Reference Design for Residential Energy Gateways

Technical Advisory Committee/Industry Presentation

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University of California Berkeley, Room 240
Sutardja Dai Hall

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Presentation Outline

- Introduction
- Gateway Overview
- Reference Design Specifics
- OSGi Software Framework Introduction
- Gateway in the OSGi framework
- User Interface
- Outstanding Issues
- Future Work

Gateway Overview

What is a Gateway?

- A device capable of communicating with appliances within the home
- A device capable of communicating with the smart meter, or other metering devices
- A device capable of communicating with the outside world (internet)
- It enables the resident to manage their energy usage more efficiently

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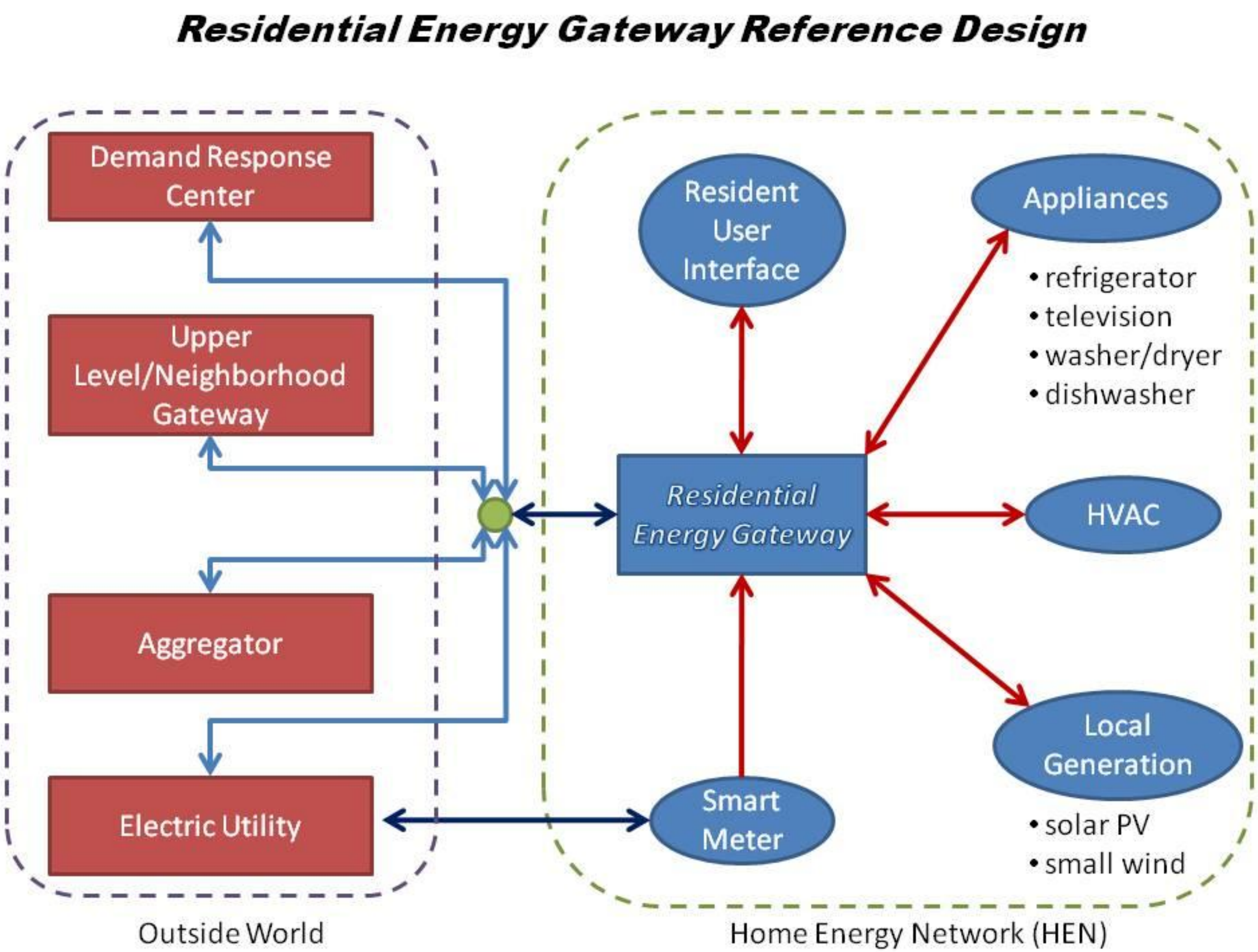
Gateway Overview



Gateway Overview

Why do we need a Residential Energy Gateway?

- Loads within the home are essentially unmanaged, substantial savings could be reaped
- The nature of future residential loads (PHEVs) is not fully known and management of these loads is important as to not overtax the grid
- Implementation of residential demand response
- Increase level of home automation
- Educate/Involve consumer in home energy management

Why do we need a reference design?

- Current Gateways lack communications over multiple mediums (ZigBee, Wi-Fi/Ethernet, Zwave)
  - HEN elements communicating over ZigBee will not communicate directly with Wi-Fi/Ethernet HEN (Home Energy Network) elements
  - This is burdensome to the consumer
- Allows smart appliances of different manufacture to be a part of the HEN
- This provides the consumer with more options

Gateway Project Overview

- Phase 1 (July 2009 – Jan. 2010): Develop a conceptual reference design to demonstrate feasibility.
- Phase 2 (Jan 2010 – Oct. 2010): Develop a working prototype and simulate/test Gateway functionality.
- Phase 3 (Oct. 2010 – Oct. 2011): Using the Gateway as a test bed, investigate advanced issues related to residential load management.
  - Control strategies based on demand response
  - Refine web-UI, database, registration

Reference Design Specifics

Centralized vs. Distributed System

- Should the Gateway physically reside within a single device (such as a computer, or router-like device)?
- Should the Gateway reside within individual components of the Home Energy Management System (such as appliances and the advanced meter)?
- A distributed system could realize most, if not all, of the desired Gateway functionality.

Reference Design Specifics

The Advantages of a Centralized System

- Optimization within the residence is a possibility.
- It is not necessary to require appliances to communicate with the outside world, individually.
- There is a central user (resident) interface, rather than having separate interfaces on each appliance.
- A single user interface would greatly increase user education possibilities

Reference Design Specifics

Hardware Requirements:

- Target platform will be computationally “modest”: less computing power than standard PC
- Target platform should be inexpensive as to not discourage the consumer
- Must be capable of supporting necessary communications media: Wi-Fi/Ethernet, ZigBee, Zwave, etc.
- Must be capable of web page hosting
- Some data storage required

DECISION: Which hardware platform suits our needs for development?

Reference Design Specifics

Target Prototype Platform:

Router-like device

Netbook

Reference Design Specifics

Router-like device:

Advantages

- Relatively inexpensive: $50 - $150 (so a Gateway with the same parts could eventually cost a similar amount)
- Commercially successful
- Could support different operating systems depending on embedded processor
- Physical characteristics suitable for mass production

Disadvantages

- Considerable internal complexity
- Very limited memory storage capacity
- Considerable effort required to construct prototype in this fashion (create PC board with processor, programming drivers, etc.)
- Access and support for modification of COTS internet router unavailable
- User interface is not clearly defined

Reference Design Specifics

Netbook:

Advantages

- Can support standard OS (windows, Linux, etc.)
- Price: $250 - $500, this price is suitable for development as a prototype
- User interface is clearly defined
- Can easily interface with external devices (WiFi, USB, Bluetooth, etc.)

Disadvantages

- Much less capable than a standard PC
- Price: $250 - $500, not suitable for mass production
- Limited memory storage (although has more than a router-like device)

CHOICE: Netbook for familiarity and for ability to emulate a router during design process

Reference Design Specifics

Operating System

- If mass quantities are produced, a royalty free OS would be a logical choice, such as Linux or freeBSD
- Cisco routers utilize VxWorks as an OS (proprietary)
- Netbooks can utilize Microsoft Windows or Linux
- Some communications protocols, such as ZigBee, may not be compatible with Linux
- Given this constraint, the application software should be written in a way that it is easily portable from one OS to another

CHOICE: Arbitrarily choose OS for development, however, write code that is OS independent

Reference Design Specifics

Software Application Language

- Compiler type languages: C, C++, C# and Java
- Scripting Language: PHP, Javascript, Python
- Scripting languages are easier to use, but lack the organization and execution efficiency of compiler-type languages
- Of the compiler languages, C++, C# and Java are object oriented (OO)
- C++ probably has the most efficient execution and smallest footprint, although Java is the most portable

CHOICE: Java, for the factors listed above and the presence of a large developer's community and widely available packages for mathematics, GUIs and networking.

Reference Design Specifics

Communication Protocols

- Perhaps the most sensitive part of the project, as all interested parties will need to adopt uniform communication protocols to communicate with the Gateway
- Possible communications protocols include: Ethernet, WiFi, IEEE 802.15.4 (ZigBee), Zwave, Pager, Cellular networks, radio frequency communications.
- ZigBee is possibly the best-known standard built on IEEE 802.15.4
- PG&E,SDG&E and SCE meters support communications based on ZigBee
- Although ZigBee adoption could be difficult considering membership and licensing fees
- Given the need to gather internet based information, the Gateway must include standard internet and wireless communications

CHOICE: ZigBee & Wi-Fi/Ethernet for development

Reference Design Specifics

ZigBee Communications on a PC

- Unlike Wi-Fi/Ethernet, ZigBee comms. are not available on a standard PC (Netbook)
- Must demonstrate connectivity over ZigBee as to show Gateway communications functionality
- Many different ZigBee specifications exist: S.E.P. 1.0, Health Care, Telecommunications
- S.E.P. 2.0 still in development
- Need to find ZigBee hardware available for rapid deployment and development given the scope of this project

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Reference Design Specifics

ZigBee Communications on a PC

- Telegesis USB dongle provides connectivity over ZigBee
- Does not utilize any aforementioned specification
- COTS product with documentation/firmware support
- Firmware provides bridge from USB to COM port in Windows
- Dongle accepts serial "AT" commands from any terminal software

Reference Design Specifics

Software Framework: Open Services Gateway Initiative (OSGi)

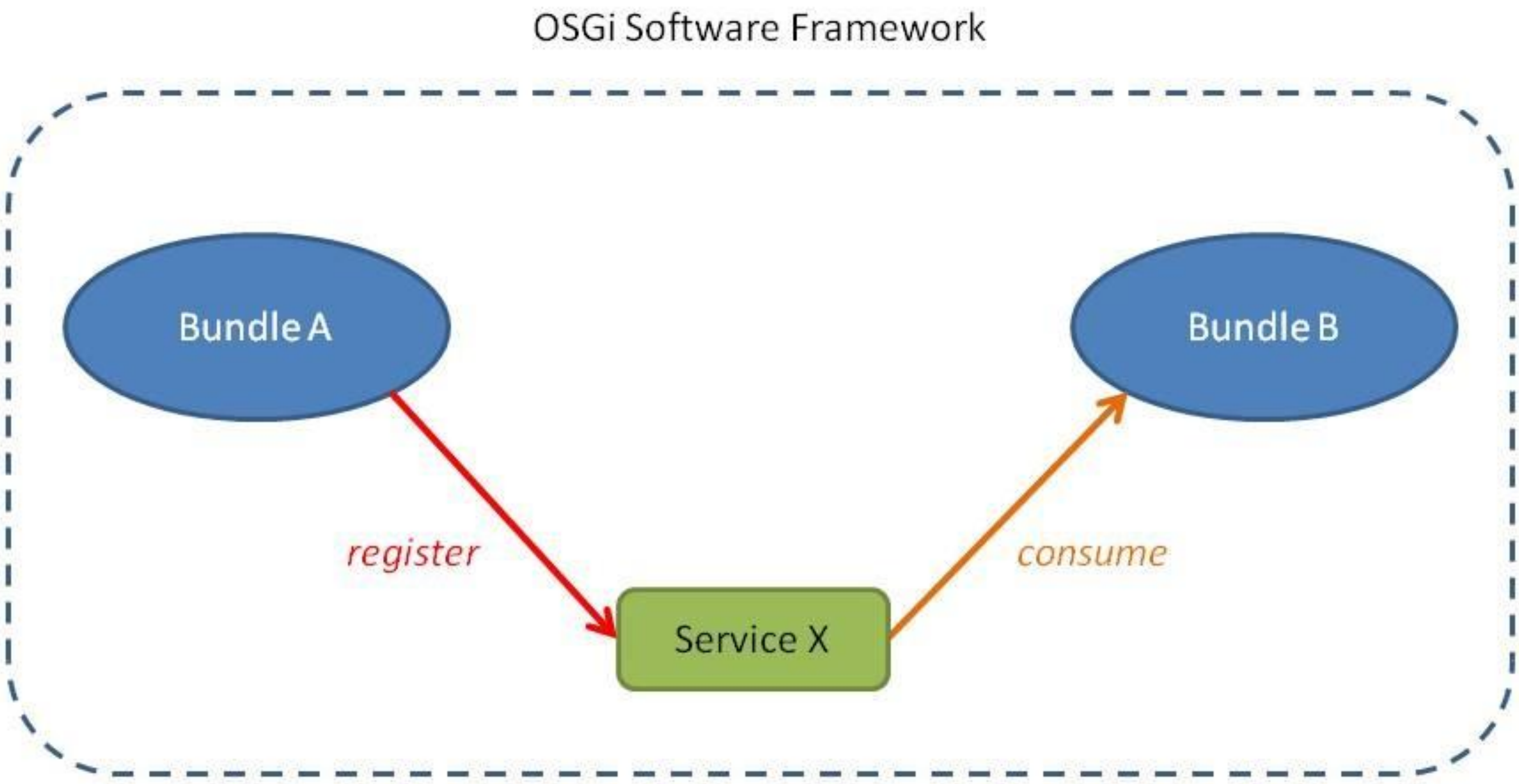
- Writing the application software completely from scratch is not feasible given the time constraints on this project.
- OSGi is a software framework which supports a dynamic module system for Java
- Software originally intended for home automation market
- Software framework is incorporated into reliable IDEs, which includes support for creating OSGi bundles
- OSGi supports a run-time environment in which bundles can be installed, uninstalled, etc. independently of one another
- OSGi bundles are created using a relatively simple Java interface
- OSGi software framework is widely (but not fully) supported in various industries (a full list is available here: http://www.osgi.org/About/Members)

OSGi Software Framework Introduction

OSGi terminology

- *Bundle* – similar to JAR file in JAVA, are visible to the user in the OSGi runtime
- *Service* – a JAVA object, not visible to the user, how information is passed from one bundle to another
- *Registration* – exporting a service from a bundle to the OSGi framework
- *Consumption* – importing a service from the OSGi framework into a bundle

OSGi Software Framework Introduction



OSGi Software Framework Introduction

Why is this advantageous?

- Bundle B requires no knowledge of Bundle A, vice versa
- Bundle A only registers Service X with the framework
- Bundle B only consumes Service X from the framework
- Consumed services can be “returned” to the framework
- Registered services can be “recalled” from the framework

Bottom Line: Bundles A and B can be operated on *independently*

Gateway in the OSGi Framework

Gateway Bundles

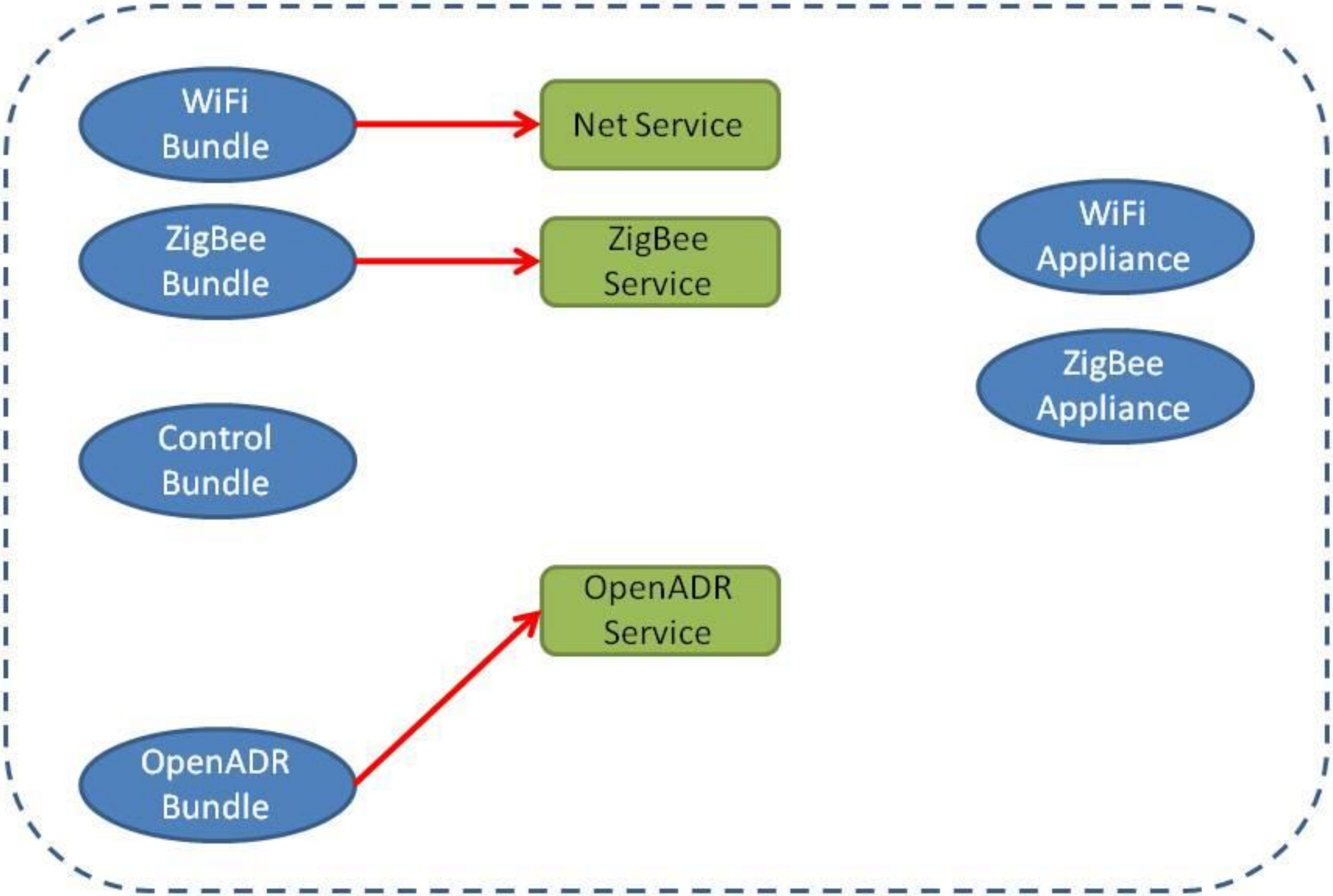
- Wi-Fi/Ethernet bundle: registers *NetService* in the OSGi framework
- ZigBee bundle: registers *ZigBeeService* with the OSGi framework
- Open Automated Demand Response (OpenADR) bundle: registers *OpenADRService* with the OSGi framework
- Control bundle: consumes *ControlService, OpenADRService*, contains control logic to actuate appliances
- Web UI bundle: controls lifecycle of Gateway web user interface, provides the resident with “opt-in” or “opt-out” capability, allows for the installation of new simulated appliances
- Utility bundle: provides support code for all Gateway services

Gateway in the OSGi Framework

Gateway Services

- NetService: facilitates a connection over JAVA network sockets with a simulated appliance
- ZigBee bundle: facilitates a connection over generic ZigBee stack with a simulated appliance
- OpenADRService: connects to Akuakom *Demand Response Actuation Server* (DRAS), receives and parses OpenADR event information
- ControlService: spawned from consumption of NetService or ZigBee service, provides methods to actuate simulated appliances

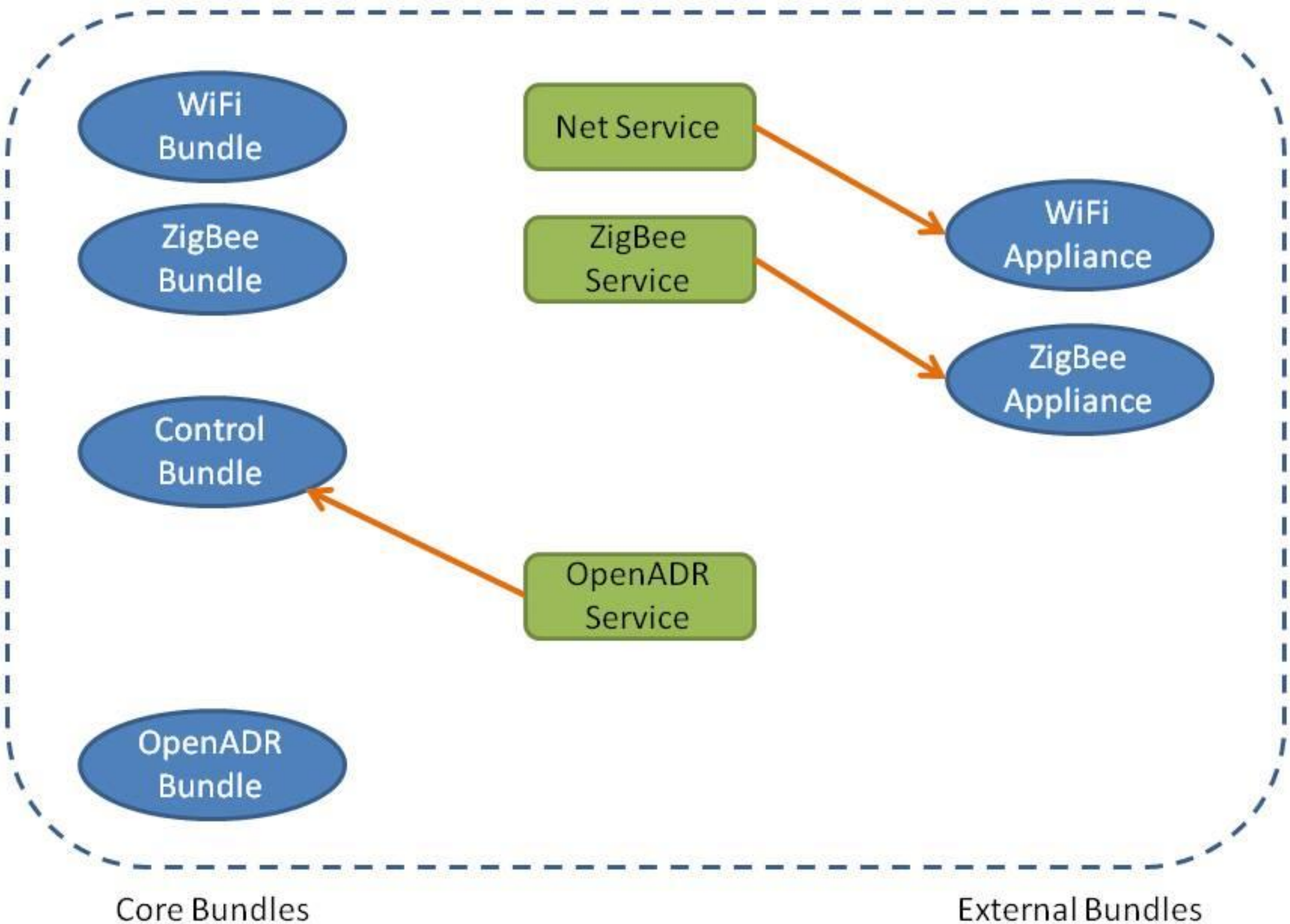
Gateway Bundles and Services – Initial Service Registration



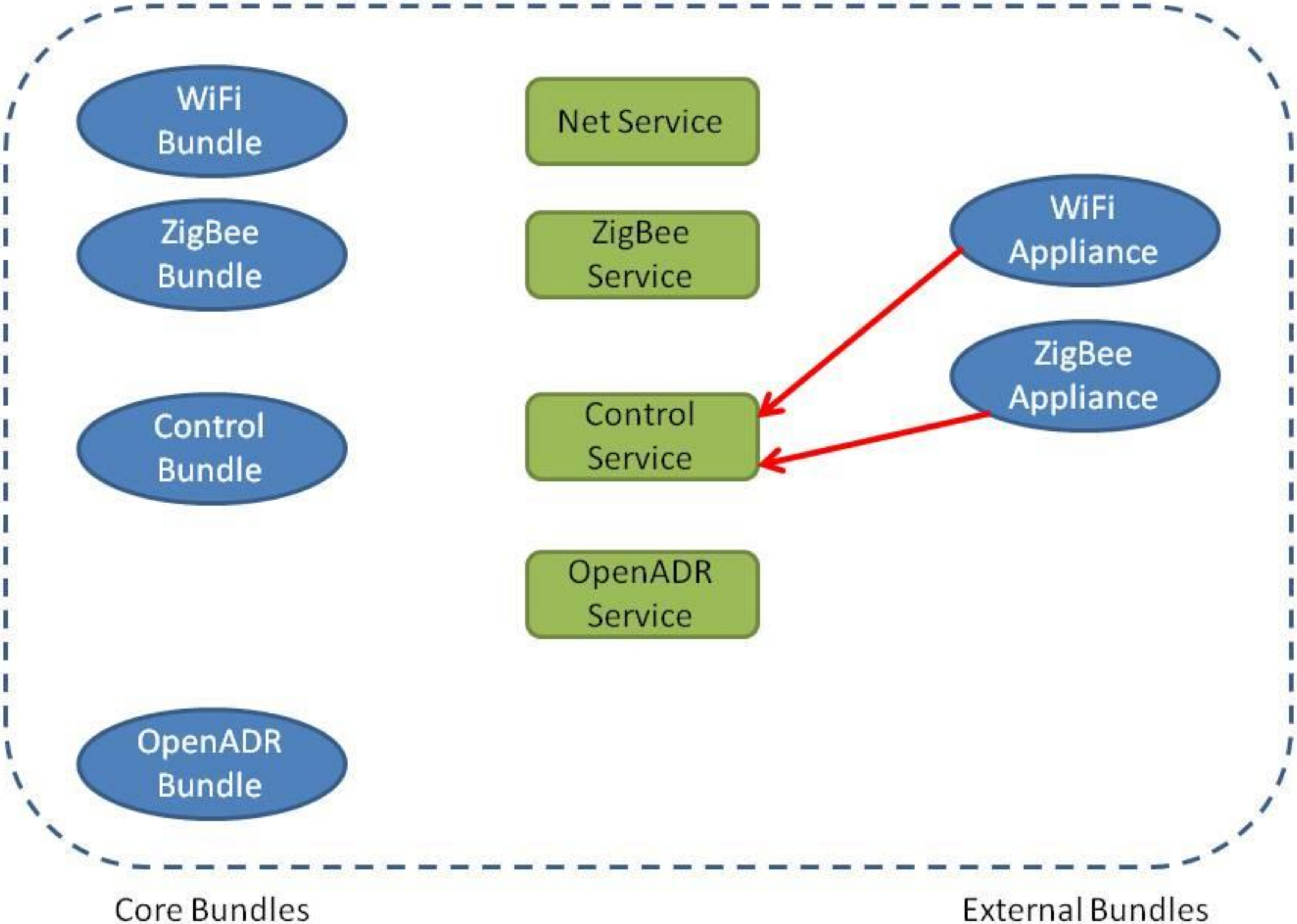
Core Bundles

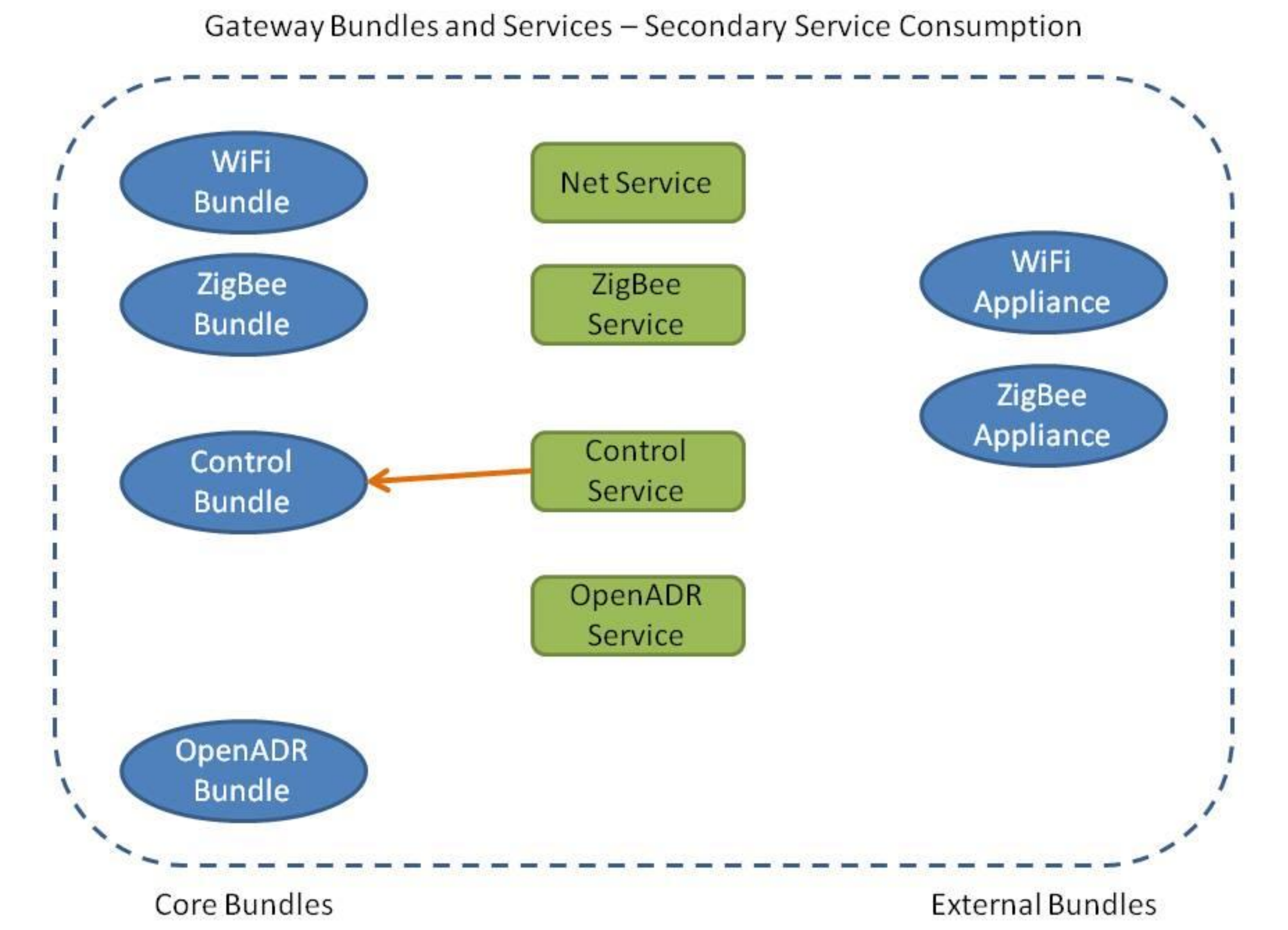
External Bundles

Gateway Bundles and Services – Initial Service Consumption



Gateway Bundles and Services – Secondary Service Registration




Gateway Bundles and Services – Secondary Service Consumption
WiFi Bundle
ZigBee Bundle
Control Bundle
OpenADR Bundle
Net Service
ZigBee Service
Control Service
OpenADR Service
WiFi Appliance
ZigBee Appliance
Core Bundles
External Bundles

Gateway in the OSGi Framework

Memory Footprint

- OSGi framework (independent of JRE): ~1.1 MB
- Gateway OSGi bundles (previously shown): ~ 1MB
- JRE6: ~90 MB (on the author’s computer)

The memory presence of the OSGi framework and the Gateway bundles, collectively, is comparatively small

Gateway User Interface

User Interface Requirements:

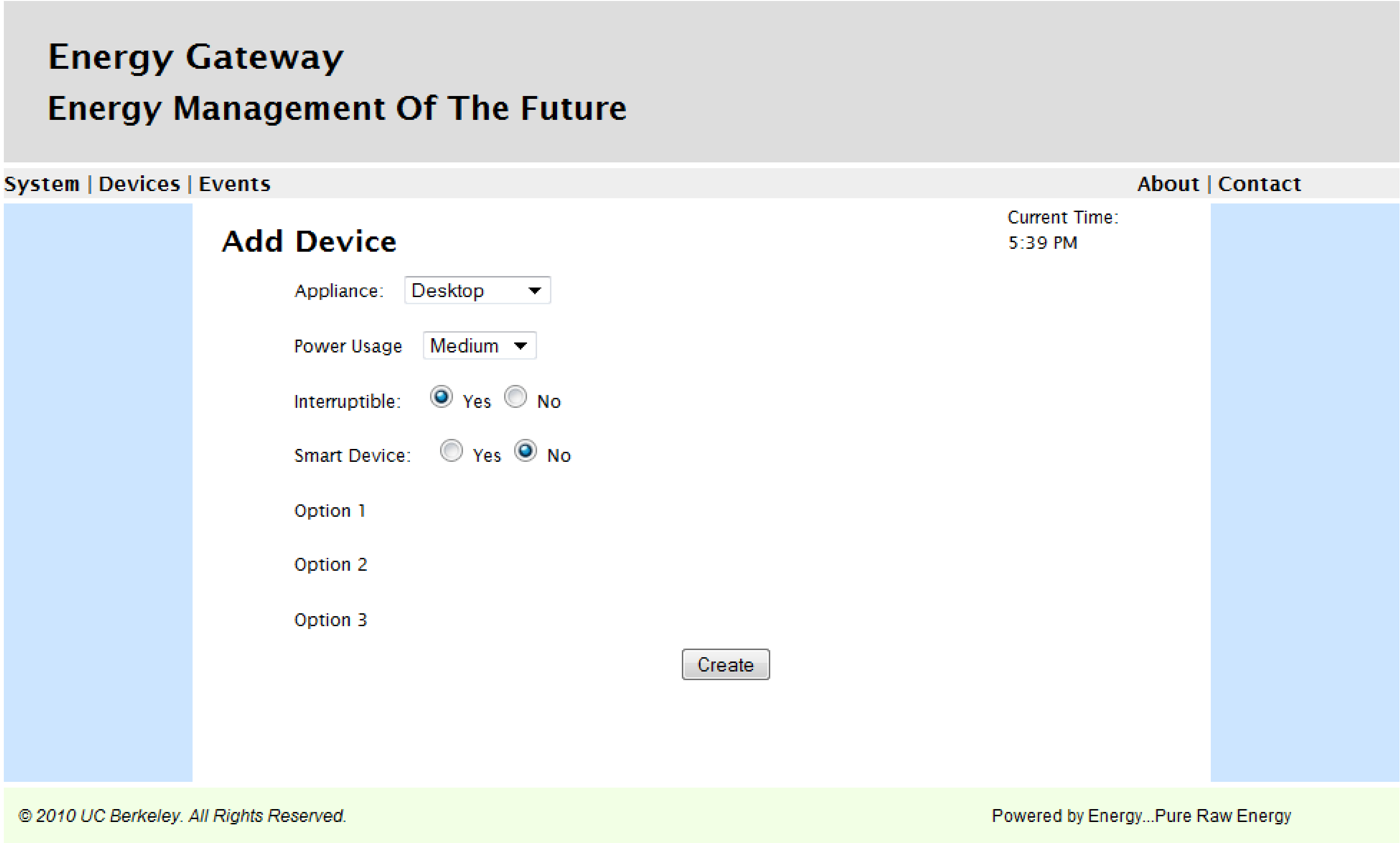
- Inform resident of aggregate energy usage information
- Inform resident of individual appliance energy usage information
- Provide ability to actuate appliances individually
- Provide for the ability to install/uninstall new appliances to the HEN
- Display relevant demand response event information
- Provide opt-in/opt-out capability for DR event participation

Gateway User Interface

Website User Interface

Gateway User Interface

Website User Interface



Gateway User Interface

Website User Interface

Energy Gateway
Energy Management Of The Future

System | Devices | Events   About | Contact

Events

Current Time:
5:40 PM

Event	Status	Time Frame	Price	Options
Event 1	Active	3:00 PM-5:00 PM	$0.30 /kWh	Accepted Opt Out
Event 2	Near	5:00 PM-9:00 PM	$0.19 /kWh	Join Deny
Event 3	Far	7:00 PM-10:00 PM	$0.15 /kWh	Join Deny

Powered by Energy...Pure Raw Energy

Outstanding Issues

User Interface

- Need to standardize data transmission from the Gateway to the Web-UI
- Allows different vendors to construct unique user interfaces
- Should allow for data connection to cloud resources (for example: Google PowerMeter)

QUESTION: What remaining functionality must be included?

Outstanding Issues

Data Model

- Information passed from External Bundles (ZigBee/WiFi Appliance) is a JAVA String of the form:

  <value>3650</value>, or *<applianceState>OFF</applianceState>*

- Data values are time-stamped by the Gateway (server-side)
- This model was adopted for convenience only
- Allows for easy parsing/writing to XML documents

QUESTION: Is there a better way to pass data between the Gateway and appliances (clients)?

Outstanding Issues

Appliance Control

- Control bundle defines some generic methods such as:

  turnApplainceOff() or *turnApplianceOn()*

- Appliances would need to adopt the Gateway data model and listen for specific JAVA strings
- Obviously, thermostats should be actuated differently than washing machines
- Individual appliances might want to respond to more specific control commands.

QUESTIONS: What generic control methods should be defined? Can we incorporate individual control methods for specific appliances?

Outstanding Issues

Appliance Registration

- Must ensure that the proper appliance is paired with the proper Gateway
- Registration similar to Bluetooth possible (code conformation)
- This process must be technically simple, as the average consumer might be confused

QUESTIONS: Should this process should be standardized despite the connection media (ZigBee or Wi-Fi)?

Outstanding Issues

Database

- The Gateway must have a mechanism to store non-volatile data (configuration details, passwords, etc.)
- This information must be robust to power failures, etc.
- This provides an opportunity to store aggregate/individual appliance energy usage data as well
- Stored data can strongly influence more sophisticated control strategies

QUESTIONS: Which database software best suits our hardware needs? What granularity of data should be stored? Is there a need to store long-term energy usage data?

Outstanding Issues

Limp-Home mode

- In the event of Gateway failure, the home must continue to operate properly
- The presence of the Gateway should in no way hinder the resident in home operation

QUESTIONS: How do we ensure that individual appliances will function without the Gateway connection?

Questions?

Thank You

For more information, please visit
http://mechatronics.berkeley.edu/gateway.htm

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