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Appliance Socket Interface

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Introduction

This document proposes the development of a standardized socket interface for appliances that would allow them to be compatible with any communication system by simply plugging-in the appropriate communication module.

In the context of this document, the term "appliance" refers to any load device including residential appliances (also referred to as "white goods"), HVAC systems, water heaters, and pool pumps. Today, most of these devices have little, if any processing capabilities. While the requirements below assume the appliance interface socket (AIS) is located on the appliance, access to the appliance via a gateway or energy management console that has an AIS is a possible alternative architecture for accessing an appliance using this method.

Appliance manufacturers and utilities are in the initial stages of developing demand response (DR) use cases for "smart" appliances based on communication connectedness. Currently, the industry does not have a sufficient business model of DR at the retail level for "crossing the chasm"[1] from trials to mass-market deployment. Over the next several years, industry stakeholders must develop and

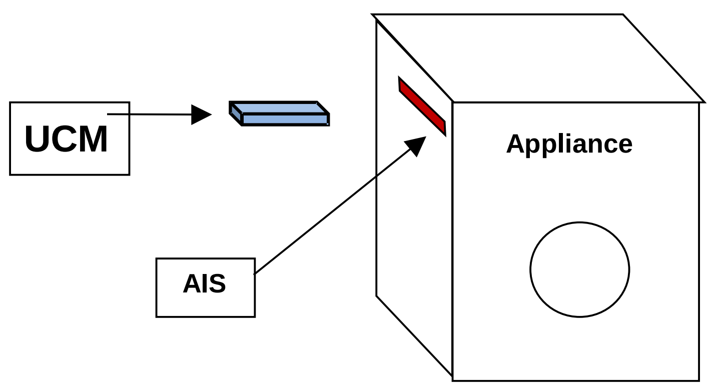
[1] See: http://en.wikipedia.org/wiki/Crossing_the_Chasm

deploy flexible DR implementations in order to understand customer requirements, while introducing appliances that will not become obsolete as new DR programs are launched over the next 15 years.

The premise of these requirements is that physical sockets are one of the most enduring of all information interfaces. PCI (Peripheral Component Interface) and the PC serial interface are two good examples of interfaces in use for more than 15 years. USB (Universal Serial Bus), while relatively new, has been one of the most successful information interfaces to date. U-SNAP™ is an example of an emerging standard supporting the "socket modularity" approach.

Definitions

AIS	Appliance Interface Socket: A standardized physical and logical interface on the appliance
DR	Demand Response
HAN	Home Area Network
NAN	Neighborhood Area Network
OEMs	Original Equipment Manufacturers
UCM	Universal Communication Module: A communication device that plugs into the AIS
WAN	Wide Area Network



General Requirements and Principles

The AIS design must be cost effective for low-end appliances. Many suitable appliances for DR (e.g., dehumidifiers, window air conditioning units, dryers, water heaters, pool pumps, refrigerators, and freezers) lack digital controls today.

The EPRI Demand Response Socket Project engaged a large number of OEMs to determine preferences and needs for an appliance interface socket. The project found no manufacturer that wished to use digital pins to provide direct control (via pin voltage levels); instead, each preferred a simple serial interface. The capabilities of the products represented were found to range widely, with some capable of handling advanced information exchange using the Internet Protocol, while others were capable of just exchanging a few bytes. The consensus of the project participants was to create a specification that enables interoperability by starting with simple capabilities requiring only a few bytes, but one that is also extensible so more advanced protocols could be used as appliances are designed to support them.

Complexity in the UCM is preferred, rather than adding requirements (with increasing cost implications) to the appliance. The most basic commands should afford OEMs the autonomy to design appropriate demand-response capabilities into their products. The commands should appear as requests for service or data, such as the cost of energy or the current state of the power grid. Appliance logic using inputs via the AIS, and from the customer via the user interface on the appliance, will determine how the appliance responds to a given message.

Customer Requirements

The UCM must be customer-installable and removable.[2] As an analogy, note that broadband connectivity did not "cross the chasm" until cable and DSL providers could distribute devices that provided both self-installation and self-provisioning.

While not a requirement, many believe an AIS/UCM standard should anticipate consumers performing a "set and forget" configuration on an appliance.

AIS Physical Requirements

The AIS must power the UCM. Initial research by EPRI indicates that at least two separate physical form factors may be required—a small form factor for a DC-powered UCM, and a larger form factor for a 120-to-240-volt AC-powered UCM. The standards working group, on the advice of OEMs, may define the need for additional form factors. Appliances must meet UL standards. The corrosive operating environment of some appliances may impose additional requirements on the electrical contacts and accessibility of these contacts.

The specification must also clarify voltage ranges and minimum / maximum current (milliamps) of the supply,[3] as well as include minimum physical dimension specifications and clearances for the volume that the UCM will occupy.

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[2] Implicit in this requirement is the fact that the customer can always override any communication signal by simply removing the device.

[3] This is a challenging requirement because of UL requirements, as well as issues like water heater support of L1, L2, and ground (no neutral). This means that without a costly transformer or power supply, only 240/208 volts is available. Accommodating PLC communication

Most aspects of user safety, aesthetics, and mechanical connection of the UCM to the appliance should be left to appliance OEMs. OEMs have the responsibility to determine the location of an AIS on the appliance; consumers will likely find it reasonable to unfasten an access plate temporarily on an internal or external surface (e.g. consider changing an oven light bulb) to enable connectivity.

<u>Data Protocol Requirements</u>

The physical layer protocol should be selected from standard serial protocols such as RS-232, RS-485, SPI (Serial Peripheral Interface), etc. For the 240-volt power interface some manufacturers have expressed interest in RS-485 because it offers superior immunity in "noisy" power applications. The details of baud rate, signal voltage, and other physical aspects of signaling must be specified.

<u>Harmonization Requirements</u>

Appliances may be able to understand more than one advanced protocol like ClimateTalk™ or Smart Energy Profile (SEP) 2.0; future appliances may even support web browsers and Internet traffic. A significant problem exists with price-sensitive appliances that are limited to an eight bit microprocessor and short message lengths. We propose to begin with a simple command set (SCS) that can be supported by most basic microprocessors. (See Appendix A for an example of a simple command set.) The appliance must NAK (negatively acknowledge) the commands it does not understand. The UCM has the responsibility of interpreting or translating higher-level commands it receives to an SCS command that is understood by the appliance. Alternatively, the service provider could directly send SCS commands so that no translation would be required. The "service provider" includes the case of an in-home energy management system that "knows" the appliance only understands certain SCS commands.

A requirement for harmonization is that the protocol must be defined so that a code at the beginning of the message identifies the protocol being "spoken."

Another likely requirement is the addition of a byte of data as an operand associated with the command code. A number of participants in the EPRI project have found value in this concept. Appendix B gives an example of an optional extension for the SCS to include an operand.

Some OEMs have existing socket interfaces. If feasible, designing the standard so two separate sockets are not required should be considered to minimize implementation costs.

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technologies requires access to line power as well. The UCM should be auto ranging between 110 and 250 volts including two-phase service common in urban apartments.

Extensibility[4]

In addition to the PHY/MAC layers, the specification should allow for extensibility in five address-space domains:

1. Interface communications, handshaking, mutual identification, heartbeat, etc. (Commands evolve over time through a standards process.)
2. Utility Command Set (Utility industry evolves these commands over time through a standards process; SEP 2.0 would map into this framework via subsequent releases of the specification.)
3. OEM Command Set (Appliance OEMs evolve commands through a standards process; ClimateTalk™ is an example.)
4. OEM Proprietary Command Address Space; an appliance OEM has exclusive control over these addresses for advanced features and/or value-added services. A separate address space would be available for each OEM, similar to how SNMP (Simple Network Management Protocol) has vendor-specific MIB OIDs (Management Information Base Object Identifiers).
5. Sandbox Command Address space; used for pilot or custom implementations. No guarantee of forward or backward compatibility.

Appliances will vary in their ability to comprehend and initiate commands; classifying devices based on these abilities must be decided early in the standard specification process to allow for extensibility. Appendix C presents examples of appliance classes including the roles and responsibilities of each class.

Handshaking Requirements: Appendix C represents one method to establish roles and responsibilities. For example, the UCM presents code 20; an appliance NAK means the appliance is Class 1 or 2, and a response of 52, 53, or 54 represent a specific class. The general requirement is that only one device needs to execute certain processes like encryption. A method must exist to determine when the UCM should pass the responsibility to the appliance. Another need is to determine which device can initiate a message, or perhaps the protocol will allow either the UCM or the appliance to initiate a conversation. If only one device initiates messages, then some sort of heartbeat signal should be supported to acknowledge health status.

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[4] This is an example of concerns that need to be addressed by a future PAP; this is **not** a specific recommendation.

The architecture above describes a method known as "duck typing."[5] Part of the standards process should evaluate whether the use of a ROM configuration space in the appliance microprocessor is a more cost-effective architecture.

Appliance OEMs Determine the Actual Demand Response

We propose to leave the appliance response to the appliance OEMs. To date, appliance OEMs have not been motivated to optimize appliance energy usage based on time-of-day, nor to create a user interface to simplify shifting energy use to non-peak hours. Like most electric customers, the engineers that design appliances have lived with time-insensitive electricity pricing for more than a century. As the industry evolves and makes time-of-day pricing commonplace, product designers will get creative in order to benefit customers. In doing so, design engineers and product managers at appliance OEMs must have autonomy to meet market needs. To establish a baseline, the electric industry should define a list of DR needs that smart appliances should address. How and whether an appliance can support these needs should be left to individual manufacturers.

[5] From Wikipedia: In **computer programming** with **object-oriented** programming languages, duck typing is a style of **dynamic typing** in which an object's current set of **methods** and properties determines the valid semantics, rather than its inheritance from a particular class or implementation of a specific interface.

Appendix A Example of a Simple Command Set (SCS)

Initial Signals that the UCM would present to an appliance

The standards process will determine a subset of these commands that would be mandatory for appliance comprehension; e.g. perhaps only the first five.

For Version 1.0 signals are Boolean–like.

	Name	Usage Meaning[6]	Mand-atory[7]	Alt. Code[8]
1	Simple Off	The appliance turns off a significant portion of the load, akin to direct load control. If supported, the appliance provides blind trust to command, subject to customer override.[9] [10]	No	3
2	Normal Price	The Service Provider recommends unrestricted usage.	**Yes**	
3	High Price	Used only with at least a second, lower price signal; shed load if possible.	**Yes**	
4	Low Price	Used only with at least a second higher price signal; this is the best time to use electricity. Price must be below the average price under this tariff. The intent of a low price is that a customer can save money by shifting usage when low price is available.	No	2
5	Critical Peak	An unusual event where supply resources are extremely limited; usually a very high price exists.	No	3
6	Grid Emergency	Suppress load as long as possible or until clear signal. For example, stove burners might go off for only 30 seconds.	No	3
7	Higher Soon	Means a change to a higher price expected in 2 hours.	No	None
8	Lower Soon	Means a change to a lower price expected in 2 hours.	No	None
9	ACK	UCM acknowledges last signal from appliance except an ACK from the appliance.	**Yes**	
10	NAK	UCM does not understand last signal from appliance.	**Yes**	
11	Operand-NS	To state non-support/understanding of operand of code.	No	None
12	MSG-?	UCM asks appliance if it supports Msg type in operand.[11]	No	None
13	UCM Healthy	Means UCM is connected to a HAN, NAN[12], or WAN	No	None
14	No Comms	Means UCM currently does not have, or has never established communication to a HAN, NAN, or WAN.	No	None
15	Sunday	Signals Sunday at 00:00:01.	No	None
16	0400	Signals local time is 04:00:01 (daily to correct timer drift and DST).	No	None
17	Send Status	UCM asks appliance to report power level.	No	None
20	Send Config	UCM asks appliance to provide configuration information.	No	None

[6] The Service Provider has the responsibility to use the correct code.
[7] Appliance must support this command.
[8] If appliance NAKs this code UCM will respond with this as substitute.
[9] Besides direct load control; this mode is useful to support sophisticated in-home energy management systems (e.g. one might be managing available power from a PV system). If supported, the appliance could have a specific setting to allow or disallow the command. If set to disallow, instead of a NAK to this command, an ACK then an override response would be preferred.
[10] The first six codes represent a demand control signal; each subsequent signal cancels/supersedes the last.
[11] EPRI recommends an operand for extensibility and harmonization with other protocols; see Extensibility above.
[12] NAN stands for Neighborhood Area Network, and refers to the communication network that supports the smart meter's data collection; also sometimes called a Field Area Network (FAN).

Initial Signals that the AIS ***might*** present to an appliance

For Version 1.0 signals are Boolean-like; no actual data is passed.

	Name	Meaning[13]	Mand-atory[14]
9	ACK	Appliance acknowledges last signal from UCM except an ACK from the appliance.	**Yes**
10	NAK	UCM does not understand last signal from appliance.	**Yes**
11	Operand-NS	To state non-support/understanding of operand of code.	**Yes**
12	MSG-?	Appliances asks appliance if is supports Msg type in operand.[15]	**Yes**
21	Service	Appliance is in need of service repair.	No
28	Reboot	Appliance requests UCM to reboot.	No
29	Customer Priority	Customer has elected to continue normal operation of appliance—that is, customer override has been implemented.	**Yes**
30	Power Down	Appliance will be powered down soon and unable to communicate.	No
49[16]	Reduced	Means appliance has implemented a load reduction action.	No
50	Operating	Means appliance is operating in a standard mode above the standby power level.	No
51	Low Power	Appliance is in rest still but communication still possible.	No
52[17]	2^{nd} Class	Appliance is of the 2^{nd} Class.	No
53	3^{rd} Class	Appliance is of the 3^{rd} Class (not supported V1.0).	No
54	4^{th} Class	Appliance is of the 4^{th} Class (not supported V1.0).	**Yes**

[13] The Appliance OEM has the responsibility to use the correct code.

[14] UCM must support this command.

[15] EPRI recommends an operand for extensibility and harmonization with other protocols; see Extensibility above.

[16] Codes 49, 50 and 51 are a response to UCM Code 17: Send Status. These would be better implemented with an operand byte.

[17] Codes 52, 53, 54 are a response to UCM Code 20: Send Configuration. These would be better implemented with an operand byte, or an alternative would be to define a ROM configuration space in the appliance microprocessor. This could include other information like appliance date of manufacture, make, model, firmware version, etc. Code 54 is considered mandatory because with this appliance class security and other functions of the Energy Service Interface as defined in OpenHAN are the responsibility of the appliance, while the UCM merely acts a physical layer conduit. Version 2.0 of a future standard must accommodate this process. The design of Version 1.0 must be extensible for this process.

Appendix B: Example of Using an Operand with SCS

Defining a Normal or Medium price is highly problematic; in fact, defining the price aspect of a Low or High signal is problematic in a simple command. The current definitions in Appendix A exclude the price connotation and simply convey *please shed* for high, *execute normal appliance behavior* under normal, and *this is a good time to use energy* for low; shifting load under this price should reduce the bill. However, the magnitude of any of these prices and the duration create too many permutations. Thus, an operand could be included in the protocol immediately after the command code. The example below shows a way to efficient convey duration and price magnitude with any price code. Simply looking at each of the first four bit segments, a "1" indicates long period and high price respectively:

Table 1: First Four Bits, Duration of Price Period

		Operand Name	**Formal Definition**
	1st 4 bits	**Name**	**Hours**
1	1	< 0.33	< 0.33
2	10	0.5	.33 to 0.75
3	11	1	>.75 to 1.4
4	100	2	1.4 to 2.4
5	101	3	2.4 to 3.5
6	110	4	>3.5 to 4.5
7	111	6	>4.5 to 6
8	1000	8	>6 to 9
9	1001	10	>9 to 11
10	1010	13	>11 to 14
11	1011	16	>14 to 17
12	1100	20	>17 to 22
13	1101	24	>22 to 30
14	1110	48	>30 to 54
15	1111	>54	>54

Table 2: Second Four Bits, Price Relative to Average Price of Tariff

		Operand Name			
	2nd 4 bits	**Name**	**Formal**	**Definition**	
1	1	< 0.30	<	0.30	
2	10	0.40	btwn	0.30	0.45
3	11	0.55	btwn	0.45	0.65
4	100	0.72	btwn	0.65	0.80
5	101	0.85	btwn	0.80	0.93
6	110	1.00	btwn	0.93	1.06
7	111	1.10	btwn	1.06	1.16
8	1000	1.23	btwn	1.16	1.30
9	1001	1.40	btwn	1.30	1.50
10	1010	1.67	btwn	1.50	1.85
11	1011	2.10	btwn	1.85	2.33
12	1100	2.65	btwn	2.33	3.00
13	1101	3.50	btwn	3.00	4.20
14	1110	5.00	btwn	4.20	6.00
15	1111	>6	>	6.00	

Appendix C Example of Appliance Control Paradigms

(Data that could be held in a ROM configuration space of the Appliance Micro)

This Appendix does not specify any requirements, but is included to describe certain issues the architecture of the specification must address to support extensibility and harmonization. This description assumes a "duck typing" approach.

Consider a definition of four control paradigms. To accelerate implementation, version 1.0 would only define specifications for the first two classes that use basic Boolean-like commands. All versions use the same serial data link technique.

Appliances of the 1st Class

This class implements only Code 1 plus the mandatory codes defined in Appendix A. For simplification, Code 3 could be interpreted the same as Code 1. UCM signals can easily be viewed as one-way requests from a service provider, as in direct load control. The most salient feature of this class is that appliances exhibit blind trust and comply if they understand the command. Because Code 1 is not mandatory, blind trust is not a requirement; an appliance can operate in Class 2 without meeting Class 1 requirements. The appliance OEM implements whatever load reduction they believe is appropriate, subject only to an override by the customer. In adding a UCM to this type of appliance, the consumer must trust their service provider. The appliance may or may not have a user interface (or additional embedded appliance logic) to disable the remote communication signals. Of course, the consumer can always unplug the UCM.

Appliances of the 2nd Class

Version 1.0 of specification would support the SCS as defined in Appendix A. The key difference between the 2nd Class and the 3rd Class (see below) is that the appliances exert autonomy and do not support higher level protocols; the UCM has the responsibility to provide mapping from whatever is received to SCS.

Appliances of the 3rd Class

This class supports the SCS as with Class 2. The key difference between the 2nd Class and the 3rd Class is that the appliance will support at least one advanced protocol like SEP, U-SNAP™, or ClimateTalk™ commands. This group still depends on the UCM for security and other Energy Service Interface requirements. The appliance may or may not support revisions to evolving standards; e.g., an appliance designed on the basis of SEP 1.0 may or may not support SEP 2.0. Ideally, version 1.0 of a "socket" will provide sufficient extensibility and harmonization capabilities to support passing more advanced protocols.

Appliances of the 4th Class

Advanced computing exists in the appliance, probably including the ability to upgrade firmware to support bugs in the Energy Service Interface requirements. Indeed, this is the most salient feature of this 4th Class—appliances at this level can initiate conversations with an Energy Management System (EMS) or other devices on a HAN. This paradigm allows for strict control of the appliance via a home energy management system. Because so much can go wrong under this model, and because we know so little about customer and utility needs in this model, the Version 1.0 specification is not expected to be able to support Class 4 appliances.