University of Southern Queensland

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Programming Sun™ SPOTs (Small Programmable Object Technology) in Java™

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Abstract

The purpose of this project was to develop a testbed for a simple wireless sensor network (WSN). In a WSN, a collection of sensor nodes, called motes, have the ability to collect information and send this information to a host computer or other motes. The WSN was developed using a Sun™SPOT Development kit. This development kit contained the hardware and software to develop a WSN. The applications for the motes were written in Squawk Java™Virtual Machine (VM). This variant of Java™runs directly on the wire, i.e. without the need for an operating system. To eliminate the need to develop any additional hardware, the eDemoBoard on the Sun™SPOTs was utilised.

The eDemoBoard included sensors, analogue and digital In/Outputs and user interfaces. Since the development kit only included two Sun™SPOTs, additional virtual motes were added to the WSN. The virtual motes were launched from Solarium. Solarium is a software application which was delivered with the development kit. Virtual and physical Sun™SPOTs were able to communicate with each other.

The WSN was implemented as a Home Automation Application (HAA). It was implemented using two different specialised motes - collector and interface motes. The environmental data was sampled and sent by the collector motes. This data was sent as a broadcast over radio communication. The receivers of the broadcast data were the interface motes and the host. The interface motes forwarded the data to the external systems, i.e. climate control, light control, alarm systems, etc.

In addition, the interface motes transmitted the status of the associated external system to the host. The host acted as a user interface, utilising the incoming data from collector and interface motes to provide relevant information to the occupant of the home.

Six testbeds were defined to verify the accuracy and performance of the WSN. The results from testbeds showed that the selected sensors were deemed to be accurate enough for a HAA. In addition, from a performance perspective the testbeds prooved that the WSN worked well. An unexpected outcome of the testbeds was the discovery that the host computer became significantly slower if too many virtual motes were running at the same time.

The high cost of the Sun™SPOT development kit compared to conventional sensors was a limiting factor in deploying a complete WSN using only physical Sun™SPOTs. However, even though the development kit only included two physical Sun™SPOTs it was possible to develop a working WSN. A combination of the physical and virtual Sun™SPOTs provided enough motes for the WSN to cover a small home.

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Nomenclature

ADC	Analog to Digital Conversion
AES	Advanced Encryption Standard
API	Application Programming Interface
ASK	Amplitude Shift Keying
BPSK	Binary Phase Shift Keying
CA	Collision Avoidance
CC2420	Radio transceiver used by Sun™SPOT
CD	Collision Detection
CDMA	Code Division Multiple Access
CSMA	Carrier Sense Multiple Access
CSS	Chirp Spread Spectrum
DC	Direct Current
DDL	Data Link Layer
DG	Datagram
DSSS	Direct Sequence Spread Spectrum
ECC	Elliptic Curve Cryptography
ECDLP	Elliptic Curve Discrete Logarithmic Problem
ED	Energy Detection
GPIO	General Purpose Digital In/Output
GPS	Global Positioning System
GTS	Guaranteed Time Slot
HAA	Home Automation Application
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers

I/O	In / Output
ISM	Industrial, Scientific, Medical Band
LDO	Low Drop Out
LED	Light Emitting Diode
LQI	Link Quality Indication
LR-WPAN	Low-Rate Wireless Personal Area Network
MAC	Medium Access Control
Mote	Wireless Network Node
NO	Normal Open
OO	Object Orientated
O-QPSK	Offset Quadrature Phase Shift Keying
OSI	Open Systems Interconnection
OTA	Over The Air Deployment
PAN	Personal Area Network
PHY	Physical Layer
pSRAM	Pseudo-static Random Access Memory
PSSS	Parallel Sequence Spread Spectrum
SDK	Software Development Kit
SE	Standard Edition
SIG	Special Interest Group
SPI	Serial Peripheral Bus
SPOT	Small Programmable Object Technology
SPST	Single Pole Single Throw
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
UWB	Ultra Wide Band
VM	Virtual Machine
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

Chapter 1

Introduction

Wireless devices have been used for a considerable time. Examples of wireless devices are radio, television and cordless phones. However, wireless devices only recently have been developed to interact with other wireless devices without the need for additional infrastructure. Wireless devices like radios and televisions receive data over a certain frequency and use the information embedded in the frequency to deliver audio and/or video. However, a television does not have the capability to communicate with other televisions. Cordless phone are able to receive and transmit voice signals via a phone network. The two phones require this phone network so the callers can communicate with each other. Recent development in wireless technologies have expanded the capabilities of wireless devices. Wireless devices are now able to interact with other devices. For example, a Bluetooth®enabled mobile phone can communicate with a Bluetooth®enabled GPS device. The two devices communicate directly without the need of other supporting communication networks or devices.

The original reason for the development of Bluetooth®was to remove the cables which connect input devices to a computer (Prasad & Deneire 2006). This allowed the user to move the input device without being restricted by the cable length. Unlike many other wireless devices, these new devices were designed for small ranges. The range of these devices has become known as Personal Area Networks (PAN). The development of Bluetooth®was used as a foundation for the IEEE 802.15.4.1 standard

The concept of two way communication between wireless devices was expanded to create wireless sensor networks. Here a collection of sensor nodes, called motes, have the ability to collect information and send this information to a host computer or other motes. The motes may also have the ability to forward information from other motes or the host.

For this project the Small Programmable Object Technology (SPOT) developed by Sun™ Microsystems was utilised. Sun™ SPOT implements Wireless Personal Area Networks (WPAN) technology with the IEEE 802.15.4 standard. Currently a Sun™ SPOT is the size of a matchbox. When fully developed a Sun™ SPOT will be the size of a speck of dust.

1.1 Broad Aims and Specific Objectives

'This project aims to experiment with a Sun™ SPOT hardware development kit so as to set up a prototype testbed for a simple wireless sensor network' (Xiang 2009). The development kit included two Sun™ SPOTs, a base station and Sun™ SPOT manager. The Sun™ SPOT manger included the application Solarium which allowed the launching of virtual Sun™ SPOTs. The development kit also included the necessary documentation to develop Sun™ SPOT applications. The plan was to create a Home Automation Application (HAA) which would utilise physical and virtual motes.

In general a WSN requires code written for the host and separate code for the motes. In the case of a Sun™ SPOT, the programming language for the motes is Squawk Java™ VM. Once the application on the Sun™ SPOT is running, the mote collects data and then send the data to the host or other motes. The motes can be configured to forward any transmissions from other motes. The programming language for applications running on the host is Standard Edition (SE) Java™ VM. When the host application is started, it listens for any new data from the motes and processes the received data. If required, the host can send information to one or more motes in the network.

To successfully design and deploy the simple WSN the capabilities and limitations of

the different elements that make up the WSN needed to be understood. Specifically the hardware, software and the 802.15.4 standard needed to be investigated to successfully complete the project.

1.2 Background Information

A WSN depends on the interaction of hardware, software and network protocol. For this project the hardware consisted of a host computer, a base station and two Sun™SPOTs. The host computer was an Intel®based Microsoft®Windows desktop computer. The base station had a main board and each Sun™SPOT consisted of a main board and an eDemoBoard. The base station was connected to the desktop computer via a Universal Serial Bus (USB) cable and acted as the gateway to the WSN.

The main board on Sun™SPOT contained the processor, memory, radio communication. (Sun 2008*c*, p.2). The main board had one power and one activity Light Emitting Diode (LED) and a power / reset switch. The eDemoBoard on the Sun™SPOT held the internal sensors, user interfaces, analogue inputs and high current outputs (Sun 2008*b*, p.33).

Communication between the host and a Sun™SPOT was achieved by USB or wireless communication. The wireless communication range of Sun™SPOT using the CC2420 radio transceiver and antenna should be about 80 meters (Smith 2007).

A Sun™SPOT is 40 mm wide, 70 mm long and 23 mm deep. When fully developed Sun™expects to shrink them to the size of a speck of dust. Currently two research projects (”Smart Dust” and ”Speckled Computing”) are being conducted by Sun™which focus on wireless networks sensor with size of 1 mm^3 or less (Horan, Bush, Nolan & Cleal 2007). The battery on the Sun™SPOT can be recharged via the USB mini Type B charger. A Sun™SPOT does not have an operating system. The Java™code runs directly on the hardware without the need for an operating system.

Figure 1.1 shows the eDemoboard of a Sun™SPOT.

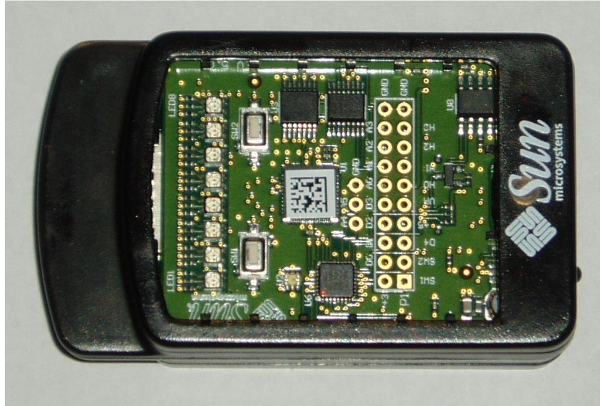

Figure 1.1: eDemoBoard of Sun™SPOT

A Sun™SPOT operates in three modes:

- deep sleep;
- idle; and
- run.

The Sun™SPOTs use the 802.15.4 standard to communicate. This standard is based on the original specification for Bluetooth®(Prasad & Deneire 2006, p.83). However, the 802.15.4 standard only "specifies the medium access control and the physical layer for low rate WPAN's"(Prasad & Deneire 2006, p.83, point 4). This standard is for low rate and low power applications, where ease of installation, reliable data transfer, short range operations, low cost and reasonable battery life is required (IEE 2006).

The applications for the host were written in SE Java™VM and in Squawk Java™VM for the Sun™SPOTs. A comparison of the two is shown in Figure 2.2. All that was required to create, compile and deploy applications was a text editor and Software Development Kit (SDK) (current version jdk1.6.0_07) environment. However, to simplify some steps, NetBeans was utilised during the project since it offerd an Integrated Development Environment (IDE).

Chapter 2

Literature Review

An important event for WPANs was the creation of a special interest group (SIG) in 1998 (Bluetooth 2009). The aim of the SIG was to eliminate communication cables (RS232, etc.) and utilise wireless communication instead.

The SIG developed Bluetooth®. The specification for Bluetooth®was used as a basis for 802.15.1. However, only certain elements of the Bluetooth®specification were standardised. Further work by task groups resulted in additional standards. One of these four original standards included the 805.15.4 standard. This standard specifies the medium access control (MAC) and physical layer (PHY) for Low Rate WPANs (LR-WPAN). Since 2006 the standard specifies four PHYs (IEE 2006).

The latest standard for IEEE 802.15.4 was released in 2006 with an amendment in 2007.

From (IEE 2006, p. 13) and IEEE 802.15.4a 2007 amendment:

> "The main objectives of an LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol. Some of the characteristics of an LR-WPAN are as follows:
>
> - Over-the-air data rates of 851 kb/s, 250 kb/s, 100 kb/s, 40 kb/s, and

20 kb/s

- Star or peer-to-peer operation
- Allocated 16-bit short or 64-bit extended addresses
- Optional allocation of guaranteed time slots (GTSs)
- Carrier sense multiple access with collision avoidance (CSMA-CA) or ALOHA [ultra-wide band (UWB)]channel access
- Fully acknowledged protocol for transfer reliability
- Low power consumption
- Energy detection (ED)
- Link quality indication (LQI)
- 16 channels in the 2450 MHz band, 30 channels in the 915 MHz band, and 3 channels in the 868 MHz band, 14 overlapping chirp spread spectrum (CSS) channels in the 2450 MHz band, and 16 channels in three UWB bands (500 MHz and 3.1 GHz to 10.6 GHz)"

Wireless communication is more susceptible to noise and is less reliable than wired communication (Tanenbaum 2003, p.297). To make the transmission of data more robust the 802.15.4 uses Direct Sequence Spread Spectrum (DSSS). DSSS is a modulation technique which operates similarly to Code Division Multiple Access (CDMA). In CDMA (Ball 2008, p.2.24) a large number of users are allocated a large bandwidth and the users are allowed to transmit at the same time. Each user is assigned a unique spreading code.

In the case of IEEE 802.15.4, communication is achieved in a similar way. Each bit of data is transmitted via 11 chips (sub-bits) and using a **Barker Sequence** (Tanenbaum 2003, p.294). The Barker Sequence (Daintith 2004) is

> "a sequence of symbols (binary or q-ary) that, when embedded in a string of randomly chosen symbols (from the same alphabet), has zero autocorrelation except in the coincidence position. Barker sequences are used to check, and if necessary to correct, the synchronization and framing of received data."

The chips do not carry any binary data (Zahariadis 2003, p.75). The protocol to identify which device is next to transmit is called CSMA and is implemented in the MAC layer (Prasad & Deneire 2006).

The IEEE 802.15.4 standard only specifies the MAC and PHY layers. These layers will be discussed now.

2.1 MAC Layer

The MAC Layer is a sublayer of the Data Link Layer (DLL) in the Open Systems Interconnection (OSI) Reference Model (Tanenbaum 2003). The MAC Layer needs 'to allocate a single broadcast channel among competing users' (Tanenbaum 2003). The task of the MAC layer is to establish which device will be the next one to access the communication channel. CSMA is a protocol to improve performance in a wireless network (Tanenbaum 2003, p.255). The CSMA type used in 802.15.4 is slotted (Prasad & Deneire 2006, p.101) and "$\cdots$ works as follows"(Tanenbaum 2003, p.256):

- station is ready to send;
- station senses the channel;
- if the channel is idle; and
- transmit with probability p.

To reduce the probability of collisions, CSMA can be implemented by either using CA or collision detection (CD). Since wireless radios usually can't send and receive at the same time 802.15.4 specifies CSMA-CA (IEE 2006, p.iii) Tannenbaum (2003) notes that CSMA-CA makes the nodes in a WSN more polite, since the node will back off and wait a random amount of time before attempting to send the data. However this creates a problem if urgent data needs to be transmitted.

2.2 Physical Layer

As mentioned above, the standard for IEEE 802.15.4 defines four PHYs. From (IEE 2006)

> "The standard now includes two optional physical layers (PHYs) yielding higher data rates in the lower frequency bands and, therefore, specifies the following four PHYs:
>
> - An 868/915 MHz direct sequence spread spectrum (DSSS) PHY employing binary phase-shift keying (BPSK) modulation
> - An 868/915 MHz DSSS PHY employing offset quadrature phase-shift keying (O-QPSK) modulation
> - An 868/915 MHz parallel sequence spread spectrum (PSSS) PHY employing BPSK and amplitude shift keying (ASK) modulation
> - A 2450 MHz DSSS PHY employing O-QPSK modulation"

The Sun™SPOTs operate in the 2450 MHz Industrial, Scientific, Medical (ISM) band (Sun 2008*c*). For 802.15.4 communication the band is divided into 16 channels with each occupying 5 MHz (Sun 2009*b*, p.16). The frequencies are listed in Table 2.1. The data rate is 250 kB/s.

There is a downside in using the 2450 MHz band. This band is also used by 802.11b/g devices, cordless phones and microwave ovens. With the increasing number of devices deployed in this frequency range, channel conflict is becoming a frequent problem (Chen, Sun & Gerla 2006).

2.3 Network Topology

One characteristics of the IEEE 802.15.4 standard is that networks can be configured as star or peer-to-peer (Figure 2.1). Both network configurations may utilise a PAN Coordinator. In the star topology the PAN Coordinator is used to 'initiate, terminate,

Channel	**Centre Frequency** (MHz)	**Channel**	**Centre Frequency** (MHz)
11	2405	19	2445
12	2410	20	2450
13	2415	21	2455
14	2420	22	2460
15	2425	23	2465
16	2430	24	2470
17	2435	25	2475
18	2440	26	2480

Table 2.1: 802.15.4. Channel Assignment

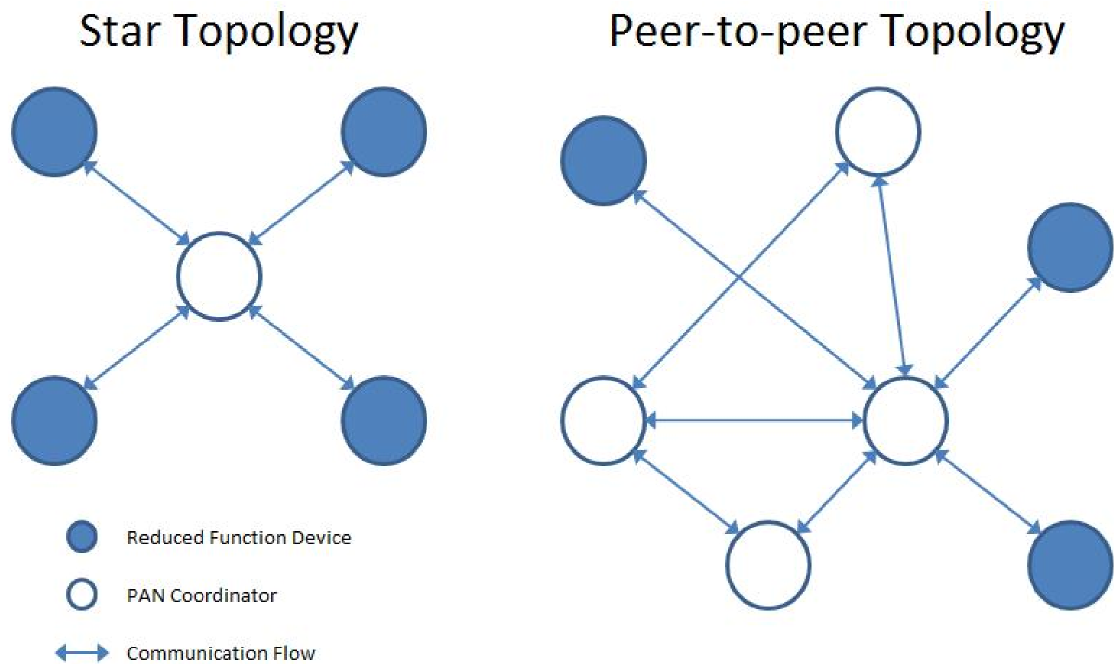

Figure 2.1: 802.15.4 Topologies

or route communication around the network' (IEE 2006, p.14). However, in a peer-to-peer network, the individual devices can communicate directly without any interaction with the PAN. Regardless of network topology each Sun™SPOT has a unique 64-bit address.

The functions for ad-hoc and self-healing networks are implemented in higher layers. As noted above, the 802.15.4 standard only considers the MAC and PHY layers. Therefore

it does not specify how a peer-to-peer network is to be implemented.

2.4 Security

There are a number of security issues which can have an impact on the integrity of the WSN. Olariu and Xu (2005) note that 'a wireless sensor network is only as good as the information it produces'.

The IEEE 802.15.4 provides a minimum standard of security in the MAC layer. The CC2420 radio in the Sun™SPOTs can provide additional security through Advanced Encryption Standard (AES) 128 hardware encryption. In addition 'developers have implemented an Elliptic Curve Cryptography' (ECC) (Boyle & Newe 2008) to increase security of the Sun™SPOT. 'ECC is a public-key cryptosystem that operates over points on an elliptic curve' (Boyle & Newe 2008, p.291). Like other public-key cryptosystems ECC relies on a public and a private key. In ECC the Elliptic Curve Discrete Logarithmic Problem (ECDLP) is utilised to make ECC more efficient than other public-key cryptosystems.

(Boyle & Newe 2008, p.291) state that if:

$$Q = kP \tag{2.1}$$

Then, according to the ECDLP, if P and Q are known it is difficult to find k. In the case of ECC k is the private key.

Since the HAA will operate in a reasonably safe environment the security of the actual sensor is not as critical. However, if the HAA will also have sensors which help to secure the home, the sensors will need to be installed so they cannot be lost, inadvertently removed or stolen.

2.5 Power supply

The Sun™SPOTs in the development kit are powered by batteries, which need to be recharged on a regular basis. The challenge will be to build a power source for the motes when they are the size of a speck of dust. Chalasani & Conrad (2008) note that the following alternative sources for power are being considered.

- mechanical vibration;
- piezoelectric materials;
- solar cells; and
- thermoelectric.

Operating Modes:
A Sun™SPOT has three operating modes. Based on which components on the Sun™SPOT are required, the Sun™SPOT can be placed into these different operating modes. The Owner's Manual lists and explains the different modes (Sun 2008*b*, p.9).

Run	Basic operation with all processors and radio running. Power required by Sun™SPOT is 70 to 120 mA. Power required by the daughterboard (if it is enabled) 400 mA.
Idle	ARM9 clock and the radio is turned off. Power requirement is approximately 24 mA.
Deep-Sleep	All regulators are off. The standby Low Drop Out (LDO), the power control of the Atmega and the pSDRAM are on. Power required is 32 μA. Typical startup time is 2 to 10 milliseconds.

Waking up the processor from deep-sleep can be achieved by the alarm, external interrupt or pressing the button power / reset button on the Sun™SPOT (Sun 2008*b*).

To conserve the battery, the motes of the HAA are only running while data is collected and sent. For the remainder of the time the motes are in the idle or sleep mode.

2.6 Wireless Sensor Node (Mote)

The main board on a Sun™ SPOT contains the following main components: (Sun 2008*c*, p.2)

- main processor, Atmel AT91RM9200 system;
- memory, 4 MB Flash Memory and 512 KB pSRAM;
- power management circuit;
- CC2420 radio transceiver (802.15.4) and antenna;
- battery connector;
- daughter board connector;
- power and activity LEDs; and
- power / reset switch.

The eDemoBoard is a daughterboard and incorporates sensors, user interfaces, analogue inputs and high current outputs (Sun 2008*b*, p.33). The eDemoBoard has an 'Atmel Atmega88 micro controller and it communicates with the main board ARM9 over the Serial Peripheral Bus (SPI) channel as a slave device' (Sun 2008*b*).

The eDemoBoard fulfills the following functions (Sun 2009*b*, p.20):

Internal Sensors:

- temperature;
- acceleration (in three dimensions); and
- light level.

User Interfaces:

- two momentary single pole single throw (SPST) normal open (NO) push buttons; and
- eight tri-colour LEDs.

General Purpose Digital I/O (GPIO):
Four GPIOs can be configured as inputs or outputs. At room temperature the source current is 16 mA and the sink current is 24 mA (Sun 2008*b*).

Analogue Inputs:
Four analogue inputs 0 Volt to 3 Volt dc. (10 bit)

High Current Outputs:
Four high current outputs 125 mA.

Analog to Digital Conversion (ADC):
The ADC is used to convert the analog signal of the accelerometer, light and temperature sensor in to digital values (Sun 2008*b*).

2.7 SE Java VM and Squawk Java VM

As previously mentioned the PAN and the motes run on different applications. The applications on the PAN are written in SE Java™VM. This programming language 'is a general-purpose, concurrent, strongly typed, class-based object-oriented language.' (Gosling, Joy, Steele & Bracha 1996).

The applications on the motes are written in Squawk Java™VM. The aim of of Squawk is to 'write as much of the virtual machine as possible in Java' (*The Squawk Virtual Machine* n.d.). Figure 2.2 shows a comparison of the two virtual machines.

The Java™VM is the technology which makes Java™hardware and operating system independent (Lindholm & Yellin 1997). It is normally compiled to the bytecode

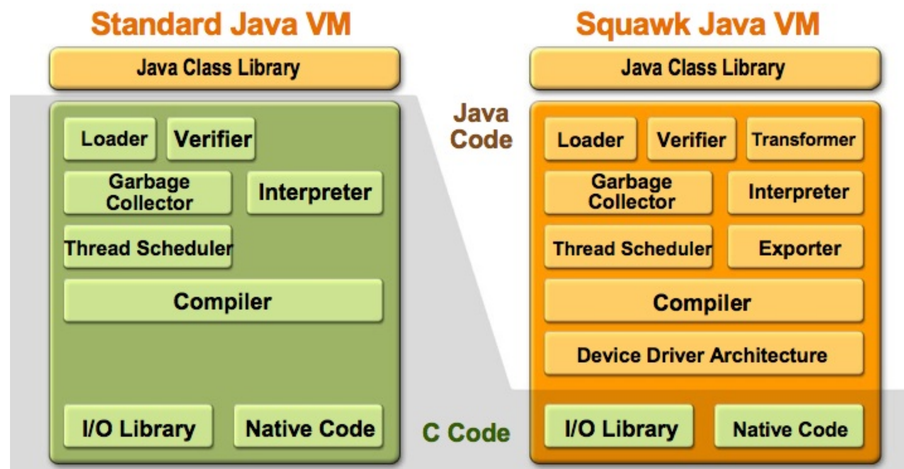

Figure 2.2: Comparison Standard Java VM versus Squawk Java VM[1]

instruction set and binary format defined in the Java™ VM Specification.

The Sun™ SPOT Owner's Manual accompanying the development kit shows a number of simple examples. One such example shows the code to measure the temperature in Celsius.

```
// Initiate the temperature sensor object
// ------------------------------------------------------------
Import com.sun.spot.sensorboard.EDemoBoard
Import com.sun.spot.sensorboard.io.ITemperatureInput
ITemperatureInput ourTempSensor = EDemoBoard.getCelsius();

// Read the temperature
// ------------------------------------------------------------
double celsiusTemp = ourTempSensor.getCelsius();
```

Listing 2.1: Measure Temperature in Celsius

The example above only executes the collection of the data. After the last statement above has been executed the mote needs to send the information to other devices over the network. This task is implemented by using radio communication. There are two protocols to transmit information. The `RadioStreamConnection` interface is a 'buffered stream-based I/O between two devices' (Sun 2008*b*). The `RadiogramConnection` interface 'allows the exchange of packets between two devices' (Sun 2008*b*).

Before any data can be sent through a radiostream the connection needs to be es-

[1]Used with permission of Sun™ Microsystems.

tablished. Again a simple example from the Sun™ SPOT Owner's Manual is shown. Comments have been added to help understand the statements.

```
// Open connection
// ------------------------------------------------------------
StreamConnection conn = (StreamConnection)
// ------------------------------------------------------------
// nnnn.nnnn.nnnn.nnnn.nnnn -> unique 64-bit IEEE Address
// xxx -> port no. 0-255, 0-31 reserved for system services
Connector.open("radiostream:\\nnnn.nnnn.nnnn.nnnn:xxx";
```

Listing 2.2: Opening a connection

All devices need to open up the same port and each will need to list the unique IEEE address (Sun 2008*b*). It is possible however, for a mote to have more than one port open at a time. At this point in the code the device has established the connection. To receive the stream the following statement can be used:

```
DataInputStream dataIn = conn.openDataInputStream();
```

Listing 2.3: Receiving a Stream

The device can establish the IEEE address with the statement:

```
string myAdress = System.getProperty("IEEE_ADDRESS");
```

Listing 2.4: Get IEEE Address

As mentioned above the exchange of packets between devices is executed via the radiogram protocol. A simple example is shown below:

```
DatagramConnection conn = (DatagramConnection)
Connector.open ("radiogram://" + myAddress + ":100");

Datagram dg = conn.newDatagram(conn.getMaximumLength());
dg.writeUTF ("Hello World!");
conn.send(dg);
```

Listing 2.5: Sample of Datagram

The radiogram protocol can broadcast messages across a network. There is no verification if the packet has been delivered (Sun 2008*b*). To broadcast the second statement in the example above is replaced with the following statement:

```
Connector.open ("radiogram://broadcast:100");
```

Listing 2.6: Sample of Broadcast Datagram

The Sun™SPOT Owner's Manual recommends to keep datagrams smaller than 200 byte when using broadcast mode.The manual also recommends to send important data as unicast via radiograms or radiostreams. Figure B.1 in Appendix B shows how an application is compiled, deployed and started on the host while a Sun™SPOT is connected to the host via USB.

Chapter 3

Methodology

3.1 Introduction

The aim of the project was to develop a simple WSN application. To fulfill the project aim and the project specification in Appendix A, the following methodology was used:

1. select scenario to implement SunSPOT testbed;
2. define testbeds within selected scenario;
3. design and implement WSN;
4. verify accuracy of data collected by the testbeds ;
5. verify performance (time delays, etc) of the testbeds; and
6. document findings and results.

This project focused on the task of programming in Java™. Therefore, throughout the project the main focus was on program development and not hardware development. Hardware development was only considered if it was not possible to complete a test bed with the hardware provided in the development kit.

Each of the above mentioned steps will be discussed in the following sections.

3.2 Select Scenario for WSN

The project aim did not outline any specific scenario for the testbed. Therefore the first task was to determine a suitable task for the WSN. Two main limiting factors needed to be considered during the selection process. These factors were:

- the development kit had only two Sun™SPOTs; and
- the physical characteristics of the motes supplied with the development kit.

A main advantage however, was the fact that the eDemoBoard had built-in sensors which had the ability to measure environmental data. This meant that a number of different environmental samples could be collected without the need for additional hardware. The accuracy of the sensor on the eDemoBoard needed to be verified by using suitable testbeds.

Through a process of elimination the idea of setting up a WSN in a home was selected. Figure E.1 in Appendix E shows the layout of the home selected as a base for the implementation of the HAA and the definition of the testbeds. The abilities of the eDemoBoard allowed the measurement of temperature and light levels without the need to develop any additional hardware. A number of other scenarios where discarded since significant additional hardware was required or the physical characteristics of the mote prevented a realistic scenario. Some of these discarded scenarios are listed below.

- roller door remote control;
- sensor to establish if an elderly or disabled person has fallen;
- remote to turn lights on or off in a room;
- establish how quickly liquid is flowing in a pipe;
- establish moisture content in soil to optimise irrigation; and
- exercise tool for rehabilitation of arm or hand movement.

3.3 Define Testbeds

Once the decision had been made to develop the WSN in a home environment, suitable testbeds had to be selected. Each testbed had to simulate a different aspect of the HAA.

The design and implementation of the computer code however, needed to ensure that the different testbeds could be implemented without the need of major code changes. In addition, each testbed needed to generate a result. Therefore each testbed had to be selected so data could be collected and used to investigate the performance and the accuracy of the WSN. The testbeds for the HAA were as follows:

- Testbed 1: Accuracy of WSN, Internal Sensor.
- Testbed 2: Accuracy of WSN, External Sensor.
- Testbed 3: Maximum Distances between WSN Members.
- Testbed 4: Impact of Noise Sources on WSN.
- Testbed 5: Multifunction Data Collection.
- Testbed 6: High Volume Data Collection.

Testbed 2 was only defined in case the results in testbed 1 were deemed to be not accurate enough for the HAA.

Chapter 4 will describe the individual testbeds in greater detail.

3.4 HAA Design and Implementation

As stated above the application had to be designed in such a way that all the testbeds could be executed with the same code. A detailed description of the design and implementation process is shown in chapter 5. In addition the chapter includes pseudo code for the main functionalities.

3.5 Verification Accuracy and Performance

Once the HAA had been implemented the various testbeds were configured and data collected to gather the results. To verify the accuracy of the data collected by the WSN external independent measuring instruments were used. The light levels were verified with a light meter. The temperature data were verified with a temperature meter.

To verify the performance the time on the host, base station and the motes were synchronised using the command shown in Listing 3.1 before each test. The command was executed from the command line interface on the host computer.

```
ant settime
```

Listing 3.1: Set Time on WSN Members

After synchronisation a reference measurement was taken to establish how long it took to:

- take one sample;
- send sample via broadcast over the WSN; and
- display the sample on the host computer terminal.

Chapter 6 will discuss these results and draw conclusions.

Chapter 4

HAA Test Beds

4.1 Introduction

This chapter will discuss the test bed configurations. Due to the limited output capabilities of the physical Sun™SPOTs only screen captures of virtual Sun™SPOTs were possible. During the early stages of setting up the test bed the limitations of the processing power of the desktop computer were discovered. It became quite clear that deploying too many virtual Sun™SPOTs put a noticeable strain on the performance of the desktop computer.

4.2 Overview Test Bed Setup

The experimental test beds for the HAA were set up as shown in Figure 4.1. The testbed consisted of the following hardware:

- one desktop computer;
- two Sun™SPOTs; and
- one base station connected to the desktop computer via USB.

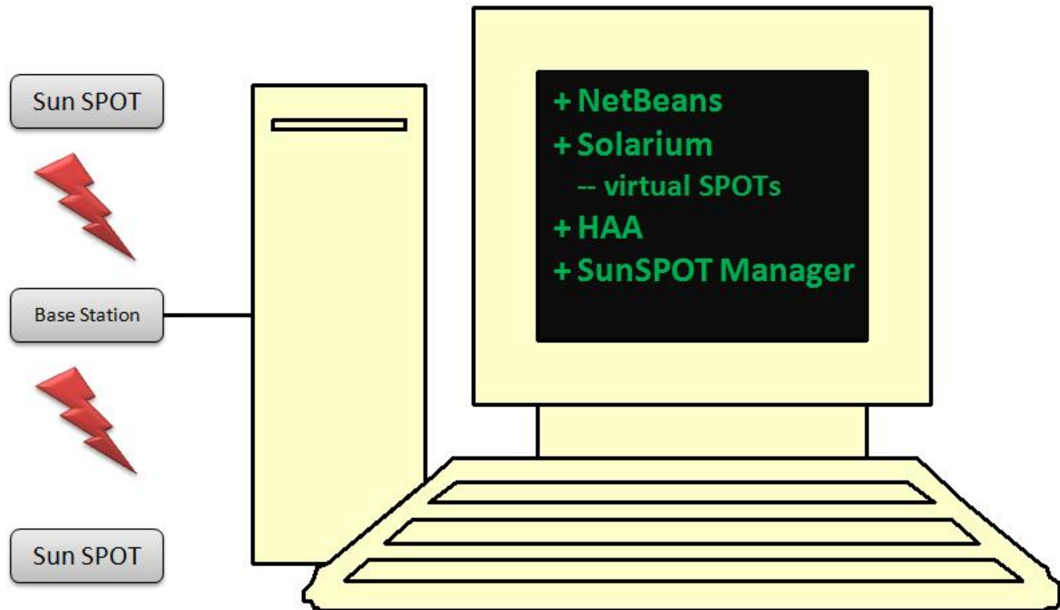

Figure 4.1: HAA Test Bed

The desktop ran multiple applications to fulfill various tasks:

- NetBeansIDE6.5.1 to launch HAA;
- Sun™SPOT Manager to launch Solarium;
- Solarium, to deploy and run the virtual Sun™SPOTs; and
- HAA, the actual application which collected data and interacted with the other members of the WSN via the base station.

The number of virtual Sun™SPOTs deployed during the tests were limited by the processing power of the desktop computer. The screen capture D.5 in Appendix D shows the performance via the Microsoft Windows XP Task Manager. The screen capture shows six virtual motes. Five virtual motes were configured to collect only one environmental data type and transmit the data via broadcast to one virtual interface mote. As specified in Section 5.3 a sample was forwarded every ten seconds from each virtual collector mote.

To reduce the possibility of complications during the tests, the number of virtual motes was limited to six. The process to set up and deploy the motes for the WSN is described below.

4.2.1 Deploying Application to Physical Motes

1. define configuration data in MANIFEST.MF file;
2. connect mote via USB to desktop computer;
3. deploy the application to the mote;
4. run application while mote was still connected to desktop computer;
5. verification that the mote was working properly;
6. disconnect USB; and
7. turn off mote.

4.2.2 Deploying Application to Virtual Motes

To configure the virtual motes, Solarium was launched from the Sun™SPOT Manger.

1. define configuration data in MANIFEST.MF file;
2. create a new virtual mote in Solarium by:
   - selecting `[Emulator] >> [New Virtual SPOT]`;
   - right-click on virtual mote and select `[Deploy MIDlet bundle...]`;
   - navigate to and select required `build.xml` file; and
   - click `[Open]`
3. right-click on virtual SPOT to display sensor panel and / or output window.

4.2.3 Deploying Host Application

The host application was launched from NetBeansIDE6.5.1 .

4.2.4 Starting Members of HAA WSN

Once all the members of the WSN had been configured they were deployed in the order shown below:

1. launch host application;
2. launch interface motes; and
3. launch collector motes.

4.3 Test Beds

4.3.1 Test Bed 1: Accuracy of WSN, Internal Sensor

As mentioned in Chapter 2, the WSN is only as good as the data it delivers. Therefore the first testbed verified the accuracy of the collected data. The configuration for this testbed required two motes to collect environmental data. Each mote collected a different type of environmental data. Due to the limited user interface capabilities of the Sun™SPOTs two possible methods to show the collected data were considered:

1. Connect the data collecting mote via the USB cable to the host computer. The accuracy of the collected data would be verified by the data pushed directly to the terminal by the mote.
2. Design and implement a simple application on the host computer which only pushes the received data to the terminal.

The second method was considered to be more realistic, since the data had to travel via the WSN to reach the host. It was also possible to move the motes to different parts of the home to establish if the accuracy changed if the distance to the host computer was increased.

Next the type of environmental data to be collected was selected. The obvious choice was to utilise the internal sensors on the eDemoBoard. Therefore, for this testbed the temperature and light level were to be measured and sent via broadcast to the host and motes. Some independent means however, were required to verify the accuracy of the collected data.

Based on the considerations above the requirements for the first testbed were:

- Data to be collected: One Sun™SPOT to measure temperature and one Sun™SPOT to measure the light level.
- Time between samples: 20 seconds.
- Receivers: Host and virtual motes.
- Independent means for verification of collected data: light and temperature meter.
- Result: Identify errors in collected data.

4.3.2 Test Bed 2: Accuracy of WSN, External Sensor

This test bed was only going to be executed if the accuracy of the internal sensors were deemed not accurate enough for the HAA. In that case, an external level sensor would have to be developed and then connected to the Sun™SPOT in order to increase accuracy. All the remaining requirements remained the same as defined for the first testbed. Therefore based on the considerations above the requirements for this testbed were:

- Data to be collected: One Sun™SPOT to measure temperature or light level with an external sensor.
- Time between samples: 20 seconds.
- Receivers: Host and virtual motes.
- Independent means for verification of collected data: light or temperature meter.
- Result: Identify any errors in collected data.

4.3.3 Test Bed 3: Maximum Distances between WSN Members

This testbed expanded the requirements for the previous testbeds. In this testbed the maximum possible distance between members of the WSN was to be investigated. As before one physical mote needed to collect a specific environmental data and send the collected data to the host and / or motes. While the data was being collected the mote was to be moved throughout the home. After each relocation of the mote it was to be verified if data was still being received by the host. If data was still being received then the mote was to be moved further away from the host. Based on these considerations the requirements for this testbed were:

- Data to be collected: One Sun™SPOT to measure environmental data.
- Receivers: Host and virtual motes.
- Measuring tape to establish the distance between the mote and the host.
- Result: Maximum possible distance between mote and host.

4.3.4 Test Bed 4: Impact of Noise Sources on WSN

This testbed had to establish if other electronic devices operating in the ISM frequency band had a negative impact on the performance of the WSN. Major other equipment which operates in the ISM band are microwave ovens, wireless networks and cordless phones. To establish if these devices had an impact on the performance of the WSN a Sun™SPOT was to be placed adjacent to these devices.

The details of the available noise sources are:

- GE Microwave, Spacemaker XL1800, output frequency 2450 MHz; and
- LINKSYS Wireless Router, WRT54G, frequency 2.4 GHz.

Based on these considerations the requirements for this testbed were:

- Data to be collected: One Sun™SPOT to measure environmental data.
- Mote placed adjacent to microwave and wireless router.
- Receivers: Host and virtual motes.
- Independent means for verification of collected data.
- Result: Performance impact if WSN is operated near the above mentioned noise sources.

4.3.5 Test Bed 5: Multifunction Data Collection

Since the eDemoBoard had multiple sensors, it was deemed to be practical for a mote to collect more than one type of data. Therefore, if a mote could collect and send more than one type of data the receiving host or mote would need to distinguish between different types of environmental data. Hence the computer code for data collection, data transmission and data receiving needed to be implemented for multiple data types.

Based on these considerations the requirements for this testbed were:

- Data to be collected: One Sun™SPOT to measure more than one environmental type of data.
- Receivers: Host and virtual motes.
- Result: The data collected, sent and received needs to be kept separate and not misread by the receivers.

4.3.6 Test Bed 6: High Volume Data Collection

This testbed investigated the capability of receivers in the WSN. A number of physical and virtual motes were to send data at progressively shorter intervals to the host. The testbed investigated how much data could be received by a single member before delays in processing the data were noticeable.

Based on these considerations the requirements for this testbed were:

- Data to be collected: Single data type collected by as many as possible physical and virtual motes.
- Receivers: Host.
- Result: Delay in processing and displaying the data.

Chapter 5

Implementation

5.1 Introduction

During the initial familiarisation in programming applications for Sun™SPOTs it became quite clear that a runtime error could prevent access via the USB port or Over The Air (OTA) because the Sun™SPOT was constantly resetting. Therefore in addition to using virtual motes to extend the number of members in the WSN, virtual motes were used to test any new applications or changes to existing applications. The process of deploying and running an application on a virtual SPOTs is shown in Chapter 4.

As previously mentioned, the Sun™SPOTs in the development kit included an eDemoBoard. The eDemoBoard has sensor and user interfaces which can be accessed via at application running on the Sun™SPOT. The capabilities of the eDemoBoard were utilised for this project. Therefore, no additional hardware had to be designed. There was a possibility that the internal sensors could be affected by other components on the eDemoBoard. If the test beds would show that this was the case then an external sensor would have to be designed. The sensors and user interfaces of the eDemoBoard were also available on the virtual motes. The capabilities of the eDemoBoard are listed in Chapter 2.

To ensure that all the different components of the WSN properly interacted with each

other clear requirements were needed. Clear requirements were also necessary as a basis for testing and implementation of the applications. Therefore this chapter will include the following sections:

- design and development process;
- requirements;
- test scripts; and
- implementation.

5.2 Design and Development Process

The code for the motes was implemented using the following process:

1. define requirement(s);
2. write pseudo code based on requirement(s);
   - if required, draw flowchart;
3. write a test script which verifies access to instance variables and method;
4. write the actual code;
5. run test script in Solarium and improve if necessary;
6. add new instance variables and methods to new or existing mote class;
7. deploy and run the real code on virtual Sun™SPOTs in Solarium; and
8. deploy and run the real code on physical Sun™SPOTs.

A simple method will be used to show the above process:

1. Requirement.

   Before a collector mote sends data it needs to verify that the number of digits after the decimal point is limited to two.

2. Pseudo code.

```
double reformatDataToBeSent(double valueIn)
  Task: remove excess digits after decimal point before sending
  Input: sampled data to be sent
  Output: number limited to 2 digits after the decimal point

  Define local variables
    double valueOut

  valueIn —> Move decimal point 2 digits to right —> assign toValueIn
  valueIn —> Round up or down —> assign to valueIn
  valueIn —> Move decimal point 2 digits to left —> assign toValueOut

  return valueOut

end of reformatTempToBeSent()
```

Listing 5.1: Example Pseudo Code

3. Test script.

   The test script is listed in the Appendix C.1.

4. Write actual code.

   The actual code is listed in the Appendix C.2.

5. Run the test script in Solarium.

   The screen capture of output from the test script is shown in Appendix D.1.

6. Add new instance variables and methods to new or existing class.

   For this example the tested method was added to the collector.java class. The listing for the common functionality of a collector mote is shown in Appendix C.9.

7. Deploy and run the actual code on virtual Sun™SPOTs in Solarium.

   The screen capture of the host output is shown in Appendix D.2.

   The screen capture of the virtual Sun™SPOT output is shown in Appendix D.3.

8. Deploy and run the actual code to physical Sun™SPOTs.

   For this method it was only possible to verify that the method operated correctly on a physical mote by analysing the data received at the host. All data received by the host was to have no more than two digits after the decimal point.

5.3 Requirements

In broad terms the HAA had to include the following functions:

1. collect environmental data;
2. forward data to external systems;
3. log events and environmental data on host computer; and
4. provide user interface on host computer.

The HAA was not going to be able to make a proper assessment of the current status in the home unless a number of Sun™SPOTs were deployed to gather environmental data. The WSN was be made up of two types of motes. The main task of each type of mote were:

Collector mote: Collects environmental data and forwards to host or other motes.

Interface mote: Receives data from host or other motes and forwards to external systems.

5.3.1 WSN Configuration

The Sun™SPOTs were to be configured to accept OTA commands and to enable OTA downloads (Sun 2009*a*, p.22). Every Sun™SPOT deployed for the HAA had to have mesh routing enabled. If mesh routing is enabled, the motes will rebroadcast packets destined for other members of the WSN. This will instruct the SPOT to forward any packet intended for other SPOTs (Sun 2009*a*, p.26).

Each member can have multiple ports open at any one time. Therefore the ports shown in Table 5.1 were used to communicate between the different members of the WSN.

Sender	Type of Communication	Port
Host	Send IEEE Address (broadcast)	66
	Listen for environmental data	67
	Listen for status	68
Interface Mote	Listen for host	66
	Listen for environmental data	67
	Send status to host (unicast)	68
Collector Mote	Send environmental data (broadcast)	67

Table 5.1: Port Allocation

5.3.2 Data Collection

Most of the data will come from different parts of the home. It is a requirement however that the outside temperature and light levels were also captured by the motes.

To streamline the deployment of the application to the individual motes a single multi-functional application was to be designed for the data collection motes.

The data to be collected was as follows:

- temperature;
- light Level;
- battery capacity;
- alarm trigger; and
- carbon monoxide level.

Each data collection function was to run in a separate thread. In addition a data collection function (thread) was only to be started if required by the configuration file. For the Sun™SPOTs the configuration file is called the MANIFEST.MF file. The developer guide (Sun 2009*a*, p. 17) states that

Identifier	Message Type
1	Temperature
2	Light
3	Battery
4	Alarm
5	Carbon Monoxide

Table 5.2: Message Type Identifier Collector Motes

> "the MANIFEST in the resource/META-INF directory contains information used by the Squawk VM to run the application. In particular it contains the name of the initial class".

In addition the MANIFEST.MF file can be used to define properties which the Sun™SPOT application can access at runtime. The details of the MANIFEST.MF file will be further explained in section 5.5.

To identify the message type at the receiver, data sent by the collector motes had to be identified with unique value of type "byte". This would allow the the other members of the WSN to establish what type of information is included in the packet. The message types are defined in table 5.2.

In addition the collector mote also needed to send the location to inform the receivers where the data was collected. This allowed the interface motes and the host to establish where the data was sampled. The location information had to be of type "String". The locations were defined in table 5.3.

To conserve power the data collection motes would be awake only if a sample was to be taken. In addition data was to be transmitted only if the new sampled value differed from the previous measurement. For trouble shooting purposes however, any sampling or sending events were to be indicated by using the LEDs located on the eDemoBoard. This would have an impact on how quickly the battery drained, but helped during testing of the different modules in the computer code.

The measured environmental data was to be sent via broadcast datagram to other

HAA Locations	
Living	Dining
Kitchen	BedMain
Bed2	Study
BathMain	Bath2
Laundry	Outside

Table 5.3: HAA Locations

Data	Sample Interval
Temperature	1 min.
Light Level	1 min.
Battery Capacity	30 min.
Alarm Trigger	1 sec.
Carbon monoxide	10 sec.

Table 5.4: Collected Environmental Data

members of the WSN. Table 5.4 shows how often the data was to be sampled. When sending a sample the sample time had to be included. The flowchart B.3 in Appendix B provides an simplified overview of the temperature collection thread.

Table 5.5 shows how often samples are to be sent via the WSN and defines the recipients of the data. However the newest data is only sent if it differs from the previous sample. The data to be sent is to be limited to two digits after the decimal point.

Data	Receivers
Temperature	Host and Climate Control Interface Mote
Light Level	Host and Light Control Interface Mote
Battery Capacity	Host
Alarm Trigger	Host and Alarm System Interface Mote
Carbon monoxide	Host and Carbon Mono Control Interface Mote

Table 5.5: Receivers of Collected Data

Based on the considerations mentioned above the pseudo code for the main functionalities of the collectors motes were developed. The complete pseudo codes are listed in Appendix C.

The Pseudo code for the main class of a Collector Mote is shown in Listings 5.2. The main task for this class is to configure the data collecting mote based on the configuration file. Once the threads have started the main class waits until all other threads have finished. The Flowchart B.2 in Appendix B provides a simplified overview of this thread.

```
Pseudo Code for Main Class of a Collector Mote
  Instance Variables
  Variables for MANIFEST.MF properties (Strings)
  Variables for MANIFEST.MF poperties
  Define boolean vaiables to set functions of mote, set to FALSE
  protected void startApp()
    Monitor the USB Port (if connected) & recognize commands from host
    Make a new instance of possible functions of mote and set to NULL
    Get configuration data from Manifest file
    Convert properties of MANIFEST file to appropriate data type
    Set required functions of mote based on properties of MANIFEST.MF
    Start new threads on a SunSPOT depending Manifest file
    Wait for functions (threads) to end
  END of startApp
END of class
```

Listing 5.2: Pseudo Code for Main Class of Collector Motes

Based on the configuration file one to five threads to collect data are started. The pseudo codes for each thread are listed over the next few pages.

Temperature Collection Function

The pseudo code for the temperature functionality is as follows:

```
Pseudo Code for Temperature Thread
  TempThread implements Runnable
  public void run()
    Start a new temperature collector mote
    Intial set up for measurement of temperature
    Intial set up for communication
```

```
    Get and push IEEE Address to terminal
    Open up a broadcast connection
    WHILE (true)
      Get the current time when sample is taken
      Get the current temperature reading to send in datagram
      Reformat tempToBeSent to ****.**
      IF (has Temperature Changed)
        Update time and temperature value to be sent
        Send current sample
      END IF (has Temperature changed)
      Move current temperature sample to previous sample variable
      Go to sleep to conserve battery
    END of WHILE
  END of run()
END of class
```

Listing 5.3: Pseudo Code for Temperature Thread

The Flowchart B.3 in Appendix B provides a simplified overview of the temperature thread.

Light Level Collection Function

The pseudo code for the light level functionality is as follows:

```
Pseudo Code for Light Level Thread
  LightThread implements Runnable
  public void run()
    Start a new light level collector mote
    Intial set up for measurement of light
    Intial set up for communication
    Get and push IEEE Address to terminal
    Open up a broadcast connection
    WHILE (true)
      Get the time when sample is taken
      Get the current light reading to send in datagram
      Reformat lightToBeSent to ****.**
      IF (has Light Changed)
        Update time and light value to be sent
        Send current sample
      END IF (has Light changed)
      Move current light sample to previous sample variable
```

```
      Go to sleep to conserve battery
    END of WHILE
  END of run()
END of class
```

Listing 5.4: Pseudo Code for Light Level Thread

Battery Capacity Function

The pseudo code for the battery capacity functionality is as follows:

```
Pseudo code for battery capacity Thread
  BatLevelThread implements Runnable
  public void run()
    Start a new battery level collector mote
    Intial set up for measurement of battery level
    Intial set up for communication
    Get and push IEEE Address to terminal
    Open up a broadcast connection
    WHILE (true)
      Get the time when sample is taken
      Get the current battery reading to send in datagram
      IF (battery level has changed)
        Update time and battery value to be sent
        Send current sample
      END IF (battery level has changed)
      Move current battery sample to previous sample variable
      Go to sleep to conserve battery
    END of WHILE
  END of run()
END of class
```

Listing 5.5: Pseudo Code for Battery Capacity Thread

Alarm Trigger Function

The pseudo code for the alarm trigger functionality is as follows:

```
Pseudo code for Alarm Trigger Thread
  AlarmThread implements Runnable
  public void run()
    Start a new alarm trigger mote
    Initial set up for alarm trigger
```

```
    Intial set up for communication
    Get and push IEEE Address to terminal
    Open up a broadcast connection
    WHILE (true) {
      WHILE(no Alarm, i.e. input is low)
        Go to sleep for specified time
        Get the time when sample is taken
      END of WHILE (no Alarm, input is low)
      Send message to notify that alarm has been triggered
      Update alarm values to be sent
      Package time & alarm trigger into a radio datagram & send
      Stop the thread until the input has been set to low
        Only send "alarm triggered" once
      Wait for pin to change state
      When pin has changed renable pin change interrupt
      IF (confirm no Alarm)
        Get the current time
        Update alarm values to be sent
        Package time & alarm trigger into radio datagram & send
      END IF (confirm no Alarm)
    END of WHILE (true)
  END of run()
END of class
```

Listing 5.6: Pseudo Code for Alarm Trigger Thread

Carbon Monoxide Detector Function

To implement the carbon monoxide detection an anlogue input was utilised. No actual hardware was designed or implemented. It was however assumed that the carbon monoxide detector would provide the carbon monoxide levels by varying the voltage at the output. This change in output would be read by the carbon monoxide function on a data collecting mote.

The pseudo code for the Carbon Monoxide detection functionality is as follows:

```
Pseudo code for carbon monoxide detector thread
  CarMonThread implements Runnable
  public void run()
    Start a new carbon monoxide detector collector mote
    Intial set up for measurement of carbon monoxide
```

```
    Intial set up for communication
    Get and push IEEE Address to terminal
    Open up a broadcast connection
    WHILE (true)
      Get the time when sample is taken
      Get the current carbon mono reading to send in datagram
      Convert Sample to volt
      Reformat sample to be sent to ****.** format
      IF (has Carbon Monoxide Level Changed)
        Update time and carbon monoxide value to be sent
        Send current sample
      END of IF (has Carbon Monoxide Level Changed)
      Move current carbon level to previous carbon level variable
      Go to sleep to conserve battery
    END of WHILE
  END of run()
END of class
```

Listing 5.7: Pseudo Code for Carbon Monoxide Detector Thread

5.3.3 Interface to External Systems

For the interface motes the following assumptions were made:

- The motes would be located near the external system.
- The motes would communicated via Universal Asynchronous Receiver/Transmitter (UART) with the external system.
- The motes would have reliable power to make them less reliant on the battery.
- The motes would be running for most of the time to listen for incoming data.

The assumption that the communication to the external system was via UART was made to reduce the number of possible ways to communicate with external systems. An exception was made for the door interface. Here it was assumed that one of the

Identifier	External System Identification
11	Climate Control
12	Light Control
13	Not used
14	Alarm System
15	Carbon Monoxide Detection System
16	Door Interface

Table 5.6: External System Identification for Interface Motes

analogue or digital outputs would be used to drive a solenoid to unlock the door. All interface motes however, should announce themselves to the WSN and communicate the status of the external interface. This will allow the host to keep track if the external system is operating.

The interface motes are to have the following capabilities:

- receive data from data collection motes;
- output the received information to the external system;
- trigger message if status of external system had changed;
- announce presence to other WSN members;
- send a periodic signal to host to indicate status of external system; and
- listen for messages from host.

Once an interface mote has been deployed it will listen for datagrams. If a datagram is received from a collector SPOT the interface SPOT verifies that the correct message type is included. If the message type is correct the interface SPOT will forward the data to the external system. In addition the interface will listen for broadcast from the host. If a broadcast message from the host is received, the interface mote will communicate to the host via unicast radiogramm connection and report the status of the external system in regular intervals.

The pseudo code for an interface mote is as follows:

```
public class InterfaceMainSPOT extends MIDlet
  Instance variables
  protected void startApp()
      Monitor the USB (if connected) and recognize commands from host
      Get configuration data from Manifest file to configure mote
      Convert Strings to appropriate data type
      Find external system status id based on MANIFEST.MF file
      Start new thread on a SunSPOT depending on MANIFEST.MF file
      SWITCH (external System Id)
        case 11:
          new ClimateInterfaceThread
          new sendStatus thread
          Wait for threads to finish
        case 12:
          new LightingInterfaceThread
          new sendStatus thread
          Wait for thread to finish
        case 14:
          new AlarmInterfaceThread
          new sendStatus thread
          Wait for thread to finish
        case 15:
          new CarbMonInterfaceThread
          new sendStatus thread
          Wait for thread to finish
        case 16:
          new DoorInterfaceThread
          new sendStatus thread
          Wait for thread to finish
      END of SWITCH (external System Id)
   END of startApp()
END of class
```

Listing 5.8: Pseudo Code for Main Class of Interface Mote

The Flowchart B.4 in Appendix B provides a simplified overview of the main interface mote thread.

Climate Control Interface

The pseudo code for the climate control interface is as follows:

```
Pseudo code for Climate Control Interface Thread
ClimateInterfaceThread implements Runnable
  public void run() {
    Start a new climate interface mote
    Get and push IEEE address
    Initial set up for communication
    Open up a broadcast connection
    Initial set up for local communication with external system
    WHILE (listen for New Datagram)
      Listen for new data packet
      IF (data is for Climate Control)
        Prepare data to send to external system via serial comm.
        Push new data to external system
      END of (data is for Climate Control)
    END of WHILE
  END run()
END of class
```

Listing 5.9: Pseudo Code for Climate Control Interface Thread

The Flowchart B.5 in Appendix B provides a simplified overview of the climate control interface mote thread.

Light Control Interface

The pseudo code for the light control interface is as follows:

```
Pseudo Code for Light Control Thread
LightingInterfaceThread implements Runnable
  public void run()
    Start a new light interface mote
    Get and push IEEE address
    Initial set up for communication
    Open up a broadcast connection
    Initial set up for local communication with external system
    WHILE (listen for New Datagram)
      Listen for new data packet
      Verify that packet has light data
      IF (data is for light control)
```

```
        Prepare data to send to external system via serial comm.
        Push new data to external system
      END of IF (listen for new data packet)
    END of WHILE
  END run()
END class
```

Listing 5.10: Pseudo Code for Light Control Interface Thread

Alarm System Interface

The pseudo code for the alarm system interface is as follows:

```
Pseudo Code for Alarm System Thread
AlarmInterfaceThread implements Runnable
  public void run()
    Start a new alarm interface mote
    Get and push IEEE address
    Initial set up for communication
    Open up a broadcast connection
    Initial set up for local communication with external system
    WHILE (listen For New Datagram)
      Listen for new data packet
      IF (data is for ALarm System)
        Prepare data to send to external system via serial comm.
        Push new data to external system
      END of IF (data is for ALarm System)
    END of WHILE
  END run()
END class
```

Listing 5.11: Pseudo Code for Alarm System Interface Thread

Carbon Monoxide Control Interface

The pseudo code for the Carbon Monoxide Control interface is as follows:

```
Pseudo Code for Carbon Monoxide Control Thread
  CarbMonInterfaceThread implements Runnable
    public void run()
      Start a new carbon monoxide interface mote
      Get and push IEEE address
      Intial set up for communication
```

```
      Open up a broadcast connection
      Initial set up for local communication with external system
      WHILE (listen For New Datagram)
        Listen for new data packet
        IF (data is for CarbonMono control)
          Prepare data to send to external system via serial comm.
          Push new data to external system
        END of IF (data is for CarbonMono control)
      END of WHILE
  END of run()
END of class
```

Listing 5.12: Pseudo Code for Carbon Monoxide Control Interface Thread

Door Interface

The pseudo code for the door interface is as follows:

```
Pseudo Code for Door Interface
DoorInterfaceThread implements Runnable
  public void run() {
    Start a new door interface mote
    Get and push IEEE address
    Initial set up for communication
    Open up a broadcast connection
    Initial set up for local communication with external system
    WHILE (listen For New Datagram)
      Listen for new data packet
      IF (data is for door)
        Prepare data to send to the external system via GPIO output
        Push new data to external system
      END of IF (data is for door)
    END of WHILE
  END run()
END class
```

Listing 5.13: Pseudo Code for Door Interface Thread

External System Status

The pseudo code for the external system status is as follows:

```
Pseudo Code to send external system status
```

```
sendStatus implements Runnable
  public void run()
      Create object to send status to host
      Initial setup for communication (listening)
      Open up a broadcast connection to listen for host
      WHILE (hostAddressNotKnown){
        Listen for host broad cast
        IF (broadcast is from host)
          Get host address
          Set flag to false (i.e. address is now known)
          Sleep for some time
        END of IF (broadcast is from host)
      END of WHILE
      Create object to send status to host
      Initial setup for communication (sending)
      Open up a radiogram connection to host
      Intial set up to verify status of external system
      WHILE (true){
        Check status of external system
        Send status to host
        Sleep
      END of WHILE
END of sendStatus
END of class
```

Listing 5.14: Pseudo Code for External System Status Thread

The Flowchart B.6 in Appendix B provides a simplified overview of the external system status thread.

5.3.4 Data Logging and User Interface on Host

The main tasks of the host is to act as the interface between the occupant of the home and the WSN. In addition, the host will log data at regular intervals and keep a log of events encountered by the WSN.

The full version of the host will provide a main menu as shown in Figure 5.1. The buttons along the top show the status of the external systems connected to the WSN.

The tree directory on the left side allowed the user to access each room or type of environmental data from all collector motes in the WSN. The three buttons along the bottom allow the user to either turn off the HAA, unlock the front door or access the system tools.

The host logs the temperature, light level, battery capacity, alarm trigger and carbon monoxide. This provides a history of the collected data.

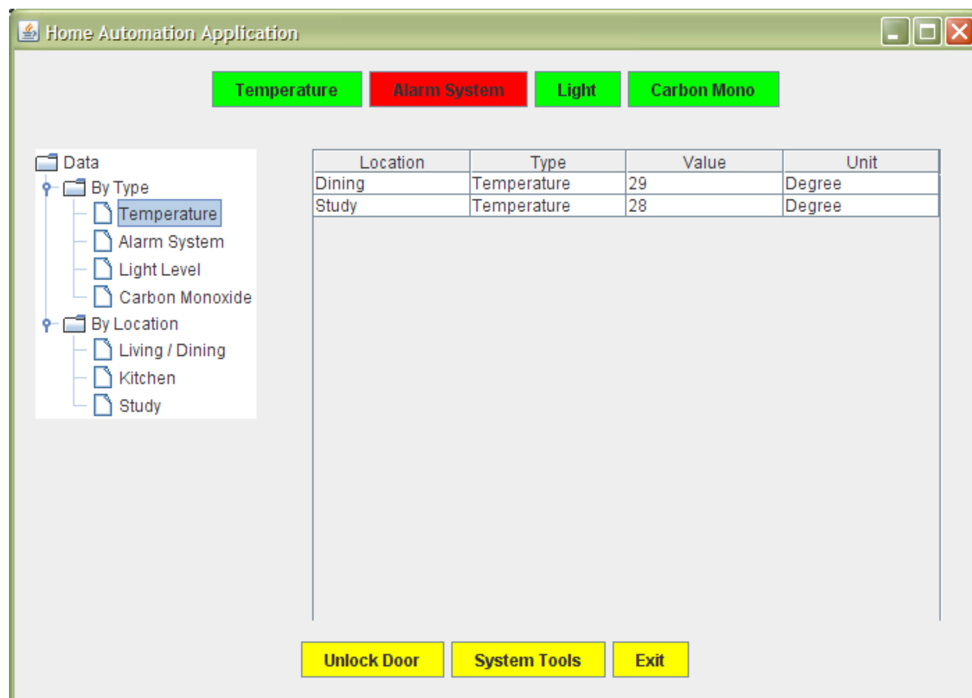

Figure 5.1: Host Main Menu

The full version of the host application has the following additional features:

- graphical user interface;
- incoming data is stored; and
- door unlock function / system tools.

For the testbeds a simplified version of the host application was used. The host application for the testbed has three main tasks:

- listen for environmental data;
- listen for external system status updates; and
- broadcast IEEE Address to other members of WSN.

These tasks are started in individual threads by the main class of the application. Once the threads have started the main class waits until the threads are finished. The pseudo code for the main class is shown below:

```
Pseudo code for Main Class on Host
public class IdentMessByByteOnHost
  Instance variables
  public static void main (String[] args)
    Start new broadcast thread
      new BroadcastHostAddress("BroadcastHostAddress", Port);

    Start new thread to listen for environmental data
      new HostIdentifyByByte("EnvironmentalData", Port);

    Start new thread to listen for external system status
      new HostIdentifyByByte("ExtSysData", port);

    Wait for threads to finish
  END of main()
END of class
```

Listing 5.15: Pseudo Code Main Class Host Testbed Version

The requirements for the two listening tasks are very similar and can be implemented in the same class. However each task is to be started in a different thread. The pseudo code is shown below:

```
Pseudo code to listen for incomming data
class HostIdentifyByByte implements Runnable
  Instance variables
  public void run()
    Start a new listener on host
      call new CommClassHost();

    Intial set up for communication
```

```
      call initBroadcastCom();
      call setPortNumber(portNumber);

    Open up a unicast (broadcast) connection
      call tryToOpenBroadcastConnection(false);

    WHILE (true)
      listen for new data packet
        call listenFor();

      Get data id from byte data in packet
        call getReadDataByte();

        IF (portNumber == 67)          // environmental data
          Push time, delay and location to terminal
            call pushTimeAndLocationToTerminal(true);

          Identify message based on message identifier, data
            call identifyMessageAndPushToTerminal (messageId);

        ELSE IF (portNumber == 68)     // ext. sys. status data
          Push time and location to terminal
            call pushTimeAndLocationToTerminal(false);

          Identify message based on message identifier
            call identifyMessageAndPushToTerminal (messageId);

        END of ELSE IF
      END WHILE
    END of run()
END of class
```

Listing 5.16: Pseudo Code Listen for Environmental Data

The third task repeatedly sends the IEEE address of the host. This thread does not listen for any incoming data. The pseudo code is shown below:

```
Pseudo code to broadcast host address
class BroadcastHostAddress implements Runnable
  Instance variables
  public void run()
```

```
    Get host address
      call RadioFactory.getRadioPolicyManager().getIEEEAddress();

    Initial setup for communication
      new CommClassHost();
      call initBroadcastCom();
      call setPortNumber(portNumber);
      call setLocation("Host");
      call setWriteDataLong(hostAddress);
      call setWriteDataByte(hostId);             // id of host

    Open up a broadcast connection
      call tryToOpenBroadcastConnection(true);

    WHILE (true){
      Send IEEE Address
        call packageAndSendRadiogram();

      Wait for 30 seconds
        Sleep(30000);
    END of WHILE
  END of run()
END of class
```

Listing 5.17: Pseudo Code Broadcast Host Address

5.4 Test Scripts

Implementing test scripts for Sun™SPOTs created some difficulties, because of the limited user interfaces on the physical motes. To help with trouble shooting, the code included statements to print information to a terminal. However, these statements were only printed on the screen if virtual motes were used or if physical motes were connected to the host via the USB connection. These statements remained in the final code. An example is shown below:

```
// ================================================================
// For trouble shooting only
// ----------------------------------------------------------------
System.out.println("Temperature data received.");
// ================================================================
```

Listing 5.18: Sample Statement to verify code

Where possible, the computer code for the motes included statements to activate / deactivate the LEDs located on the eDemoBoard. Except for the events listed in 5.3, all other LED indications were removed after testing and trouble shooting was completed.

As mentioned previously any new code was tested using Solarium before deploying the code to a real Sun™SPOT. If there was a problem with the new application it was easier to terminate the faulty application by deleting the virtual Sun™SPOT. In addition, each mote was associated with an output window to see the print statements included throughout the code.

5.5 Implementation

This section of the chapter will focus on the implementation of the HAA based on the requirements outlined in 5.3. The data collector motes, external systems interface motes and the host performed different functions in the WSN. To ensure that these three main areas functioned properly a clear understanding on what type of data was to be passed from one area to the other was needed.

To implement the required code Application Programming Interfaces (API) were utilised. An API is a guide to find the appropriate class in a package. The APIs are available online and can be searched via the package name or alphabetical by class. Three APIs were used during the design and development of the HAA.

- Java™SE API (Systems 2009*a*);
- Sun™SPOT Host API (Systems 2009*b*); and
- Sun™SPOT API (Systems 2009*c*).

The APIs were visited on a regular basis between March and October 2009. No actual code was copied from these websites. All code was typed in NetBeans. The auto complete feature in NetBeans was enabled to reduce typing and syntax errors.

In addition two books were used as reference

- Java™Head First (Sierra & Bates 2005); and
- Java™: The Complete Reference (Schildt 2007).

5.5.1 General HAA Configurations

Configuring Mesh Routing and OTA Commands

The requirements in 5.3 state that mesh routing is to be enabled. The easiest way to enable this function was to connect each physical Sun™SPOT via USB to the host computer and type the following command in a command line prompt(Sun 2009*a*, p.26).

```
ant set−system−property Dkey=spot.mesh.enable Dvalue=true
```

Listing 5.19: Enable Mesh Routing on Sun™SPOT

The applications on the host and motes needed to include statements for the maximum number of hops when broadcasting. The default value for the maximum number of hops is two. This value was increased to four due to the fact that communication between the host and the base station is one hop (Sun 2009*a*, p.19).

An additional requirement defined in 5.3 was that OTA commands were to be enabled so commands from the host could be executed. To enable this feature the following command needed to be entered at the command line prompt (Sun 2009*a*, p.21).

```
ant enableota
```

Listing 5.20: Enable Over-the-Air (OTA) commands on Sun™SPOT

5.5.2 Implementation of Data Collection

This section will outline the implementation of the collector motes. First the different classes will be shown. These classes acted as building blocks for the different functions assigned to the motes. Once these classes have been shown the implementation for the different collector functions will be shown. Each of these functions will run in a separate thread. A thread will only run if required by the configuration data in the MANIFEST.MF file.

Once the threads have been shown the main class of the collector mote will be outlined. This class essentially extracts the data from the MANIFEST.MF file and configures the mote. When all the required threads have been started the main class waits for the threads to finish.

Configuring Collector Mote Settings

The MANIFEST.MF was utilised to instruct the collector SPOTs which environmental data was to be collected. The properties in the MANIFEST.MF file were edited with

a text editor before an application was deployed to a mote.

As an example the MANIFEST.MF file for a collector SPOTs is shown below:

```
MIDlet-Name: CollectorSPOT
MIDlet-Version: 1.0.0
MIDlet-Vendor: Sun Microsystems Inc
MIDlet-1: CollectMainSPOT, , org.sunspotworld.CollectMainSPOT
MicroEdition-Profile: IMP-1.0
MicroEdition-Configuration: CLDC-1.1
Location: Kitchen
IdentTemp: 1
Temperature: 1
IdentLight: 2
LightLevel: 1
IdentBat: 3
Battery: 0
IdentAlarm: 4
Alarm: 0
IdentCarbonMono: 5
CarbonMono: 0
SampleTimeTemp: 10
SampleTimeLight: 10
SampleTimeBattery: 10
SampleTimeAlarm: 1
SampleTimeCarbonMono: 1
```

Listing 5.21: MANIFEST.MF file for Collector Mote

A brief explanation of the MANIFEST.MF file follows. The entries in lines 1 to 6 are included for any application to be run on a Sun™SPOT. The entry in line four is the name of the initial class for the mote. It is the most important entry in any MANIFEST file.

The entries in lines 7 to 22 are specific properties to configure a Sun™SPOT for the HAA.

The location states in which room the Sun™SPOT is located. The HAA locations are defined in Table 5.3. The properties Temperature, LightLevel, Battery, Alarm and CarbonMono hold either a '1' or a '0'.

- '1' indicates that this environmental information is to be collected and sent.
- '0' indicates that this particular mote does not sample this information.

The entries in lines 18 to 22 set the time between samples depending on the type of sample to be taken.

The data in the MANIFST.MF file can be accessed at run time (Sun 2009*a*, p.17). The data is read by the application as a String and then converted to the appropriate data type for further use.

Implementation Collector Mote Class

Based on the requirements in Section 5.3 and the fact that sections of the pseudo codes were similar, the decision was made to combine the generic functions of a collector mote into one class. An overview of the collector.java class is given in Table 5.7.

To implement the various functions, the collector.java class was extended to include the special functions outlined with an overview for each given in Tables 5.8 to 5.12.

Temperature Collection Class

The main task of the temperature collection class was to intialise the temperature sensor on the eDemoBoard. Once the temperature sensor was initialised a temperature sample was taken based on the sample time defined in the MANIFEST.MF file. In addition this class verified that the temperature changed. The new sample was only sent if the temperature had changed. Table 5.8 gives an overview of this class.

Light Collection Class

The main task of the light collection class was to intialise the light sensor on the eDemoBoard. Once the light sensor was initialised the average of 17 light sample was taken based on the sample time defined in the MANIFEST.MF file. As with the temperature collection class a new sampled value was only sent via radio communication if the sample had changed compared to the previous sample. Table 5.9 gives an overview of this class.

Battery Capacity Collection Class

The main task of the battery capacity collection class was to initialise the battery

Class: CollectorMote.java	
Instance Variables	private RadiogramConnection rCon private Datagram dg private String location private int portNumber private long writeDataLong private byte writeDataByte private int writeDataInt private double writeDataDouble
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initBroadcastCom () void getPushAddress() void tryToOpenBroadcastConnection() void packageAndSendRadiogram() void sleepForSomeTime(long samplePeriod, long lastTimeToBeSent) long getCurrentTime() double reformatDataToBeSent(double valueIn)

Table 5.7: CollectorMote.java class

Class: CollectorTempMote.java **Extends:** CollectorMote.java	
Instance Variables	private double currentTemp private double previousTemp private ITemperatureInput temperatureSensor
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initTemperatureMeasurement() double takeTemperatureSample() boolean hasTemperatureChanged() void moveCurrentTempToPreviousTemp()

Table 5.8: CollectorTempMote.java class

Class: CollectorLightMote.java **Extends:** CollectorMote.java	
Instance Variables	private int currentLightLevelAverage private int previousLightLevelAverage private ILightSensor lightSensor
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initLightMeasurement() double takeLightSample() boolean hasLightChanged() void moveCurrentLightToPreviousLight()

Table 5.9: CollectorLightMote.java class

Class: CollectorBattMote.java **Extends:** CollectorMote.java	
Instance Variables	private int currentBattLevel private int previousBattLevel private IBattery battStatus
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initBattMeasurement() double takeBattSample() boolean hasBattChanged() void moveCurrentBattToPreviousBatt()

Table 5.10: CollectorBattMote.java class

measurement. When initialised, a sample was taken based on the sample time defined in the MANIFEST.MF file. As with the temperature collection class, a new sample is only sent via radio communication if the sample had changed compared to the previous sample. Table 5.10 gives an overview of this class.

Alarm Trigger Class

The main task for this class was to initialise one of the digital I/O to be used as the alarm trigger. First the input to be monitored had to be defined. After selection of the input the pin direction had to be set to "input". To avoid repeated broadcasting of an alarm, the pin interrupt was disabled until the input was returned to normal. Table 5.11 gives an overview of this class.

Carbon Monoxide Level Class

The main task of this class is to initialise one of the analog I/O to be used to measure the input signal. Table 5.12 gives an overview of this class. First the input to be monitored had to be defined. The voltage levels were read by using the ADT7411 ADC converter(Sun 2009*b*, p.22). Characteristics of the Analog inputs and the Analog to Digital Converter are:

Class: CollectorAlarmMote.java **Extends:** CollectorMote.java	
Instance Variables	private PinDescriptor AlarmTriggerInput private EDemoBoard test private EDemoController testController private InputPin pin
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initAlarm() boolean pinStatus() void setEnablePinChangeInterruptsToTrue()

Table 5.11: CollectorAlarmMote.java class

<table>
<tr><td colspan="2">Class: CollectorCarbonMonoMote.java
Extends: CollectorMote.java</td></tr>
<tr><td>Instance Variables</td><td>private double currentCarbonMonoLevel
private double previousCarbonMonoLevel
private int currentSample
private EDemoBoard carbonMonoSensor
private IScalarInput analogInputs[]</td></tr>
<tr><td>Methods</td><td>Setter methods for Instance Variables
Getter methods for Instance Variables
void initCarbonMonoMeasurement()
int takeCarbonMonoSample()
double convertCarbonMonoSampleToVolt(int currentSample)
boolean hasCarbonMonoLevelChanged()
void moveCurrentCarbonMonoToPreviousCarbonMono()</td></tr>
</table>

Table 5.12: CollectorCarbonMonoMote.java class

- voltage range at input is 0 to 3 Volt Direct Current (DC)
- The resolution is:

$$ADC = \frac{V_{in} \times 1024}{V_{ref}} \tag{5.1}$$

To forward the actual voltage level to the external system the actual voltage was calculated as shown

$$V_{in} = \frac{ADC \times V_{ref}}{1024} \tag{5.2}$$

The calculation was implemented in the method

double convertCarbonMonoSampleToVolt(int currentSample)

Having outlined the classes available for a collector mote the associated threads will be listed now. As mentioned above the threads will start based on the properties set in the MANIFEST.MF file (see Listing 5.21).

Temperature Collection Thread

The detailed pseudo code for this thread is shown in Appendix C.3. It was expanded from the pseudo code in Listing 5.3

Light Collection Thread

The detailed pseudo code for this thread is shown in Appendix C.4. It was expanded from the pseudo code in Listing 5.4

Battery Capacity Thread

The detailed pseudo code for this thread is shown in Appendix C.5. It was expanded from the pseudo code in Listing 5.5

Alarm Trigger Thread

The detailed pseudo code for this thread is shown in Appendix C.6. It was expanded from the pseudo code in Listing 5.6

Carbon Monoxide Collection Thread

The detailed pseudo code for this thread is shown in Appendix C.7. It was expanded from the pseudo code in Listing 5.7.

Collector Mote Main Thread

The detailed pseudo code for this thread is shown in Appendix C.8. It was expanded from the pseudo code in Listing 5.2

5.5.3 Implementation of Interface to External Systems

Configuring Interface Mote Settings

As with the collector motes the MANIFEST.MF file will be used to configure the interface motes. The additional entries were required to identify the external system. Table 5.6 shows all possible identifiers for interface motes.

The entries in line 6 and 7 were the properties required for the configuration of an interface mote. As an example the configuration for a mote used as a door interface is shown.

```
MIDlet-Name: InterfaceSPOT
MIDlet-Version: 1.0.0
MIDlet-Vendor: Sun Microsystems Inc
MIDlet-1: InterfaceMainSPOT, , org.sunspotworld.InterfaceMainSPOT
MicroEdition-Profile: IMP-1.0
MicroEdition-Configuration: CLDC-1.1
Interface: 11
DoorOpenTime: 2000
```

Listing 5.22: MANIFEST.MF file for Interface Mote

The entry in line 7 is used at runtime to verify that the data in the packet is appropriate for this interface mote. The entry in line 8 is only required for a door interface mote. This property indicates how long the door is to remain unlocked. The value is given in milliseconds.

Implementation Interface Mote Class

Based on the requirements in 5.3 and the fact that sections of the pseudo codes were similar the decision was made to combine the generic functions of an interface mote into one class. An overview of the collector.java class is given in Table 5.13. As with the collector mote the various functions of the interface motes were implemented by extending the generic functions class InterfaceMote.java. These are outlined in Tables 5.14 to 5.18.

Climate Interface Class

The main task of this class was to prepare the data intended for the climate control system. The input data which included location and value was packaged into a single string with the two entires separated by a comma. Table 5.14 gives an overview of this class.

Light Interface Class

The main task of this class was to prepare the data intended for the lighting control system. The input data which included location and value was packaged into a single string with the two entires separated by a comma. Table 5.15 gives an overview of this class.

Class: InterfaceMote.java	
Instance Variables	private String systemInterface private int portNumber private RadiogramConnection rCon private Datagram dg private long readDataLong private byte readDataByte private String readDataUTF private int readDataInt private double readDataDouble EDemoBoard serialComm EDemoBoard.getInstance() private int baud private int databits private int parity private int stopbits private String externalDataString private ITriColorLED[] sendCommIndication EDemoBoard.getInstance().getLEDs()
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initInterfaceMoteCommunication() void getPushAddress() void tryToOpenBroadcastConnection() void listenFor() void sleepForSomeTime(long samplePeriod, long getCurrentTime() void initExternalCommunication() void sendDataToExternalSystem()

Table 5.13: InterfaceMote.java class

Class: ClimateInterfaceMote.java **Extends:** InterfaceMote.java	
Instance Variables	none
Methods	packageTempDataToSendToClimateControl (String location, double value)

Table 5.14: ClimateInterfaceMote.java class

Class: LightInterfaceMote.java **Extends:** InterfaceMote.java	
Instance Variables	none
Methods	packageLightDataToSendToLightControl (String location, int value)

Table 5.15: LightInterfaceMote.java class

Alarm Interface Class

The main task of this class was to prepare the data intended for the alarm system. The input data which included location and value was packaged into a single string with the two entires separated by a comma. Table 5.16 gives an overview of this class.

Carbon Monoxide Interface Class

The main task of this class was to prepare the data intended for the carbon monoxide control system. The input data which included location and value was packaged into a single string with the two entires separated by a comma. Table 5.17 gives an overview of this class.

Class: AlarmInterfaceMote.java **Extends:** InterfaceMote.java	
Instance Variables	none
Methods	packageAlarmDataToSendToAlarmSystem (String location, int value)

Table 5.16: AlarmInterfaceMote.java class

Class: CarbMonInterfaceMote.java **Extends:** InterfaceMote.java	
Instance Variables	none
Methods	packageCarbonMonoDataToSendToCarbMonSystem (String location, double value)

Table 5.17: CarbMonInterfacMote.java class

Class: DoorInterfaceMote.java **Extends:** InterfaceMote.java	
Instance Variables	private PinDescriptor unlockDoorOutput private EDemoBoard doorCommand private EDemoController doorCommandController private InputPin pin private ITriColorLED[] indicateDoorUnlocked EDemoBoard.getInstance().getLEDs()
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initDoorInterface() void unlockTheDoor(long unlockDoorTime)

Table 5.18: DoorInterfacMote.java class

Door Interface Class

The main task of this class was to use one of the digital I/Os to lock / unlock a door. One of the pins was configured as an output. The output was set to high for the time set given by the variable `unlockDoorTime`. After the time had elapsed the output was set to low to lock the door. Table 5.18 gives an overview of this class.

Radiogram Comm Class

The main task of this class was to periodically send the status of an external system. The class also included methods to set up a radiogram unicast connection. Table 5.19 gives an overview of this class.

Class: RadiogramCommClass.java	
Instance Variables	private RadiogramConnection rCon private Datagram dg private PinDescriptor statusExternalSystem private EDemoBoard status private EDemoController statusController private InputPin pin private boolean extSysStatus private String location private String hostAddress private int portNumber private long writeDataLong private byte writeDataByte private int writeDataInt private double writeDataDouble private boolean writeDataBool
Methods	Setter methods for Instance Variables Getter methods for Instance Variables void initRadiogramCom() void tryToOpenRadiogramConnection() void initExternalSystemStatus() boolean errorExternalSystem() void packageAndSendRadiogram()

Table 5.19: RadiogramCommClass.java class

5.5.4 Implementation of Host Application

Only a brief overview of the implementation of the host application used with the testbeds will be given. The host application for the testbeds only pushed the data to the output window of NetBeansIDE6.5.1 .

All functionalities of the host were implemented in one class. Table 5.20 gives an overview of this class. The code for the host is shown in Listings C.42 to C.45.

5.6 Conclusion Implementation

The chapter outlined the implementation of the design and development of the HAA. The requirements were defined for the collector motes, interface motes and the host applications. Based on these requirements the classes and MANIFEST.MF files were developed. The next chapter will show the results obtained from the different testbeds.

<table>
<tr><td colspan="2">Class: CommClassHost.java</td></tr>
<tr><td>Instance Variables</td><td>private RadiogramConnection rCon
private Datagram dg
private String location
private int portNumber
private long writeDataLong
private byte writeDataByte
private int writeDataInt
private double writeDataDouble
private boolean writeDataBool
private long readDataLong
private byte readDataByte
private String readDataUTF
private int readDataInt
private double readDataDouble
private boolean readDataBool
DateFormat fmt = DateFormat.getTimeInstance()
long timeOfReading
long nowOnHost
long delaySampleToTerminal</td></tr>
<tr><td>Methods</td><td>Setter methods for Instance Variables
Getter methods for Instance Variables
void initBroadcastCom()
void tryToOpenBroadcastConnection()
void packageAndSendRadiogram()
void listenFor()
void pushTimeAndLocationToTerminal
void identifyMessageAndPushToTerminal</td></tr>
</table>

Table 5.20: CommClassHost.java class

Chapter 6

Results

This chapter documents the results from the six testbeds. The following calibrated instruments were used to verify the accuracy of the data collected by the WSN testbeds.

- EXTECH 401036 Light Meter;
- FLUKE 115 True RMS Multimeter; and
- ΩEOMEGA RH 101 Temperature Humidity Meter.

6.1 Testbed 1: Accuracy of WSN, Internal Sensor

Table 6.1 shows the accuracy of the light level measurements taken by the WSN in testbed 1 compared to light meter. The light meter and the motes were placed next to each other during the test.

Table 6.2 shows the accuracy of the temperature measurements taken by the WSN in testbed 1 compared to temperature meter. Before taking the measurements both the mote and the instrument were placed in position to adjust to the current ambient temperature.

Sample No.	**WSN (Lux)**	**Instrument (Lux)**	**Error (Lux)**
1	400	417	+17
2	414	417	+3
3	396	417	+21
4	428	417	-11
5	416	417	+1
6	412	416	+4
7	410	417	+7
8	404	415	+11
9	402	415	+13
10	414	414	0

Table 6.1: Results Testbed 1, Light Level Accuracy

Sample No.	**WSN (° C)**	**Instrument (° C)**	**Error (° C)**
1	27.5	28	-0.5
2	27.25	28	-0.25
3	27.5	28	-0.5
4	27.25	28	-0.25
5	27.5	28	-0.5
6	27.25	28	-0.25
7	27.25	28	-0.25
8	27.5	28	-0.5
9	27.25	28	-0.25
10	27.5	28	-0.5

Table 6.2: Results Testbed 1, Temperature Accuracy

6.2 Testbed 2: Accuracy of WSN, External Sensor

This testbed was not completed, since the results for testbed 1 were deemed to be accurate for the HAA.

6.3 Testbed 3: Maximum Distances between WSN Members

The host computer was located in the study (see Figure E.1). Except of the main bedroom, it was possible for a mote to communicate directly with the host. This distance between the main bedroom and the study was approximately 16 meters. Therefore, regardless of location within the apartment no more than two hopes were required to reach any other Sun™SPOTs in the WSN. To reach the host from the the main bedroom 3 hops were required.

6.4 Testbed 4: Impact of Noise Sources on WSN

Neither of the identified noise sources had an impact on the Sun™SPOTs. The motes were placed around all accessible areas of the noise source. The microwave was built-in to the kitchen cabinets. Therefore the motes could only be placed above, on the sides and below the microwave. During this test, the environmental data to be collected was not changed. The data received by the host was always exactly the same.

6.5 Testbed 5: Multifunction Data Collection

The code for the collector motes, interface motes and host were implemented by using identifiers. These identifiers indicate to the receivers what type of data is being received. Each type of data to be collected also ran in a separate thread. At no time was any incorrect data received by the host or interface mote.

6.6 Testbed 6: High Volume Data Collection

To establish how long it took from sampling at the mote to when the data was received a small application was written for the host. This application did not have any user

Sample No.	**Delay** (ms)	**Sample No.**	**Delay** (ms)
1	2273	6	2406
2	2382	7	2419
3	2286	8	2527
4	2300	9	2495
5	2409	10	2537

Table 6.3: Results Testbed 6, Time Delay, 2 seconds between samples

interface. The application was launched from NetBeansIDE6.5.1 . The output window was utilised to show:

- the incoming data;
- time when sample was taken;
- time when sample was received by host; and
- time delay.

The reference measurement showed that the delay was 2288 ms for one sample to be received by the host. The mote was only collecting carbon monoxide data via the analogue input.

Table 6.3 shows the delay for 10 samples. The sample time was set to 2000 ms. The table shows that no significant increase in delay was experienced when the sample time was reduced to 2 seconds.

Table 6.4 shows the delay for 10 samples. The sample time was set to 1000 ms. Again the table shows that no increase in delay was experienced when the sample time was reduced to 1 second.

Table 6.5 shows the delay for five samples each from the two physical motes. The sample time was set to 1000 ms on both motes. The applications on both motes were started at the same time. The table shows that even after only five samples there was a significant delay from when the sample was taken to when it was received by the

Sample No.	**Delay** (ms)	**Sample No.**	**Delay** (ms)
1	2073	6	2253
2	2087	7	2251
3	2101	8	2265
4	2225	9	2325
5	2223	10	2339

Table 6.4: Results Testbed 6, Time Delay, 1 second between Samples

Mote 1		**Mote 2**	
Sample No.	**Delay** (ms)	**Sample No.**	**Delay** (ms)
1	2115	1	3115
2	3145	2	4145
3	4158	3	5158
4	5173	4	6172
5	6172	5	7171

Table 6.5: Results Testbed 6, Time Delay, 1 second between Samples, two Motes

host. Therefore with an increase in motes in a WSN delay may become significant if the sample time is not carefully selected.

This testbed turned out to be somewhat challenging to execute. As mentioned in Section 3.5, the time needed to be synchronised before each test. This reference value was then used for comparison during the actual tests. It was not actually possible however, to confirm if all the times of the WSN members were exactly the same. During initial testing while setting up this testbed delay times of less than one second were recorded.

6.7 Test Result and Conclusion

As specified each testbed provided a result. Testbed 6 provided some minor inconclusive results, since it was not possible to establish if all members of the WSN had exactly

the same time. It was however, possible to show that multiple Sun™SPOTs sending data in short intervals could cause significant delays. The original sample intervals in Table 5.4 were increased based on the results obtained in Testbed 6.

The fully completed and tested code for the Sun™SPOTs was very stable. Hence, it was possible to run the applications on the Sun™SPOTs for extended periods of time.

Chapter 7

Conclusions and Further Work

The aim of the project was to develop a testbed for a simple WSN. The WSN was implemented using a Sun™SPOT development kit from Sun™Microsystems.

Even though the development kit only included two physical motes, it was possible to create a WSN with the available Sun™SPOTs and the use of virtual motes. The limited number of physical motes however, prevented the deployment of a complete WSN for the proposed HAA.

Due to the limited user interfaces on the physical Sun™SPOTs, challenges were encountered during the implementation and testing of the applications. Generous use of LEDs on the eDemoBoard during testing of the code overcame some of these challenges. On completion of trouble shooting and testing most of the LED indications were removed from the final code to maximise the time between battery charges.

The applications for the motes were written in Squawk Java™VM. The application for the host was written in SE Java™VM. The final code for both the motes and the host computer, were very stable.

Six testbeds were selected to simulate realistic events within the WSN. Each testbed aimed to verify a different aspect of a deployed HAA. The selected testbeds provided results in regards to:

- accuracy of the collected data;
- performance; and
- maximum distance between members of the WSN.

Minor performance issues were encountered on the host computer if too many virtual Sun™SPOTs were deployed. The performance issues were managed by limiting the number of virtual Sun™SPOTs running on the host to six.

7.1 Achievement of Project Objectives

The research aspects of the project specification were addressed in Chapter 2. The design, develop and implementation aspects of the project specification were addressed in Chapters 3, 4 and 5. Two points in regards to the HAA were not fully satisfied.

1. Item 5.2 of the Project Specification was not completed to full satisfaction. It was not possible to establish if the power consumption of the home would be reduced by using the HAA. To investigate this objective a testbed containing approximately twenty physical Sun™SPOTs would have to be deployed and interfaced to the external systems.

   To further increase the potential for energy savings the alarm functionality could have been adapted to show if a person was present in a room. This would have allowed the HAA to adjust lighting or temperature levels.

2. Due to time constraints, item 5.3 of the test specification was implemented without the use of fully developed additional hardware. This meant that the carbon monoxide feature was implemented using an analogue input on the eDemoBoard. The change in carbon monoxide levels was simulated by using a three terminal potentiometer.

7.2 Further Work

Since WSNs rely on the interaction of software, hardware and networking a great number of projects and further tests could be conducted. Additional projects could therefore be defined to focus on any or all of these specific technical aspects.

By using the eDemoBoard it was possible to implement a WSN without the need to develop any additional hardware. As mentioned in Section 3.1 however, a number of scenarios were discarded due to the physical characteristics of the Sun™SPOTs in the development kit. Developing specific motes to overcome the limitations of the Sun™SPOTs would allow the implementation of some of these scenarios and therefore further the understanding of WSNs.

Another limiting factor was the small number of physical motes available in the development kit. It was relatively easy to deploy a new application to the two physical motes. This process was completed within a few minutes and was completed by connecting the Sun™SPOTs via USB connection to the host computer.

If however, a large number of motes (e.g. 10,000) were deployed in a WSN even a simple task like deploying a new application to all motes could become challenging.

In addition, projects could focus on applications which could only be implemented if the motes are fully developed. The small size of the fully developed motes could also be used as a base to investigate ethical implications. Due to the very small size of the motes an individual or group of people may not be aware that they are being observed.

Based on the above consideration a number of projects are proposed below. Some of these projects could be implemented by using the discarded ideas in Section 3.1.

- Performance impact within a WSN, if a large number of physical motes are deployed.
- Maintain a large WSN after initial deployment.
- Develop power supplies for very small motes.

- Determine how to replace a system of wired sensors with a WSN in an existing control system.
- Investigate performance and security issues if multiple WSN are deployed within the same geographical area.
- Develop hardware for single purpose motes.
- Implement a WSN to constantly measure the blood pressure or other vital signs of a patient.
- Investigate the ethical implications if motes are of size 1 mm^3 or less.

Overall, despite the limitations of the development kit, a WSN was deployed and various testbeds were investigated. This project was a first step to gain understanding of WSNs and the positive results obtained by the testbeds could be used as a foundation for future studies.

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Appendix A

Project Specification

Replace with project specification

Replace with project specification

Appendix B

Flowcharts

B.1 Flowchart Compile and Run Process

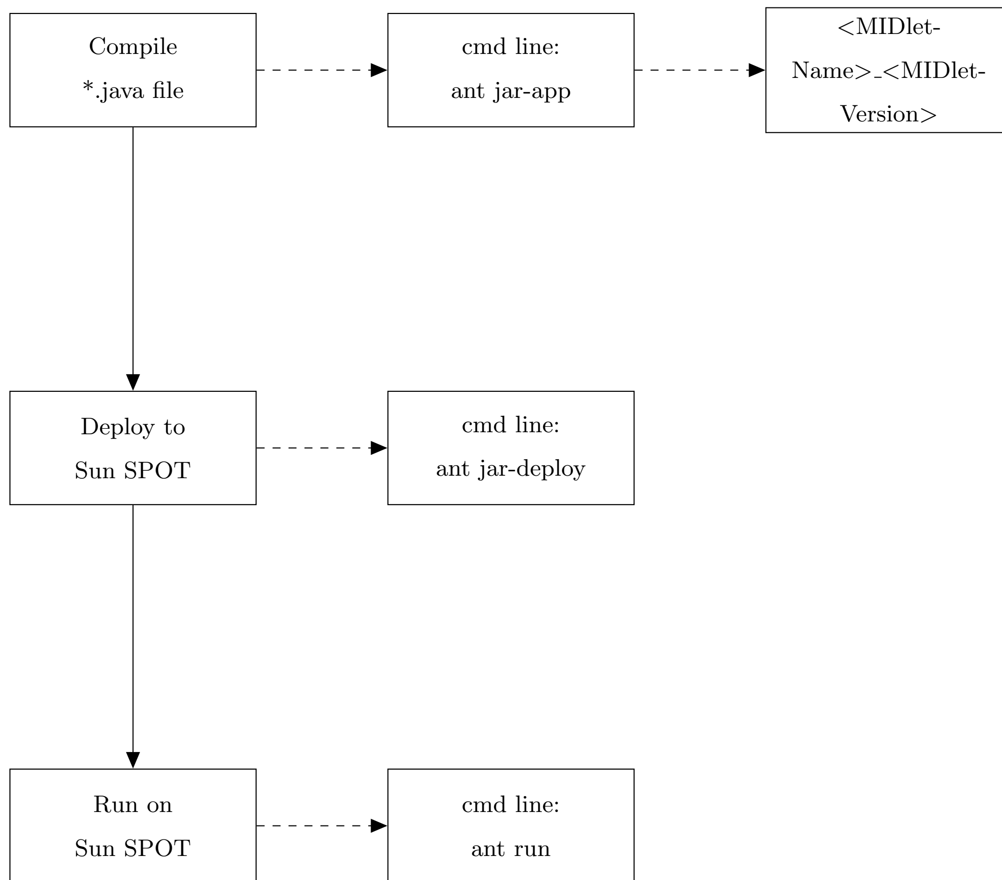


Figure B.1: Flowchart Showing Compile and Run Process

B.2 Flowchart Main: Collector Mote

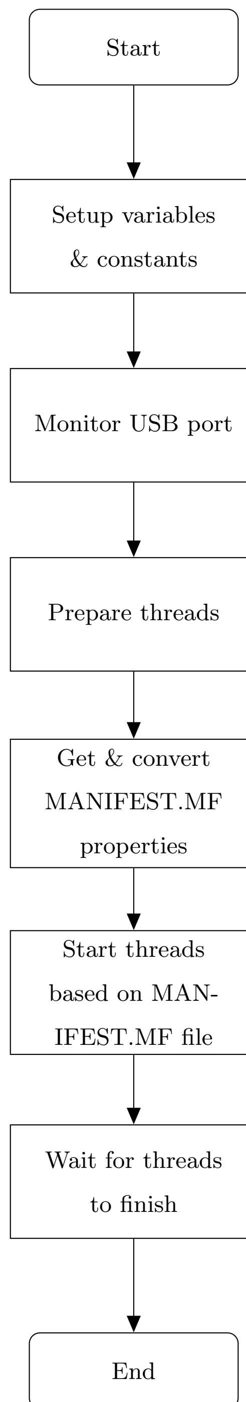


Figure B.2: Flowchart Main Collector Mote

B.3 Flowchart: Temperature Collecting Thread

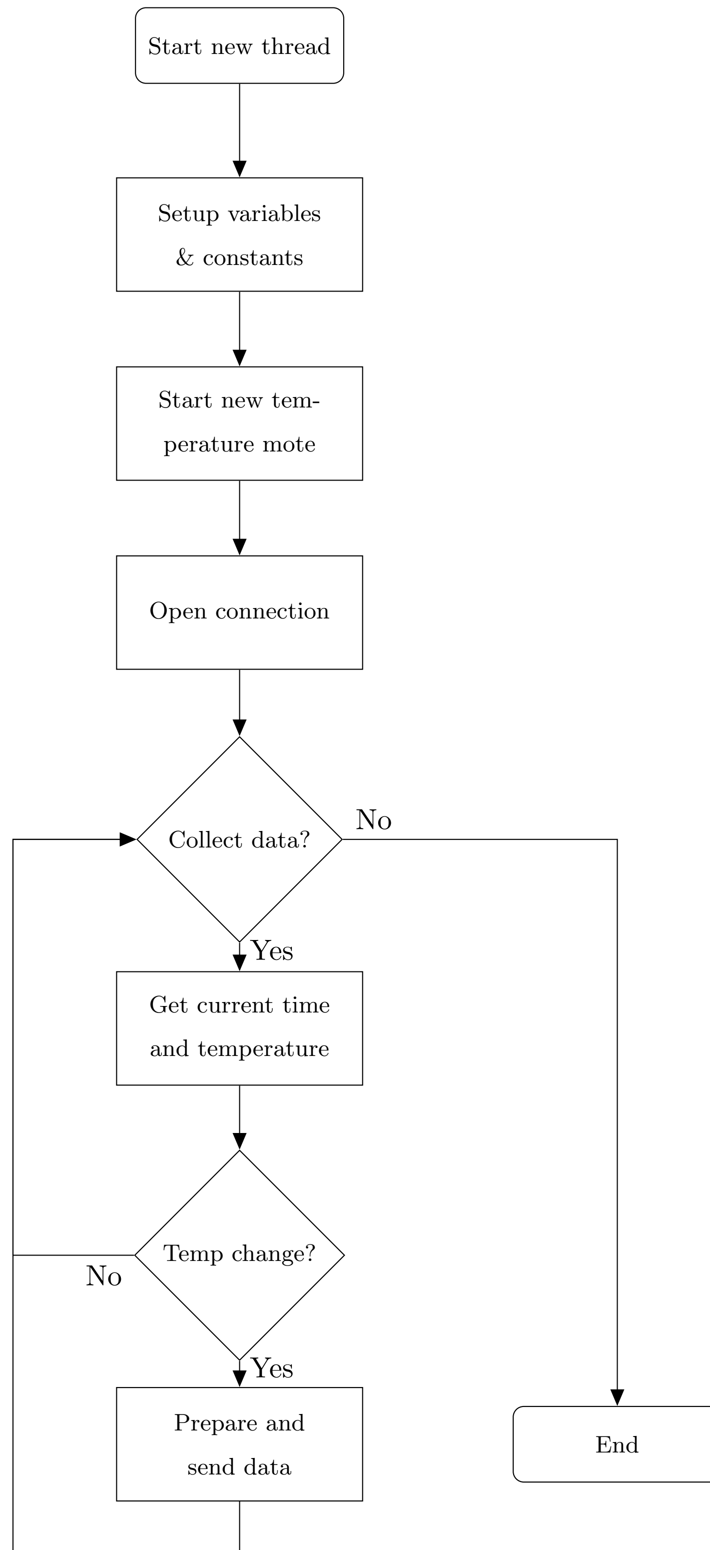


Figure B.3: Flowchart Temperature Thread

B.4 Flowchart Main: Interface Mote

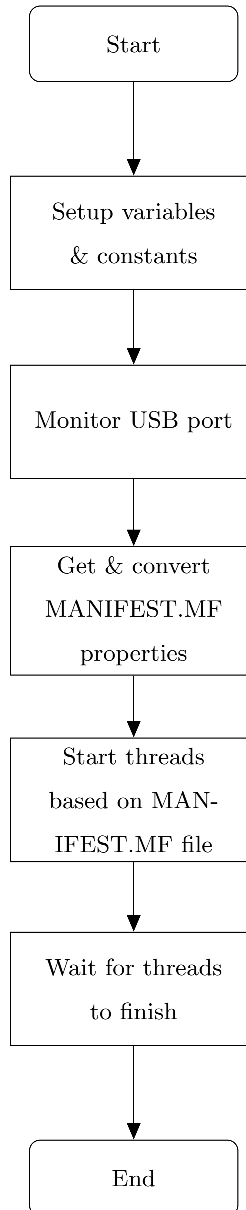


Figure B.4: Flowchart Main Interface Mote

B.5 Flowchart: Climate Interface Thread

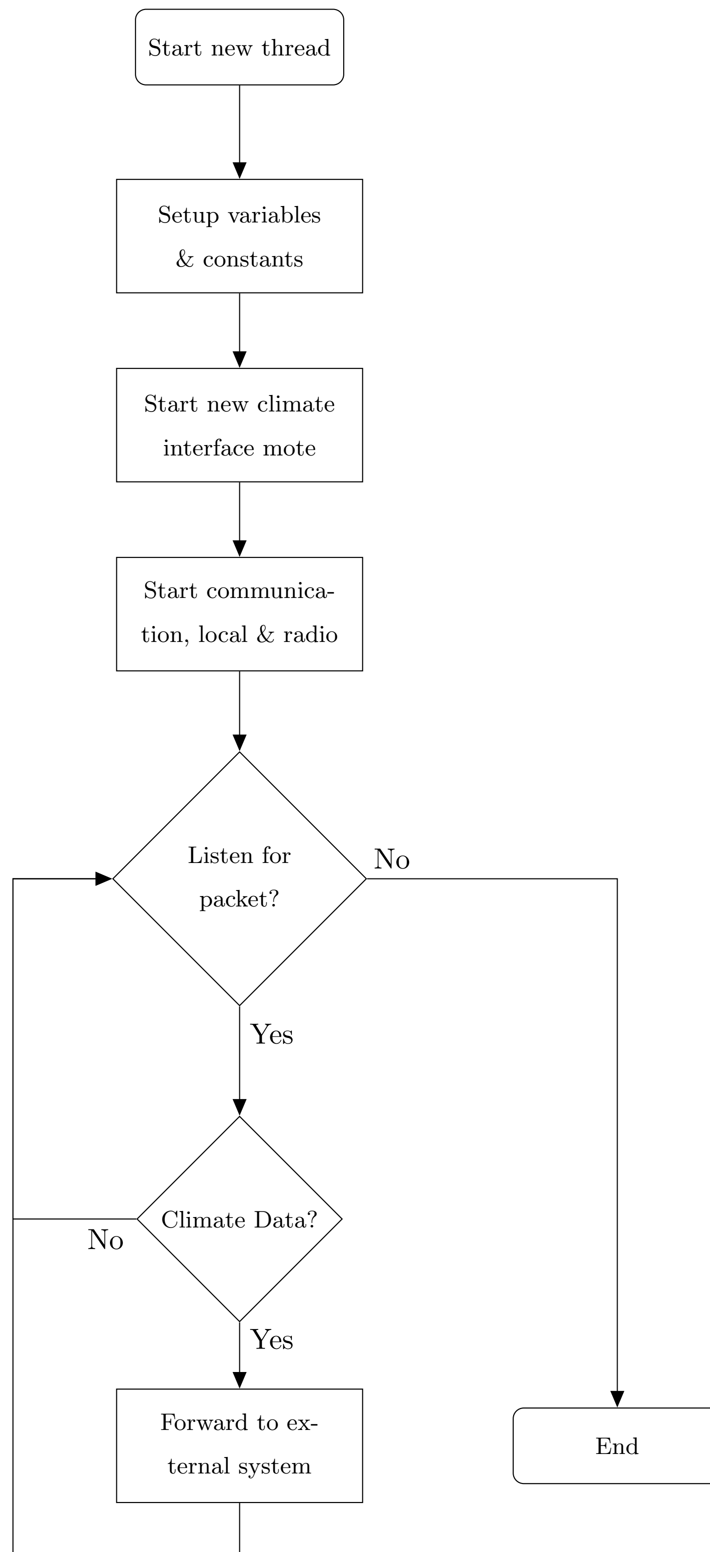


Figure B.5: Flowchart Climate Interface Thread

B.6 Flowchart: Send External System Status Thread

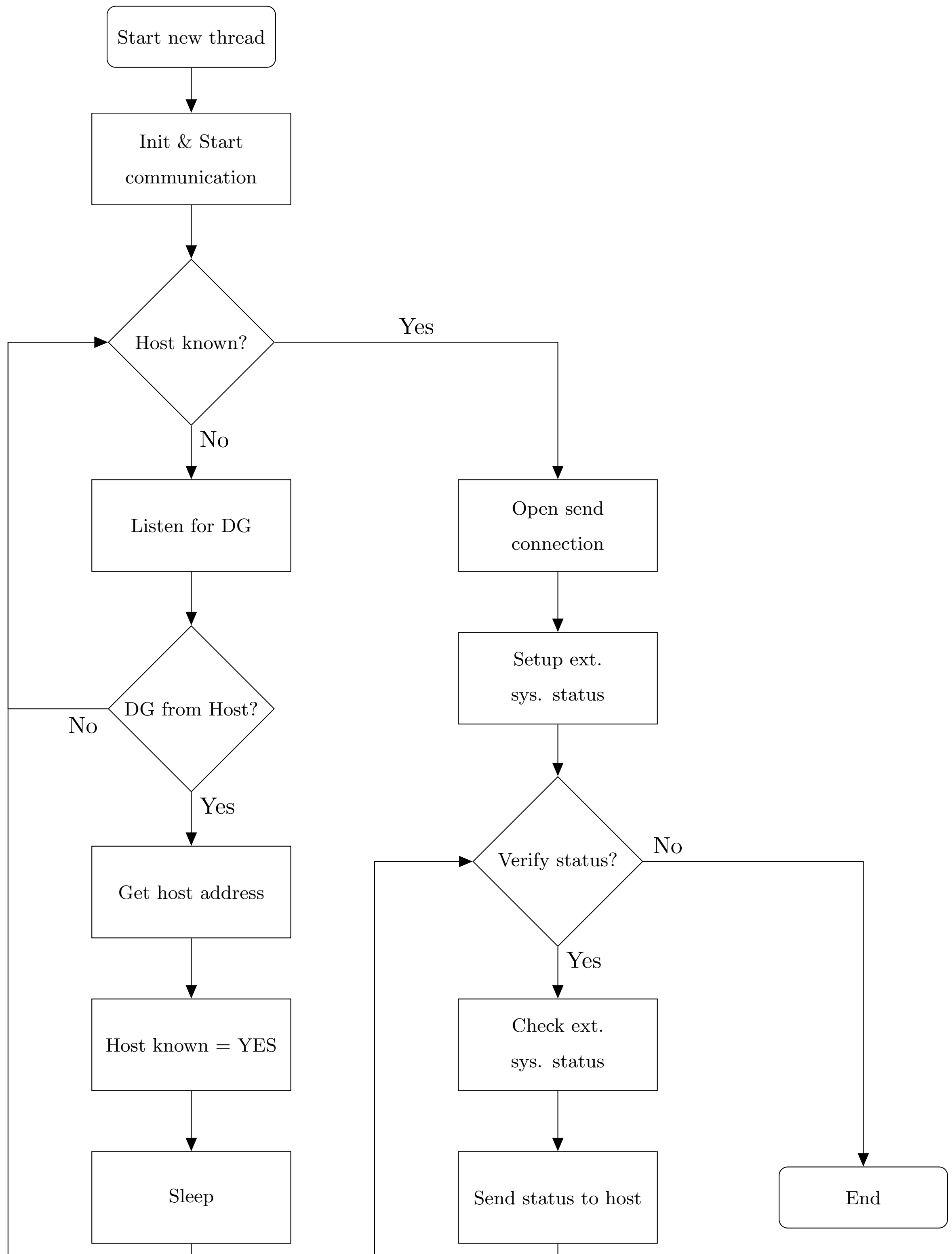


Figure B.6: Flowchart Send External System Status Thread

Appendix C

Code Listings

C.1 Example Implement Code

C.1.1 Example of Test Script

```
/* ****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ****************************************************************
 */

/* ****************************************************************
 * Purpose      :  Test script
 * Inputs       :  4 random important values
 * Outputs      :  4 values limited to 2 digits after decimal point
 * ****************************************************************
 */
package org.sunspotworld;

import javax.microedition.midlet.MIDlet;
import javax.microedition.midlet.MIDletStateChangeException;

/**
 * The startApp method of this class is called by the VM to start the
 * application.
 *
 * The manifest specifies this class as MIDlet-1, which means it will
 * be selected for execution.
 */
public class testChangeDataFormat extends MIDlet {

   protected void startApp() throws MIDletStateChangeException {

      // variables
      double valueIn = 0.0;
      double valueOut = 0.0;

      ChangeDataFormat newTest = new ChangeDataFormat();

      System.out.println("");
      valueIn = 125.5678789657456456456456456;
      valueOut = newTest.reformatDataToBeSent(valueIn);
      System.out.println(valueIn + " becomes " + valueOut);

      System.out.println("");
      valueIn = -25.5678789657456456456456456;
      valueOut = newTest.reformatDataToBeSent(valueIn);
      System.out.println(valueIn + " becomes " + valueOut);

      System.out.println("");
      valueIn = 5.917;
      valueOut = newTest.reformatDataToBeSent(valueIn);
      System.out.println(valueIn + " becomes " + valueOut);

      System.out.println("");
      valueIn = -5.997;
```

```
        valueOut = newTest.reformatDataToBeSent(valueIn);
        System.out.println(valueIn + " becomes " + valueOut);


    } // end of startApp()

    protected void pauseApp() {
        // This is not currently called by the Squawk VM
    }

    /**
     * Called if the MIDlet is terminated by the system.
     */
    protected void destroyApp(boolean unconditional) throws
            MIDletStateChangeException {
    }
}
```

Listing C.1: Test Code Example Implementation

C.1.2 Example of the New Method to be Tested

```
/* ***********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ***********************************************************************
 */

/* ***********************************************************************
 * Purpose      :  This class changes the format of data of the type long.
 * Purpose      :  It will be include in collectorMote class when tested.
 * Input        :  data to be reformatted
 * Outputs      :  formatted data
 * ***********************************************************************
 */
package org.sunspotworld;

import com.sun.squawk.util.MathUtils;

public class ChangeDataFormat{

  double reformatDataToBeSent(double valueIn){

        // ==================================================================
        // local variable
        // ------------------------------------------------------------------
        double valueOut = 0;
        // ==================================================================

        // ==================================================================
        // For trouble shooting only
        // ------------------------------------------------------------------
        System.out.println("Print input value: " + valueIn);
```

```
        // ===================================================================

        // ===================================================================
        // Move decimal point 2 digits to the right
        // -------------------------------------------------------------------
        valueIn = valueIn * 100;
        // ===================================================================

        // ===================================================================
        // For trouble shooting only
        // -------------------------------------------------------------------
        System.out.println("After * operator: " + valueIn);
        // ===================================================================

        // ===================================================================
        // Round up or down
        // -------------------------------------------------------------------
        valueIn = MathUtils.round(valueIn);
        // ===================================================================

        // ===================================================================
        // For trouble shooting only
        // -------------------------------------------------------------------
        System.out.println("After rounding: " + valueIn);
        // ===================================================================

        // ===================================================================
        // Move decimal point 2 digits to the left
        // -------------------------------------------------------------------
        valueOut = valueIn / 100;
        // ===================================================================

        // ===================================================================
        // For trouble shooting only
        // -------------------------------------------------------------------
        System.out.println("After / operator: " + valueOut);
        // ===================================================================

        System.out.println("Data to be returned: "
                + valueOut);
        return valueOut;

    } // end of reformatDataToBeSent()
} // end of class
```

Listing C.2: Actual Code Example Implementation

C.2 Pseudo Code Collector Motes

C.2.1 Pseudo Code for Temperature Thread

```
Pseudo Code for Temperature Thread
TempThread implements Runnable
  Instance variables
    String location;
    Thread t;
    hostPortNumber;
    dataIdentifier;
    long sampleTime;
    long timeToBeSent;
    double tempToBeSent;

  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run()
    Start a new temperature collector mote
      new CollectorTempMote

    Intial set up for measurement of temperature
      call initTemperatureMeasurement()

    Intial set up for communication
      call initBroadcastCom();
      call setPortNumber(hostPortNumber);
      call setLocation(location);
      call setWriteDataByte(dataIdentifier);

    Get and push IEEE Address to terminal
      call getPushAddress();

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    WHILE (true)
      Get the sample time
        callgetCurrentTime();

      Indicate sample event (start, i.e LED on)
        call sampleEventIndication();

      Get the current temperature reading to send in datagram
        call takeTemperatureSample();

      Indicate sample event (end, i.e LED off)
        call sampleEventIndication();

      Reformat tempToBeSent to ****.**
        call reformatDataToBeSent(tempToBeSent);

      IF (temperature has changed)
        Update time and temperatur value to be sent
          call setWriteDataLong(timeToBeSent);
          call setWriteDataDouble(tempToBeSent);
```

```
        Send current sample
          call packageAndSendRadiogram();
      END of IF (temperature has changed)

      Move current temp sample to previous sample variable
        call moveCurrentTempToPreviousTemp();

      Go to sleep to conserve battery
        call sleepForSomeTime(sampleTime, timeToBeSent);

    END of WHILE loop
 END of run()
END of class
```

Listing C.3: Pseudo Code Temperature Collection Thread

C.2.2 Pseudo Code for Light Level Thread

```
Pseudo code for light thread
LightThread implements Runnable
  Instance variables
    private String location;
    private Thread t;
    private int hostPortNumber;
    private byte dataIdentifier;
    private long sampleTime;
    private long timeToBeSent;
    private int lightToBeSent;

  Methods to access instance variables, setter methods
  Methods to access instance variables, setter methods

  public void run() {
    Start a new light level collector mote
      new CollectorLightMote();

    Intial set up for measurement of light level
      call initLightMeasurement();

    Intial set up for communication
      call initBroadcastCom();
      call setPortNumber(hostPortNumber);
      call setLocation(location);
      call setWriteDataByte(dataIdentifier);

    Get and push IEEE Address to terminal
      call getPushAddress();

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    WHILE (true)
      Get the sample time
        call getCurrentTime();

      Indicate sample event (start, i.e LED on)
```

```
        call sampleEventIndication();

      Get the current light reading to send in datagram
        call takeLightSample();

      Indicate sample event (end, i.e LED off)
        call sampleEventIndication();

      IF(light has changed)
        Update time and light value to be sent
          call setWriteDataLong(timeToBeSent);
          call setWriteDataInt(lightToBeSent);

        Send current sample
         call packageAndSendRadiogram();
      END of IF (light has changed)

      Move current light sample to previous sample variable
        call moveCurrentLightToPreviousLight();

      Go to sleep to conserve battery
        call sleepForSomeTime(sampleTime, timeToBeSent);

    END of WHILE
  END of run()
END of class
```

Listing C.4: Pseudo Code Light Collection Thread

C.2.3 Pseudo Code for Battery Capacity Thread

```
Pseudo Code for Battery Capacity
BatLevelThread implements Runnable
  Instance Variables
    private String location;
    private Thread t;
    private int hostPortNumber;
    private byte dataIdentifier;
    private long sampleTime;
    private long timeToBeSent;
    private int battToBeSent;

    Methods to access instance variables, setter methods
    Methods to access instance variables, setter methods

    public void run() {
      Start a new battery level collector mote
        new CollectorBattMote();

      Intial set up for measurement of battery level
        call initBattMeasurement();

      Intial set up for communication
        call initBroadcastCom();
        call setPortNumber(hostPortNumber);
        call setLocation(location);
```

```
        call setWriteDataByte(dataIdentifier);

      Get and push IEEE Address to terminal
        call getPushAddress();

      Open up a broadcast connection
        call tryToOpenBroadcastConnection();

      WHILE (true){
        Get the sample time
          call getCurrentTime();

        Indicate sample event (start, i.e LED on)
          call sampleEventIndication

        Get the current battery reading to send in datagram
          call takeBattSample();

        Indicate sample event (end, i.e LED off)
          call sampleEventIndication

        IF (has the Battery capacity changed)
          Update time and battery value to be sent
            call setWriteDataLong(timeToBeSent);
            call setWriteDataInt(battToBeSent);

          Send current sample
            callpackageAndSendRadiogram();

        END of IF(has the Battery capacity changed)

        Move current battery sample to previous sample variable
          call moveCurrentBattToPreviousBatt();

        Go to sleep to conserve battery
          call sleepForSomeTime(sampleTime, timeToBeSent);
      END of WHILE
  END of run()
END of class
```

Listing C.5: Pseudo Code Battery Capacity Thread

C.2.4 Pseudo Code for Alarm Trigger Thread

```
Pseudo code for alarm trigger thread
AlarmTriggerThread implements Runnable
  Instance variables
    private String location;
    private Thread t;
    private int hostPortNumber;
    private byte dataIdentifier;
    private long sampleTime;
    private long timeToBeSent;

  Methods to access instance variables, setter methods
  Methods to access instance variables, setter methods
```

```
  public void run() {
    Start a new alarm trigger mote
      new CollectorAlarmMote();

    Intial set up for measurement for alarm trigger
      call initAlarm();

    Intial set up for communication
      call initBroadcastCom();
      call setPortNumber(hostPortNumber);
      call setLocation(location);
      call setWriteDataByte(dataIdentifier);

    Get and push IEEE Address to terminal
      call getPushAddress();

    Open up a broadcast connection
      tryToOpenBroadcastConnection();

      WHILE (true)

        WHILE (is the input pin low)
          Since alarm is not triggered go to sleep for specified time
            call sleepForSomeTime(sampleTime,timeToBeSent);
          Get the current time. I.e. time when sample is taken
            call getCurrentTime();
        END of WHILE (is the input pin low)

        Update alarm values to be sent
          call setWriteDataLong(timeToBeSent);
          call setWriteDataInt(1);              // 1 = alarm triggered

        Package time & alarm trigger into a radio datagram & send
          call packageAndSendRadiogram();

        Stop the thread until the input has been set to low
          call getPinStatus().waitForChange();
          call setEnablePinChangeInterruptsToTrue();

        IF (input pin is not triggered)
          Get the current time
            call getCurrentTime();

          Update alarm values to be sent
            call setWriteDataLong(timeToBeSent);
            call setWriteDataInt(2);    // 2 = alarm not triggered

          Package time & alarm trigger into radio datagram & send
            call packageAndSendRadiogram();
        END of IF(input pin is not triggered)

    END of WHILE
  END of run()
END of class
```

Listing C.6: Pseudo Code Alarm Trigger Thread

C.2.5 Pseudo Code for Carbon Monoxide Thread

```
Pseudo Code for Carbon Mono thread
class CarMonThread implements Runnable {
  Instance variables
    private String location;
    private Thread t;
    private int hostPortNumber;
    private byte dataIdentifier;
    private long sampleTime;
    private long timeToBeSent;
    private double carbonMonoToBeSent;
    private int currentCarbonMonoSample;

    Methods to access instance variables, setter methods
    Methods to access instance variables, getter methods

    public void run() {
      Start a new carbon mono collector mote
        new CollectorCarbonMonoMote();

      Intial set up for measurement of carbon mono
        call initCarbonMonoMeasurement();

      Intial set up for communication
        call initBroadcastCom();
        call setPortNumber(hostPortNumber);
        call setLocation(location);
        call setWriteDataByte(dataIdentifier);

      Get and push IEEE Address to terminal
        call getPushAddress();

      Open up a broadcast connection
        call tryToOpenBroadcastConnection();

      WHILE (true)
        Get the sample time
          call getCurrentTime();

        Indicate sample event (start, i.e LED on)
          call sampleEventIndication();

        Get the current carbon mono reading to send in datagram
          call takeCarbonMonoSample();

        Indicate sample event (end, i.e LED off)
          call sampleEventIndication();

        Convert Sample to volt
        call moteCarMon.convertCarbonMonoSampleToVolt(
                  currentCarbonMonoSample);

        Reformat sample to be sent to ****.** format
          call reformatDataToBeSent(carbonMonoToBeSent);

        IF (Carbon Mono Level has Changed)
          Update time and light value to be sent
            call setWriteDataLong(timeToBeSent);
            call setWriteDataDouble(carbonMonoToBeSent);
```

```
          Send current sample
            call packageAndSendRadiogram();
        END of IF (Carbon Mono Level has Changed)

        Move current carbon level to previous carbon level variable
          call moveCurrentCarbonMonoToPreviousCarbonMono();

        Go to sleep to conserve battery
          call sleepForSomeTime(sampleTime, timeToBeSent);

      END of WHILE
   END of run()
END of class
```

Listing C.7: Pseudo Code Carbon Monoxide Thread

C.2.6 Pseudo Code for Collector Mote Main Thread

```
Pseudo Code for Main Class of a Collector Mote
  Instance Variables
    Define constants
      int HostPort
      long DefaultSampleTime

    Define variables for MANIFEST.MF properties (Strings)
      MANI_LOCATION, MANI_IDENT_TEMP, MANI_TEMPERATURE, MANI_IDENT_LIGHT,
      MANI_LIGHT_LEVEL, MANI_IDENT_BAT, MANI_BATTERY, MANI_IDENT_ALARM,
      MANI_ALARM, MANI_IDENT_CARBON_MONO, MANI_CARBON_MONO

    Define variables for MANIFEST.MF poperties
      byte
        identByteTemp, identByteLight, identByteBat, identByteAlarm,
        identByteCarbonMono
      int
      tempInt, lightInt, batInt, alarmInt, carbonInt

    Define boolean variables to set functions of mote, set to FALSE
      tempFlag, lightFlag, batFlag, alarmFlag, carbonMonoFlag

   protected void startApp() {
      Monitor the USB Port (if connected) & recognize commands from host
      Make a new instance of possible functions of mote and set to NULL
        BatLevelThread
        TempThread
        LightThread
        AlarmTriggerThread
        CarMonThread

      Get configuration data from Manifest file

      Convert properties of MANIFEST file to appropriate data type

      Set required functions of mote based on properties of MANIFEST.MF
        Set flags for functions, if 1 --> true --> function required
```

```
        Start new threads on a mote depending Manifest file
          IF (tempFlag)
            new TempThread
          IF (lightFlag)
            new LightThread
          IF (batFlag)
            new BatLevelThread
          IF (alarmFlag)
            new AlarmTriggerThread
          IF (carbonMonoFlag)
            new CarMonThread

      Wait for functions (threads) to end

   END of startApp()
END of class
```

Listing C.8: Pseudo Code Collector Main Thread

C.3 Code Listings for Collector Mote

C.3.1 CollectorMote.java

```
/* ********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ********************************************************************
 */

/* ********************************************************************
 * Purpose      :  This class includes all the common functions of a ...
 * Purpose      :  collector mote. Usually this class will be extended ...
 * Purpose      :  to add the specific capability for the collection ...
 * Purpose      :  of the environmental data.
 * ********************************************************************
 */

package org.sunspotworld;

import com.sun.spot.io.j2me.radiogram.RadiogramConnection;
import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ITriColorLED;
import com.sun.spot.util.Utils;
import com.sun.squawk.util.MathUtils;
import java.io.IOException;
import javax.microedition.io.Connector;
import javax.microedition.io.Datagram;


class CollectorMote {

    // ===================================================================
    // Instance variables
    // -------------------------------------------------------------------
    private RadiogramConnection rCon;
    private Datagram dg;
    private String location;
    private int portNumber;

    private long writeDataLong = 0;
    private byte writeDataByte = 0;
    private int writeDataInt = 0;
    private double writeDataDouble = 0;
    private boolean writeDataBool = false;

    private ITriColorLED[] sampleEvent = EDemoBoard.
            getInstance().getLEDs();
    // ===================================================================

    // ===================================================================
    // methods to access instance variables, setter methods
    // ===================================================================
    void setLocation(String setLoc){
        location = setLoc;
```

```
}

void setPortNumber(int setPort){
    portNumber = setPort;
}

void setWriteDataLong(long setDataLong){
    writeDataLong = setDataLong;
}

void setWriteDataByte(byte setDataByte){
    writeDataByte = setDataByte;
}

void setWriteDataInt(int setDataInt){
    writeDataInt = setDataInt;
}

void setWriteDataDouble(double setDataDouble){
    writeDataDouble = setDataDouble;
}

void setWriteDataBoolean(boolean setDataBoolean){
    writeDataBool = setDataBoolean;
}

// ============================================================

// ============================================================
// methods to access instance variables, getter methods
// ============================================================
String getLocation(){
    return location;
}

int getPortNumber(){
    return portNumber;
}

long getWriteDataLong(){
    return writeDataLong;
}

byte getWriteDataByte(){
    return writeDataByte;
}

int getWriteDataInt(){
    return writeDataInt;
}

double getWriteDataDouble(){
    return writeDataDouble;
}

boolean getWriteDataBoolean(){
    return writeDataBool;
}

// ============================================================
```

```
// ==========================================================================
// All other methods
// ==========================================================================
void initBroadcastCom (){
    // ======================================================================
    // Intial set up for communication
    // ----------------------------------------------------------------------
    rCon = null;
    dg = null;
    // ======================================================================

} // end initBroadcastCom

void getPushAddress() {
    // ======================================================================
    // get and push IEEE Address to terminal. Troubleshoot only
    // ----------------------------------------------------------------------
    String ourAddress = System.getProperty("IEEE_ADDRESS");
    System.out.println("Starting app. on " + ourAddress + " ...");
    // ======================================================================

} // end getPushAddress()

void tryToOpenBroadcastConnection(){
    try {
        // ==================================================================
        // Open up a broadcast connection to the host port where the ...
        // ... the host will be listening.
        // ------------------------------------------------------------------
        rCon = (RadiogramConnection) Connector.open(
              "radiogram://broadcast:" + portNumber);
        dg = rCon.newDatagram(rCon.getMaximumLength());
        // ==================================================================

        // ==================================================================
        // For trouble shooting only
        // ------------------------------------------------------------------
        System.out.println("Broadcast is open.");
        // ==================================================================

    } catch (IOException ex) {
        ex.printStackTrace();
    } // end try / catch
} // end tryToOpenBroadcastConnection()

void packageAndSendRadiogram(){

    // ======================================================================
    // package data into datagram and send
    // ----------------------------------------------------------------------
    dg.reset();
    try {
        dg.writeLong(writeDataLong);
        dg.writeByte(writeDataByte);
        dg.writeUTF(location);
        dg.writeInt(writeDataInt);
        dg.writeDouble(writeDataDouble);
        dg.writeBoolean(writeDataBool);
```

```
            rCon.send(dg);
            // ==========================================================

            // ==========================================================
            // For trouble shooting only
            // ----------------------------------------------------------
            System.out.println("Data packet sent.");
            // ==========================================================


        } catch (IOException ex) {
            ex.printStackTrace();
        } // end try / catch
    } // end packageAndSendRadiogram()

    void sleepForSomeTime(long samplePeriod, long lastTimeToBeSent) {
        // ==============================================================
        // let the mote rest to conserve battery
        // --------------------------------------------------------------
        Utils.sleep(samplePeriod - (System.currentTimeMillis() -
                lastTimeToBeSent));
        // ==============================================================

    } // end of sleepForSomeTime()

    long getCurrentTime(){
        // ==============================================================
        // take time of sample
        // --------------------------------------------------------------
        return System.currentTimeMillis();
        // ==============================================================

    } // end getCurrentTime()

    double reformatDataToBeSent(double valueIn){
        /* **************************************************************
        * Purpose    :  Method changes format of data of type long.
        * Purpose    :  Limit data to 2 digits after decimal point
        * Input      :  Data to be changed
        * Outputs    :  Data limited to two decimals
        * **************************************************************
        */

        // ==============================================================
        // local variable
        // --------------------------------------------------------------
        double valueOut = 0;
        // ==============================================================

        // ==============================================================
        // For trouble shooting only
        // --------------------------------------------------------------
        System.out.println("Print input value: " + valueIn);
        // ==============================================================

        // ==============================================================
        // Move decimal point 2 digits to the right
        // --------------------------------------------------------------
        valueIn = valueIn * 100;
        // ==============================================================
```

```
    // ==================================================================
    // For trouble shooting only
    // ------------------------------------------------------------------
    System.out.println("After * operator: " + valueIn);
    // ==================================================================

    // ==================================================================
    // Round up or down
    // ------------------------------------------------------------------
    valueIn = MathUtils.round(valueIn);
    // ==================================================================

    // ==================================================================
    // For trouble shooting only
    // ------------------------------------------------------------------
    System.out.println("After rounding: " + valueIn);
    // ==================================================================

    // ==================================================================
    // Move decimal point 2 digits to the left
    // ------------------------------------------------------------------
    valueOut = valueIn / 100;
    // ==================================================================

    // ==================================================================
    // For trouble shooting only
    // ------------------------------------------------------------------
    System.out.println("After / operator: " + valueOut);
    // ==================================================================

    System.out.println("Data to be returned: "
            + valueOut);
    return valueOut;

  } // end of reformatTempToBeSent()

  void sampleEventIndication (boolean turnIndicationOn, int i) {
     if(turnIndicationOn){
         sampleEvent[i].setRGB(0, 0, 255);
         sampleEvent[i].setOn();                // LED on
     } else {
         sampleEvent[i].setOff();               // LED off
     } // end of IF/ ELSE

  } // end of sampleEventIndication ()

} // end CollectorMote class
```

Listing C.9: Generic Functions of a Collector Mote

C.3.2 CollectorTempMote.java

```
/* *******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
```

```
 * Student No. :  0039840087
 * Purpose     :  Project for Semester 1 & 2, 2009
 * Purpose     :  09-036 Programming Sun SPOTs in JAVA
 * **********************************************************************
 */

/* **********************************************************************
 * Purpose     :  This class includes all the specific functions of a ...
 * Purpose     :  temperature collector mote.
 * **********************************************************************
 */

package org.sunspotworld;

import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ITemperatureInput;
import java.io.IOException;

class CollectorTempMote extends CollectorMote{

    // ======================================================================
    // Instance variables
    // ----------------------------------------------------------------------
    private double currentTemp = 0.0;       // current temperature sample
    private double previousTemp = 0.0;      // previous temperature sample
    private ITemperatureInput temperatureSensor;
    // ======================================================================

    // ======================================================================
    // methods to access instance variables, setter methods
    // ======================================================================
    void setCurrentTemp(double setCurTemp){
        currentTemp = setCurTemp;
    }

    void setPreviousTemp(double setPrevTemp){
        previousTemp = setPrevTemp;
    }
    // ======================================================================

    // ======================================================================
    // methods to access instance variables, getter methods
    // ======================================================================
    double getCurrentTemp(){
        return currentTemp;
    }

    double getPreviousTemp(){
        return previousTemp;
    }
    // ======================================================================


    // ======================================================================
    // All other methods
    // ======================================================================
    void initTemperatureMeasurement(){
        // ==================================================================
        // initialise temperature measurement capability of mote
        // ------------------------------------------------------------------
```

```
        temperatureSensor = EDemoBoard.getInstance().getADCTemperature();
        // ================================================================

    } // end initTemperatureMeasurement()

    double takeTemperatureSample(){

        try {
            // ============================================================
            // take sample of current temperature
            // ------------------------------------------------------------
            currentTemp = temperatureSensor.getCelsius();
            // ============================================================

            // ============================================================
            // For trouble shooting only
            // ------------------------------------------------------------
            System.out.println("Temperature sample taken: " + currentTemp);
            System.out.println("Previous temp: " + previousTemp);
            // ============================================================

        } catch (IOException ex) {
            ex.printStackTrace();
        }

        return currentTemp;
    } // end takeTemperatureSample()

    boolean hasTemperatureChanged(){
        // ================================================================
        // For trouble shooting only
        // ----------------------------------------------------------------
        System.out.println("Check if temp has changed.");
        // ================================================================

        // ================================================================
        // return FALSE if previous temp equals current temp
        // ----------------------------------------------------------------
        return currentTemp != previousTemp;
        // ================================================================

    } // end hasTemperatureChanged()

    void moveCurrentTempToPreviousTemp(){
        // ================================================================
        // For trouble shooting only
        // ----------------------------------------------------------------
        System.out.println("Move current temp to previous temp.");
        // ================================================================

        // ================================================================
        // move current temp sample to previous sample
        // ----------------------------------------------------------------
        previousTemp = currentTemp;
        // ================================================================

    } // end moveCurrentTempToPreviousTemp()
} // end CollectorTempMote
```

Listing C.10: Special Functions of a Temperature Collector Mote

C.3.3 CollectorLightMote.java

```
/* *******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *******************************************************************
 */

/* *******************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
 * Purpose      :  light collector mote.
 * *******************************************************************
 */

package org.sunspotworld;

import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ILightSensor;
import java.io.IOException;

class CollectorLightMote extends CollectorMote {

   // ==================================================================
   // Instance variables
   // ------------------------------------------------------------------
   private int currentLightLevelAverage = 0;    // current light level
   private int previousLightLevelAverage = 0;   // previous light level
   private ILightSensor lightSensor;
   // ==================================================================

   // ==================================================================
   // methods to access instance variables, setter methods
   // ==================================================================
   void setCurrentLight(int setCurLight){
      currentLightLevelAverage = setCurLight;
   }

   void setPreviousLight(int setPrevLight){
      previousLightLevelAverage = setPrevLight;
   }
   // ==================================================================

   // ==================================================================
   // methods to access instance variables, getter methods
   // ==================================================================
   int getCurrentLight(){
      return currentLightLevelAverage;
   }

   int getPreviousLight(){
      return previousLightLevelAverage;
   }
   // ==================================================================


   // ==================================================================
   // All other methods
```

```
// ==========================================================================
void initLightMeasurement(){
   // =======================================================================
   // initialise light measurement capability of mote
   // -----------------------------------------------------------------------
   lightSensor = EDemoBoard.getInstance().getLightSensor();
   // =======================================================================

} // end initLightMeasurement()

int takeLightSample(){

   try {
      // ====================================================================
      // take sample of current light level
      // --------------------------------------------------------------------
      currentLightLevelAverage = lightSensor.getAverageValue();
      // ====================================================================

      // ====================================================================
      // For trouble shooting only
      // --------------------------------------------------------------------
      System.out.println("Light sample taken: " +
              currentLightLevelAverage);
      System.out.println("Previous light: " +
              previousLightLevelAverage);
      // ====================================================================

   } catch (IOException ex) {
      ex.printStackTrace();
   }

   return currentLightLevelAverage;
} // end takeLightSample()


int convertRawDataToLux(){
   return 2 * currentLightLevelAverage;    // Lux = 2 times raw data

} // end of convertRawDataToLux()

boolean hasLightChanged(){
   // =======================================================================
   // For trouble shooting only
   // -----------------------------------------------------------------------
   System.out.println("Check if light level has changed.");
   // =======================================================================

   // =======================================================================
   // return FALSE if previous light level equals current light level
   // -----------------------------------------------------------------------
   return currentLightLevelAverage != previousLightLevelAverage;
   // =======================================================================

} // end hasLightChanged()

void moveCurrentLightToPreviousLight(){
   // =======================================================================
   // For trouble shooting only
   // -----------------------------------------------------------------------
```

```
        System.out.println("Move current light level to " +
                "previous light level.");
        // ========================================================

        // ========================================================
        // move current light sample to previous sample
        // --------------------------------------------------------
        previousLightLevelAverage = currentLightLevelAverage;
        // ========================================================

    } // end moveCurrentTempToPreviousTemp()

} // end of CollectorLightMote class
```

Listing C.11: Special Functions of a Light Collector Mote

C.3.4 CollectorBattMote.java

```
/* ******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ******************************************************************
 */

/* ******************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
 * Purpose      :  battery collector mote.
 * ******************************************************************
 */

package org.sunspotworld;

import com.sun.spot.peripheral.IBattery;
import com.sun.spot.peripheral.Spot;

class CollectorBattMote extends CollectorMote {
   // ================================================================
   // Instance variables
   // ----------------------------------------------------------------
   private int currentBattLevel = 0;         // current battery level
   private int previousBattLevel = 0;        // previous battery level
   private IBattery battStatus;              // init battery capacity;
   // ================================================================

   // ================================================================
   // methods to access instance variables, setter methods
   // ================================================================
   void setCurrentBatt(int setCurBatt){
      currentBattLevel = setCurBatt;
   }

   void setPreviousBatt(int setPrevBatt){
      previousBattLevel = setPrevBatt;
   }
   // ================================================================

   // ================================================================
   // methods to access instance variables, getter methods
   // ================================================================
   int getCurrentBatt(){
      return currentBattLevel;
   }

   int setPreviousBatt(){
      return previousBattLevel;
   }
   // ================================================================


   // ================================================================
   // All other methods
   // ================================================================
   void initBattMeasurement(){
```

```
        // ================================================================
        // initialise battery measurement capability of mote
        // ----------------------------------------------------------------
        battStatus = Spot.getInstance().getPowerController().getBattery();
        // ================================================================

    } // end initLightMeasurement()

    int takeBattSample() {

        // ============================================================
        // take sample of current battery capacity
        // ------------------------------------------------------------
        currentBattLevel = battStatus.getBatteryLevel();
        // ============================================================

        // ============================================================
        // For trouble shooting only
        // ------------------------------------------------------------
        System.out.println("Battery sample taken: " +
                currentBattLevel);
        System.out.println("Previous temp: " +
                previousBattLevel);
        // ============================================================

        return currentBattLevel;

    } // end takeBattSample()

    boolean hasBattChanged(){
        // ================================================================
        // For trouble shooting only
        // ----------------------------------------------------------------
        System.out.println("Check if battery capacity has changed.");
        // ================================================================

        // ================================================================
        // return FALSE if previous batt level equals current batt level
        // ----------------------------------------------------------------
        return currentBattLevel != previousBattLevel;
        // ================================================================

    } // end hasBattChanged()

    void moveCurrentBattToPreviousBatt(){
        // ================================================================
        // For trouble shooting only
        // ----------------------------------------------------------------
        System.out.println("Move current battery level to previous batt.");
        // ================================================================

        // ================================================================
        // move current temp sample to previous sample
        // ----------------------------------------------------------------
        previousBattLevel = currentBattLevel;
        // ================================================================

    } // end moveCurrentBattToPreviousBatt()

} // end of CollectorBattMote
```

Listing C.12: Special Functions of a Battery Collector Mote

C.3.5 CollectorAlarmMote.java

```
/* *******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *******************************************************************
 */

/* *******************************************************************
 * Purpose      :  This class includes all specific functions of an ...
 * Purpose      :  alarm collector mote.
 * *******************************************************************
 */

package org.sunspotworld;

import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.EDemoController;
import com.sun.spot.sensorboard.io.InputPin;
import com.sun.spot.sensorboard.io.PinDescriptor;


class CollectorAlarmMote extends CollectorMote {
    // ===================================================================
    // Instance variables
    // -------------------------------------------------------------------
    private PinDescriptor AlarmTriggerInput;
    private EDemoBoard test;
    private EDemoController testController;
    private InputPin pin;
    // ===================================================================

    // ===================================================================
    // methods to access instance variables, setter methods
    // ===================================================================
    void setPinStatus(InputPin setPin){
        pin = setPin;
    }
    // ===================================================================

    // ===================================================================
    // methods to access instance variables, getter methods
    // ===================================================================
    InputPin getPinStatus(){
        return pin;
    }

    // ===================================================================
```

```
    // ============================================================
    // All other methods
    // ============================================================
    void initAlarm(){
        // ========================================================
        // initialise alarm capability of mote
        // --------------------------------------------------------
        AlarmTriggerInput = EDemoController.D2;
        test = EDemoBoard.getInstance();
        testController = test.getEDemoController();
        pin = new InputPin(AlarmTriggerInput, testController);
        testController.setPinDirection(AlarmTriggerInput, false);
        testController.enablePinChangeInterrupts(pin);
        // ========================================================

    } // end initAlarm()

    boolean pinStatus(){
        // ========================================================
        // Check if input is low on D2. Low means no alarm triggered
        // --------------------------------------------------------
        return (pin.isLow());
        // ========================================================

    }// end pinStatus()

    void setEnablePinChangeInterruptsToTrue(){
        testController.enablePinChangeInterrupts(pin);
    } // end setEnablePinChangeInterruptsToTrue()


} // end CollectorAlarmMote class
```

Listing C.13: Special Functions of a Alarm Trigger Mote

C.3.6 CollectorCarbonMonoMote.java

```
/* *****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *****************************************************************
 */

/* *****************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
 * Purpose      :  carbon mono collector mote.
 * *****************************************************************
 */

package org.sunspotworld;

import com.sun.spot.sensorboard.EDemoBoard;
```

```
import com.sun.spot.sensorboard.io.IScalarInput;
import java.io.IOException;

class CollectorCarbonMonoMote extends CollectorMote {
    // ================================================================
    // Instance variables
    // ----------------------------------------------------------------
    private double currentCarbonMonoLevel = 0;       // in volt
    private double previousCarbonMonoLevel = 0;      // in volt
    private int currentSample = 0;                   // converted to volt
    private EDemoBoard carbonMonoSensor;
    private IScalarInput analogInputs[];
    // ================================================================

    // ================================================================
    // methods to access instance variables, setter methods
    // ================================================================
    void setCurrentCarbonMono(double setCurCarbonMono){
        currentCarbonMonoLevel = setCurCarbonMono;
    }

    void setPreviousCarbonMono(double setPrevCarbonMono){
        previousCarbonMonoLevel = setPrevCarbonMono;
    }

    void setCurrentSample(int setCurSamp){
        currentSample = setCurSamp;
    }
    // ================================================================

    // ================================================================
    // methods to access instance variables, getter methods
    // ================================================================
    double getCurrentCarbonMono(){
        return currentCarbonMonoLevel;
    }

    double getPreviousCarbonMono(){
        return previousCarbonMonoLevel;
    }
    int setCurrentSample(){
        return currentSample;
    }
    // ================================================================


    // ================================================================
    // All other methods
    // ================================================================
    void initCarbonMonoMeasurement(){
        // ============================================================
        // initialise carbon mono measurement capability of mote
        // ------------------------------------------------------------
        carbonMonoSensor = EDemoBoard.getInstance();
        analogInputs = carbonMonoSensor.getScalarInputs();
        // ============================================================

    } // end of initCarbonMonoMeasurement()

    int takeCarbonMonoSample(){
```

```
        try {
            // ======================================================
            // take sample of current carbon mono
            // ------------------------------------------------------
            currentSample = analogInputs[0].getValue();
            // ======================================================

            // ======================================================
            // For trouble shooting only
            // ------------------------------------------------------
            System.out.println("Carbon mono sample taken: " +
                    currentSample);
            // ======================================================

        } catch (IOException ex) {
            ex.printStackTrace();
        }

        return currentSample;
    } // end takeCarbonMonoSample()

    double convertCarbonMonoSampleToVolt(int currentSample){
        // ==========================================================
        // For trouble shooting only
        // ----------------------------------------------------------
        System.out.println("Current Sample: " + currentSample);
        // ==========================================================


        // ==========================================================
        // Convert sample to volt (see Theory of Operation, blue (p. 19))
        // ----------------------------------------------------------
        currentCarbonMonoLevel = (double)currentSample * 3 / 1024;
        // ==========================================================


        // ==========================================================
        // For trouble shooting only
        // ----------------------------------------------------------
        System.out.println("Sample in Volt: " + currentCarbonMonoLevel);
        // ==========================================================

        return currentCarbonMonoLevel;
        // ==========================================================

    } // end convertCarbonMonoSampleToVolt()

    boolean hasCarbonMonoLevelChanged(){
        // ==========================================================
        // For trouble shooting only
        // ----------------------------------------------------------
        System.out.println("Check if carbon mono level has changed.");
        // ==========================================================

        // ==========================================================
        // return FALSE if previous temp equals current temp
        // ----------------------------------------------------------
        return currentCarbonMonoLevel != previousCarbonMonoLevel;
        // ==========================================================
```

```
    } // end hasLightChanged()

    void moveCurrentCarbonMonoToPreviousCarbonMono(){
        // ==============================================================
        // For trouble shooting only
        // --------------------------------------------------------------
        System.out.println("Move current carbon mono to previous.");
        // ==============================================================

        // ==============================================================
        // move current temp sample to previous sample
        // --------------------------------------------------------------
        currentCarbonMonoLevel = previousCarbonMonoLevel;
        // ==============================================================

    } // end moveCurrentCarbonMonoToPreviousCarbonMono()

} // end of CollectorCarbonMonoMote class
```

Listing C.14: Special Functions of a Carbon Monoxide Collector Mote

C.3.7 CollectMainSPOT.java

```
/* *********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *********************************************************************
 */

/* *********************************************************************
 * Description  :  Main class for the collector SPOTs.
 * Inputs       :  MANIFEST.MF file properties
 * Outputs      :  None
 * Purpose      :  Reads properties from MANIFEST.MF file & configures ...
 * Purpose      :  ... collector SPOT based on the MANIFEST.MF file.
 * Purpose      :  After the appropriate functions (threads) have been ...
 * Purpose      :  ... started the class waits for all threads to finish.
 * Purpose      :  When all treads are finished, class finishes.
 * *********************************************************************
 */

package org.sunspotworld;

import com.sun.spot.util.*;
import javax.microedition.midlet.MIDlet;
import javax.microedition.midlet.MIDletStateChangeException;


public class CollectMainSPOT extends MIDlet {
    // ==================================================================
    // Instance variables
    // ------------------------------------------------------------------
```

```
// ------------------------------------------------------------------
// Define constants
// ------------------------------------------------------------------
private static final int HOST_PORT = 67;     // Broadcast port
private static final long SAMPLE_TIME_DEFAULT = 1000;
// ------------------------------------------------------------------

// ------------------------------------------------------------------
// Manifest file configuration information will be saved to the ...
// ... following variables
// ------------------------------------------------------------------
private String MANI_LOCATION = null;            // location of SPOT
private String MANI_IDENT_TEMP = null;          // IDs temp data
private String MANI_TEMPERATURE = null;         // temp measure
private String MANI_IDENT_LIGHT = null;         // IDs light data
private String MANI_LIGHT_LEVEL = null;         // light measure
private String MANI_IDENT_BAT = null;           // IDs bat data
private String MANI_BATTERY = null;             // battery measure
private String MANI_IDENT_ALARM = null;         // IDs alarm data
private String MANI_ALARM = null;               // alarm required
private String MANI_IDENT_CARBON_MONO = null;   // Ids carbmon data
private String MANI_CARBON_MONO = null;         // carbon monoxide
// ------------------------------------------------------------------

// ==================================================================
// The data from the manifest file is of type String. Therefore ...
// ... to make further processing easier they will be converted to ...
// ... variables of type byte or int.
// ------------------------------------------------------------------
private byte identByteTemp = 0;
private byte identByteLight = 0;
private byte identByteBat = 0;
private byte identByteAlarm = 0;
private byte identByteCarbonMono = 0;
private int tempInt = 0;
private int lightInt = 0;
private int batInt = 0;
private int alarmInt = 0;
private int carbonInt = 0;
// ------------------------------------------------------------------

// ------------------------------------------------------------------
// Create boolean variables to set functions a SPOT needs. These ...
// ... variables will be set based on the entries in the manifest.
// ------------------------------------------------------------------
private boolean tempFlag = false;       // true if MANI_TEMPERATURE = 1
private boolean lightFlag = false;      // true if MANI_LIGHT_LEVEL = 1
private boolean batFlag = false;        // true if MANI_BATTERY = 1
private boolean alarmFlag = false;      // true if MANI_ALARM = 1
private boolean carbonMonoFlag = false;// true if MANI_CARBON_MONO = 1
// ==================================================================

protected void startApp() {
    // ==============================================================
    // monitor the USB (if connected) and recognize commands from host
    // --------------------------------------------------------------
    new BootloaderListener().start();
    // ==============================================================
```

```
// =====================================================================
// Names of the different functions a SPOT can have. Function...
// ... will only start if the manifest file instructs to run.
// Each function will start a new thread.
// ---------------------------------------------------------------------
BatLevelThread measureBat = null;            // place holder for now
TempThread measureTemp = null;               // place holder for now
LightThread measureLight = null;             // place holder for now
AlarmTriggerThread detectAlarm = null;     // place holder for now
CarMonThread detectCarbonMono = null;        // place holder for now
// =====================================================================

// =====================================================================
// Get configuration data from Manifest file. After data has ...
// ... been read from manifest it will be used to configure the ...
// ... SPOT.
// ---------------------------------------------------------------------
try {
    MANI_LOCATION = this.getAppProperty("Location");
    MANI_IDENT_TEMP = this.getAppProperty("IdentTemp");
    MANI_TEMPERATURE = this.getAppProperty("Temperature");
    MANI_IDENT_LIGHT = this.getAppProperty("IdentLight");
    MANI_LIGHT_LEVEL = this.getAppProperty("LightLevel");
    MANI_IDENT_BAT = this.getAppProperty("IdentBat");
    MANI_BATTERY = this.getAppProperty("Battery");
    MANI_IDENT_ALARM = this.getAppProperty("IdentAlarm");
    MANI_ALARM = this.getAppProperty("Alarm");
    MANI_IDENT_CARBON_MONO = this.getAppProperty("IdentCarbonMono");
    MANI_CARBON_MONO = this.getAppProperty("CarbonMono");

    // -----------------------------------------------------------------
    // For trouble shooting only
    // -----------------------------------------------------------------
    System.out.println("Configuration data OK");
    // -----------------------------------------------------------------

} catch (NullPointerException e) {
    System.out.println("Problem reading MANIFEST.MF " + e);
} // end try / catch
// =====================================================================


// =====================================================================
// For trouble shooting only
// ---------------------------------------------------------------------
System.out.println("The location is: " + MANI_LOCATION);
// =====================================================================

// =====================================================================
// convert Strings to appropriate data type
// ---------------------------------------------------------------------
try {
    identByteTemp = Byte.parseByte(MANI_IDENT_TEMP);
    tempInt = Integer.parseInt(MANI_TEMPERATURE);
    identByteLight = Byte.parseByte(MANI_IDENT_LIGHT);
    lightInt = Integer.parseInt(MANI_LIGHT_LEVEL);
    identByteBat = Byte.parseByte(MANI_IDENT_BAT);
    batInt = Integer.parseInt(MANI_BATTERY);
    identByteAlarm = Byte.parseByte(MANI_IDENT_ALARM);
    alarmInt = Integer.parseInt(MANI_ALARM);
```

```
        identByteCarbonMono = Byte.parseByte(MANI_IDENT_CARBON_MONO);
        carbonInt = Integer.parseInt(MANI_CARBON_MONO);
    } catch (NumberFormatException numberFormatException) {
        System.out.println("Problem converting data: "
                + numberFormatException
        );
    } // end try / catch
    // ==================================================================

    // ==================================================================
    // Set flags for functions, if 1 --> true --> function required
    // ------------------------------------------------------------------
    if (tempInt == 1) {tempFlag = true;}            // temperature
    if (lightInt == 1) {lightFlag = true;}          // light
    if (batInt == 1) {batFlag = true;}              // battery capacity
    if (alarmInt == 1) {alarmFlag = true;}          // alarm
    if (carbonInt == 1) {carbonMonoFlag = true;}    //carbon monoxide
    // ==================================================================

    // ==================================================================
    // start new threads on a SunSPOT depending Manifest file
    // ------------------------------------------------------------------
    if (tempFlag) {
        long SampleTimeTempStatus =
                Long.parseLong(
                this.getAppProperty("SampleTimeTemp")
                );
        measureTemp = new TempThread(
             MANI_LOCATION, HOST_PORT, identByteTemp,
             SampleTimeTempStatus * SAMPLE_TIME_DEFAULT
        );
    } // end if (tempFlag)

    if (lightFlag) {
        long SampleTimeLightStatus =
                Long.parseLong(
                this.getAppProperty("SampleTimeLight")
                );
        measureLight = new LightThread(
             MANI_LOCATION, HOST_PORT, identByteLight,
             SampleTimeLightStatus * SAMPLE_TIME_DEFAULT
        );
    } // end if (lightFlag)

    if (batFlag) {
        long SampleTimeBattStatus =
                Long.parseLong(
                this.getAppProperty("SampleTimeBattery")
                );
        measureBat = new BatLevelThread(
             MANI_LOCATION, HOST_PORT, identByteBat,
             SampleTimeBattStatus * SAMPLE_TIME_DEFAULT
        );
    } // end if (batFlag)

    if (alarmFlag) {
        long SampleTimeAlarmStatus =
                Long.parseLong(
                this.getAppProperty("SampleTimeAlarm")
                );
```

```
            detectAlarm = new AlarmTriggerThread(
                    MAN_LOCATION, HOST_PORT, identByteAlarm,
                    SampleTimeAlarmStatus * SAMPLE_TIME_DEFAULT
            );
        } // end if (alarmFlag)

        if (carbonMonoFlag) {
            long SampleTimeCarbonMonoStatus =
                        Long.parseLong(
                        this.getAppProperty("SampleTimeCarbonMono")
                        );
            detectCarbonMono = new CarMonThread(
                    MAN_LOCATION, HOST_PORT, identByteCarbonMono,
                    SampleTimeCarbonMonoStatus * SAMPLE_TIME_DEFAULT
            );
        } // end if (carbonMonoFlag)
        // ==================================================================

        // ==================================================================
        // Wait for functions (threads) to end
        // ------------------------------------------------------------------
        try {
            System.out.println("Wait for threads to finish.");
            if (measureTemp != null) {measureTemp.getThread().join();}

            if (measureLight != null) {measureLight.getThread().join();}

            if (measureBat != null) {measureBat.getThread().join();}

            if (detectAlarm != null) {detectAlarm.getThread().join();}

            if (detectCarbonMono != null) {detectCarbonMono.getThread().
                        join();}

        } catch (InterruptedException e) {
            System.out.println("Main thread interrupted." + e);
        } // end try / catch
        // ==================================================================

        // ==================================================================
        // For trouble shooting only
        // ------------------------------------------------------------------
        System.out.println("Main thread exiting.");
        // ==================================================================

        // ==================================================================
        // cause the midlet to exit
        // ------------------------------------------------------------------
        notifyDestroyed();
        // ==================================================================
    } // end startApp()

    protected void pauseApp() {
        // This is not currently called by the Squawk VM
    } // end pauseApp()

    /**
     * Called if the MIDlet is terminated by the system.
     */
    protected void destroyApp(boolean arg0) throws
```

```
            MIDletStateChangeException {

    } // end destroyApp()
} // end class
```

Listing C.15: Main Thread of Collector Mote

C.3.8 TempThread.java

```
/* ********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ********************************************************************
 */

/* ********************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has temp ...
 * Purpose      :  measurement set to TRUE.
 * Inputs       :  Location of mote,
                   port used by host,
                   data type,
                   sample time
 * Outputs      :  Collected environmental data
 * ********************************************************************
 */

package org.sunspotworld;


class TempThread implements Runnable {
    // ================================================================
    // Instance variables
    // ----------------------------------------------------------------
    private String location;
    private Thread t;
    private int hostPortNumber;
    private byte dataIdentifier;
    private long sampleTime;
    private long timeToBeSent;
    private double tempToBeSent;
    // ================================================================

    TempThread(String threadname, int portNo, byte dataType,
            long timeBetweenSamples) {
        location = threadname;
        t = new Thread(this, location);
        hostPortNumber = portNo;
        dataIdentifier = dataType;
        sampleTime = timeBetweenSamples;
        System.out.println("New thread: " + t);
        t.start();
    }
```

```
// ============================================================
// methods to access instance variables, setter methods
// ============================================================
void setLocThread(String setLoc){
   location = setLoc;
}

void setThread(Thread setThread){
   t = setThread;
}

void setPortThread(int setPort){
   hostPortNumber = setPort;
}

void setDataIdType(byte setDataType){
   dataIdentifier = setDataType;
}

void setTimeBetweenSamples(long setSampleInterval){
   sampleTime = setSampleInterval;
}

void setTimeForSending(long setSendTime){
   timeToBeSent = setSendTime;
}

void setTempForSending(double setSendTemp){
   tempToBeSent = setSendTemp;
}
// ============================================================


// ============================================================
// methods to access instance variables, getter methods
// ============================================================
String getLocThread(){
   return location;
}

Thread getThread(){
   return t;
}

int getPortThread(){
   return hostPortNumber;
}

byte getDataIdType(){
   return dataIdentifier;
}

long getTimeBetweenSamples(){
   return sampleTime;
}

long getTimeForSending(){
   return timeToBeSent;
}
```

```
double getTempForSending(){
    return tempToBeSent;
}
// ======================================================================


// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
// entry point for temp thread
// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

public void run() {

    // ==================================================================
    // For trouble shooting only
    // ------------------------------------------------------------------
    System.out.println("Start temp thread: " + location);
    // ==================================================================

    // ==================================================================
    // start a new temperature collector mote
    // ------------------------------------------------------------------
    CollectorTempMote moteTemp = new CollectorTempMote();
    // ==================================================================

    // ==================================================================
    // Intial set up for measurement of temperature
    // ------------------------------------------------------------------
    moteTemp.initTemperatureMeasurement();
    // ==================================================================

    // ==================================================================
    // Intial set up for communication
    // ------------------------------------------------------------------
    moteTemp.initBroadcastCom();
    moteTemp.setPortNumber(hostPortNumber);
    moteTemp.setLocation(location);
    moteTemp.setWriteDataByte(dataIdentifier);
    // ==================================================================

    // ==================================================================
    // get and push IEEE Address to terminal
    // ------------------------------------------------------------------
    moteTemp.getPushAddress();
    // ==================================================================

    // ==================================================================
    // Open up a broadcast connection
    // ------------------------------------------------------------------
    moteTemp.tryToOpenBroadcastConnection();
    // ==================================================================

    // ==================================================================
    // Get the current temperature reading and send in datagram
    // ------------------------------------------------------------------
    while (true) {
        // ==============================================================
        // Get the sample time
        // --------------------------------------------------------------
        timeToBeSent = moteTemp.getCurrentTime();
        // ==============================================================
```

```
// ============================================================
// Indicate sample event (start, i.e LED on)
// ------------------------------------------------------------
moteTemp.sampleEventIndication(true, 1);
// ============================================================

// ============================================================
// Get the current temperature reading to send in datagram
// ------------------------------------------------------------
tempToBeSent = moteTemp.takeTemperatureSample();
// ============================================================

// ============================================================
// Indicate sample event (end, i.e LED off)
// ------------------------------------------------------------
moteTemp.sampleEventIndication(false, 1);
// ============================================================

// ============================================================
// Reformat tempToBeSent to ****.**
// ------------------------------------------------------------
tempToBeSent = moteTemp.reformatDataToBeSent(tempToBeSent);
// ============================================================

// ============================================================
// For trouble shooting only
// ------------------------------------------------------------
System.out.println("Has temp changed? " +
        moteTemp.hasTemperatureChanged());
// ============================================================

if(moteTemp.hasTemperatureChanged()){
    // ========================================================
    // For trouble shooting only
    // --------------------------------------------------------
    System.out.println("Try to send sample.");
    // ========================================================

    // ========================================================
    // Update time and temperatur value to be sent
    // --------------------------------------------------------
    moteTemp.setWriteDataLong(timeToBeSent);
    moteTemp.setWriteDataDouble(tempToBeSent);
    // ========================================================

    // ========================================================
    // Send current sample
    // --------------------------------------------------------
    moteTemp.packageAndSendRadiogram();
    // ========================================================

} // end if block

// ============================================================
// move current temp sample to previous sample variable
// ------------------------------------------------------------
moteTemp.moveCurrentTempToPreviousTemp();
// ============================================================
```

```
        // ===========================================================
        // Go to sleep to conserve battery
        // -----------------------------------------------------------
        moteTemp.sleepForSomeTime(sampleTime, timeToBeSent);
        // ===========================================================

      } // end of while loop
    } // end of run()
} // end of class
```

Listing C.16: Temperature Collector Thread

C.3.9 LightThread.java

```
/* ********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ********************************************************************
 */

/* ********************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has light ...
 * Purpose      :  measurement set to TRUE.
 * Inputs       :  Location of mote,
                   port used by host,
                   data type,
                   sample time
 * Outputs      :  Environmental data
 * ********************************************************************
 */

package org.sunspotworld;


class LightThread implements Runnable {
    // ================================================================
    // Instance variables
    // ----------------------------------------------------------------
    private String location;
    private Thread t;
    private int hostPortNumber;
    private byte dataIdentifier;
    private long sampleTime;
    private long timeToBeSent;
    private int lightToBeSent;
    // ================================================================

    LightThread(String threadname, int portNo, byte dataType,
            long timeBetweenSamples) {
        location = threadname;
        t = new Thread(this, location);
        hostPortNumber = portNo;
        dataIdentifier = dataType;
```

```
        sampleTime = timeBetweenSamples;
        System.out.println("New thread: " + t);
        t.start();
    }

    // ==========================================================
    // methods to access instance variables, setter methods
    // ==========================================================
    void setLocThread(String setLoc){
        location = setLoc;
    }

    void setThread(Thread setThread){
        t = setThread;
    }

    void setPortThread(int setPort){
        hostPortNumber = setPort;
    }

    void setDataIdType(byte setDataType){
        dataIdentifier = setDataType;
    }

    void setTimeBetweenSamples(long setSampleInterval){
        sampleTime = setSampleInterval;
    }

    void setTimeForSending(long setSendTime){
        timeToBeSent = setSendTime;
    }

    void setLightForSending(int setSendLight){
        lightToBeSent = setSendLight;
    }
    // ==========================================================


    // ==========================================================
    // methods to access instance variables, setter methods
    // ==========================================================
    String getLocThread(){
        return location;
    }

    Thread getThread(){
        return t;
    }

    int getPortThread(){
        return hostPortNumber;
    }

    byte getDataIdType(){
        return dataIdentifier;
    }

    long getTimeBetweenSamples(){
        return sampleTime;
    }
```

```
long getTimeForSending(){
   return timeToBeSent;
}

int getLightForSending(){
   return lightToBeSent;
}
// ================================================================


// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
// entry point for light thread
// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

public void run() {
   // ============================================================
   // For trouble shooting only
   // ------------------------------------------------------------
   System.out.println("Start light thread: " + location);
   // ============================================================

   // ============================================================
   // Start a new light level collector mote
   // ------------------------------------------------------------
   CollectorLightMote moteLight = new CollectorLightMote();
   // ============================================================

   // ============================================================
   // Intial set up for measurement of light level
   // ------------------------------------------------------------
   moteLight.initLightMeasurement();
   // ============================================================

   // ============================================================
   // Intial set up for communication
   // ------------------------------------------------------------
   moteLight.initBroadcastCom();
   moteLight.setPortNumber(hostPortNumber);
   moteLight.setLocation(location);
   moteLight.setWriteDataByte(dataIdentifier);
   // ============================================================

   // ============================================================
   // get and push IEEE Address to terminal
   // ------------------------------------------------------------
   moteLight.getPushAddress();
   // ============================================================

   // ============================================================
   // Open up a broadcast connection
   // ------------------------------------------------------------
   moteLight.tryToOpenBroadcastConnection();
   // ============================================================

   // ============================================================
   // Get the current light reading and send in datagram
   // ------------------------------------------------------------
   while (true){
      // ========================================================
```

```
// Get the current time. I.e. time when sample is taken
// ---------------------------------------------------------------
timeToBeSent = moteLight.getCurrentTime();
// ===============================================================

// ===============================================================
// Indicate sample event (start, i.e LED on)
// ---------------------------------------------------------------
moteLight.sampleEventIndication(true, 2);
// ===============================================================

// ===============================================================
// Get the current light reading to send in datagram
// ---------------------------------------------------------------
lightToBeSent = moteLight.takeLightSample();
// ===============================================================

// ===============================================================
// Indicate sample event (end, i.e LED off)
// ---------------------------------------------------------------
moteLight.sampleEventIndication(false, 2);
// ===============================================================

// ===============================================================
// Convert raw data to luminance (lux). Based on Sun SPOT ...
// Theory of Operation [p. 21] Luminance = 2 times raw data
// ---------------------------------------------------------------
lightToBeSent = moteLight.convertRawDataToLux();

// ===============================================================
// For trouble shooting only
// ---------------------------------------------------------------
System.out.println("Has light changed? " +
        moteLight.hasLightChanged());
// ===============================================================

if(moteLight.hasLightChanged()){
    // ===========================================================
    // For trouble shooting only
    // -----------------------------------------------------------
    System.out.println("Try to send sample.");
    // ===========================================================

    // ===========================================================
    // Update time and light value to be sent
    // -----------------------------------------------------------
    moteLight.setWriteDataLong(timeToBeSent);
    moteLight.setWriteDataInt(lightToBeSent);
    // ===========================================================

    // ===========================================================
    // Send current sample
    // -----------------------------------------------------------
    moteLight.packageAndSendRadiogram();
    // ===========================================================

} // end if block

// ===============================================================
// move current light sample to previous sample variable
```

```
        // ----------------------------------------------------------------
        moteLight.moveCurrentLightToPreviousLight();
        // ================================================================

        // ================================================================
        // Go to sleep to conserve battery
        // ----------------------------------------------------------------
        moteLight.sleepForSomeTime(sampleTime, timeToBeSent);
        // ================================================================

      } // end of while loop
   } // end of run()
} // end of class
```

Listing C.17: Light Collector Thread

C.3.10 BatLevelThread.java

```
/* ****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ****************************************************************
 */

/* ****************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has battery ...
 * Purpose      :  measurement set to TRUE.
 * Inputs       :  Location of mote,
                   port used by host,
                   data type,
                   sample time
 * Outputs      :  Environmental data collected
  ****************************************************************
 */
package org.sunspotworld;

import com.sun.spot.peripheral.Battery.*;

class BatLevelThread implements Runnable {

   private String location;                          // name of thread
   private Thread t;
   private int hostPortNumber;
   private byte dataIdentifier;
   private long sampleTime;
   private long timeToBeSent;
   private int battToBeSent;

   BatLevelThread(String threadname, int portNo, byte dataType,
           long timeBetweenSamples) {
      location = threadname;
      t = new Thread(this, location);
      hostPortNumber = portNo;
      dataIdentifier = dataType;
      sampleTime = timeBetweenSamples;
      System.out.println("New thread: " + t);
      t.start();
   }

   // ==================================================================
   // methods to access instance variables, setter methods
   // ==================================================================
   void setLocThread(String setLoc){
      location = setLoc;
   }

   void setThread(Thread setThread){
      t = setThread;
   }

   void setPortThread(int setPort){
      hostPortNumber = setPort;
   }
```

```
void setDataIdType(byte setDataType){
    dataIdentifier = setDataType;
}

void setTimeBetweenSamples(long setSampleInterval){
    sampleTime = setSampleInterval;
}

void setTimeForSending(long setSendTime){
    timeToBeSent = setSendTime;
}

void setBattForSending(int setSendBatt){
    battToBeSent = setSendBatt;
}
// ==========================================================


// ==========================================================
// methods to access instance variables, setter methods
// ==========================================================
String getLocThread(){
    return location;
}

Thread getThread(){
    return t;
}

int getPortThread(){
    return hostPortNumber;
}

byte getDataIdType(){
    return dataIdentifier;
}

long getTimeBetweenSamples(){
    return sampleTime;
}

long getTimeForSending(){
    return timeToBeSent;
}

int getBattForSending(){
    return battToBeSent;
}
// ==========================================================


// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
// entry point for battery level thread
// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

public void run() {
    // ======================================================
    // For trouble shooting only
    // ------------------------------------------------------
```

```
    System.out.println("Start battery thread: " + location);
    // ================================================================

    // ================================================================
    // Start a new battery level collector mote
    // ----------------------------------------------------------------
    CollectorBattMote moteBatt = new CollectorBattMote();
    // ================================================================

    // ================================================================
    // Intial set up for measurement of battery level
    // ----------------------------------------------------------------
    moteBatt.initBattMeasurement();
    // ================================================================

    // ================================================================
    // Intial set up for communication
    // ----------------------------------------------------------------
    moteBatt.initBroadcastCom();
    moteBatt.setPortNumber(hostPortNumber);
    moteBatt.setLocation(location);
    moteBatt.setWriteDataByte(dataIdentifier);
    // ================================================================

    // ================================================================
    // get and push IEEE Address to terminal
    // ----------------------------------------------------------------
    moteBatt.getPushAddress();
    // ================================================================

    // ================================================================
    // Open up a broadcast connection
    // ----------------------------------------------------------------
    moteBatt.tryToOpenBroadcastConnection();
    // ================================================================

    // ================================================================
    // Get the current battery reading and send in datagram
    // ----------------------------------------------------------------
    while (true){
        // ============================================================
        // Get the current time. I.e. time when sample is taken
        // ------------------------------------------------------------
        timeToBeSent = moteBatt.getCurrentTime();
        // ============================================================

        // ============================================================
        // Indicate sample event (start, i.e LED on)
        // ------------------------------------------------------------
        moteBatt.sampleEventIndication(true, 3);
        // ============================================================

        // ============================================================
        // Get the current battery reading to send in datagram
        // ------------------------------------------------------------
        battToBeSent = moteBatt.takeBattSample();
        // ============================================================

        // ============================================================
        // Indicate sample event (end, i.e LED off)
```

```
            // ---------------------------------------------------------------
            moteBatt.sampleEventIndication(false, 3);
            // ===============================================================

            // ===============================================================
            // For trouble shooting only
            // ---------------------------------------------------------------
            System.out.println("Has battery capacity changed? " +
                    moteBatt.hasBattChanged());
            // ===============================================================

            if(moteBatt.hasBattChanged()){
                // ===========================================================
                // For trouble shooting only
                // -----------------------------------------------------------
                System.out.println("Try to send sample.");
                // ===========================================================

                // ===========================================================
                // Update time and battery value to be sent
                // -----------------------------------------------------------
                moteBatt.setWriteDataLong(timeToBeSent);
                moteBatt.setWriteDataInt(battToBeSent);
                // ===========================================================

                // ===========================================================
                // Send current sample
                // -----------------------------------------------------------
                moteBatt.packageAndSendRadiogram();
                // ===========================================================

            } // end if block

            // ===============================================================
            // move current battery sample to previous sample variable
            // ---------------------------------------------------------------
            moteBatt.moveCurrentBattToPreviousBatt();
            // ===============================================================

            // ===============================================================
            // Go to sleep to conserve battery
            // ---------------------------------------------------------------
            moteBatt.sleepForSomeTime(sampleTime, timeToBeSent);
            // ===============================================================

        } // end of while loop
    } // end of run()
} // end of class
```

Listing C.18: Battery Collector Thread

C.3.11 AlarmTriggerThread.java

```
/* ********************************************************************
 * Author       : Severin Willisch
 * email        : d9840087@mail.connect.usq.edu.au
```

```
 * Student No. : 0039840087
 * Purpose     : Project for Semester 1 & 2, 2009
 * Purpose     : 09-036 Programming Sun SPOTs in JAVA
 * ***********************************************************************
 */

/* ***********************************************************************
 * Purpose     :  This class monitors a specific input to tigger an ...
 * Purpose     :  alarm. If the level is low everything is normal, ...
 * Purpose     :  i.e. no alarm has been activated. The input is ...
 * Purpose     :  checked once every second. If an alarm is triggered ...
 * Purpose     :  a broadcast message is sent out. After the message ...
 * Purpose     :  has been sent, the thread waits until the the D2 pin ...
 * Purpose     :  has been set to low. This prevents the SPOT from ...
 * Purpose     :  sending out message that alarm has been triggered. ...
 * Purpose     :  After input has been set to low the thread continues ...
 * Purpose     :  to monitor the D2 input.
 * Inputs      :  Location of mote,
                  port used by host,
                  data type,
                  sample time
 * Outputs     :  Alarm trigger sent via radio
 * ***********************************************************************
 */

package org.sunspotworld;

class AlarmTriggerThread implements Runnable {

   private String location;
   private Thread t;
   private int hostPortNumber;
   private byte dataIdentifier;
   private long sampleTime;
   private long timeToBeSent;


   AlarmTriggerThread(String threadname, int portNo, byte dataType,
           long timeBetweenSamples) {

      location = threadname;
      t = new Thread(this, location);
      hostPortNumber = portNo;
      dataIdentifier = dataType;
      sampleTime = timeBetweenSamples;
      System.out.println("New thread: " + t);
      t.start();
   }

   // ==================================================================
   // methods to access instance variables, setter methods
   // ==================================================================
   void setLocThread(String setLoc){
      location = setLoc;
   }

   void setThread(Thread setThread){
      t = setThread;
   }
```

```
void setPortThread(int setPort){
    hostPortNumber = setPort;
}

void setDataIdType(byte setDataType){
    dataIdentifier = setDataType;
}

void setTimeBetweenSamples(long setSampleInterval){
    sampleTime = setSampleInterval;
}

void setTimeForSending(long setSendTime){
    timeToBeSent = setSendTime;
}
// ==================================================================

// ==================================================================
// methods to access instance variables, setter methods
// ==================================================================
String getLocThread(){
    return location;
}

Thread getThread(){
    return t;
}

int getPortThread(){
    return hostPortNumber;
}

byte getDataIdType(){
    return dataIdentifier;
}

long getTimeBetweenSamples(){
    return sampleTime;
}

long getTimeForSending(){
    return timeToBeSent;
}

// ==================================================================


// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
// entry point for alarm trigger thread
// ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

public void run() {

    // ==============================================================
    // For trouble shooting only
    // --------------------------------------------------------------
    System.out.println("Start alarm thread: " + location);
    // ==============================================================

    // ==============================================================
```

```
// start a new alarm trigger mote
// ------------------------------------------------------------------------
CollectorAlarmMote moteAlarm = new CollectorAlarmMote();
// ========================================================================

// ========================================================================
// Initial set up for alarm trigger
// ------------------------------------------------------------------------
moteAlarm.initAlarm();
// ========================================================================

// ========================================================================
// Initial set up for communication
// ------------------------------------------------------------------------
moteAlarm.initBroadcastCom();
moteAlarm.setPortNumber(hostPortNumber);
moteAlarm.setLocation(location);
moteAlarm.setWriteDataByte(dataIdentifier);
// ========================================================================

// ========================================================================
// get and push IEEE Address to terminal
// ------------------------------------------------------------------------
moteAlarm.getPushAddress();
// ========================================================================

// ========================================================================
// Open up a broadcast connection
// ------------------------------------------------------------------------
moteAlarm.tryToOpenBroadcastConnection();
// ========================================================================

while (true) {

    // ====================================================================
    // Check if input is low. Low means no alarm triggered
    // --------------------------------------------------------------------
    while (moteAlarm.pinStatus()) {
        // ================================================================
        // if alarm is not triggerd go to sleep for specified time
        // ----------------------------------------------------------------
        moteAlarm.sleepForSomeTime(sampleTime,timeToBeSent);
        // ================================================================

        // ================================================================
        // Get sample time
        // ----------------------------------------------------------------
        timeToBeSent = moteAlarm.getCurrentTime();
        // ================================================================

        System.out.println("timeToBeSent: " + timeToBeSent);
        System.out.println("sampleTime   : " + sampleTime);

    } // end of while (pin.isLow()) loop
    // ====================================================================

    // ====================================================================
    // The application only gets to here because pin is no longer...
    // ... low. Therefore, send message to notify that an alarm ...
    // ... has been triggered.
```

```
//  ======================================================================

//  ======================================================================
//  For trouble shooting only
//  ----------------------------------------------------------------------
System.out.println("Send data");
//  ======================================================================

//  ======================================================================
//  Update alarm values to be sent
//  ----------------------------------------------------------------------
moteAlarm.setWriteDataLong(timeToBeSent);
moteAlarm.setWriteDataInt(1);                  // 1 = alarm triggered
//  ======================================================================

//  ======================================================================
//  Package time & alarm trigger into a radio datagram & send
//  ----------------------------------------------------------------------
moteAlarm.packageAndSendRadiogram();
//  ======================================================================

//  ======================================================================
//  For trouble shooting only
//  ----------------------------------------------------------------------
System.out.println("Data sent");
//  ======================================================================

//  ======================================================================
//  Stop the thread until the input has been set to low. Only ...
//  send "alarm triggered" once. Wait for pin D2 to change ...
//  state. Once the pin has changed renable pin change ...
//  interrupt (listen for new alarm)
//  ----------------------------------------------------------------------
moteAlarm.getPinStatus().waitForChange();
moteAlarm.setEnablePinChangeInterruptsToTrue();
//  ======================================================================

//  ======================================================================
//  For trouble shooting only
//  ----------------------------------------------------------------------
System.out.println("After waitForChange() statement");
//  ======================================================================

//  ======================================================================
//  The input has changed back to normal. Therefore send info ...
//  to notify of return to "No alarm". First verify that the ...
//  the input is back to normal postion, then send datagram.
//  ======================================================================
if (moteAlarm.pinStatus()) {
    try {
        //  ==================================================================
        //  For trouble shooting only
        //  ------------------------------------------------------------------
        System.out.println("Send data");
        //  ==================================================================

        //  ==================================================================
        //  Get the current time
        //  ------------------------------------------------------------------
        timeToBeSent = moteAlarm.getCurrentTime();
```

```
            // ==================================================================

            // ==================================================================
            // Update alarm values to be sent
            // ------------------------------------------------------------------
            moteAlarm.setWriteDataLong(timeToBeSent);
            moteAlarm.setWriteDataInt(2);    // 2 = alarm not triggered
            // ==================================================================

            // ==================================================================
            // Package time & alarm trigger into radio datagram & send
            // ------------------------------------------------------------------
            moteAlarm.packageAndSendRadiogram();
            // ==================================================================

            // ==================================================================
            // For trouble shooting only
            // ------------------------------------------------------------------
            System.out.println("Data sent");
            // ==================================================================

         } catch (Exception ex) {
            System.out.println("Problem sending datagram" + ex);
         }
      } // end of if(pin.isLow())
    } // end of loop always

  } // end of run()
} // end of class
```

Listing C.19: Alarm Trigger Thread

C.3.12 CarMonThread.java

```
/* ******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ******************************************************************
 */

/* ******************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has carbon ...
 * Purpose      :  mono measurement set to TRUE.
 * Inputs       :  Location of mote,
 *                 port used by host,
 *                 data type,
 *                 sample time
 * Outputs      :  Enviromental data collected
 * ******************************************************************
 */
package org.sunspotworld;

class CarMonThread implements Runnable {
```

```
// ============================================================
// Instance variables
// ------------------------------------------------------------
private String location;
private Thread t;
private int hostPortNumber;
private byte dataIdentifier;
private long sampleTime;
private long timeToBeSent;
private double carbonMonoToBeSent;
private int currentCarbonMonoSample;
// ============================================================

CarMonThread(String threadname, int portNo, byte dataType,
        long timeBetweenSamples) {
    location = threadname;
    t = new Thread(this, location);
    hostPortNumber = portNo;
    dataIdentifier = dataType;
    sampleTime = timeBetweenSamples;
    System.out.println("New thread: " + t);
    t.start();
}

// ============================================================
// methods to access instance variables, setter methods
// ============================================================
void setLocThread(String setLoc) {
    location = setLoc;
}

void setThread(Thread setThread) {
    t = setThread;
}

void setPortThread(int setPort) {
    hostPortNumber = setPort;
}

void setDataIdType(byte setDataType) {
    dataIdentifier = setDataType;
}

void setTimeBetweenSamples(long setSampleInterval) {
    sampleTime = setSampleInterval;
}

void setTimeForSending(long setSendTime) {
    timeToBeSent = setSendTime;
}

void setTempForSending(double setSendTemp) {
    carbonMonoToBeSent = setSendTemp;
}
// ============================================================


// ============================================================
// methods to access instance variables, getter methods
```

```
// ===========================================================
String getLocThread() {
   return location;
}

Thread getThread() {
   return t;
}

int getPortThread() {
   return hostPortNumber;
}

byte getDataIdType() {
   return dataIdentifier;
}

long getTimeBetweenSamples() {
   return sampleTime;
}

long getTimeForSending() {
   return timeToBeSent;
}

double getTempForSending() {
   return carbonMonoToBeSent;
}
// ===========================================================


// +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
// entry point for carbon mono thread
// +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
public void run() {

   // ========================================================
   // For trouble shooting only
   // --------------------------------------------------------
   System.out.println("Start carbon mono thread: " + location);
   // ========================================================

   // ========================================================
   // start a new carbon monoxide collector mote
   // --------------------------------------------------------
   CollectorCarbonMonoMote moteCarMon = new CollectorCarbonMonoMote();
   // ========================================================

   // ========================================================
   // Intial set up for measurement of carbon monoxide
   // --------------------------------------------------------
   moteCarMon.initCarbonMonoMeasurement();
   // ========================================================

   // ========================================================
   // Intial set up for communication
   // --------------------------------------------------------
   moteCarMon.initBroadcastCom();
   moteCarMon.setPortNumber(hostPortNumber);
   moteCarMon.setLocation(location);
```

```
moteCarMon.setWriteDataByte(dataIdentifier);
// ==========================================================

// ==========================================================
// get and push IEEE Address to terminal
// ----------------------------------------------------------
moteCarMon.getPushAddress();
// ==========================================================

// ==========================================================
// Open up a broadcast connection
// ----------------------------------------------------------
moteCarMon.tryToOpenBroadcastConnection();
// ==========================================================

// ==========================================================
// read the current value on the A0 input
// ----------------------------------------------------------
while (true) {
    // ======================================================
    // Get the current time. I.e. time when sample is taken
    // ------------------------------------------------------
    timeToBeSent = moteCarMon.getCurrentTime();
    // ======================================================

    // ======================================================
    // Indicate sample event (start, i.e LED on)
    // ------------------------------------------------------
    moteCarMon.sampleEventIndication(true, 5);
    // ======================================================

    // ======================================================
    // Get the current carbon mono reading to send in datagram
    // ------------------------------------------------------
    currentCarbonMonoSample = moteCarMon.takeCarbonMonoSample();
    // ======================================================

    // ======================================================
    // Indicate sample event (end, i.e LED off)
    // ------------------------------------------------------
    moteCarMon.sampleEventIndication(false, 5);
    // ======================================================

    // ======================================================
    // Convert Sample to volt
    // ------------------------------------------------------
    carbonMonoToBeSent = moteCarMon.
            convertCarbonMonoSampleToVolt(currentCarbonMonoSample);
    // ======================================================

    // ======================================================
    // Reformat sample to be sent to ****.** format
    // ------------------------------------------------------
    carbonMonoToBeSent = moteCarMon.reformatDataToBeSent(
            carbonMonoToBeSent);
    // ======================================================

    // ======================================================
    // For trouble shooting only
    // ------------------------------------------------------
```

```
        System.out.println("Has carbon mono level changed? " +
                moteCarMon.hasCarbonMonoLevelChanged());
        // ======================================================

        if (moteCarMon.hasCarbonMonoLevelChanged()) {
            // ==================================================
            // For trouble shooting only
            // --------------------------------------------------
            System.out.println("Try to send sample.");
            // ==================================================

            // ==================================================
            // Update time and carbon mono value to be sent
            // --------------------------------------------------
            moteCarMon.setWriteDataLong(timeToBeSent);
            moteCarMon.setWriteDataDouble(carbonMonoToBeSent);
            // ==================================================

            // ==================================================
            // Send current sample
            // --------------------------------------------------
            moteCarMon.packageAndSendRadiogram();
            // ==================================================

        } // end if block

        // ======================================================
        // move current carbon level to previous carbon level variable
        // ------------------------------------------------------
        moteCarMon.moveCurrentCarbonMonoToPreviousCarbonMono();
        // ======================================================

        // ======================================================
        // Go to sleep to conserve battery
        // ------------------------------------------------------
        moteCarMon.sleepForSomeTime(sampleTime, timeToBeSent);
        // ======================================================

      } //end of while loop
   } // end of run()
} // end of class
```

Listing C.20: Carbon Monoxide Collector Thread

C.4 Pseudo Code for Interface Mote

C.4.1 Pseudo Code for Climate Interface Thread

```
Pseudo Code for Temperature Interface
  ClimateInterfaceThread implements Runnable
  Instance variables
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private byte interfaceIdAsByte;
    private byte dataIdAsByte = 1;               // identifies temp data
    private boolean listenForNewDatagram = true;

  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run() {
    Start a new climate interface mote
      call new ClimateInterfaceMote();

    Get and push IEEE address
      call getPushAddress();

    Initial set up for communication
      call initInterfaceMoteCommunication();
      call setPortNumber(hostPortNumber);

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    Initial set up to communicate with external system
      call initExternalCommunication();

    WHILE (listenForNewDatagram)
      Listen for new data packet
        call listenFor()

      IF (is data for Climate Interface)
        Prepare data to send to external system via serial comm.
          call packageTempDataToSendToClimateControl(
                   getReadDataUTF(),
                   getReadDataDouble());

        Push new data to external system
          call sendDataToExternalSystem();
      ELSE
        call sendExternalSystemStatus();

      END IF (is data for Climate Interface)

    END of WHILE
  END of run()
END of class
```

Listing C.21: Pseudo Code Climate Interface Thread

C.4.2 Pseudo Code for Light Interface Thread

```
Pseudo Code for Light Interface Thread
LightingInterfaceThread implements Runnable

  Instance variables
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private byte interfaceIdAsByte;
    private byte dataIdAsByte = 2;                // identifies light data
    private boolean listenForNewDatagram = true;

  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run()
    Start a new climate interface mote
      new LightInterfaceMote();

    Get and push IEEE address
      call getPushAddress();

    Initial set up for communication
      call initInterfaceMoteCommunication();
      call setPortNumber(hostPortNumber);

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    Initial set up to communicate with external system
      call initExternalCommunication();

    WHILE (listenForNewDatagram)
      Listen for new data packet
        call listenFor();

      IF (data is for Light Interface)
        Prepare data to send to external system via serial comm.
          call packageLightDataToSendToLightControl(getReadDataUTF(),
                    getReadDataInt());
        Push new data to external system
          call sendDataToExternalSystem();
      END of IF (data is for Light Interface)

      END of WHILE
  END of run()
END of class
```

Listing C.22: Pseudo Code Light Interface Thread

C.4.3 Pseudo Code for Alarm Interface Thread

```
Pseudo code for Alarm Interface Thread
AlarmInterfaceThread implements Runnable
```

```
  Instance variables
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private byte interfaceIdAsByte;
    private byte dataIdAsByte = 4;               // identifies temp data
    private boolean listenForNewDatagram = true;

  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run() {
    Start a new alarm interface mote
      new AlarmInterfaceMote();

    Get and push IEEE address
      call getPushAddress();

    Initial set up for communication
      call initInterfaceMoteCommunication();
      call setPortNumber(hostPortNumber);

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    Initial set up to interface with external system
      call initExternalCommunication();

    WHILE (listenForNewDatagram) {
      Listen for new data packet
        call listenFor();

      IF(data is for Alarm Interface)
        Prepare data to send to external system via serial comm.
          call packageAlarmDataToSendToAlarmSystem(getReadDataUTF(),
                   getReadDataInt());
        Push new data to external system
          call sendDataToExternalSystem();
      END of IF(data is for Alarm Interface)

    END of WHILE
  END of run()
END of class
```

Listing C.23: Pseudo Code Alarm Interface Thread

C.4.4 Pseudo Code for Carbon Monoxide Interface Thread

```
Pseudo code for Carbon monoxide Interface
CarbMonInterfaceThread implements Runnable

  Instance variables
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private byte interfaceIdAsByte;
```

```
    private byte dataIdAsByte = 5;                // identifies CarMon data
    private boolean listenForNewDatagram = true;

  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run() {
    Start a new carbon monoxide interface mote
      new CarbMonInterfaceMote();

    Get and push IEEE address
      call getPushAddress();

    Initial set up for communication
      call initInterfaceMoteCommunication();
      call setPortNumber(hostPortNumber);

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    Initial set up to interface with external system
      call initExternalCommunication();

    WHILE (listenForNewDatagram)
      Listen for new data packet
        call listenFor();

      IF (data is for Carbon Mono Interface)
        Prepare data to send to external system via serial comm.
          call packageCarbonMonoDataToSendToCarbMonSystem(
                   getReadDataUTF(),
                   getReadDataDouble());

        Push new data to external system
          call sendDataToExternalSystem();
      END of IF (data is for Carbon Mono Interface)
    END of WHILE
  END of run()
END of class
```

Listing C.24: Pseudo Code Carbon Monoxide Interface Thread

C.4.5 Pseudo Code for Door Interface Thread

```
Pseudo Code for Door Interface
DoorInterfaceThread implements Runnable

  Instance variables
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private long unlockTime;
    private byte interfaceIdAsByte;
    private byte dataIdAsByte = 16;               // identifies unlock door
    private boolean listenForNewDatagram = true;
```

```
  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run() {
    Start a new climate interface mote
      new DoorInterfaceMote();

    Get and push IEEE address
      call getPushAddress();

    Intial set up for communication
      call initInterfaceMoteCommunication();
      call setPortNumber(hostPortNumber);

    Open up a broadcast connection
      call tryToOpenBroadcastConnection();

    Intial set up to interface with external system
      call initDoorInterface();

    WHILE (listenForNewDatagram)
      Listen for new data packet
        call listenFor();

      IF (data is for door interface)
        Push new data to external system
          call unlockTheDoor(unlockTime);
      END of IF (data is for door interface)

    END of WHILE
  END of run()
END of class
```

Listing C.25: Pseudo Code Door Interface Thread

C.4.6 Pseudo Code to Send External System Status Thread

```
Pseudo Code to send external system status
sendStatus implements Runnable

  Instance variables
    private String systemInterface;
    private Thread t;
    private int portNumberSend;
    private int portNumberListen;
    private byte statusIdentification;
    private String hostAddress;

    private boolean extSystemOK = false;
    private boolean hostAddressNotKnown = true;

  Methods to access instance variables, setter methods
  Methods to access instance variables, getter methods

  public void run()
      Create object to send status to host
```

```
        new InterfaceMote();

       Initial setup for communication (listening)
         call initInterfaceMoteCommunication();
         call setPortNumber(portNumberListen);

       Open up a broadcast connection to listen for host
         call tryToOpenBroadcastConnection();

       WHILE (hostAddressNotKnown){
         Listen for host broad cast
           call listenFor();

         IF (broadcast is from host)
           Get host address
             call getReadDataLong();

           Set flag to false (i.e. address is now known)
           Sleep for some time
         END of IF (broadcast is from host)
       END of WHILE

       Create object to send status to host
         new RadiogramCommClass();

       Initial setup for communication (sending)
         call initRadiogramCom();
         call setPortNumber(portNumberSend);
         call setLocation(systemInterface);
         call setHostAddress(hostAddress);
         call setWriteDataByte(statusIdentification);

       Open up a radiogram connection to host
         call tryToOpenRadiogramConnection();

       Intial set up to verify status of external system
         call initExternalSystemStatus();

         WHILE (true){
           Check status of external system
             call errorExternalSystem();
             call setWriteBoolean(extSystemOK);

           Send status to host
             call packageAndSendRadiogram();

           Sleep
         END of WHILE

END of sendStatus

END of class
```

Listing C.26: Pseudo Code Send External System Status Thread

C.4.7 Pseudo Code for Interface Mote Main Thread

```
Pseudo Code for Main Class of Interface Mote
InterfaceMainSPOT extends MIDlet

  Instance variables
    private static final int HOST_PORT = 67;     // Broadcast port
    private String MANI_INTERFACE = null;
    private String MANI_DOOR_OPEN_TIME = null;
    private byte interfaceByteId = 0;
    private long doorOpenTime = 0;
    private String interfaceStringId = null;

  protected void startApp()
    Monitor the USB (if connected) and recognize commands from host
      new BootloaderListener().start();

    Get configuration data from Manifest file

    Convert Strings to appropriate data type

    Find external system status id based on MANIFEST.MF file
      add 100 to interfaceByteId

    Start new thread depending on MANIFEST.MF file
      SWITCH (Identification of interface)
        CASE 11:
          new ClimateInterfaceThread
          new sendStatus
          Wait for thread to finish
          BREAK;

        CASE 12:
          new LightingInterfaceThread
          new sendStatus
          Wait for thread to finish
          BREAK;

        CASE 14:
          new AlarmInterfaceThread
          new sendStatus
          Wait for thread to finish
          BREAK;

        CASE 15:
          new CarbMonInterfaceThread
          new sendStatus
          Wait for thread to finish
          BREAK;

        CASE 16:
          new DoorInterfaceThread
          new sendStatus
          Wait for thread to finish
          BREAK;
      END of SWITCH (Identification of interface)
  END of startApp()
END of class
```

Listing C.27: Pseudo Code Interface Main Thread

C.5 Code Listings for Interface Mote

C.5.1 InterfaceMote.java

```
/* ****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ****************************************************************
 */

/* ****************************************************************
 * Purpose      :  This class includes all the common functions of a ...
 * Purpose      :  interface mote. Usually this class will be extended ...
 * Purpose      :  to add the specific capability for the interface ...
 * Purpose      :  to external systems.
 * ****************************************************************
 */

package org.sunspotworld;

import com.sun.spot.io.j2me.radiogram.RadiogramConnection;
import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ITriColorLED;
import java.io.IOException;
import javax.microedition.io.Connector;
import javax.microedition.io.Datagram;
import com.sun.spot.util.Utils;

class InterfaceMote {

   // ==================================================================
   // Instance variables
   // ------------------------------------------------------------------
   private String systemInterface;
   private int portNumber;
   private String ourAddress;
   private RadiogramConnection rCon;
   private Datagram dg;

   private long readDataLong = 0;
   private byte readDataByte = 0;
   private String readDataUTF = null;
   private int readDataInt = 0;
   private double readDataDouble = 0;
   private boolean readDataBool = false;

   EDemoBoard serialComm = EDemoBoard.getInstance();
   private int baud = 19200;
   private int databits = 8;
   private int parity = 1;            // 0 = none, 1 = odd, 2 = even
   private int stopbits = 1;
   private String externalDataString = null;

   private ITriColorLED[] sendCommIndication = EDemoBoard.
          getInstance().getLEDs();
```

```
// ===========================================================================

// ===========================================================================
// methods to access instance variables, setter methods
// ===========================================================================
void setSystemInterface(String setLoc){
   systemInterface = setLoc;
}

void setPortNumber(int setPort){
   portNumber = setPort;
}

void setBaud (int baudValue){
   baud = baudValue;
}

void setDatabits(int databitsValue){
   databits = databitsValue;
}

void setParity (int parityValue) {
   parity = parityValue;
}

void setStopbits (int stopbitsValue) {
   stopbits = stopbitsValue;
}

void setExternalDataString (String dataOut) {
   externalDataString = dataOut;
}

// ===========================================================================

// ===========================================================================
// methods to access instance variables, getter methods
// ===========================================================================
String getSystemInterface(){
   return systemInterface;
}

String getOurAddress(){
   return ourAddress;
}

int getPortNumber(){
   return portNumber;
}

long getReadDataLong(){
   return readDataLong;
}

byte getReadDataByte(){
   return readDataByte;
}

String getReadDataUTF(){
```

```
        return readDataUTF;
    }

    int getReadDataInt(){
        return readDataInt;
    }

    double getReadDataDouble(){
        return readDataDouble;
    }

    boolean getReadDataBoolean(){
        return readDataBool;
    }

    int getBaud (){
        return baud;
    }

    int getDatabits(){
        return databits;
    }

    int getParity () {
        return parity;
    }

    int getStopbits () {
        return stopbits;
    }

    String getExternalDataString () {
        return externalDataString;
    }

    // ==========================================================


    // ==========================================================
    // All other methods
    // ==========================================================
    void initInterfaceMoteCommunication (){
        // =======================================================
        // Intial set up for communication
        // -------------------------------------------------------
        rCon = null;
        dg = null;
        // =======================================================

    } // end initBroadcastCom

    void getPushAddress() {
        // =======================================================
        // get and push IEEE Address to terminal. Troubleshoot only
        // -------------------------------------------------------
        ourAddress = System.getProperty("IEEE_ADDRESS");
        System.out.println("Starting app. on " + ourAddress + " ...");
        // =======================================================

    } // end getPushAddress()
```

```
void tryToOpenBroadcastConnection(){
   try {
      // ==============================================================
      // Open up a radiogram connection to listen for data from ...
      // collector motes.
      // --------------------------------------------------------------
      rCon = (RadiogramConnection) Connector.open(
           "radiogram://:" + portNumber);
      dg = rCon.newDatagram(rCon.getMaximumLength());
      // ==============================================================

      // ==============================================================
      // For trouble shooting only
      // --------------------------------------------------------------
      System.out.println("Radiogramm connection is open.");
      // ==============================================================

   } catch (IOException ex) {
      ex.printStackTrace();
   } // end try / catch

} // end tryToOpenBroadcastConnection()

void listenFor(){

   // =================================================================
   // listen for new datagram data
   // -----------------------------------------------------------------
   try {
      rCon.receive(dg);
      readDataLong = dg.readLong();
      readDataByte = dg.readByte();
      readDataUTF = dg.readUTF();
      readDataInt = dg.readInt();
      readDataDouble = dg.readDouble();
      readDataBool = dg.readBoolean();
      // ==============================================================

      // ==============================================================
      // For trouble shooting only
      // --------------------------------------------------------------
      System.out.println("Data packet received. " + readDataByte);
      // ==============================================================


   } catch (IOException ex) {
      ex.printStackTrace();
   } // end try / catch
} // end listenFor()

void sleepForSomeTime(long samplePeriod, long lastTimeToBeSent) {
   // =================================================================
   // let the mote rest to conserve battery, probably never called ...
   // in interface mote.
   // -----------------------------------------------------------------
   Utils.sleep(samplePeriod - (System.currentTimeMillis() -
              lastTimeToBeSent));
   // =================================================================
```

```
    } // end of sleepForSomeTime()

    long getCurrentTime(){
       // ==========================================================
       // take time of sample
       // ----------------------------------------------------------
       return System.currentTimeMillis();
       // ==========================================================

    } // end getCurrentTime()

    void initExternalCommunication(){
       // ==========================================================
       // For troubleshooting only
       // ----------------------------------------------------------
       System.out.println("Baud\t: " + baud);
       System.out.println("Databits\t: " + databits);
       System.out.println("Parity\t: " + parity);
       System.out.println("Stop bits\t: " + stopbits);

       // ==========================================================
       // Init serial communication to external system
       // ----------------------------------------------------------
       serialComm.initUART(baud, databits, parity, stopbits);
       // ==========================================================

    } // end of initExternalCommunication()

   void sendDataToExternalSystem(){
       // ==========================================================
       // Send data via serial communication to external system
       // ----------------------------------------------------------
       for (int i = 0; i<8; i++){
          sendCommIndication[i].setRGB(0, 0, 255);
          sendCommIndication[i].setOn();
       } // set each LED to blue and turn on

       serialComm.writeUART(externalDataString);

       for (int i = 7; i >= 0; i--){
          sendCommIndication[i].setOff();
       } // turn LEDs off


       System.out.println("Data sent via serial comm to external system");
       // ==========================================================
    } // end of sendDataToExternalSystem()

} // end CollectorMote class
```

Listing C.28: Generic Functions of an Interface Mote

C.5.2 ClimateInterfaceMote.java

```
/* ****************************************************************
 * Author      :  Severin Willisch
```

```
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *********************************************************************
 */

/* *********************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
 * Purpose      :  climate interface mote.
 * *********************************************************************
 */

package org.sunspotworld;


class ClimateInterfaceMote extends InterfaceMote{

   void packageTempDataToSendToClimateControl(String location,
            double value){
      // =================================================================
      // Prepare data to send via serial communication
      // Required data: >> location --> String
      //                >> value    --> double
      // -----------------------------------------------------------------
      StringBuffer prepareOutputString = new StringBuffer(location);

      prepareOutputString.append(",");
      prepareOutputString.append(value);

      setExternalDataString(prepareOutputString.toString());
      // =================================================================
      // For trouble shooting only
      // -----------------------------------------------------------------
      System.out.println(getExternalDataString());
      // =================================================================

   }  // end of packageDataToSendToExternalSystem()

} // end of class
```

Listing C.29: Special Functions of Climate Interface Mote

C.5.3 LightInterfaceMote.java

```
/* *********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *********************************************************************
 */

/* *********************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
```

```
 * Purpose      :  light control interface mote.
 * ****************************************************************
 */
package org.sunspotworld;

class LightInterfaceMote extends InterfaceMote {
   void packageLightDataToSendToLightControl(String location,
            int value){
      // ===========================================================
      // Prepare data to send via serial communication
      // Required data: >> location --> String
      //                >> value    --> int
      // -----------------------------------------------------------
      StringBuffer prepareOutputString = new StringBuffer(location);

      prepareOutputString.append(",");
      prepareOutputString.append(value);

      setExternalDataString(prepareOutputString.toString());
      // ===========================================================
      // For trouble shooting only
      // -----------------------------------------------------------
      System.out.println(getExternalDataString());
      // ===========================================================

   }  // end of packageDataToSendToExternalSystem()
} // end of class
```

Listing C.30: Special Functions of Light Interface Mote

C.5.4 AlarmInterfaceMote.java

```
/* ****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ****************************************************************
 */

/* ****************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
 * Purpose      :  alarm interface mote.
 * ****************************************************************
 */

package org.sunspotworld;

class AlarmInterfaceMote extends InterfaceMote{

  void packageAlarmDataToSendToAlarmSystem(String location,
            int value) {
      // ===========================================================
      // Prepare data to send via serial communication
      // Required data: >> location --> String
```

```
        //                  >> value     --> int
        // -----------------------------------------------------------------
        StringBuffer prepareOutputString = new StringBuffer(location);

        prepareOutputString.append(",");
        prepareOutputString.append(value);

        setExternalDataString(prepareOutputString.toString());
        // =================================================================
        // For trouble shooting only
        // -----------------------------------------------------------------
        System.out.println(getExternalDataString());
        // =================================================================


    } // end of packageAlarmDataToSendToClimateControl()

} // end of class
```

Listing C.31: Special Functions of Alarm Interface Mote

C.5.5 CarbMonInterfaceMote.java

```
/* *****************************************************************
 * Author      :  Severin Willisch
 * email       :  d9840087@mail.connect.usq.edu.au
 * Student No. :  0039840087
 * Purpose     :  Project for Semester 1 & 2, 2009
 * Purpose     :  09-036 Programming Sun SPOTs in JAVA
 * *****************************************************************
 */

/* *****************************************************************
 * Purpose     :  This class includes all the specific functions of a ...
 * Purpose     :  carbon mono interface mote.
 * *****************************************************************
 */

package org.sunspotworld;

class CarbMonInterfaceMote extends InterfaceMote{
    void packageCarbonMonoDataToSendToCarbMonSystem(String location,
            double value) {
        // =================================================================
        // Prepare data to send via serial communication
        // Required data: >> location --> String
        //                >> value     --> double
        // -----------------------------------------------------------------
        StringBuffer prepareOutputString = new StringBuffer(location);

        prepareOutputString.append(",");
        prepareOutputString.append(value);

        setExternalDataString(prepareOutputString.toString());
        // =================================================================
        // For trouble shooting only
```

```
        // ------------------------------------------------------------------------
        System.out.println(getExternalDataString());
        // ========================================================================

    }   // end of packageCarbonMonoDataToSendToClimateControl()

} // end of class
```

Listing C.32: Special Functions of Carbon Monoxide Interface Mote

C.5.6 DoorInterfaceMote.java

```
/* ***********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ***********************************************************************
 */

/* ***********************************************************************
 * Purpose      :  This class includes all the specific functions of a ...
 * Purpose      :  door interface mote. A digital output will be used ...
 * Purpose      :  to forward the command to unlock the door.
 * ***********************************************************************
 */

package org.sunspotworld;

import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.EDemoController;
import com.sun.spot.sensorboard.io.InputPin;
import com.sun.spot.sensorboard.io.PinDescriptor;
import com.sun.spot.sensorboard.peripheral.ITriColorLED;
import com.sun.spot.util.Utils;

class DoorInterfaceMote extends InterfaceMote{
    // ===========================================================================
    // Instance variables
    // ---------------------------------------------------------------------------
    private PinDescriptor unlockDoorOutput;
    private EDemoBoard doorCommand;
    private EDemoController doorCommandController;
    private InputPin pin;

    private ITriColorLED[] indicateDoorUnlocked = EDemoBoard.
            getInstance().getLEDs();
    // ===========================================================================

    // ===========================================================================
    // methods to access instance variables, setter methods
    // ===========================================================================
    void setPinStatus(InputPin setPin){
        pin = setPin;
    }
```

```
// ==========================================================================

// ==========================================================================
// methods to access instance variables, getter methods
// ==========================================================================
InputPin getPinStatus(){
   return pin;
}
// ==========================================================================

// ==========================================================================
// All other methods
// ==========================================================================
void initDoorInterface() {
   // ======================================================================
   // initialise door unlocking function of mote
   // ----------------------------------------------------------------------
   unlockDoorOutput = EDemoController.D2;
   doorCommand = EDemoBoard.getInstance();
   doorCommandController = doorCommand.getEDemoController();
   pin = new InputPin(unlockDoorOutput, doorCommandController);
   doorCommandController.setPinDirection(unlockDoorOutput, true);
   // ======================================================================

} // end initLightMeasurement()

void unlockTheDoor(long unlockDoorTime) {

   // ======================================================================
   // Activate one LED to show that door is unlocked
   // ----------------------------------------------------------------------
   indicateDoorUnlocked[1].setRGB(0, 0, 255);
   indicateDoorUnlocked[1].setOn();
   // ======================================================================

   // ======================================================================
   // Set pin to unlock(true)
   // ----------------------------------------------------------------------
   doorCommandController.setPinValue(unlockDoorOutput, true);
   // ======================================================================

   // ======================================================================
   // For trouble shooting only
   // ----------------------------------------------------------------------
   System.out.println("Door unlocked");
   // ======================================================================

   Utils.sleep(unlockDoorTime);     // door unlocked while mote sleeps

   // ======================================================================
   // Set pin to lock(false)
   // ----------------------------------------------------------------------
   doorCommandController.setPinValue(unlockDoorOutput, false);
   // ======================================================================

   // ======================================================================
   // Deactivate LED to show that door is locked
   // ----------------------------------------------------------------------
   indicateDoorUnlocked[1].setRGB(0, 0, 255);
   indicateDoorUnlocked[1].setOff();
```

```
        // ==========================================================

        // ==========================================================
        // For trouble shooting only
        // ----------------------------------------------------------
        System.out.println("Door locked");
        // ==========================================================

    } // end of pushDataToExternalSystem()
} // end of class
```

Listing C.33: Special Functions of Door Interface Mote

C.5.7 RadiogramCommClass.java

```
/* ******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ******************************************************************
 */

/* ******************************************************************
 * Purpose      :  This class includes all the special functionalities ...
 * Purpose      :  to send the status of an external system to the host.
 * ******************************************************************
 */
package org.sunspotworld;

import com.sun.spot.io.j2me.radiogram.RadiogramConnection;
import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.EDemoController;
import com.sun.spot.sensorboard.io.InputPin;
import com.sun.spot.sensorboard.io.PinDescriptor;
import java.io.IOException;
import javax.microedition.io.Connector;
import javax.microedition.io.Datagram;

class RadiogramCommClass {
    // ==============================================================
    // Instance variables
    // --------------------------------------------------------------
    private RadiogramConnection rCon;
    private Datagram dg;

    private PinDescriptor statusExternalSystem;
    private EDemoBoard status;
    private EDemoController statusController;
    private InputPin pin;

    private boolean extSysStatus = false;
    private String location;
    private String hostAddress;
    private int portNumber;
```

```
private long writeDataLong = 0;
private byte writeDataByte = 0;
private int writeDataInt = 0;
private double writeDataDouble = 0;
private boolean writeDataBool = false;
// ==================================================================

// ==================================================================
// methods to access instance variables, setter methods
// ==================================================================
InputPin getPinStatus() {
   return pin;
}

void setLocation(String setLoc) {
   location = setLoc;
}

void setPortNumber(int setPort) {
   portNumber = setPort;
}

void setHostAddress(String hostAddr) {
   hostAddress = hostAddr;
}

void setWriteDataLong(long setDataLong) {
   writeDataLong = setDataLong;
}

void setWriteDataByte(byte setDataByte) {
   writeDataByte = setDataByte;
}

void setWriteDataInt(int setDataInt) {
   writeDataInt = setDataInt;
}

void setWriteDataDouble(double setDataDouble) {
   writeDataDouble = setDataDouble;
}

void setWriteBoolean(boolean setDataBoolean) {
   writeDataBool = setDataBoolean;
}
// ==================================================================

// ==================================================================
// methods to access instance variables, getter methods
// ==================================================================
String getLocation() {
   return location;
}

int getPortNumber() {
   return portNumber;
}

String getHostAddress() {
```

```
        return hostAddress;
    }

    long getWriteDataLong() {
        return writeDataLong;
    }

    byte getWriteDataByte() {
        return writeDataByte;
    }

    int getWriteDataInt() {
        return writeDataInt;
    }

    double getWriteDataDouble() {
        return writeDataDouble;
    }

    boolean getWriteDataBoolean() {
        return writeDataBool;
    }

    // ==================================================================

    // ==================================================================
    // All other methods
    // ==================================================================
    void initRadiogramCom() {
        // ==============================================================
        // Intial set up for communication
        // --------------------------------------------------------------
        rCon = null;
        dg = null;
        // ==============================================================

    } // end initRadiogramCom()

    void tryToOpenRadiogramConnection() {
        try {
            // ==========================================================
            // Open up a radiogram connection to the host
            // ----------------------------------------------------------
            rCon = (RadiogramConnection) Connector.open(
                    "radiogram://" + hostAddress + ":" + portNumber);
            ((RadiogramConnection) rCon).setMaxBroadcastHops(4);
            dg = rCon.newDatagram(rCon.getMaximumLength());
            // ==========================================================

            // ==========================================================
            // For trouble shooting only
            // ----------------------------------------------------------
            System.out.println("Broadcast is open.");
            // ==========================================================

        } catch (IOException ex) {
            ex.printStackTrace();
        } // end try / catch
    } // end tryToOpenaRadiogramConnection()
```

```
void initExternalSystemStatus() {
    statusExternalSystem = EDemoController.D2;
    status = EDemoBoard.getInstance();
    statusController = status.getEDemoController();
    pin = new InputPin(statusExternalSystem, statusController);
    statusController.setPinDirection(statusExternalSystem, false);
    statusController.enablePinChangeInterrupts(pin);

    // ============================================================
    // For trouble shooting only
    // ------------------------------------------------------------
    System.out.println("External system status initialised.");
    // ============================================================

} // end of initExternalSystemStatus()

boolean errorExternalSystem() {
    // ============================================================
    // Check if input is low on D2. Low = external System OK
    // ------------------------------------------------------------
    extSysStatus = pin.isLow();
    // ============================================================

    // ============================================================
    // For trouble shooting only
    // ------------------------------------------------------------
    System.out.println("External System Status: " + extSysStatus);
    // ============================================================

    return extSysStatus;
    // ============================================================

} // end of errorExternalSystem()

void packageAndSendRadiogram() {

    // ============================================================
    // package data into datagram and send
    // ------------------------------------------------------------
    dg.reset();
    try {
        dg.writeLong(writeDataLong);
        dg.writeByte(writeDataByte);
        dg.writeUTF(location);
        dg.writeInt(writeDataInt);
        dg.writeDouble(writeDataDouble);
        dg.writeBoolean(writeDataBool);
        rCon.send(dg);
        // ========================================================

        // ========================================================
        // For trouble shooting only
        // --------------------------------------------------------
        System.out.println("Data packet sent.");
        // ========================================================


    } catch (IOException ex) {
        ex.printStackTrace();
    } // end try / catch
```

```
    } // end packageAndSendRadiogram()
} // end of RadiogramCommClass()
```

Listing C.34: Radiogram Communication Class

C.5.8 InterfaceMainSPOT.java

```
/* ******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ******************************************************************
 */

/* ******************************************************************
 * Description  :  Main class for the interface SPOTs.
 * Inputs       :  MANIFEST.MF file properties
 * Outputs      :  None
 * Purpose      :  Reads properties from MANIFEST.MF file & configures ...
 * Purpose      :  collector SPOT based on the MANIFEST.MF file.
 * Purpose      :  After the appropriate functions (threads) have been ...
 * Purpose      :  started the class waits for all threads to finish.
 * Purpose      :  When all treads are finished, class finishes.
 * ******************************************************************
 */

package org.sunspotworld;


import com.sun.spot.util.*;
import javax.microedition.midlet.MIDlet;
import javax.microedition.midlet.MIDletStateChangeException;

public class InterfaceMainSPOT extends MIDlet {
    // ================================================================
    // Instance variables
    // ----------------------------------------------------------------
    private static final int PORT_LISTEN_HOST = 66;
    private static final int PORT_LISTEN_SPOT = 67;
    private static final int PORT_SEND_HOST = 68;

    private String MANI_INTERFACE = null;
    private String MANI_DOOR_OPEN_TIME = null;
    private byte interfaceByteId = 0;
    private byte expandByte = 100;
    private byte statusByteId = 0;
    private long doorOpenTime = 0;
    private String interfaceStringId = null;
    // ================================================================

    protected void startApp() throws MIDletStateChangeException {
        // ============================================================
        // monitor the USB (if connected) and recognize commands from host
        // ------------------------------------------------------------
```

```
new BootloaderListener().start();
// ========================================================================

// ========================================================================
// Get configuration data from Manifest file. After data has ...
// ... been read from manifest it will be used to configure the ...
// ... SPOT.
// ------------------------------------------------------------------------
try {
    MANI_INTERFACE = this.getAppProperty("Interface");
    MANI_DOOR_OPEN_TIME = this.getAppProperty("DoorOpenTime");

    // --------------------------------------------------------------------
    // For trouble shooting only
    // --------------------------------------------------------------------
    System.out.println("Configuration data OK");
    // --------------------------------------------------------------------

} catch (NullPointerException e) {
    System.out.println("Problem reading MANIFEST.MF " + e);
} // end try / catch
// ========================================================================

// ========================================================================
// convert Strings to appropriate data type
// ------------------------------------------------------------------------
try {
    interfaceByteId = Byte.parseByte(MANI_INTERFACE);
    doorOpenTime = Long.parseLong(MANI_DOOR_OPEN_TIME);
} catch (NumberFormatException numberFormatException) {
    System.out.println("Problem converting data: "
            + numberFormatException
    );
} // end try / catch
// ========================================================================

// ========================================================================
// Find external system status id based on MANIFEST.MF file
// ------------------------------------------------------------------------
statusByteId = (byte) (interfaceByteId + expandByte);
// ========================================================================

// ========================================================================
// start new thread on a SunSPOT depending on MANIFEST.MF file
// ------------------------------------------------------------------------
switch (interfaceByteId){
    case 11:
        interfaceStringId = "Climate Control";
        ClimateInterfaceThread climateInterMote =
                new ClimateInterfaceThread(
                interfaceStringId, PORT_LISTEN_SPOT,
                interfaceByteId);

        // ================================================================
        // Start thread to send status of external system to host
        // ----------------------------------------------------------------
        SendStatus tempSysStatus = new SendStatus("statusClimate",
                PORT_SEND_HOST, PORT_LISTEN_HOST, statusByteId);
        // ================================================================
```

```
        try {
            // ==================================================================
            // wait for thread to finish
            // ------------------------------------------------------------------
            climateInterMote.getThread().join();
            tempSysStatus.getThread().join();
            // ==================================================================
        } catch (InterruptedException ex) {
            ex.printStackTrace();
        } // end of try / catch

        break;

    case 12:
        interfaceStringId = "Lighting Control";
        LightingInterfaceThread lightingInterMote =
                new LightingInterfaceThread(
                interfaceStringId, PORT_LISTEN_SPOT,
                interfaceByteId);

        // ==================================================================
        // Start thread to send status of external system to host
        // ------------------------------------------------------------------
        SendStatus lightSysStatus = new SendStatus("statusLight",
                PORT_SEND_HOST, PORT_LISTEN_HOST, statusByteId);
        // ==================================================================

        try {
            // ==================================================================
            // wait for thread to finish
            // ------------------------------------------------------------------
            lightingInterMote.getThread().join();
            lightSysStatus.getThread().join();
            // ==================================================================
        } catch (InterruptedException ex) {
            ex.printStackTrace();
        } // end of try / catch

        break;

    case 14:
        interfaceStringId = "Alarm System";
        AlarmInterfaceThread alarmInterMote =
                new AlarmInterfaceThread(
                interfaceStringId, PORT_LISTEN_SPOT,
                interfaceByteId);

        // ==================================================================
        // Start thread to send status of external system to host
        // ------------------------------------------------------------------
        SendStatus alarmSysStatus = new SendStatus("statusAlarm",
                PORT_SEND_HOST, PORT_LISTEN_HOST, statusByteId);
        // ==================================================================

        try {
            // ==================================================================
            // wait for thread to finish
            // ------------------------------------------------------------------
            alarmInterMote.getThread().join();
            alarmSysStatus.getThread().join();
```

```
            // ==================================================
        } catch (InterruptedException ex) {
            ex.printStackTrace();
        } // end of try / catch

        break;

    case 15:
        interfaceStringId = "Carbon Mono System";
        CarbMonInterfaceThread ventInterMote =
                new CarbMonInterfaceThread(
                interfaceStringId, PORT_LISTEN_SPOT,
                interfaceByteId);

        // ====================================================
        // Start thread to send status of external system to host
        // ----------------------------------------------------
        SendStatus carbMonSysStatus = new SendStatus("statusCarbMon",
                PORT_SEND_HOST, PORT_LISTEN_HOST, statusByteId);
        // ====================================================

        try {
            // ==================================================
            // wait for thread to finish
            // --------------------------------------------------
            ventInterMote.getThread().join();
            carbMonSysStatus.getThread().join();
            // ==================================================
        } catch (InterruptedException ex) {
            ex.printStackTrace();
        } // end of try / catch

        break;

    case 16:
        interfaceStringId = "Door Interface";
        DoorInterfaceThread doorInterMote =
                new DoorInterfaceThread(
                interfaceStringId, PORT_LISTEN_SPOT, interfaceByteId,
                doorOpenTime);

        // ====================================================
        // Start thread to send status of external system to host
        // ----------------------------------------------------
        SendStatus doorSysStatus = new SendStatus("statusDoor",
                PORT_SEND_HOST, PORT_LISTEN_HOST, statusByteId);
        // ====================================================

        try {
            // ==================================================
            // wait for thread to finish
            // --------------------------------------------------
            doorInterMote.getThread().join();
            doorSysStatus.getThread().join();
            // ==================================================
        } catch (InterruptedException ex) {
            ex.printStackTrace();
        } // end of try / catch

        break;
```

```
      } // end of switch (interfaceByteId)
      // ================================================================

   } // end of startApp()

   protected void pauseApp() {
      // This is not currently called by the Squawk VM

   } // end of pauseApp()

  protected void destroyApp(boolean arg0) throws
          MIDletStateChangeException {

   } // end of destroyApp()
} // end of class
```

Listing C.35: Main Thread of Interface Mote

C.5.9 ClimateInterfaceThread.java

```
/* **********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * **********************************************************************
 */

/* **********************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has climate ...
 * Purpose      :  interface as a requirement.
 * Inputs       :  External System Type,
                   port used by host,
                   interface type as a byte
 * **********************************************************************
 */

package org.sunspotworld;

class ClimateInterfaceThread implements Runnable {

   // ====================================================================
   // Instance variables
   // --------------------------------------------------------------------
   private String systemInterface;
   private Thread t;
   private int hostPortNumber;
   private byte interfaceIdAsByte;
   private byte dataIdAsByte = 1;              // identifies temp data
   private boolean listenForNewDatagram = true;
   // ====================================================================

   ClimateInterfaceThread(String threadname, int portNo, byte moteType) {
      systemInterface = threadname;
```

```
        t = new Thread(this, systemInterface);
        hostPortNumber = portNo;
        interfaceIdAsByte = moteType;
        System.out.println("New thread: " + t);
        t.start();
    } // end constructor

    // ========================================================================
    // methods to access instance variables, setter methods
    // ========================================================================
    void setThread(Thread setThread) {
        t = setThread;
    }

    void setListenForNewDatagram(boolean lisForDgs) {
        listenForNewDatagram = lisForDgs;
    }
    // ========================================================================

    // ========================================================================
    // methods to access instance variables, getter methods
    // ========================================================================
    Thread getThread() {
        return t;
    }

    boolean getListenForNewDatagram() {
        return listenForNewDatagram;
    }
    // ========================================================================

    public void run() {
        // ====================================================================
        // For trouble shooting only
        // --------------------------------------------------------------------
        System.out.println("Start interface thread: " +
                systemInterface + " " + interfaceIdAsByte);
        // ====================================================================

        // ====================================================================
        // start a new climate interface mote
        // --------------------------------------------------------------------
        ClimateInterfaceMote moteClimate = new ClimateInterfaceMote();
        // ====================================================================

        // ====================================================================
        // get and push IEEE address
        // --------------------------------------------------------------------
        moteClimate.getPushAddress();
        // ====================================================================

        // ====================================================================
        // Intial set up for communication
        // --------------------------------------------------------------------
        moteClimate.initInterfaceMoteCommunication();
        moteClimate.setPortNumber(hostPortNumber);
        // ====================================================================

        // ====================================================================
        // Open up a broadcast connection
```

```
        // ------------------------------------------------------------------------
        moteClimate.tryToOpenBroadcastConnection();
        // ========================================================================

        // ========================================================================
        // Intial set up to communicate with external system
        // ------------------------------------------------------------------------
        moteClimate.initExternalCommunication();
        // ========================================================================

        // ========================================================================
        // For trouble shooting only
        // ------------------------------------------------------------------------
        System.out.println("Start listening for datagrams on port: " +
                hostPortNumber);
        // ========================================================================

        while (listenForNewDatagram) {
            // ====================================================================
            // listen for new data packet
            // --------------------------------------------------------------------
            moteClimate.listenFor();
            // ====================================================================

            // ====================================================================
            // Verify that packet has temperature data
            // --------------------------------------------------------------------
            if (moteClimate.getReadDataByte() == dataIdAsByte) {
                // ================================================================
                // For trouble shooting only
                // ----------------------------------------------------------------
                System.out.println("Temperature data received.");
                // ================================================================

                // ================================================================
                // Prepare data to send to external system via serial comm.
                // ----------------------------------------------------------------
                moteClimate.packageTempDataToSendToClimateControl(
                        moteClimate.getReadDataUTF(),
                        moteClimate.getReadDataDouble());

                // ================================================================

                // ================================================================
                // Push new data to external system
                // ----------------------------------------------------------------
                moteClimate.sendDataToExternalSystem();
                // ================================================================

            } // end of if packet has temperature data
            // ====================================================================

        } // end of while loop

    } // end run()

} // end class
```

Listing C.36: Climate Interface Thread

C.5.10 LightingInterfaceThread.java

```
/* ********************************************************************
 * Author        :  Severin Willisch
 * email         :  d9840087@mail.connect.usq.edu.au
 * Student No.   :  0039840087
 * Purpose       :  Project for Semester 1 & 2, 2009
 * Purpose       :  09-036 Programming Sun SPOTs in JAVA
 * ********************************************************************
 */

/* ********************************************************************
 * Purpose       :  This class runs if the MANIFEST.MF file has light ...
 * Purpose       :  interface as a requirement.
 * Inputs        :  External System Type,
                    port used by host,
                    interface type as a byte
 * ********************************************************************
 */

package org.sunspotworld;

class LightingInterfaceThread implements Runnable {
    // ===================================================================
    // Instance variables
    // -------------------------------------------------------------------
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private byte interfaceIdAsByte;
    private byte dataIdAsByte = 2;           // identifies light data
    private boolean listenForNewDatagram = true;
    // ===================================================================


    LightingInterfaceThread(String threadname, int portNo, byte moteType){
        systemInterface = threadname;
        t = new Thread(this, systemInterface);
        hostPortNumber = portNo;
        interfaceIdAsByte = moteType;
        System.out.println("New thread: " + t);
        t.start();
    } // end constructor

    // ===================================================================
    // methods to access instance variables, setter methods
    // ===================================================================
    void setThread(Thread setThread) {
        t = setThread;
    }

    void setListenForNewDatagram(boolean lisForDgs) {
        listenForNewDatagram = lisForDgs;
    }
    // ===================================================================

    // ===================================================================
    // methods to access instance variables, getter methods
    // ===================================================================
    Thread getThread() {
```

```
    return t;
}

boolean getListenForNewDatagram() {
    return listenForNewDatagram;
}
// ============================================================

public void run() {
    // ==========================================================
    // For trouble shooting only
    // ----------------------------------------------------------
    System.out.println("Start interface thread: " +
            systemInterface + " " + interfaceIdAsByte);
    // ==========================================================

    // ==========================================================
    // start a new light interface mote
    // ----------------------------------------------------------
    LightInterfaceMote moteLight = new LightInterfaceMote();
    // ==========================================================

    // ==========================================================
    // get and push IEEE address to terminal
    // ----------------------------------------------------------
    moteLight.getPushAddress();
    // ==========================================================

    // ==========================================================
    // Intial set up for communication
    // ----------------------------------------------------------
    moteLight.initInterfaceMoteCommunication();
    moteLight.setPortNumber(hostPortNumber);
    // ==========================================================

    // ==========================================================
    // Open up a broadcast connection
    // ----------------------------------------------------------
    moteLight.tryToOpenBroadcastConnection();
    // ==========================================================

    // ==========================================================
    // Intial set up to communicate with external system
    // ----------------------------------------------------------
    moteLight.initExternalCommunication();
    // ==========================================================

    // ==========================================================
    // For trouble shooting only
    // ----------------------------------------------------------
    System.out.println("Start listening for datagrams on port: " +
            hostPortNumber);
    // ==========================================================

    while (listenForNewDatagram) {
        // ======================================================
        // listen for new data packet
        // ------------------------------------------------------
        moteLight.listenFor();
        // ======================================================
```

```
        // ================================================================
        // Verify that packet has light data
        // ----------------------------------------------------------------
        if (moteLight.getReadDataByte() == dataIdAsByte) {
            // ============================================================
            // For trouble shooting only
            // ------------------------------------------------------------
            System.out.println("Light data received.");
            // ============================================================

            // ============================================================
            // Prepare data to send to external system via serial comm.
            // ------------------------------------------------------------
            moteLight.packageLightDataToSendToLightControl(
                    moteLight.getReadDataUTF(),
                    moteLight.getReadDataInt());
            // ============================================================

            // ============================================================
            // Push new data to external system
            // ------------------------------------------------------------
            moteLight.sendDataToExternalSystem();
            // ============================================================

        } // end of if packet has light data
        // ================================================================

    } // end of while loop

  } // end run()

} // end class
```

Listing C.37: Light Interface Thread

C.5.11 AlarmInterfaceThread.java

```
/* *********************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *********************************************************************
 */

/* *********************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has alarm ...
 * Purpose      :  interface as a requirement.
 * Inputs       :  External System Type,
                   port used by host,
                   interface type as a byte
 * *********************************************************************
 */
```

```
package org.sunspotworld;

class AlarmInterfaceThread implements Runnable {

    // ========================================================================
    // Instance variables
    // ------------------------------------------------------------------------
    private String systemInterface;
    private Thread t;
    private int hostPortNumber;
    private byte interfaceIdAsByte;
    private byte dataIdAsByte = 4;              // identifies temp data
    private boolean listenForNewDatagram = true;
    // ========================================================================

    AlarmInterfaceThread(String threadname, int portNo, byte moteType) {
        systemInterface = threadname;
        t = new Thread(this, systemInterface);
        hostPortNumber = portNo;
        interfaceIdAsByte = moteType;
        System.out.println("New thread: " + t);
        t.start();
    } // end constructor

    // ========================================================================
    // methods to access instance variables, setter methods
    // ========================================================================
    void setThread(Thread setThread) {
        t = setThread;
    }

    void setListenForNewDatagram(boolean lisForDgs) {
        listenForNewDatagram = lisForDgs;
    }
    // ========================================================================

    // ========================================================================
    // methods to access instance variables, getter methods
    // ========================================================================
    Thread getThread() {
        return t;
    }

    boolean getListenForNewDatagram() {
        return listenForNewDatagram;
    }
    // ========================================================================

    public void run() {
        // ====================================================================
        // For trouble shooting only
        // --------------------------------------------------------------------
        System.out.println("Start interface thread: " +
                systemInterface + " " + interfaceIdAsByte);
        // ====================================================================

        // ====================================================================
        // start a new alarm interface mote
        // --------------------------------------------------------------------
        AlarmInterfaceMote moteAlarm = new AlarmInterfaceMote();
```

```
// ============================================================

// ============================================================
// get and push IEEE address
// ------------------------------------------------------------
moteAlarm.getPushAddress();
// ============================================================

// ============================================================
// Intial set up for communication
// ------------------------------------------------------------
moteAlarm.initInterfaceMoteCommunication();
moteAlarm.setPortNumber(hostPortNumber);
// ============================================================

// ============================================================
// Open up a broadcast connection
// ------------------------------------------------------------
moteAlarm.tryToOpenBroadcastConnection();
// ============================================================

// ============================================================
// Intial set up to interface with external system
// ------------------------------------------------------------
moteAlarm.initExternalCommunication();
// ============================================================

// ============================================================
// For trouble shooting only
// ------------------------------------------------------------
System.out.println("Start listening for datagrams on port: " +
        hostPortNumber);
// ============================================================

while (listenForNewDatagram) {
    // ========================================================
    // listen for new data packet
    // --------------------------------------------------------
    moteAlarm.listenFor();
    // ========================================================

    // ========================================================
    // Verify that packet has alarm data
    // --------------------------------------------------------
    if (moteAlarm.getReadDataByte() == dataIdAsByte) {
        // ====================================================
        // For trouble shooting only
        // ----------------------------------------------------
        System.out.println("Alarm data received.");
        // ====================================================

        // ====================================================
        // Prepare data to send to external system via serial comm.
        // ----------------------------------------------------
        moteAlarm.packageAlarmDataToSendToAlarmSystem(
                moteAlarm.getReadDataUTF(),
                moteAlarm.getReadDataInt());

        // ====================================================
        // Push new data to external system
```

```
            // ————————————————————————————————————————————————————————————
            moteAlarm.sendDataToExternalSystem();
            // ============================================================

         } // end of if packet has alarm data
         // ===============================================================

      } // end of while loop

   } // end run()

} // end class
```

Listing C.38: Alarm Interface Thread

C.5.12 CarbMonInterfaceThread.java

```
/* ****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ****************************************************************
 */

/* ****************************************************************
 * Purpose      :  This class runs if MANIFEST.MF file has CarbonMon ...
 * Purpose      :  interface as a requirement.
 * Inputs       :  External System Type,
                   port used by host,
                   interface type as a byte
 * ****************************************************************
 */

package org.sunspotworld;

class CarbMonInterfaceThread implements Runnable {

   // ================================================================
   // Instance variables
   // ————————————————————————————————————————————————————————————————
   private String systemInterface;
   private Thread t;
   private int hostPortNumber;
   private byte interfaceIdAsByte;
   private byte dataIdAsByte = 5;               // identifies CarMon data
   private boolean listenForNewDatagram = true;
   // ================================================================

   CarbMonInterfaceThread(String threadname, int portNo, byte moteType) {
      systemInterface = threadname;
      t = new Thread(this, systemInterface);
      hostPortNumber = portNo;
      interfaceIdAsByte = moteType;
      System.out.println("New thread: " + t);
```

```
    t.start();
} // end constructor

// ==========================================================
// methods to access instance variables, setter methods
// ==========================================================
void setThread(Thread setThread) {
    t = setThread;
}

void setListenForNewDatagram(boolean lisForDgs) {
    listenForNewDatagram = lisForDgs;
}
// ==========================================================

// ==========================================================
// methods to access instance variables, getter methods
// ==========================================================
Thread getThread() {
    return t;
}

boolean getListenForNewDatagram() {
    return listenForNewDatagram;
}
// ==========================================================

public void run() {
    // ======================================================
    // For trouble shooting only
    // ------------------------------------------------------
    System.out.println("Start interface thread: " +
            systemInterface + " " + interfaceIdAsByte);
    // ======================================================

    // ======================================================
    // start a new carbon mono interface mote
    // ------------------------------------------------------
    CarbMonInterfaceMote moteCarbMon = new CarbMonInterfaceMote();
    // ======================================================

    // ======================================================
    // get and push IEEE address
    // ------------------------------------------------------
    moteCarbMon.getPushAddress();
    // ======================================================

    // ======================================================
    // Intial set up for communication
    // ------------------------------------------------------
    moteCarbMon.initInterfaceMoteCommunication();
    moteCarbMon.setPortNumber(hostPortNumber);
    // ======================================================

    // ======================================================
    // Open up a broadcast connection
    // ------------------------------------------------------
    moteCarbMon.tryToOpenBroadcastConnection();
    // ======================================================
```

```
        // ===========================================================
        // Intial set up to interface with external system
        // -----------------------------------------------------------
        moteCarbMon.initExternalCommunication();
        // ===========================================================

        // ===========================================================
        // For trouble shooting only
        // -----------------------------------------------------------
        System.out.println("Start listening for datagrams on port: " +
                hostPortNumber);
        // ===========================================================

        while (listenForNewDatagram) {
            // =======================================================
            // listen for new data packet
            // -------------------------------------------------------
            moteCarbMon.listenFor();
            // =======================================================

            // =======================================================
            // Verify that packet has carbon mono data
            // -------------------------------------------------------
            if (moteCarbMon.getReadDataByte() == dataIdAsByte) {
                // ===================================================
                // For trouble shooting only
                // ---------------------------------------------------
                System.out.println("Carbon mono data received.");
                // ===================================================

                // ===================================================
                // Prepare data to send to external system via serial comm.
                // ---------------------------------------------------
                moteCarbMon.packageCarbonMonoDataToSendToCarbMonSystem(
                        moteCarbMon.getReadDataUTF(),
                        moteCarbMon.getReadDataDouble());

                // ===================================================

                // ===================================================
                // Push new data to external system
                // ---------------------------------------------------
                moteCarbMon.sendDataToExternalSystem();
                // ===================================================

            } // end of if packet has carbon mono data
            // =======================================================

        } // end of while loop

    } // end run()

} // end class
```

Listing C.39: Carbon Monoxide Thread

C.5.13 DoorInterfaceThread.java

```
/* *****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *****************************************************************
 */

/* *****************************************************************
 * Purpose      :  This class runs if the MANIFEST.MF file has door ...
 * Purpose      :  interface as a requirement.
 * Inputs       :  External System Type,
                   port used by host,
                   interface type as a byte
 * *****************************************************************
 */

package org.sunspotworld;

class DoorInterfaceThread implements Runnable{
   // ==================================================================
   // Instance variables
   // ------------------------------------------------------------------
   private String systemInterface;
   private Thread t;
   private int hostPortNumber;
   private long unlockTime;
   private byte interfaceIdAsByte;
   private byte dataIdAsByte = 16;              // identifies unlock door
   private boolean listenForNewDatagram = true;
   // ==================================================================

   DoorInterfaceThread(String threadname, int portNo, byte moteType,
          long doorTime){
      systemInterface = threadname;
      t = new Thread(this, systemInterface);
      hostPortNumber = portNo;
      interfaceIdAsByte = moteType;
      unlockTime = doorTime;
      System.out.println("New thread: " + t);
      t.start();

   } // end constructor

   // ==================================================================
   // methods to access instance variables, setter methods
   // ==================================================================
   void setThread(Thread setThread) {
      t = setThread;
   }

   void setListenForNewDatagram(boolean lisForDgs) {
      listenForNewDatagram = lisForDgs;
   }
   // ==================================================================

   // ==================================================================
```

```java
// methods to access instance variables, getter methods
// ==========================================================
Thread getThread() {
   return t;
}

boolean getListenForNewDatagram() {
   return listenForNewDatagram;
}
// ==========================================================

public void run() {
   // ======================================================
   // For trouble shooting only
   // ------------------------------------------------------
   System.out.println("Start interface thread: " +
           systemInterface + " " + interfaceIdAsByte);
   // ======================================================

   // ======================================================
   // start a new door interface mote
   // ------------------------------------------------------
   DoorInterfaceMote moteDoor = new DoorInterfaceMote();
   // ======================================================

   // ======================================================
   // get and push IEEE address
   // ------------------------------------------------------
   moteDoor.getPushAddress();
   // ======================================================

   // ======================================================
   // Intial set up for communication
   // ------------------------------------------------------
   moteDoor.initInterfaceMoteCommunication();
   moteDoor.setPortNumber(hostPortNumber);
   // ======================================================

   // ======================================================
   // Open up a broadcast connection
   // ------------------------------------------------------
   moteDoor.tryToOpenBroadcastConnection();
   // ======================================================

   // ======================================================
   // Intial set up to interface with external system
   // ------------------------------------------------------
   moteDoor.initDoorInterface();
   // ======================================================

   // ======================================================
   // For trouble shooting only
   // ------------------------------------------------------
   System.out.println("Start listening for datagrams on port: " +
           hostPortNumber);
   // ======================================================

   while (listenForNewDatagram) {
      // ===================================================
      // listen for new data packet
```

```
        // ---------------------------------------------------------------
        moteDoor.listenFor();
        // ===============================================================

        // ===============================================================
        // Verify that packet has door data
        // ---------------------------------------------------------------
        if (moteDoor.getReadDataByte() == dataIdAsByte) {
            // ===========================================================
            // For trouble shooting only
            // -----------------------------------------------------------
            System.out.println("Door data received.");
            // ===========================================================

            // ===========================================================
            // Push new data to external system
            // -----------------------------------------------------------
            moteDoor.unlockTheDoor(unlockTime);
            // ===========================================================

        } // end of if packet has temperature data
        // ===============================================================

      } // end of while loop

   } // end run()

} // end class
```

Listing C.40: Door Interface Thread

C.5.14 SendStatus.java

```
/* *****************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *****************************************************************
 */

/* *****************************************************************
 * Purpose      :  This thread sends the status of the external system ...
 * Purpose      :  to the host.
 * *****************************************************************
 */

package org.sunspotworld;

import com.sun.spot.util.IEEEAddress;

class SendStatus implements Runnable{

   // ================================================================
   // Instance variables
```

```
// ---------------------------------------------------------------------------
private String systemInterface;
private Thread t;
private int portNumberSend;
private int portNumberListen;
private byte statusIdentification;
private String hostAddress;

private boolean extSystemOK = false;
private boolean hostAddressNotKnown = true;
// ===========================================================================

SendStatus(String threadname, int portSend, int portList,
        byte byteId){
   systemInterface = threadname;
   t = new Thread(this, systemInterface);
   portNumberSend = portSend;
   portNumberListen = portList;
   statusIdentification = byteId;
   System.out.println("New thread: " + t);
   t.start();
} // end constructor


// ===========================================================================
// methods to access instance variables, setter methods
// ===========================================================================
void setThread(Thread setThread) {
   t = setThread;
}
// ===========================================================================

// ===========================================================================
// methods to access instance variables, getter methods
// ===========================================================================
Thread getThread() {
   return t;
}
// ===========================================================================

public void run() {
   // ========================================================================
   // For trouble shooting only
   // ------------------------------------------------------------------------
   System.out.println("Start external system status thread: " +
           systemInterface);
   System.out.println("Listening on port: " + portNumberListen);
   // ========================================================================

   // ========================================================================
   // Create object to send status to host
   // ------------------------------------------------------------------------
   InterfaceMote listenForHost = new InterfaceMote();
   // ========================================================================

   // ========================================================================
   // Initial setup for communication (listening)
   // ------------------------------------------------------------------------
   listenForHost.initInterfaceMoteCommunication();
   listenForHost.setPortNumber(portNumberListen);
```

```
// ==================================================================

// ==================================================================
// Open up a broadcast connection to listen for host
// ------------------------------------------------------------------
listenForHost.tryToOpenBroadcastConnection();
// ==================================================================

// ==================================================================
// Wait for host address
// ------------------------------------------------------------------
while (hostAddressNotKnown){
   listenForHost.listenFor();
   if(listenForHost.getReadDataByte() == 99){
      hostAddress = IEEEAddress.toDottedHex
              (listenForHost.getReadDataLong());

      // =============================================================
      // For trouble shooting only
      // -------------------------------------------------------------
      System.out.println("Host address received: " + hostAddress);
      // =============================================================

      // =============================================================
      // Set flag to false (i.e. address is now known)
      // -------------------------------------------------------------
      hostAddressNotKnown = false;
      // =============================================================

      try {
         Thread.sleep(2000);
      } catch (InterruptedException ex) {
         ex.printStackTrace();
      }
   } // end of IF

} // end of WHILE
// ==================================================================

// ==================================================================
// Create object to send status to host
// ------------------------------------------------------------------
RadiogramCommClass sendExternalSystemStatus =
        new RadiogramCommClass();
// ==================================================================

// ==================================================================
// Initial setup for communication (sending)
// ------------------------------------------------------------------
sendExternalSystemStatus.initRadiogramCom();
sendExternalSystemStatus.setPortNumber(portNumberSend);
sendExternalSystemStatus.setLocation(systemInterface);
sendExternalSystemStatus.setHostAddress(hostAddress);
sendExternalSystemStatus.setWriteDataByte(statusIdentification);
// ==================================================================

// ==================================================================
// Open up a radiogram connection to host
// ------------------------------------------------------------------
sendExternalSystemStatus.tryToOpenRadiogramConnection();
```

```
        // ============================================================

        // ============================================================
        // Intial set up to verify status of external system
        // ------------------------------------------------------------
        sendExternalSystemStatus.initExternalSystemStatus();
        // ============================================================

        while (true){

            // ========================================================
            // check status of external system
            // --------------------------------------------------------
            extSystemOK = sendExternalSystemStatus.errorExternalSystem();
            sendExternalSystemStatus.setWriteBoolean(extSystemOK);
            // ========================================================

            // ========================================================
            // send status to host
            // --------------------------------------------------------
            sendExternalSystemStatus.packageAndSendRadiogram();

            try {

                Thread.sleep(30000);
            } catch (InterruptedException ex) {
                ex.printStackTrace();
            }

        } // end of WHILE

    } // end of SendStatus

} // end of class
```

Listing C.41: Send External System Status Thread

C.6 Code Listings for Host

C.6.1 CommClassHost.java

```
/* ***************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * ***************************************************************
 */

/* ***************************************************************
 * Purpose      :  This class includes functionalities to send and ...
 * Purpose      :  receive data.
 * ***************************************************************
 */

package org.sunspotworld;

import com.sun.spot.io.j2me.radiogram.RadiogramConnection;
import java.io.IOException;
import java.text.DateFormat;
import java.util.Date;
import javax.microedition.io.Connector;
import javax.microedition.io.Datagram;


class CommClassHost {

    // ==============================================================
    // Instance variables
    // --------------------------------------------------------------
    private RadiogramConnection rCon;
    private Datagram dg;
    private String location;
    private int portNumber;

    private long writeDataLong = 0;
    private byte writeDataByte = 0;
    private int writeDataInt = 0;
    private double writeDataDouble = 0;
    private boolean writeDataBool = false;

    private long readDataLong = 0;
    private byte readDataByte = 0;
    private String readDataUTF = null;
    private int readDataInt = 0;
    private double readDataDouble = 0;
    private boolean readDataBool = false;

    DateFormat fmt = DateFormat.getTimeInstance();
    long timeOfReading = 0;
    long nowOnHost = 0L;
    long delaySampleToTerminal = 0L;
    // ==============================================================
```

```
// ===========================================================================
// methods to access instance variables , setter methods
// ===========================================================================
void setLocation(String setLoc){location = setLoc;}

void setPortNumber(int setPort){portNumber = setPort;}

void setWriteDataLong(long setDataLong){writeDataLong = setDataLong;}

void setWriteDataByte(byte setDataByte){writeDataByte = setDataByte;}

void setWriteDataInt(int setDataInt){writeDataInt = setDataInt;}

void setWriteDataDouble(double setDataDouble){
   writeDataDouble = setDataDouble;}

void setWriteDataBool(boolean setDataBool){
   writeDataBool = setDataBool;}

// ===========================================================================

// ===========================================================================
// methods to access instance variables , getter methods
// ===========================================================================
String getLocation(){return location;}

int getPortNumber(){return portNumber;}

long getWriteDataLong(){return writeDataLong;}

byte getWriteDataByte(){return writeDataByte;}

int getWriteDataInt(){return writeDataInt;}

double getWriteDataDouble(){return writeDataDouble;}

long getReadDataLong(){return readDataLong;}

byte getReadDataByte(){return readDataByte;}

String getReadDataUTF(){return readDataUTF;}

int getReadDataInt(){return readDataInt;}

double getReadDataDouble(){return readDataDouble;}

boolean getReadDataBool(){return readDataBool;}
// ===========================================================================

// ===========================================================================
// All other methods
// ===========================================================================
void initBroadcastCom (){
   // ========================================================================
   // Intial set up for communication
   // ------------------------------------------------------------------------
   rCon = null;
   dg = null;
   // ========================================================================
```

```
} // end initBroadcastCom

void tryToOpenBroadcastConnection(boolean broadRequired) {
   try {
      if (broadRequired) {
         // =========================================================
         // Open up a broadcast connection.
         // ---------------------------------------------------------
         rCon = (RadiogramConnection) Connector.open(
                 "radiogram://broadcast:" + portNumber);
      // =========================================================
      } else {
         // =========================================================
         // Open up a unicast connection.
         // ---------------------------------------------------------
         rCon = (RadiogramConnection) Connector.open(
                 "radiogram://:" + portNumber);
      // =========================================================
      }
      dg = rCon.newDatagram(rCon.getMaximumLength());
      // =========================================================

      // =========================================================
      // For trouble shooting only
      // ---------------------------------------------------------
      System.out.println("Broadcast is open.");
   // =========================================================

   } catch (IOException ex) {
      ex.printStackTrace();
   } // end try / catch
} // end tryToOpenBroadcastConnection()

void packageAndSendRadiogram(){

   // =========================================================
   // package data into datagram and send
   // ---------------------------------------------------------
   dg.reset();
   try {
      dg.writeLong(writeDataLong);
      dg.writeByte(writeDataByte);
      dg.writeUTF(location);
      dg.writeInt(writeDataInt);
      dg.writeDouble(writeDataDouble);
      dg.writeBoolean(writeDataBool);
      rCon.send(dg);
      // =========================================================

      // =========================================================
      // For trouble shooting only
      // ---------------------------------------------------------
      System.out.println("Data packet sent.");
      // =========================================================


   } catch (IOException ex) {
      ex.printStackTrace();
   } // end try / catch
} // end packageAndSendRadiogram()
```

```
void listenFor(){

    // ==========================================================
    // listen for new datagram data
    // ----------------------------------------------------------
    try {
        rCon.receive(dg);
        readDataLong = dg.readLong();
        readDataByte = dg.readByte();
        readDataUTF = dg.readUTF();
        readDataInt = dg.readInt();
        readDataDouble = dg.readDouble();
        readDataBool = dg.readBoolean();
        // ======================================================

        // ======================================================
        // For trouble shooting only
        // ------------------------------------------------------
        System.out.println("Data packet received. " + readDataByte);
        // ======================================================

    } catch (IOException ex) {
        ex.printStackTrace();
    } // end try / catch
} // end listenFor()

void pushTimeAndLocationToTerminal(boolean timeDelay){
    nowOnHost = System.currentTimeMillis();
    System.out.print("Time on Host: " +
            fmt.format(new Date(nowOnHost)) + " ");

    if(timeDelay){
        delaySampleToTerminal = nowOnHost - readDataLong;
        System.out.print(delaySampleToTerminal + " ms ");
        System.out.print(fmt.format(new Date(readDataLong)));
    }
    System.out.print("Location: " + readDataUTF + "\t");
} // end of pushTimeAndLocationToTerminal()

void identifyMessageAndPushToTerminal(int messageType){
    // ==========================================================
    // Identify the data in the packets
    // ----------------------------------------------------------
    switch (messageType) {
        case 1:
            System.out.println("Temperature (Celsius): " +
                    readDataDouble);
            break;
        case 2:
            System.out.println("Light (lux): " + readDataInt);
            break;
        case 3:
            System.out.println("Battery Capacity (%): " +
                    readDataInt);
            break;
        case 4:
            if (readDataInt == 1) {
                System.out.println("\tAlarm activated");
            } else if (readDataInt == 2) {
```

```
                System.out.println("\tNo alarm");
            } else {
                System.out.println("\tProblem, check SPOT");
            }
            break;
        case 5:
            System.out.println("Carbon Monoxide (Volt): " +
                    readDataDouble);
            break;
        case 111:
        case 112:
        case 113:
        case 114:
        case 115:
        case 116:
        case 117:
        case 118:
        case 119:
            if (readDataBool == true) {
                System.out.println(" Status --> OK");
            } else {
                System.out.println(" Status --> not OK");
            }
        } // end switch
        // ================================================================

    } // end of identifyMessageAndPushToTerminal()

} // end CollectorMote class
```

Listing C.42: Host Functions

C.6.2 IdentMessByByteOnHost.java

```
/* ******************************************************************
 * Author      :  Severin Willisch
 * email       :  d9840087@mail.connect.usq.edu.au
 * Student No. :  0039840087
 * Purpose     :  Project for Semester 1 & 2, 2009
 * Purpose     :  09-036 Programming Sun SPOTs in JAVA
 * ******************************************************************
 */

/* ******************************************************************
 * Purpose     :  This is the main class for the application used ...
 * Purpose     :  during the test beds. The class launches 3 threads.
 * Purpose     :  Once threads are launched this class waits until ...
 * Purpose     :  all threads are finished. This class runs on the host.
 * ******************************************************************
 */

package org.sunspotworld;

public class IdentMessByByteOnHost {
    // ================================================================
    // Instance variables
```

```
    // ----------------------------------------------------------------------
    private static final int HOST_PORT_SEND = 66;
    private static final int HOST_PORT_LISTEN_DATA = 67;
    private static final int HOST_PORT_LISTEN_STATUS = 68;
    // ======================================================================

    public static void main(String[] args) {
        // ==================================================================
        // Set the host up to identify information in data packet
        // based.
        // ------------------------------------------------------------------
        BroadcastHostAddress myHostAddress = new BroadcastHostAddress(
                "BroadcastHostAddress", HOST_PORT_SEND);

        HostIdentifyByByte enviroData = new HostIdentifyByByte(
                "EnvironmentalData", HOST_PORT_LISTEN_DATA);

        HostIdentifyByByte statusReport = new HostIdentifyByByte(
                "ExtSysData", HOST_PORT_LISTEN_STATUS);
        // ==================================================================


        try {
            // ==============================================================
            // For trouble shooting only
            // --------------------------------------------------------------
            System.out.println("Wait for thread to finish.");
            // --------------------------------------------------------------
            enviroData.t.join();
            statusReport.t.join();
            myHostAddress.t.join();

        } catch (InterruptedException e) {
            System.out.println("Main thread interrupted.");
        }
        System.out.println("Main thread exiting.");
    }
}
```

Listing C.43: Main Thread on the Host

C.6.3 HostIdentifyByByte.java

```
/* *********************************************************************
 * Author      :  Severin Willisch
 * email       :  d9840087@mail.connect.usq.edu.au
 * Student No. :  0039840087
 * Purpose     :  Project for Semester 1 & 2, 2009
 * Purpose     :  09-036 Programming Sun SPOTs in JAVA
 * *********************************************************************
 */

/* *********************************************************************
 * Purpose     :  This class is used to establish if data received ...
 * Purpose     :  by the host is a status update or environmental data.
 * *********************************************************************
```

```
 */

package org.sunspotworld;

import com.sun.spot.io.j2me.radiogram.*;
import javax.microedition.io.*;

class HostIdentifyByByte implements Runnable {

    // ============================================================
    // Instance variables
    // ------------------------------------------------------------
    RadiogramConnection rCon = null;
    Datagram dg = null;

    String name;                          // name of thread
    Thread t;
    int portNumber;

    byte byteData = 0;
    double doubleData = 0.0;
    int intData = 0;
    String addr = null;
    String location = null;
    int messageIdentifier = 0;
    // ============================================================


    HostIdentifyByByte(String threadname, int portNo) {
        name = threadname;
        t = new Thread(this, name);
        portNumber = portNo;
        System.out.println("New thread: " + t);
        t.start();
    }

    // ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    // entry point for thread
    // ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

    public void run() {

        // ========================================================
        // For trouble shooting only
        // --------------------------------------------------------
        System.out.println("Start new " + name + " thread on " +
                portNumber);
        // ========================================================

        // ========================================================
        // Start a new listener on host
        // --------------------------------------------------------
        CommClassHost hostListener = new CommClassHost();
        // ========================================================

        // ========================================================
        // Intial set up for communication
        // --------------------------------------------------------
        hostListener.initBroadcastCom();
        hostListener.setPortNumber(portNumber);
```

```
    // ===================================================================

    // ===================================================================
    // Open up a unicast (broadcast) connection
    // -------------------------------------------------------------------
    hostListener.tryToOpenBroadcastConnection(false);
    // ===================================================================

    // ===================================================================
    // Main data collection loop
    // -------------------------------------------------------------------
    while (true) {
        // ===============================================================
        // listen for new data packet
        // ---------------------------------------------------------------
        hostListener.listenFor();
        // ===============================================================

        // ===============================================================
        // Set value for switch case
        // ---------------------------------------------------------------
        messageIdentifier = hostListener.getReadDataByte();
        // ===============================================================

        if(portNumber == 67){
            // ===========================================================
            // push time, delay and location to terminal for packets ...
            // from collector SPOTs
            // -----------------------------------------------------------
            hostListener.pushTimeAndLocationToTerminal(true);
            // ===========================================================

            // ===========================================================
            // Identify message based on message identifier, data
            // -----------------------------------------------------------
            hostListener.identifyMessageAndPushToTerminal
                    (messageIdentifier);
            // ===========================================================

        } else if(portNumber == 68){
            // ===========================================================
            // push time, delay and location to terminal for packets ...
            // from interface hosts
            // -----------------------------------------------------------
            hostListener.pushTimeAndLocationToTerminal(false);
            // ===========================================================

            // ===========================================================
            // Identify message based on message identifier
            // -----------------------------------------------------------
            hostListener.identifyMessageAndPushToTerminal
                    (messageIdentifier);
            // ===========================================================

        } // end of ELSE IF

    } // end while

} // end run()
```

```
} // end class
```

Listing C.44: Listening Class on Host

C.6.4 BroadcastHostAddress.java

```
/* *******************************************************************
 * Author       :  Severin Willisch
 * email        :  d9840087@mail.connect.usq.edu.au
 * Student No.  :  0039840087
 * Purpose      :  Project for Semester 1 & 2, 2009
 * Purpose      :  09-036 Programming Sun SPOTs in JAVA
 * *******************************************************************
 */

/* *******************************************************************
 * Purpose      :  This class is used to broadcast the IEEE address of ...
 * Purpose      :  the host. The interface motes will listen for this ...
 * Purpose      :  broadcast.
 * *******************************************************************
 */

package org.sunspotworld;

import com.sun.spot.peripheral.radio.RadioFactory;
import com.sun.spot.util.IEEEAddress;
import java.util.logging.Level;
import java.util.logging.Logger;

class BroadcastHostAddress implements Runnable {
   String name;                                   // name of thread
   Thread t;
   int portNumber;

   BroadcastHostAddress(String threadname, int portNo) {
      name = threadname;
      t = new Thread(this, name);
      portNumber = portNo;
      System.out.println("New thread: " + t);
      t.start();
   }

   // ===================================================================
   // Instance variables
   // -------------------------------------------------------------------
   long hostAddress = 0;
   byte hostId = 99;
   // ===================================================================

   public void run() {

      // ================================================================
      // Get and push host address to terminal
      // ----------------------------------------------------------------
      hostAddress = RadioFactory.getRadioPolicyManager().
               getIEEEAddress();
```

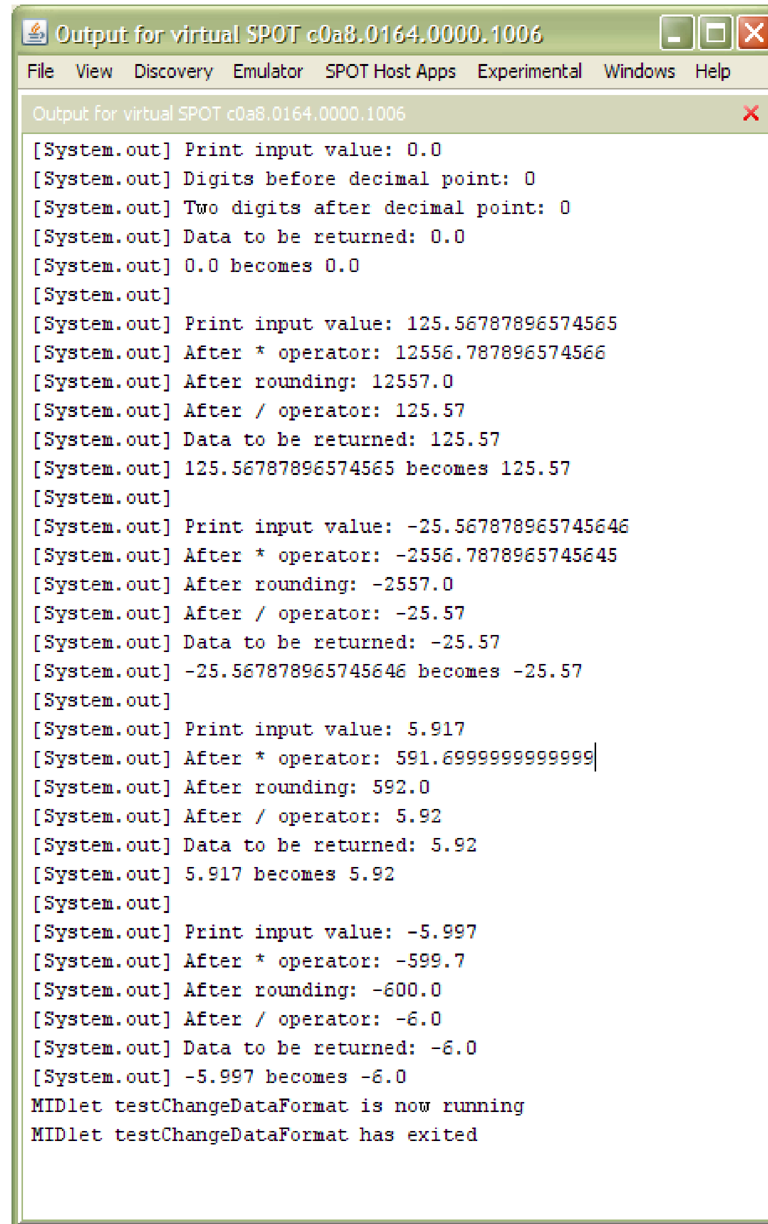
```
        System.out.println("Our radio address (long)= " +
                IEEEAddress.toDottedHex(hostAddress));
        // ================================================================

        // ================================================================
        // Initial setup for communication
        // ----------------------------------------------------------------
        CommClassHost newBroadcast = new CommClassHost();
        newBroadcast.initBroadcastCom();
        newBroadcast.setPortNumber(portNumber);
        newBroadcast.setLocation("Host");
        newBroadcast.setWriteDataLong(hostAddress);
        newBroadcast.setWriteDataByte(hostId);          // id of host
        // ================================================================

        // ================================================================
        // Open up a broadcast connection
        // ----------------------------------------------------------------
        newBroadcast.tryToOpenBroadcastConnection(true);
        // ================================================================

        while (true){
            newBroadcast.packageAndSendRadiogram();
            // ============================================================
            // For trouble shooting only
            // ------------------------------------------------------------
            System.out.println("Host broadcasted address");

            try {
                Thread.sleep(30000);
            } catch (InterruptedException ex) {
                Logger.getLogger(BroadcastHostAddress.class.getName()).
                        log(Level.SEVERE, null, ex);
            }
        } // end of WHILE

    } // end of run()

} // end of class
```

Listing C.45: Broadcast Host Address Class

Appendix D

Screen Captures

D.1 Example Implementation Code




```
[System.out] Print input value: 0.0
[System.out] Digits before decimal point: 0
[System.out] Two digits after decimal point: 0
[System.out] Data to be returned: 0.0
[System.out] 0.0 becomes 0.0
[System.out]
[System.out] Print input value: 125.56787896574565
[System.out] After * operator: 12556.787896574566
[System.out] After rounding: 12557.0
[System.out] After / operator: 125.57
[System.out] Data to be returned: 125.57
[System.out] 125.56787896574565 becomes 125.57
[System.out]
[System.out] Print input value: -25.567878965745646
[System.out] After * operator: -2556.7878965745645
[System.out] After rounding: -2557.0
[System.out] After / operator: -25.57
[System.out] Data to be returned: -25.57
[System.out] -25.567878965745646 becomes -25.57
[System.out]
[System.out] Print input value: 5.917
[System.out] After * operator: 591.6999999999999
[System.out] After rounding: 592.0
[System.out] After / operator: 5.92
[System.out] Data to be returned: 5.92
[System.out] 5.917 becomes 5.92
[System.out]
[System.out] Print input value: -5.997
[System.out] After * operator: -599.7
[System.out] After rounding: -600.0
[System.out] After / operator: -6.0
[System.out] Data to be returned: -6.0
[System.out] -5.997 becomes -6.0
MIDlet testChangeDataFormat is now running
MIDlet testChangeDataFormat has exited
```

Figure D.1: Screen Capture Test Script Output

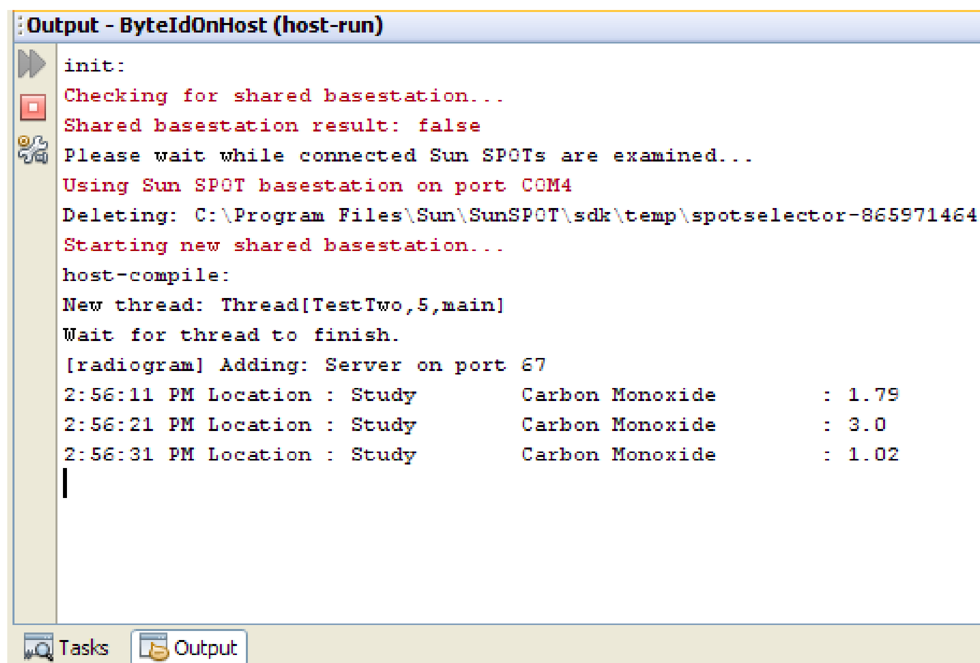


Figure D.2: Screen Capture Test Run Host Output

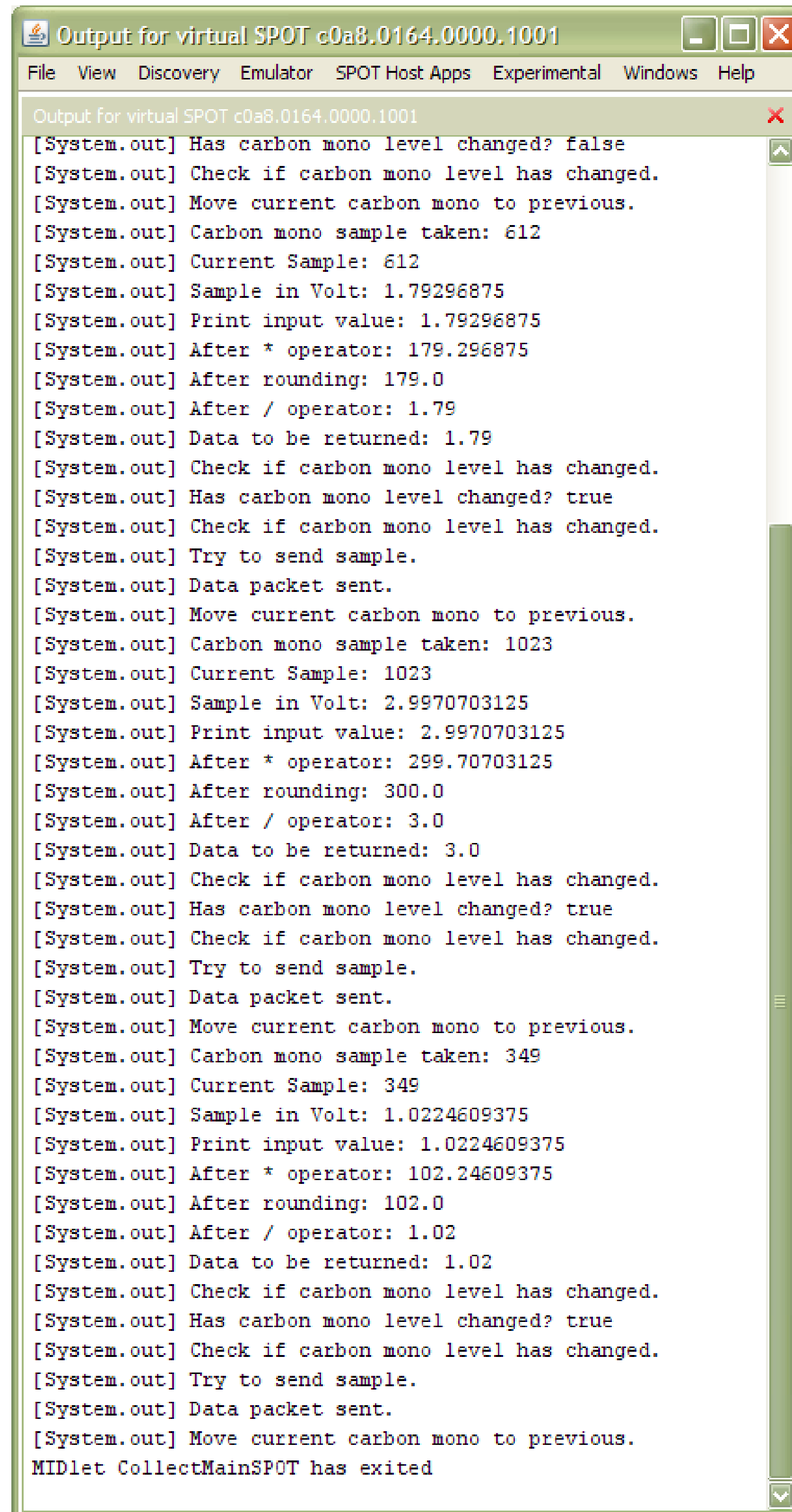


Figure D.3: Screen Capture Test Run Virtual SPOT Output

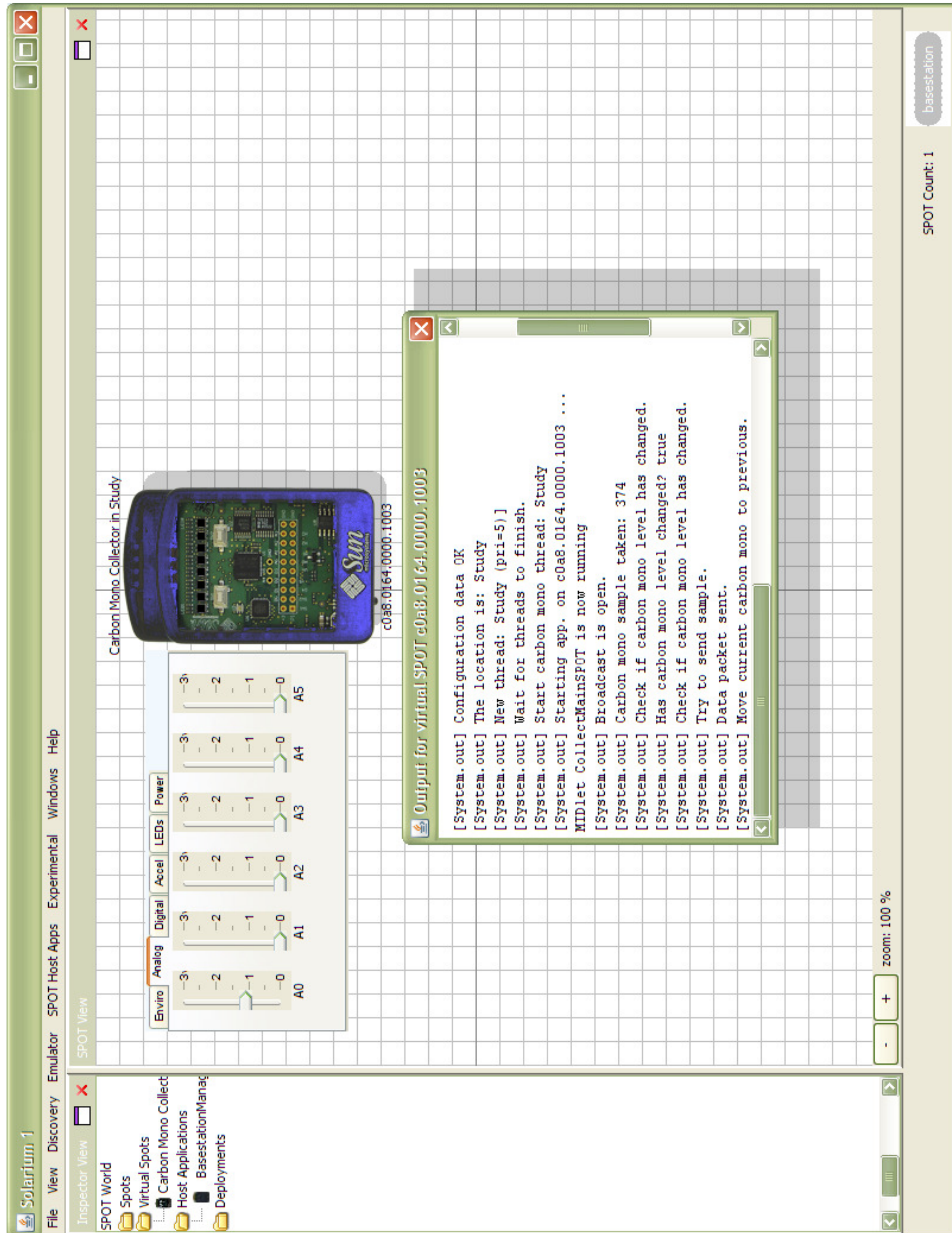


Figure D.4: Screen Capture Solarium with Virtual SPOT

D.2 Screen Captures HAA Test Bed

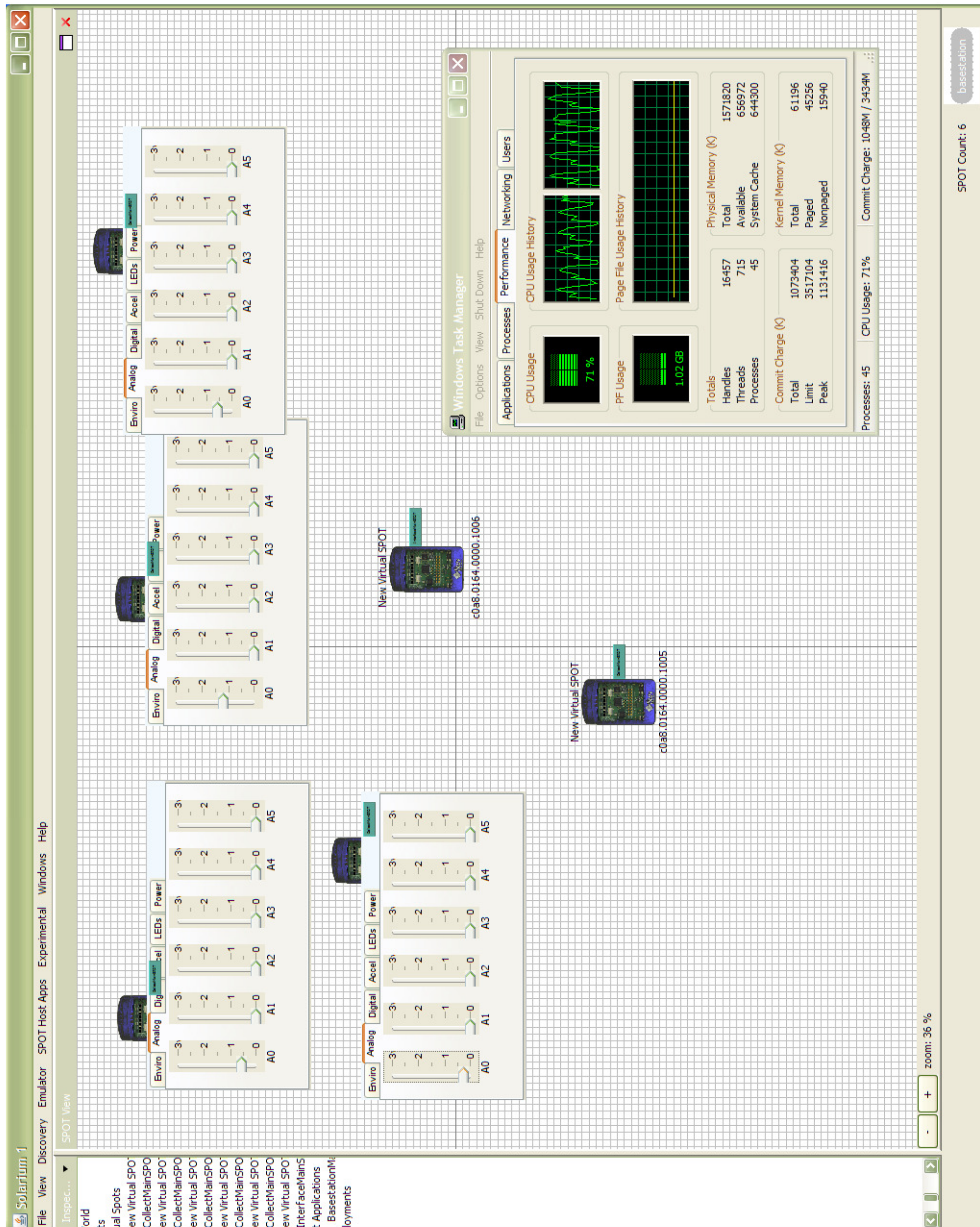


Figure D.5: Screen Capture HAA Test Bed with Six Virtual SPOT

Appendix E

Building Layout

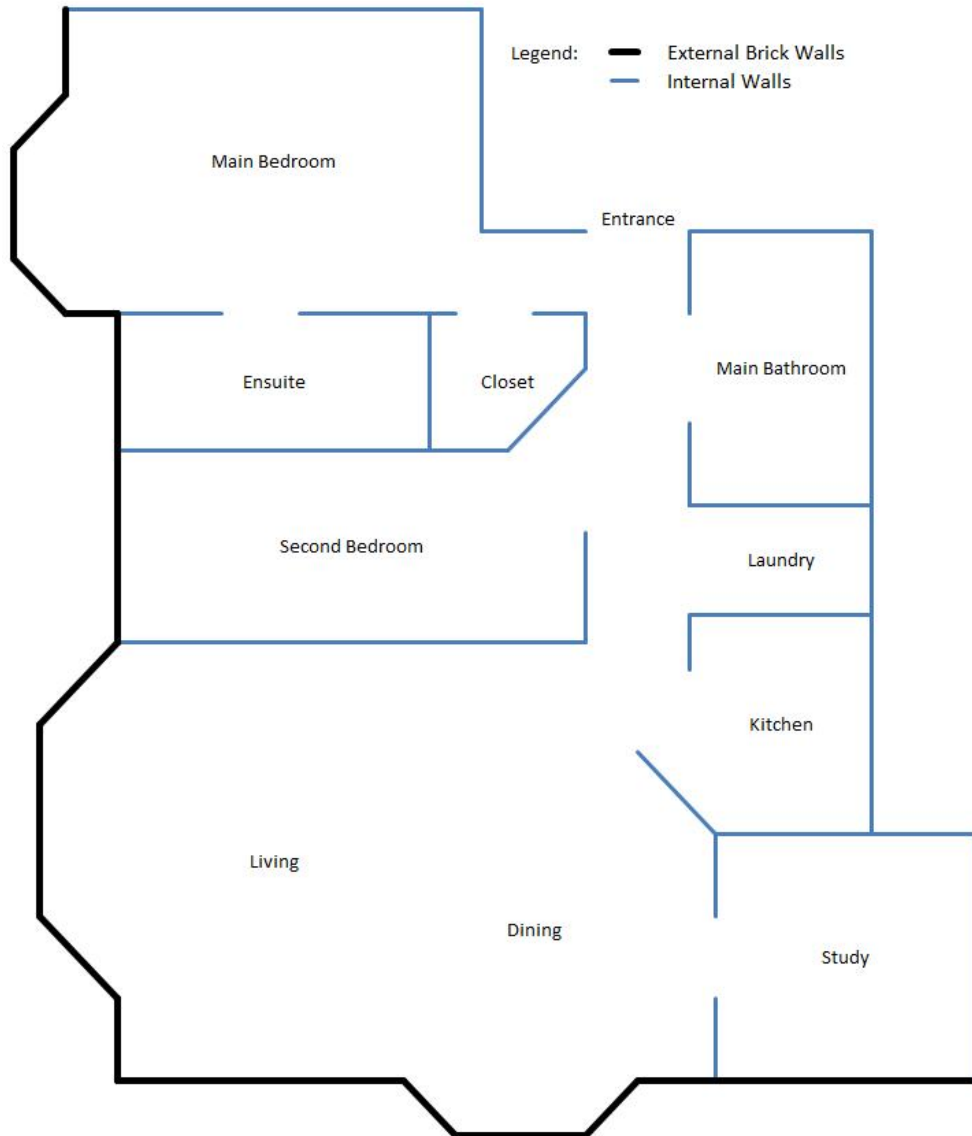


Figure E.1: Home Layout