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<th>Date</th>
<th>Revision</th>
<th>Description</th>
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<tr>
<td>December 2014</td>
<td>001</td>
<td>Initial public release</td>
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<td>11/11/2014</td>
<td>V0.4.3</td>
<td>Improve document format</td>
</tr>
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<td>V0.4</td>
<td>Basic content included</td>
</tr>
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<td>Initial internal draft</td>
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1 Introduction

Energy conservation and environment protection are among the most important strategic and fast-growing markets in IoT due to their economic and social benefit. Energy efficiency management system (EEMS) builds the foundation of this industry and is expected to be the fastest growing energy conservation approach.

IoT (Internet of Things) based energy acquisition and processing are the anchor technologies enabling energy management. This paper introduces an energy management gateway design, based on Intel® Quark processor, covering both hardware specification and software stacks. The design and specification are based on comprehensive study of energy management requirements and can be served as valuable references.

The hardware design leverages a core board, which can greatly reduce design cycle of the hardware gateway. The software section describes the programmable gateway software framework design and features, which eases the development of gateway applications, including the integration of energy meters, application management, gateway maintenance, etc. Wind River IDP (Intelligent Device Platform) is the recommended software middleware for the energy management gateway. IDP enhances the connectivity, manageability and security functionality of the gateway platform which further simplifies energy gateway management and software development.

1.1 Terminology

Table 1. Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IDP</td>
<td>Intelligent Device Platform</td>
</tr>
<tr>
<td>SoC</td>
<td>System On Chip</td>
</tr>
<tr>
<td>PCI-E</td>
<td>Peripheral Component Interconnect Express</td>
</tr>
<tr>
<td>PHY</td>
<td>Physical Layer</td>
</tr>
<tr>
<td>RMII</td>
<td>Reduced Media Independent Interface</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsche Industrie Normen (=German Industry Standard)</td>
</tr>
<tr>
<td>CCC</td>
<td>China Cube Confederation</td>
</tr>
</tbody>
</table>
2 Overview

2.1 Energy Management Gateway Requirement

Energy management gateway devices are generally installed near energy meters and sensors in solution deployments. Energy consumption data is read from meters via standard buses such as RS485 in the physical layer and communication protocol such as Modbus and DL/T 645 in the application layer. After protocol conversion, energy consumption data is sent to servers via LAN, WIFI, or 2G/3G network occasionally. Zigbee wireless protocol support is optional as it is used in limited scenarios. USB host port is required to provide convenient data exporting and local configuring support. Meanwhile, in order to facilitate the development and debugging of the system and applications, one debug console port should be provided. Recovery button and Reset button are required for system reset and recovery.

In summary, gateway hardware basic requirements are recommended as follows:

- Intel® Quark™ processor, 256M or more memory
- Communication system supports: 2G/3G , LAN, Zigbee (optional)
- 2-way RS485 / RS232
- USB host port
- Wide voltage input: DC9-36V
- Recovery and Reset button
- DIN rail installation Support

The gateway software stacks serve the purpose of simplifying the development, integration, and deployment of IoT gateways. Customers may have various requirements on the detailed functionalities of the gateway, depending on factors such as customers’ technical capability, business model, and the scope of the existing solutions provided. Since customers in energy management market can engage in different market segments, it is important for the software stack to be adequately general to meet the core requirements of most customers and yet be sufficiently flexible to allow customization and integration. Customer survey reveals that energy gateways are not only the system to run applications, but also the platform that needs to enable gateway management, application management and remote diagnosis. Such software requirements are applicable to different energy management market verticals, such as manufacturing, environmental, and smart building.

Intel's energy gateway solution provides comprehensive software stacks covering from firmware, operating system, middleware, and energy specific application support. The software architecture is designed with the end-to-end system taken into consideration, focusing on energy sensor integration, energy data delivery and aggregation, device management, and platform management. Particularly, the following aspects will be supported and optimized:

- Support typical energy meter bus standard (RS485, Modbus)
- Optimized for small burst data
- Platform compatibility and extendibility
- Device management API abstraction
- Sensor plugins
- System scalability
- System and data security

Considering the ecosystem of software tool support, Linux operating system is recommended for energy gateway. The software platform is suggested to support the following features.

- Web-based local configuration
- Remote configuration
- Application remote deployment and management
- System remote upgrading
- Gateway status monitoring
- Local data storage and caching
- Remote manageable log and alarm
- Application layer protocols such as Modbus and DL/T 645

2.2 Intel® Quark™ Based Energy Management Gateway Introduction

The recommended Intel® Quark™ Based Energy Management Gateway solution includes the following components:

- Core Module with Quark processor
- I/O carrier board provided by partner
- Intel® Gateway Solutions software (Wind River Linux and IDP)
- Programmable gateway software framework
- Sensor plug-in, the network program and applications provided by third party partner

Figure 1 shows the layered view of these components.

Figure 1. Intel® Quark™ Based Energy Management Gateway Components
3 Energy Management Gateway Hardware

3.1 Hardware Platform Overview

Energy management hardware platform is based on the Intel® Quark™ SoC X1000 series, which is a single core SoC product featuring high level I/O integration. This platform demonstrates the SoC in an embedded, lower power, and small form factor solution. The hardware platform consists of one core module and one I/O carrier board. Section 3.2 introduces the reference design. The hardware feature specification for energy management gateway is described in Section 3.3.

3.2 Reference Design Overview

In the reference design, a core module and the I/O board are connected with a pair of 2*40 pin connector. The size of the core board is limited at 57mm*42mm. It’s a modular, bootable, and Intel® Quark™ processor based computer block. The key component placement is shown in Figure 2.

Figure 2. Core Module PCB Placement
Table 2 describes the I/O function groups routed out by the two*40 pin connector.

**Table 2. Core Module Key Hardware Interface**

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet</td>
<td>2 * 10 and 100 Mbps data transfer rates with RMII interface to communicate with an external Fast Ethernet PHY</td>
</tr>
<tr>
<td>PCI-E</td>
<td>2 * PCI Express* root ports, each supporting the PCI-e Base Specification Rev2.0 at a maximum of 2.5GT/s data transfer rates</td>
</tr>
<tr>
<td>USB</td>
<td>2 * USB 2.0 host, 1 * USB 2.0 device interface</td>
</tr>
<tr>
<td>Storage</td>
<td>1 port configurable as an SD, SDIO, or eMMC interface, Micro SD slot</td>
</tr>
<tr>
<td>I2C</td>
<td>1* I2C interface, supports standard (100 Kbit/s) and fast (400 Kbit/s) data rates</td>
</tr>
<tr>
<td>UART</td>
<td>2 * UART interfaces, supported Baud rates from 300 to 2764800 (UART1 for debugging console port)</td>
</tr>
<tr>
<td>JTAG</td>
<td>1* JTAG interface for OpenOCD</td>
</tr>
<tr>
<td>SPI</td>
<td>2* SPI interface for peripheral devices, 1* Legacy SPI for BIOS boot</td>
</tr>
<tr>
<td>GPIOs</td>
<td>10* General Purpose I/Os available in the customization</td>
</tr>
</tbody>
</table>

The I/O Board carries all I/Os of the system. All I/O device functions supported by core module can be demonstrated and validated by the I/O carrier board. The design is an open reference design which provides OrCAD* format design and Allegro* PCB layout design. These design documents saves design cost and speeds up time-to-market.

### 3.3 Energy Management Gateway Hardware Feature Specification

To meet the common use cases and functionalities of the energy gateway, a typical hardware feature specification and minimal requirements are summarized in Table 3. The specifications listed in the table are recommended for use with an Intel® Quark™ based energy management gateway.
### Table 3. Energy Management Gateway Feature Specification

<table>
<thead>
<tr>
<th>Category</th>
<th>Function</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Processor</td>
<td>Intel® Quark SoC, 400Mhz</td>
<td>Yes</td>
</tr>
<tr>
<td>Memory</td>
<td>RAM</td>
<td>DDR3 800/1066MT/s, 256MB, Memory down</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
<td>On board 64Mb SPI flash,</td>
<td>Yes</td>
</tr>
<tr>
<td>Wireless Communication</td>
<td>WLAN</td>
<td>802.11 b/g/n Wireless Module, external antenna, Support 1x Half PCI-E Wireless card</td>
<td>Optional</td>
</tr>
<tr>
<td></td>
<td>3G Module</td>
<td>1x PCI-E 3G with SIM slot</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>ZigBee*</td>
<td>Low power Zigbee Module, external antenna</td>
<td>Optional</td>
</tr>
<tr>
<td></td>
<td>GRPS</td>
<td>1x, external antenna</td>
<td>Yes</td>
</tr>
<tr>
<td>I/O Interface</td>
<td>Ethernet</td>
<td>2x10/100-BaseT(RJ45)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>USB</td>
<td>1xUSB2.0 Host (Type A)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>RS485/232 Port</td>
<td>2xRS232/RS485 with isolation protection</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Console Port</td>
<td>1xRS232 (UART1)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>RTC</td>
<td>Supported</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>I²C</td>
<td>EEPROM for MAC address</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Button</td>
<td>Reset Button, Recovery Button</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>LED Indicator</td>
<td>LAN, 2G/3G PWR, RUN</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zigbee*, ALARM</td>
<td>Optional</td>
</tr>
<tr>
<td>Storage</td>
<td>SD card</td>
<td>2GB SD card</td>
<td>Yes</td>
</tr>
<tr>
<td>Software</td>
<td>OS</td>
<td>Linux, Wind River* Linux preferred</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Middleware</td>
<td>Wind River IDP* preferred</td>
<td>Yes</td>
</tr>
<tr>
<td>Power</td>
<td>Input Voltage</td>
<td>9-36V DC</td>
<td>Yes</td>
</tr>
<tr>
<td>Misc.</td>
<td>Mounting</td>
<td>DIN Rail</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Cooling Mode</td>
<td>Fanless, heat sink</td>
<td>Yes</td>
</tr>
<tr>
<td>Environmental and Certification</td>
<td>Temperature</td>
<td>Operating: -20°C ~ +50°C, Storage: -40°C ~ +60°C</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Relative Humidity</td>
<td>10-95%@35°C (non-condensing)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>EMC &amp; Safety</td>
<td>CCC</td>
<td>Yes</td>
</tr>
</tbody>
</table>
4 Energy Management Gateway Software

4.1 Software Stack Architecture Overview

A high level architecture view of typical energy management end-to-end solution is shown in Figure 3. The gateway supports the energy sensors and its industry standard communication protocols (e.g., Modbus) such that data can be accessed by the applications running on the gateway. The gateway also provides management middleware and application middleware to enable remote device and application management. These features are exposed securely via the gateway API. To further facilitate and ease management tasks, a cloud management layer can optionally be provided, such that gateway control, energy application management, and sensor data query can be done via cloud APIs.

Figure 3. Energy Management Gateway Software Stack Overview
4.1.1 Software Stack Basic Components

The main components and functionality of the energy gateway can be categorized into three layers: the generic operating system (OS) and driver layer, the gateway management framework, and then the energy-specific application framework.

The OS layer is the base platform where either commercial or free Linux can be used. It is important to tune and configure the OS for the targeted usage scenario. Configurable components include kernel modules, core libraries, runtime, communication protocols, support application and utilities, and so on. The OS has to meet the constraints posed by the computation, memory, and storage aspects of the edge gateway hardware. For critical applications, it is recommended to adopt commercial OS such as Intel Wind River Linux for system stability and customer support.

The gateway management framework can improve the edge solution in the following aspects, management, connectivity and security. It integrates technologies and protocols for networking, embedded control, enterprise-grade security, and easy manageability on which application-specific software can run. Specifically, the framework can provide generic capability in the following topics:

- Connectivity down to sensors and existing controllers embedded in the system, such as enabling BLE, Zigbee, and driver framework.
- Connectivity up to the cloud and enterprises, e.g., communication libraries, messaging support.
- Data encryption, application attestation, and software lockdown for security, to prevent the gateway to be compromised.
- Simple gateway maintenance and application management
- A application framework to simplify application development and integration

Additionally, with the help of the gateway management framework, energy-specific application framework can be included to ease energy edge application development and integration.

4.1.2 Application Frameworks

The energy application framework makes the gateway programmable and provides actuator functionality for energy application, such as application management, energy message communication protocol, and energy sensor data collection and pre-processing.

The application framework enables energy application management on edge devices, including application configuration management, messaging system configuration, message and data encapsulation, message delivery, and application status monitoring. This will further reduce the engineering effort for solution operators as remote device and application management can be easily conducted. Furthermore, a sensor protocol plugin framework can be used to support energy industry standard protocols, particularly Modbus and DL/T645 used by smart meters. Using the application framework, application development for the edge gateway will be greatly simplified: the sensor data will read from provided sensor APIs; the data can be submitted to the cloud with configurable destination paths and message encoding options, which are specified in application configuration and supported by the framework; the application status monitoring and upgrade capability are also available by default.
4.1.3 **Cloud Management**

Operating a large number of gateway devices directly could be a time-consuming and error-prone task. A centralized cloud platform automating this management task will help customers reduce cost and time-to-market. In the cloud, since the device remote control functionality works with gateways remotely, special consideration must be taken into account for latency tolerant operations, scalable batch operations, seamless device authentication, and secure messaging with MQTTs. With a large number of gateways, configuration and asset management become critical. Cloud platform can provide flexible asset management and energy metadata abstraction, and consequently ensure the consistency of these data.

4.1.4 **Security**

Security is one of the key requirements for the energy gateway. Intel requires the gateway software to be designed for security from day one. Security covers all software layers and software components, including the device authorization and authentication, OS run time, application attestation, communication security, data security, etc. These security requirements can be categorized into high level groups: gateway platform security, communication security, data security, and cloud service security.

The gateway platform security protects the edge gateway system and its application from external tampering and information leaks. Intel is at a unique position to provide the most secure system with security technology covering from CPU, SoC, firmware, OS, and application framework. Intel Wind River IDP platform integrates trusted boot, secured OS to ensure gateway platform security.

The application framework leverages platform security features together with AES encryption and SSL to ensure data communication security.

4.2 **IDP Feature and Specification**

Wind River Intelligent Device Platform is based on Wind River industry-leading operating systems, which are standards-compliant and fully tested, as well as Wind River development tools. The platform provides device security, smart connectivity, rich network options, and device management. Intelligent Device Platform XT is part of Intel Gateway Solutions for IoT, a family of platforms that enables companies to seamlessly interconnect industrial devices and other systems into a system of systems. Intel Gateway Solutions for IoT enables customers to securely aggregate, share, and filter data for analysis. It helps ensure that federated data generated by devices and systems can travel securely and safely from the edge to the cloud and back—without replacing existing infrastructure.
Intel Gateway Solutions for IoT offers companies a key building block to enable the connectivity of legacy industrial devices and other systems to IoT. It integrates technologies and protocols for networking, embedded control, enterprise-grade security, and easy manageability on which application-specific software can run. Connectivity, manageability, and security are core IoT building blocks, essential to reducing device manufacturers' time-to-market, complexity, and risk. Wind River Intelligent Device Platform XT natively delivers on all three as shown in Figure 4.

4.2.1 Connectivity

Pre-integrated smart and connected capabilities enable rich network options to save development time and costs. Validated and flexible firmware provides an extensive network of connectivity choices, including broad modem support and PAN, LAN, and WAN network access.

4.2.2 Manageability

Platform customization significantly reduces development time while increasing the product's life span and uptime. Long-term secure remote manageability simplifies deployment, maintenance, and management of remote devices.
4.2.3 Security

Features, from a hardware root of trust to boot and software loading, are designed for IoT software development to protect critical data throughout the device lifecycle. With support for secure image, secure data, and secure management, the device and data are protected from boot to operations and management.

Customizable secure remote management ensures end device integrity via secure boot, provides encrypted communication between device and cloud-based management console, and limits exposure of untrusted applications through device resource management.

4.3 Energy Gateway Software Framework

In order to assist solution providers to develop IoT-ready gateways, Intel® Quark™ based energy management gateway design provides a software framework on top of the Wind River Linux and IDP. In this framework, common functions such as reading data from sensors and sending data over the network are wrapped as Plugins. Application developers can choose necessary plugins and assemble data collection applications easily. The framework code handles the details of plugin loading, execution and monitoring. The framework also contains service codes to handle management requests from the cloud, and report system-wide events back to the cloud.

The framework consists of the following components:

- **Gateway Management Agent:** Responsible for managing applications’ configuration and status. It connects to cloud through control channel, reports gateway status and responds to management requests.
- **Application:** There are one or more applications in the framework, each designed to achieve pre-defined functions, such as periodically collecting data from a sensor and sending to the cloud. Applications can be dynamically setup and configured by the cloud.
- **Data Collection Agent and Legacy Application Agent:** Each application has one agent working as the controller. A Data Collection Agent manages all plugins in an application that collect, process, and send the data. A Legacy Application Agent controls and monitors a traditional Linux daemon, making it manageable by the Management Agent.
- **Plugin:** A plugin implements the function of one step in the three-step data procedure (collection, processing, and sending). Plugins can be provided by both the Intel Energy Solution and the eco-system, or be developed by the solution providers if needed.

The structure of the software framework is shown in Figure 5.
With the application framework, the gateway can perform these operations:

- **Data collection**: collect data from sensor at a pre-defined interval or on demand, and then send the data over the network.
- **Self-diagnosis**: monitor application status. If an application exits unexpectedly, an event will be reported to the cloud.
- **Remote configuration**: dynamically download, start, stop and configure applications after the gateway is deployed.
- **Remote management**: perform maintenance work such as upgrading the OS image or restarting the gateway remotely.

To use the framework, developers first choose the protocols to be used, for example, Modbus or MQTT. If plugins supporting these protocols are available, they can be reconfigured and reused. If not, developers can write new plugins. Once the required plugins are ready, developers can use the Data Agent to link all the plugins together and create a new application.

Once an application is created, it can either be installed in the gateway prior deployment, or be packaged into an application package and deployed remotely.

Management functions of the framework are designed to work with different cloud platforms by using different Management Channel Plugins.
5 Reference Applications

Intel energy management gateway is currently targeted for energy consumption related sectors of the smart energy industry. The gateway will be used to collect electricity, water, gas, oil, heating and other energy resource consumption.

5.1 Application of Building Energy Management

In energy management applications, processing and handling energy data include the following steps:

- Energy data acquisition
- Energy data storage
- Energy statistics
- Energy data analysis
- Energy benchmarking data
- Energy target management

In these steps, energy management gateways are primarily involved in energy data collection. The rest is mainly done by the back-end energy management system. Figure 6 explains the energy data layers.

Figure 6. Energy Data Layers
In a typical energy management application, there are usually a variety of data sources, including but not limited to:

- a variety of RS485 meter, such as water/point/gas/oil/heat meters
- network-accessible database
- TCP Modbus equipment
- OPC devices

The programmable gateway software framework provides sensor plug-in features to support multiple data sources. This method scales well, and is more flexible and real-time.

The gateway device may support multiple data uploading protocol in different projects. Network plugins can be used to implement diversified data protocols. The programmable gateway application framework enables data transfer from sensor plugins to network plugins via inter-process communication instead of database, which incurs much less latency.

Typically energy management gateways are installed in different buildings, posing a challenge for gateway management. The gateway remote management capability becomes useful in this scenario. Remote gateway management has the following valuable features:

- Gateway online status monitoring
- Remote configuration management
- Remote application deployment and management
- System state monitoring
- System upgrades. Wind River IDP has built-in support for TR-069 and OMA DM management protocols. Customers can also develop customized device management functionality based on the programmable gateway software framework.

Security is another important requirement for energy gateways, including:

- Gateway device security
- Data storage security
- Data transmission security. Intel® Quark™ processor supports secure boot. Wind River IDP provides application integrity checking that further improves device security. Additionally, Wind River Linux and IDP support storage encryption to provide data storage security. IDP also supports industry standard encryption standards such as SSL/TLS for data transmission security.

To summarize, Intel® Quark™ based energy management gateway simplifies application development for data collection and transmission. In addition to built-in management protocols, the software framework also enables customized device management development. Leveraging Intel® Quark™ processor and IDP security features, complexity in securing end-to-end gateway solution is greatly reduced. Through these hardware and software capacities, building an energy management gateway solution based on Intel® Quark™ becomes efficient and cost effective.
6 Summary

Intel is working closely with ecosystem partners to explore the opportunities in smart energy industry, particularly on energy efficiency management system. After engaging with a number of local and global partners focusing on energy management market, covering vertical including environmental, manufacturing, and smart building, Intel builds the Quark-based energy management gateway solution. This programmable gateway solution meets the core requirements of energy management project from the perspective of both hardware and software. This document describes the gateway’s hardware specification and it’s rational. It also covers the gateway software stack layers with the requirement, functionalities, and design principle. The software stack on the gateway shall enhance the gateway to simplify the development, integration, and deployment of energy applications, so application centric management, integration, and development support become the key cornerstones of Intel's energy gateway solution. Intel's Wind River IDP provides comprehensive solution covering all the key building blocks of IoT gateways, including connectivity, management, and security.

This document also includes detailed case studies of energy management application on building industry, including the detailed requirement and challenge analysis, and how Intel's programmable gateway solution is being used to meet these requirements and challenges. The case study shares the experience learned from actual energy management solutions.