenarios that a technology solution would need to implement. In parallel, the team created a new technology concept, of persistent, or "sleeping" content streams, as the mechanism for inter-device communication. This concept appeared to satisfy the use case needs. The researchers asked technology standard developers and committees to review the sleeping stream concept, and requested comments and consideration. The Consumer Electronics Association (CEA) ultimately created a working group to write an umbrella standard to implement persistent streams. Individual technology standards will add necessary features identified in the CEA standard. Device manufacturers can then include behaviors specified by the standard.

Audio and video devices in U.S. homes are estimated to consume about 140 TWh/year (Urban et al., 2010]. An unknown portion of these devices are on, but not in use. If A/V devices are left on unintentionally 10 percent of the time, this translates to more than 1 TWh/year in wasted energy or well over $1 billion per year in wasted energy cost. Anticipated costs to consumers for adding power management to A/V devices is negligible or low, making these strategies highly cost-effective.

Project Purpose

The purpose of this project is to create a new technology that can make power control of A/V devices more automatic so that devices spend as little time as possible being fully "on" when not in use. Most A/V devices exist in local networks, where more than one device is involved in any particular stream of content. A simple case is when a source of content such as a media player or set-top box passes a content stream to a television for display. With more than one device involved in the content stream, managing the power state inherently involves coordination among the connected devices. In addition, users need mechanisms to express their choices (e.g. a remote control). Today's technologies have limited abilities to pass power control signals from one device to another, and to pass functional information so that a device react to power control status about power control. However, these current capabilities are inadequate to cover all usages; they are often incomplete, incompatible, and for some technologies nonexistent. Further, manually managing power state (for example, using the remote control power button) can be non-intuitive and cumbersome. As a result, neither users nor devices can reliably control power, and many devices remain fully on after their use has completed — sometimes for hours or days– wasting energy.

We sought to affect the behavior of A/V devices by changing the communication standards used to pass A/V data streams. Additional data exchanged between devices could provide information so that devices can self-monitor their own power state. Communication standards can require specific features, which manufacturers would then need to implement in products. Thus, changing the standards is a way to change future products.

Communication standards are created by committees with representatives from A/V manufacturers. Changing the standard requires convincing the committee of the merit of the change. This project aimed to minimize the burden on manufacturers by making it easy to include the new technology in their products. This approach was embedded in the project plan from the beginning.

Public energy efficiency programs, both voluntary and mandatory, will be able to reference new technology standards developed in this project. For example, Energy Star has a long history of referencing technology standards that have efficiency advantages, several of which have been produced, in part, with support from the California Energy Commission.

Technology interconnection standards are an area of innovation distinct from the technology development done by individual companies. Interconnection standards impose requirements on products that sometimes determine energy use. The standards can prohibit or require particular energy saving features. Since these standards are the result of collective activities, building support for adoption can readily involve the public sector. In contrast, it is difficult for the public sector to engage corporate or proprietary technology development in electronics. Public sector involvement in standard development can leverage the resulting savings, yielding a highly cost effective public investment. The savings achieved by communication standards cannot be attained by other means.

Project Results

The project began with the development of a principle to maximize the energy efficiency of A/V devices. The researchers assessed the current status of products and standards, and confirmed that there was a clear gap in capabilities to manage A/V streams in a way that would be compatible with the project principle. The researchers then created a set of use cases to cover typical usages, and a technology concept capable of implementing the A/V device behavior principle. Finally, the team confirmed that it was feasible and reasonable to add the principle and concept to the important technology standards in use today.

While the project is complete, the technology is not being incorporated into future products. The CEA committee's will take the draft standard content produced by this project and turn it into a final document and have that receive approval by the CEA standards process. Next, the features described in the standard need to be added to communication protocols. Finally, the features need to be put into products, both in implementing the protocol features, and in device behavior. Note that some of these could be done in parallel to reduce the time from now until people can buy products that implement the technology.

Project Benefits

This project has several sets of benefits. The first is energy savings. Power control standards for A/V devices will affect future products. A recent estimate of all electronics use in the U.S. is over 380 TWh/year for the U.S. as a whole. Of this, about 130 TWh/year is due to devices that have conventional A/V content streams as their primary function, with TVs being the largest portion of this. Another 150 TWh/year is from devices that can be part of A/V content streams, such as PCs, plus small amounts from A/V devices that do not send or receive A/V content with other devices. Experience with personal computers shows that energy use of devices when not in use can be well into the double digits of percent of annual consumption. It seems quite plausible that A/V power control technology could save on the order of 10 percent of consumption of the core A/V devices today or 13 TWh/year. It also seems plausible that 5 percent in the PC and related device energy could be saved for another 8 TWh/year. The total of both groups is about 20 TWh/year. Assuming that California is typical of the U.S., and reflects 12 percent of the population, this amounts to a total of about 2.4 TWh/year for California.

Another benefit is user convenience. People interact frequently with A/V systems, and this is likely to grow. As the price of displays continues to fall and their energy efficiency increases, people will have the practical economic ability to have more displays and use them more frequently. Thus, it is increasingly urgent to embed automatic power control in these devices.

This project addressed A/V power control at a high level with wide impact, developing a broad basis of support. In the absence of this project, A/V power control would likely have continued its existing development trend, siloed, within individual technologies. This would have produced solutions that would have limited uses, proved burdensome for consumers and manufacturers alike, and provided fewer benefits.

Finally, this project illustrates that energy can be saved through the development and amendment of technology standards. This is one of the few ways that the public sector can

create new energy savings opportunities in the electronics end use. Most public effort is currently expended on regulations or voluntary programs requiring or encouraging manufacturers to produce, and consumers to buy, products that will use less power; this is one of the few efforts that covers the time dimension of energy use of electronics.

This report 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.

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CHAPTER 1: Background

This chapter introduces the project and related concepts, discusses the project purpose and objectives, describes A/V systems and elements, and outlines the research approach.

1.1 Introduction

Audio and video devices in U.S. homes are estimated to consume about 140 TWh/year (Urban et al, 2011). What portion of these devices is on, but not in use, is unknown. Estimates of only 10 percent would result in well over $1 billion/year in wasted energy. In comparison, this is about 5 percent of electricity use in buildings, and more than three times the energy used by electronics in data centers (servers, storage, and associated network equipment). Developing strategies to reduce energy used by A/V services is a pressing issue and the focus of this research.

While progress has been made in reducing power levels of electronic devices, as energy is consumed over time, it is essential to have strategies that encompass the time element of electronics energy use, as well as power levels. The mechanisms proposed by this project do not increase the manufacturing cost of products, yielding a high return on investment.

Audio/Video (A/V) systems today vary widely in vintage, technologies, and size. However new devices evolve from current devices and contexts, exerting significant influence on the future.

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 after they are needed, wasting energy. This report primarily explores the power control of these devices in the future. The team proposes a framework for managing A/V device power state based on the key principle that each device should:

"wake up when it needs to, and go to sleep when it can."

This principle will enable power control to be more automatic and reliable, provide greater usability, and save energy.

1.2 Project Purpose

This project sought to create a new technology that can make power control of audio/video devices more automatic allowing devices to spend as little time as possible at full power when not in use. Power control is the mechanism to change the power state of a device. Electronics generally use "on," "sleep," and "off." These were standardized by IEEE in 2004 based on research from an earlier CEC/PIER-funded project (Nordman, 2003). Power control can be manual (e.g. pressing a power switch on a device or remote control), or automatic (e.g. a device powering down after a sufficient time of non-use, or waking up based on data sent by another device). Familiar examples of automatic power control include PCs, monitors, and printers

going to sleep after a time delay when not in use, as well as printers waking up when a print job arrives over a network connection.

Most A/V devices exist in local networks, where more than one device is involved in any particular stream of content. A simple case is when a source of content such as a media player or set-top box passes a content stream to a television for display. With more than one device involved in the content stream, managing the power state inherently involves coordination among the connected devices. In addition users need mechanisms to implement their desires (e.g. a remote control).

This research targeted A/V devices within a single building. The project did not address communications with devices elsewhere, such as from a service provider to a set-top box or with devices elsewhere on the Internet (these often have proprietary technologies and include issues other than simple A/V stream transmission). The team focused primarily on content streams that include both audio and video, and that usually end up being displayed on a television. However, streams with only audio or video are also within scope, as are streams that terminate elsewhere, such as being recorded rather than displayed. All communications technologies are in scope, though those that are based on digital technology, rather than analog, are of much more interest.

1.3 Audio/Video 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). Most A/V systems are found in residences, but they are present in all building types, including vehicles. Many A/V systems interact with devices in other locations via the Internet or through subscription television (cable/satellite) infrastructure. These remote devices are not part of the local A/V system. Information Technology (IT) devices like computers are increasingly connected to A/V systems, and to be compatible — including for power control — IT devices they need to implement the same protocols and behaviors as A/V devices.

Typical residential A/V systems fall into two categories. In a simple system, there is no separate A/V receiver, so that all audio comes from the TV itself. Complex systems have a receiver which provides multi-channel sound and is used to select among the various sources (and can be a source itself). These systems commonly included Ethernet, Wi-Fi, HDMI, Audio, Composite video, and pay-TV connections. Many devices sold today already have some power management capabilities. For example, many subwoofers will go to sleep automatically if the audio input is silent for an extended period of time, and then wake when the audio signal reappears. Many A/V devices have an auto power-down feature that initiates after an extended time with no user input, but these typically lack a corresponding wake-up feature.

A/V system and product characteristics are reviewed in more detail in Appendix A. Topics include product modes, power control mechanisms, and other relevant features found on A/V products for sale at that time.

Appendix B reviews details of communications technologies used in A/V systems. It covers traditional analog technologies, digital technologies that use the Internet Protocol (IP) and other protocols, protocols that operate at intermediate layers, mechanisms for device service discovery, protocols for remote display, and control paradigms.

Creating this new architecture was a multistep process. Appendix A is a review of characteristics and features relevant to power control of current A/V devices; Appendix B does the same for communications technologies.

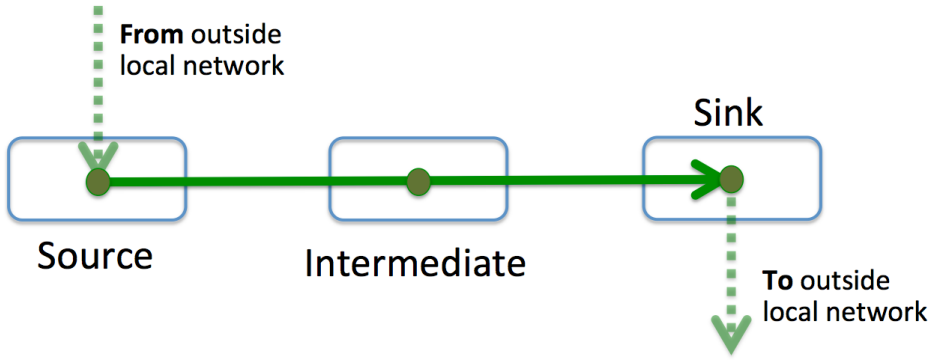
1.4 A/V System Elements

The basic unit of an A/V system is a device, which operates in distinct power states. 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 (e.g. an A/V receiver). In addition to the content streams, other transmitted data includes control signals. Details of each of these concepts are covered below. Figure 1 shows how basic A/V devices map into the source, sink, and intermediate concepts. Figure 2 presents an abstract representation of the same thing. The experience of the users who actually consume the content or otherwise interact with the devices is often overlooked when considering A/V systems.

Figure 1: Basic stream structure and typical components

Source: LBNL

Figure 2: Abstract stream structure (links to outside local network optional)



Source: LBNL

1.4.1 Devices

Each device is individually powered, and has its own power state. It also has one or many communications interfaces, and usually encompasses a variety of technologies (see Interfaces and Links below),

1.4.2 Power States

The overall power state of a device determines the types of functionality, its responsiveness to the various interfaces, its front panel user interface, and its 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 so 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, 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, on and off. Off includes disconnection from their power source (which occurs only rarely), and the "standby" state, which is only exited with a power command, and so also 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. In future, it will be important to make A/V power states more clear and consistent in operation and in the user interface.

1.4.3 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.

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

1.4.4 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 more links, of the same or different technologies. It 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).

1.4.5 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).

1.4.6 Sinks

A sink is the final destination of a stream, with the most common sink 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".

1.4.7 Intermediate Devices

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.

1.4.8 Control Signals

Control signals are data 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.

1.5 Power Control in Current A/V 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 this paper addresses 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.

Today's technologies have abilities to pass power control signals from one device to another, or to pass functional information that a device could use to make its own decisions about power control, but these are limited. However, there are not enough capabilities to properly cover all usages, and the implementation of those that are present is often incomplete or incompatible. Thus, users and devices cannot rely on them to accomplish power control. In addition, these abilities are also fragmented by technology, so that a mechanism that exists within one protocol (e.g. HDMI) will not apply to a part of the same content stream that also passes over an Internet Protocol, before or after its passing over HDMI. This makes using the features much more confusing and less effective.

A result is that many devices end up remaining on after their functional purpose for being on is complete, sometimes for hours or days at a time. This is wasted energy. A related problem is that manually managing power state (as with using the remote control power button) is cumbersome and annoying. Thus, nearly everyone who uses A/V devices suffers from current technology, wasting energy, wasting time, or some combination of the two.

1.6 Research Approach

The mechanism by which the team seeks to affect the behavior of A/V devices is to change the communication standards that they use to pass the A/V data streams. Additional data exchanged between devices could enable better decisions by devices about their power state. Communication standards can require specific features, which product manufacturers would then need to implement. Thus, changing the standards is a way to change future products.

Communication standards are created by committees with representatives from manufacturers of devices that make A/V devices. As a result, changing the standard requires convincing them of the merit of the change. In addition, minimizing the amount of work the committee members need to do increases their likelihood to move something forward. So, this project aimed to make it as easy as possible for manufacturers to agree with the research conclusions, by minimizing the burden on them as individuals, and as companies to include the new technology in their products. This approach was part of the project plan from the beginning.

A benefit of embodying project results into technology standards is that they can be referenced by public efficiency programs, voluntary or mandatory. For example, Energy Star has a long history of referencing technology standards that have efficiency advantages, several of which have been produced in part with support from the CEC/PIER Program.

The core approach of this project was to do the time-consuming work of coming up with a technology solution in this area, then present it mostly complete to companies and standards organizations. While the individuals and organizations involved might be inclined to favor interoperability and energy savings, the scope of this type of project does not typically rise to

top priority for the involved companies. Addressing policies that affect the public good is a key need for and benefit from public sector participation.

This report summarizes the purpose, results, and benefits of the project. First, key concepts for A/V systems are defined and explained. Chapter 2 proposes a candidate architecture and considers detailed operational issues. Chapter 3 describes the development and implementation of standards to comprehensively address A/V power control. Finally, there is consideration of the transition period with many legacy devices and a summary of next steps. Appendices A and B present background research on current products and communications technologies. Appendix C is the analysis of use cases and presentation of the sleeping streams concept. Appendix D has proposed content for the technology standard to address sleeping streams.

CHAPTER 2:
A/V Power Control Architecture

This section describes principles for a new A/V power control architecture, the project use case analysis, issues in changing power state, what this means for how devices behave, and user interface concerns.

2.1 An Improved A/V Architecture

Our new A/V power control architecture builds on existing technologies, and includes key changes and additions. The core concept addresses how devices should behave in an optimal future with all new devices; how the team manages the transition, with mixed systems of old and new products, is considered later. Power control is primarily about transitions – how a device knows when its state should change.

Appendix C presents a detailed exploration of how the concept of sleeping streams would affect the operation of devices and protocols. Appendix C assesses use cases for device and stream operation, the needed device behaviors, and particular issues requiring special attention.

Technology architectures cannot be proved to be optimal nor can they be derived from data like many physical principles. Rather, they can simply be described and explored, and compared to other technologies for their capabilities and burdens (such as complexity). One alternative architecture to the sleeping stream one would include a central control device that would manage the power state of all A/V devices in a local network. This approach appears to be more costly, less effective, and more likely to fail than the sleeping stream approach. One could require that all devices participate in a single network protocol. This is unlikely, at least for the foreseeable future (principally due to the very different link technologies involved), and in comparison to the sleeping stream model, seems unnecessary. Sleeping streams create a distributed network of intelligent devices, each aiming to minimize energy use.

2.2 Starting Principles

This project builds on lessons learned over the last several decades on how to manage digital devices in a network context. A/V devices are beginning to adopt many conventions and technologies from computers on communication and behavior. Examples include the change from relying solely on data links (e.g. the old RS-232 connections to printers), to increasingly exploiting network connections that are digital and bi-directional, and the ability of some A/V devices to perform multiple tasks simultaneously. Thus, lessons from PC power management are likely to apply to A/V devices. Key among these lessons are:

- Use a three-state power state model (not two) and make this model clear in the user interface.
- Maintain network connectivity in sleep.
- Ensure that power management is as automatic as possible.

- Require delays on device wakeup to be 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.

Additional goals include a distributed solution, with devices controlling their own state. The technology should be automatic, enabled by default, and require no configuration. Central control can be implemented through layering on top of automatic distributed control; a key concept is that the central control can stop operating and the system will continue to work.

Returning to the fundamental principle describing how a device should operate:

"wake up when it needs to, and go to sleep when it can."

This has two components. The "wake up" and "go to sleep" are about what a device does, which is a result of behavior. The "when need to" and "when can" are about how a device knows what to do, which is a result of communication.

In constructing the use cases for this project (see below), a design criterion was that users primarily care that devices are on and available when they are wanted so that 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). Devices need to always wake if they need to (or even just might need to), in order to maximize user convenience and fulfill expectations. If devices fail to respond instantly, users will likely disable power saving features leading to much energy waste.

Most people value convenience. An automatic system to power down devices will attract considerably more users than manually controlled devices.

These principles, and consideration of how people use A/V devices today and in the future, led to the sleeping stream and associated concepts.

2.3 Use Case Analysis

The analysis began with an assessment of abstracted use cases of device operation that affect power states in the context of sleeping streams. The researchers' analysis was extensive and the full set of use cases and details considered are presented in Appendix C. There is a minimum set of use cases that covers the needed complexity, and beyond this, additional cases only raise issues already covered by the basic set. For example, cases with more than three devices simply have several intermediate devices, each of which has the behaviors of the intermediate in the three-device case, so that no cases with more than three devices are needed. These use cases all

have an initiating action, which can be to a device or a stream. Each then contains a behavior, which is an action in response to the first action. There may be a string of behaviors that result before the system stabilizes again.

Table 1 shows an example use case with two devices and one content stream. The START and END lines show the power state of each device, while the intermediate lines show the sequence of actions taken by individual entities. If the TV had already been on at the start of the process, the resulting sequence would be effectively the same, since waking the stream would not require step 3 to wake the TV but would be otherwise identical. This is an example of an alternate use case that would add no new device behaviors.

Table 1: Use case example: DVD player powers up

Step	DVD	TV	Stream	Comments
START	Sleep	Sleep	Sleep	
				DVD power-up command (manual or internal timer) or manual play command
1	Wake			
2			Wake	DVD wakes up last stream it participated in
3		Wake		Stream involves TV so TV must power up
4		Input		Change Input (If necessary)
5	Play		On	Only after both devices fully wake (only applies to fixed streams)
END	On	On	On	

Source: LBNL

Table 1 refers to a "fixed" stream. This is a content stream of finite duration, such as a movie. Other streams, such as broadcast media, are continuous and have no definite limit. Device behaviors will sometimes differ between these two stream types. The analysis covered five one-device use cases, nine two-device cases, and two three-device cases. The team also considered two cases in which the stream was addressed directly, rather than via one of the devices; and two example cases of "failure" when a device does not behave as intended and the resulting action is compromised. It is abnormal cases such as failure that can create the most complexity for manufacturers and the most difficulty for users, so it is helpful when the core technology is as simple as possible.

Note that this architecture specifies the results rather than the mechanisms by which the communication enables the sequences of actions. Other standards — extensions to existing standards — provide the mechanisms.

In addition to device (and stream) power states and actions that entities engage in, the use cases also contain other elements. One is user action, which can be direct (e.g. use of a remote control), or indirect (e.g. change of state in an occupancy sensor). Another is a delay timer, such as a period of time of no activity that might initiate a power-down sequence, or the length of time that a warning is displayed of an imminent power-down. A third type of action is unexpected failures of a device or communications link.

The use cases were evaluated to identify standard behaviors that devices should implement. Table 2 shows a portion of the result – behaviors that a source device must have. Appendix C has corresponding tables for sinks, intermediates, streams, and failure modes. While the use cases in Appendix C on first glance suggest significant complexity, the behaviors show that in fact the system is based on a modest number of rules. The relative simplicity of the system is good for the design of needed communication protocols needed, the design of products which implement the protocols and behaviors, and for the ordinary human beings who must use the resulting products and systems.

Table 2: Source Behaviors

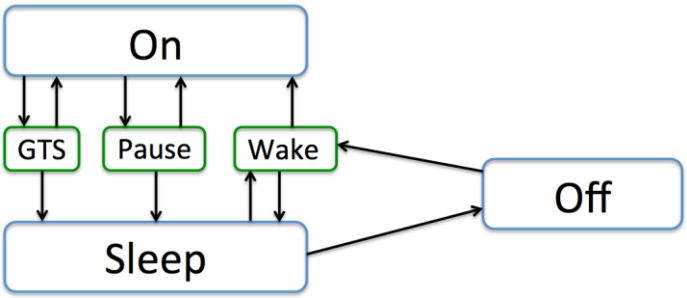
On		
	Notified stream to go to sleep - Pause stream if fixed - Go to sleep	Source paused - Wait for X time - Tell stream to sleep
	Fixed Streams only	
	Fixed content ends - Menu for X time - Tell stream to sleep	“All devices ready" signal from stream - Play content
Sleep		
	Powered up - Wake self - Wake stream	

Source: LBNL

In the course of the analysis, it became clear that several temporary transitional states were needed for such a system to work. Figure 3 demonstrates how the three basic stream states and three transitional states might relate to each other; “GTS” is going-to-sleep. Devices commonly have internal transitional states but the system architecture may not need to represent them externally in the way that recognizes detailed stream states.

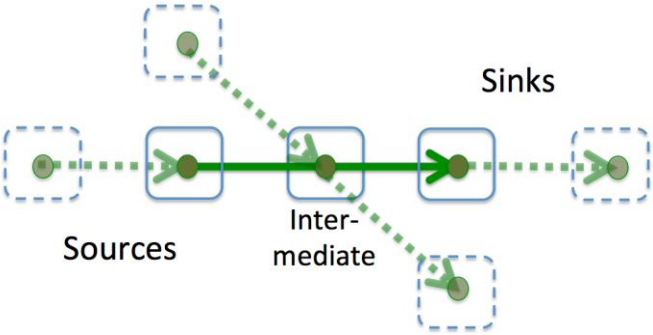
Content streams today are usually simple, involving no more than three devices all arranged in a linear fashion. However, it is quite possible, and even likely, that future streams will include branches into or out of the core stream as well as being longer than three devices. Figure 4 shows this graphically; in this case, the diagonal lines show branches that could be to additional sources or sinks, but they could also include additional intermediate devices (the sleeping stream concept does not limit to the complexity of the device topology). It is not apparent that such complexity needs to change the basic operation of streams sleeping and waking, except for how failure modes are treated.

Figure 3: State diagram for stable and transitional stream states



Source: LBNL

Figure 4: More complex stream topologies



Source: LBNL

2.4 Sleeping Streams

We chose the term "sleeping streams" as the overarching concept of this project as it simply and effectively summarizes the concept. People will likely associate sleeping streams with product sleep states which are so instrumental in saving energy. An equivalent term that can be used is "persistent streams" to indicate that the streams exist over long periods of time rather than being ephemeral. Media content streams are the core of A/V system functionality and need to evolve new capabilities 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 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 streams can be considered separately from the power state of the involved devices (that is, while stream state influences device state and vice-versa, they are often not the same). In general, the three-state model has advantages over its two-state counterpart.

A "sleeping" stream maintains its representation within devices and networks, but no media content is communicated. This enables new functionality and what is desired by the user can more easily match the power and functional state of devices. A sleeping stream is more available than a stream which does not exist. Creation of a new stream requires a series of link and inter-device negotiation steps, requiring time and user effort. In contrast, waking a sleeping

stream requires many fewer steps. A sleeping stream is 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 always contain a static image of the pause point. Pausing usually is for only seconds or minutes. Sleeping can extend for months or years. While a device can be turned off and then turned back on again, the alternative to a stream being on or asleep is for it to be deleted. Once deleted, it must be recreated from scratch for it to exist again.

As with sleeping devices, people may find it useful to have a mental model of the sleep state of a stream to understand its functionality, and how devices are used. 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 specific television (or group of displays) when it becomes active. By contrast, a smart 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 bi-directional 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 receiving the request can refuse. 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, and does not require a higher device power state. Thus, the existence of a potential flow of data is decoupled from the actual flow of data.

An attribute of the sleeping stream concept is that when a new stream is to be created, all of the involved devices must be fully awake. This reduces the complexity that a sleeping device must implement. For example, security and authentication present significant challenges and these are only addressed by devices that are fully on.

The use case and behavior analysis showed that the combination of sleeping devices and sleeping streams provides 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. The previous parts of the project set the stage for it, by clarifying the current context of technologies and devices, but this part of the project fleshed out the persistent stream concept, and demonstrated that it works well for a wide variety of usage contexts.

2.5 User Interfaces

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 effect on manufacturing cost, and improves the overall user experience. One need is to clearly embody the three-state power model into A/V devices, in hardware (including

indicator lights), and software controls (IEEE, 2004; Nordman, 2003). Also, user interfaces for device control should include device power state information, so that when available devices are shown, there are subtle distinctions made between those that are fully on and those that are asleep (currently, off devices are 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 diagnose problems, e.g. identifying devices that are fully on, unnecessarily. Many users do not normally see A/V devices, storing them in cabinets, closets, or elsewhere.

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 use case so it is premature to comment on it from the energy perspective. However, a clear visual distinction between streams that are on or asleep is needed, and this can be standardized (a possible approach is to dim or 'grey-out' a textual or iconic representation of a sleeping stream).

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 improvements. However, it is clear that the energy savings benefits from improved user interfaces is orders of magnitude larger than the cost of deploying them.

2.6 Other Considerations

In the analysis, the team considered a variety of issues that the architecture, protocols, and devices must cover. The following are the major issues considered; full detail in Appendix C.

2.6.1 Named streams.

For device-device communication as well as device-human communication, streams will need to be distinguished from each other, which requires some mechanism for identification. The simplest way to do this is with a human-readable name. Such names will need to be unique within a local network.

2.6.2 Occupancy

As the purpose of audio/video streams is to communicate information to people, the occupancy of a person or people in a space can be critical information to know when to begin or end displaying a stream. Mechanisms to acquire and distribute occupancy information among devices will be a key technology innovation. This can also be extended to other uses of energy such as lighting and climate control.

2.6.3 Failures

When a device or communications link fails, the interaction between people and devices can be the most intense and important. Thus, how devices respond to failure conditions is critical to their user amenity and ultimately energy savings.

2.6.4 Multiple streams in a network

Local networks may contain multiple simultaneously active content streams, with some devices involved in more than one.

2.6.5 Multiple streams per device

While today collections of A/V devices usually only involve a single content stream at one time, in future many of these will be capable of, and commonly implement, more than one simultaneously. This will require adaptations to technologies, products, and user experience.

2.6.6 Multiple sinks and/or sources

Streams today usually involve a single source device and a single sink (an exception is when an A/V receiver sends audio to speakers independently of the video signal sent to a TV). As the availability of sources expands, the team can expect more ability to merge multiple sources into a single stream. In addition, as the cost of displays drops, and the ability to direct data to multiple displays increases, it will be attractive for people in homes (and other use contexts) to replicate a content stream across multiple displays. Both of these will require the same sorts of changes that multiple simultaneous streams do.

2.6.7 Creating and maintaining streams

With persistent existence, there will necessarily be some overhead for both people and devices in managing streams. The burden of this needs to be kept as low as possible while providing needed capability and flexibility.

2.6.8 Emergency broadcasts

As content streams become networked, the possibility of using them for disaster notifications (natural and otherwise) will become apparent and emergency functionality will be implemented. This will require specific network availability of devices, authentication needs, and user preferences for this purpose.

2.6.9 Transitioning Legacy Devices

Even when a well-functioning system is implemented in all new devices, the team will still have a huge stock of existing “legacy” devices with which new devices will need to interoperate. 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 so adjust their behaviors. Some existing technologies have command/control mechanisms useful here. A new device could use these to manage the power state of legacy devices to which it is connected. New devices could also provide user direction to manually manage legacy device power state when no other mechanism is available.

CHAPTER 3:
Standard Development and Implementation

This section describes how the sleeping stream concept can be moved into technology standards, then into products to begin saving energy.

3.1 Standardization

Once the technology concept was developed, the next step was to bring it to individuals who work in the relevant product and technology areas. The goal was to confirm that the idea was sound, valuable, and compatible with existing technologies, and to develop support in the standards arena. The team had extensive discussions with individuals and with standards committees. Among them were HDMI, IEEE 1722.1 (for AVB systems), UPnP, DisplayPort, and HML. The team has yet to have such a discussion with Apple for the Airplay technology. In all cases, the team found that current technologies do not have all the elements needed for sleeping streams, but there was no conflict between existing standards and sleeping streams. In some cases, existing elements of technologies can be expanded to implement sleeping streams.

As part of the outreach to standards committees, the team created the project/concept logo shown in Figure 5. The moon is the same geometry as recommended in IEEE 1621. The stylized "stream" of data is shown to be digital.

Figure 5: A/V Control project logo

Source: LBNL

The model the team proposes is a core standard that defines the overall concept of sleeping streams, needed protocol characteristics, devices behavior capabilities, and guidance on how to present this all to users.

We identified the Consumer Electronics Association (CEA) as the organization best suited to host the core standard. At the outset of the project, the team presented the concepts of this project to the CEA Technology and Standards "Industry Forum." Towards the end of the project, the team presented the sleeping streams technology to another Industry Forum, in October 2013.

Figure 6: Consumer Electronics Association (CEA) logo

Source: CEA

Many conversations with CEA staff and people from various manufacturers indicated support for a standard for sleeping streams in general, and with CEA as the host. To create a standard requires a working group, and a working group is created by a standing committee. Of the nine CEA regular standing committees, "R07 Home Networks Committee" was the best match for sleeping streams. The mandate of the Home Networks Committee is that:

> "R07 provides coordination for, and encourages cooperation among, all CEA home network standardization efforts as well as providing a forum for non-CEA home network standards formulating bodies interested in working with CEA. The primary goal is to ensure current and future home networks can coexist within a home and share information through the use of industry standard interfaces. R07 and its subcommittees will develop and maintain all CEA standards pertaining to home networks that currently exist, are being developed or may be initiated in the future." (Source: CEA)

Coordinating with non-CEA standards is a core part of the committee's scope. LBNL has previously participated in CEA study groups. For example, the team participated ten years ago in writing a CEA technical report on power management of A/V devices that are networked (CEA, 2004). The report aimed to influence energy policy rather than create a technology standard.

In December 2013, R07 approved creating a committee for sleeping streams, with the intent that it should complete work before the end of 2014.

While seeking industry support for the project's technology, the team prepared a document which expressed the content in the form of a CEA standard; included here as Appendix D. The information is derivative of the more detailed information in Appendix C.

CHAPTER 4:
Conclusions and Next Steps

4.1 Project Results

We began the project with developing a principle to maximize the energy efficiency of A/V devices. The team assessed the current status of products and standards, and confirmed that there was a clear gap in capabilities to manage A/V streams in a way that would be compatible with the principle. In parallel, the team then created a set of use cases to cover typical usages, and a technology concept capable of implementing the A/V device behavior principle. Finally, the team confirmed that it was feasible and reasonable to add the principle and concept to the important technology standards in use today.

Finally, the team concluded that technology interconnection standards are a critical area of innovation distinct from technology development which is typically undertaken by individual companies. These standards impose requirements on products that sometimes determine the energy use of the products. The standards can prohibit, require, or encourage particular energy saving features. Collective activities--including public sector participation--culminate in the standards, whereas the public sector is generally excluded from technology development. Public sector involvement can:

1. Leverage energy savings though standards development, which is a highly cost-effective investment;
2. Attain savings through communication standards that cannot be realized using other means.

4.2 Project Benefits

This project has several sets of benefits. The first is energy savings. Future savings from this technology are problematic to estimate, but the current waste is likely in excess of 6 TWh/year. However, power control standards for A/V devices will affect future products, which could otherwise waste significantly more than occurs today. A recent estimate of all electronics use in the U.S. is over 380 TWh/year for the U.S. as a whole (Nordman & Cheung, 2013; Malinowski et al., 2014). Of this, about 130 TWh/year[1] is due to devices that have conventional A/V content streams as their primary function, with TVs being the largest portion of this. Another 150 TWh/year is from devices that can be part of A/V content streams, such as PCs, plus small amounts from A/V devices that do not send or receive A/V content with other devices. Experience with personal computers shows that energy consumption of devices not in use can be in the double digits of percent of annual consumption. It seems quite plausible that A/V power control technology could save on the order of 10 percent of consumption of the core A/V

[1] Earlier the team referenced 140 TWh/year, but this includes some devices that are always stand-alone and so not relevant to content streams that pass between devices.

devices today or 13 TWh/year. It also seems plausible that 5 percent in the PC and related device energy could be saved for another 8 TWh/year. The total of both groups is about 20 TWh/year. Assuming that California is typical of the U.S., and reflects 12 percent of the population, this amounts to a total of about 2.4 TWh/year for California.

The above analysis indicates the magnitude of savings that the team can expect, once the technology is deployed in most buildings. Some devices should be able to act on behalf of older devices that lack sleeping stream technology, so realizing energy savings will not require a full stock turnover. However, it is important to be clear that there is great uncertainty in forecasting savings, since between now and then; the team will see continued evolution in products, efficiency, technologies, ownership patterns, and usage patterns. All of these could drive total use, and potential savings, both up or down. Just as the way the team use audio/video devices today is substantially different from that of ten years ago, the team should expect a similar change – and perhaps a larger one – in the coming decade.

Another benefit is user convenience. People interact frequently with A/V systems, and this is likely to grow. As the price of displays continues to fall and their energy efficiency increases, people will have the practical economic ability to have more displays and use them more frequently. Thus, it is increasingly urgent to embed automatic power control within these devices.

This project has started A/V power control on a new path, jumping tracks from siloed technology solutions. Solutions derived from existing technologies would have covered some usages but not many others, proved burdensome for consumers and manufacturers alike, and provided fewer benefits. The team welcomes the opportunity to address A/V power control at a high level with wide impact, and the team has developed a broad basis of support.

4.3 Considerations for Energy Policy

Energy can be conserved through the development and amendment of technology standards. Most public effort is currently expended on regulations or voluntary programs requiring or encouraging manufacturers to produce, and consumers to buy, products that will use less energy. Technology standards development is a key channel through which the public sector can influence, guide, and help create new energy saving opportunities in the electronics end use.

Energy policy can be utilized to speed up development and implementation of the sleeping stream technology. As a precedent, the Energy Star program has had a strong influence on the evolution of communications technologies, and the nature of information technology suggests that this will be more possible and needed in future. The team hopes that the energy policies developed in this research will have a similarly useful trajectory.

Many energy policy programs have an implicit objective to be “technology neutral--” to not favor or require technologies that may unfairly advantage specific companies. This is sometimes extended to avoiding specifying network interoperability technologies. This is a mistaken application of the technology neutrality principle, as open standards do not favor specific

companies but are rather available to any company. In addition, some energy savings opportunities are only available if companies implement specific technologies so that failure to embrace them forecloses some potential savings.

Once the technology has significant penetration into the sales of new devices, then it could be considered for inclusion into mandatory energy standards (e.g. California's Title 20) for relevant devices. At that time, it could be considered whether this is necessary (market forces may make it a standard feature), or if so, how to do it in a way that ensures savings but does not impede valuable innovation.

4.4 Next Steps

For this technology to be adopted into future products and use, the team has outlined the following stages:

- The CEA committee will take the draft standard content developed in this project, finalize, and submit for approval by the CEA standards process. This would establish the overall architecture of the solution.
- The features described in the standard need to be added to communication protocols. This would involve adopting the three-state power model for devices and streams.
- The features need to be put into products, both in implementing the protocol features, and in device behavior.

Note that some of the above activities could be done in parallel, to compress the time to market. The following steps will result in product adoption and implementation.

- Create a standard that describes the overall scheme of sleeping streams and associated details that could be forwarded to standards organizations for consideration. This should enable product designers to understand what to do and why, how to present this to users, and how to adapt the sleeping stream concept to new circumstances.
- Review communication technologies to identify gaps between what they do today and the sleeping stream architecture.
- Address gaps by amending technology standards.
- Embed the technology within new products. Some features could be included in products even before the standards development is complete.
- Create a detailed summary of recommendations to address legacy products.

The most common digital communications standard in use today is HDMI (HDMI, 2010). In addition to providing the needed data path to send video data, HDMI also protects content, addressing the piracy concerns of many companies. HDMI is most commonly understood as a point-to-point mechanism, but it facilitates 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," such as over the Ethernet channel present in newer versions of the standard. The UPnP protocol may also be critical.

One or more standards will likely get wide use for transporting A/V streams over Ethernet and Wi-Fi. These standards will also need to implement sleeping streams.

Review of relevant interface technologies from manufacturers of A/V devices, and the standards committees will be pivotal to the success of the project. A critical mass of support from these individuals and organizations will be essential. Manufacturers need to be assured that user amenity is the top priority.

4.5 Conclusions

A/V device control is a complex topic with diverse devices, interfaces, technologies, system construction, and usage models. Power control has not been a high priority for the industries, so it is not surprising that power control is poorly articulated. Digital technologies not only add new functionalities, but also offer the possibility of a more robust system for power control. This rapidly evolving marketplace is stimulating environment in which to construct and implement new power control architecture, presenting dramatic opportunities for saving energy. There is significant uncertainty in estimating the achievable savings; however 10 percent of current relevant device consumption would yield about 1.0 TWh/year in energy savings for California, with additional savings in the same range for PC and related devices that also increasingly participate in A/V streams. This results in a total of about 2.4 TWh/year in California.

GLOSSARY

Term	Definition
AVB	Audio Video Bridging
AVR	Audio-Video Receiver
A/V system	Audio/Video System
CEA	Consumer Electronics Association
CEC-PIER	California Energy Commission – Public Interest Energy Research
CEC	Consumer Electronics Control (HDMI)
Content stream	A sequence of data that represents ongoing audio and/or video content
Composite	An analog technology for transmitting color television video signals
DisplayPort	A digital interface for sending content to a computer monitor
DVD	An optical disk medium standard (commonly Digital Versatile Disc)
DVR	Digital Video Recorder
Ethernet	A standard for transmitting packetized data over wires or optical cable
HDMI	High Definition Multimedia Interface
IEEE 1722.1	IEEE Standard for Device Discovery, Connection Management, and Control Protocol for IEEE 1722(TM) Based Devices
IEEE 1722	Layer 2 Transport Protocol Working Group for Time-Sensitive Streams
IT	Information Technology
IP	Internet Protocol
MHL	Mobile High-Definition Link
PC	Personal Computer
PIER	Public Interest Energy Research
RS-232	A standard for digital transmission of data across a single link
TV	Television
TWh/year	Tera-Watt-hour per year
UPnP	Universal Plug and Play

UI	User Interface
Wi-Fi	A standard for local wireless transmission of IP data packets

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APPENDIX D:
“Sleeping Streams” Technology Standards Proposal

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