Remote Access to Sensor Networks

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Problem Definition

Today Sensor Networks form an important part of various agencies. It is sometimes not possible for humans to reach areas where sensors can be easily fit in. These sensors can act as cognitive devices performing the tasks which otherwise a human would have performed. Being mechanical, they have a better sensing technology which sometimes makes it easier to access the environment around them and report them to a central server.

Sun SPOT sensors are a great way of deploying a network, especially due to the flexibility offered by them. This sensor runs a Java Virtual Machine on it and hence can run all the elementary programs which are written in Java. The J2ME modules and architecture also allows a lot of flexibility and code migration making it even more useful.

There are some issues and overheads involved with setting up sensors. This is not possible for naïve users, since it involves a lot of configurations which are more advanced. Furthermore, since it is programmable, without an efficient program, it is not possible to use such a device off the shelf.

For an illustration, let us take an example of a weather bureau which wants to deploy sensors which will sense the temperature and weather changes in order to make a prediction for the weather. In such a case, the end user may not have knowledge of how to configure the system in a way so as to start collecting data. An experienced java programmer can write a program to get the data, but it is of no use if it is not collected properly. Hence the flexibility has its own flip side and that is problems in deployment.

Another issue with SPOT Sensors is their range. While the devices have a very good range, it is still not global. Many times outsourcing of work also makes work more efficient. As a result sometimes the sensors can be half the globe away from where this information could make a difference. The base station has to be strategically placed in such a case. Hence it was important to make the base station independent from the control station and the information processing center in order to efficiently use the networks.

In some cases, the number of SPOT devices might change. Everytime a new device comes into the picture, due to the nature of the devices, a fresh configuration has to be done. In such a case, the network is static and not conducive for growth. Furthermore, since the required communication is mostly unicast, it involves configuring the sender and receiver in order to successfully start the communication without any handshake protocol. A quick fix to this solution to have all the sensors broadcasting their data at the same time and the receiver reading all the broadcasts one after the other, but a quick thought tells us all the negative points associated with such an approach, security and network congestion being the prime factor in mind.

A factor to consider is the setting up of a database. Most relational models do not support temporal changes, but in case of our need, the Database is inherently temporal since data keeps changing and a snapshot is definitely not intuitive enough for most of our results.

In most cases Sensor Networks need an efficient access mechanism and the data is supposed to be aggregated in order to be presented. The data in such cases is not important on its own but important only when it is aggregated properly.

As seen above, Sensor Networks can be a great tool for monitoring and administering various parameters related to environment. This is where the project comes into the picture. The project aims at simplifying the use of Sun SPOT Sensors and then in turn using them for performing analysis on various parameters such as charts, extrapolation etc.

The main idea is to have the base station connected to the internet and a centralized database in such a way as to facilitate remote connection over a web site or a web service. This way, the scope is globalized.

As always the project also aims at simplifying the various problems associated with sensor networks such as soft expansion. For an example, the ability to add a sensor to the network without reconfiguration or the ability to start off and or stop the network without any changes in the network is an example of the simplification process.

And last but not the least, it is important to add a simple and aesthetically good interface to the application. Since the web applications have progressed in the recent past, it seemed the right way to access the sensor networks. All these problems have been dealt with by the application. The details of which are present in the subsequent chapters of this document.

Project Specifications

SPOT Specifications:

Device built with an embedded Squawk Virtual Machine running Java 1.3 with SPOT App which is capable of

1) **Plug and Play Connectivity**
2) **Graceful Exits**
3) **Searching for Base when required**

This program can be run and deployed using the ANT build script. It also has a few LED's for debugging.

It also has support to change the running frequency based on the various parameters available in the sensors.

Host App:

Built on Java Version 1.6 capable of Plug and Play addition and restarting of SPOT(s) and registering new SPOT(s) automatically for future use. This supports both, the dedicated as well as the shared mode for the base station. The program is built and run using the ANT build tool as provided by most J2EE applications.

Database:

SQL Server 2008 Database backend running on a windows environment with support for DAC

The Diagram of this database has been attached later on in this document. The database when empty is around 3.8 MB and can expand as per requirement. Since it is SQL Server 2008, it supports all the ACID Properties as declared by Microsoft

Web Site

This is an ASP .NET website which supports direct access of the Data in the Database. A part of it has been reconstructed using the MVVM Design pattern and a special emphasis on various object oriented technologies.

This website also has some Atlas Ajax controls for improving the UI and the look and feel of the application.

Background and Literature Review

Sensor Networks are basically a set of devices which communicate with each other over an adhoc or an infrastructure based setup. While most networks are infrastructure based, there are a few systems which demand the use of adhoc networks. A sensor is a device which as the name suggests, senses a particular parameter and reports this to the rest of the network. A system which works at a higher level accumulates all the data reported by all these sensor networks and then makes its own report. This report could be anything from a temperature prediction to critical information about dynamics of a vehicle. The sections to come will go into details of this setup.

Applications and Types

Sensors have their application in almost all types of fields and hence the Sensor Networks is an upcoming field. Some of the common applications of sensors include

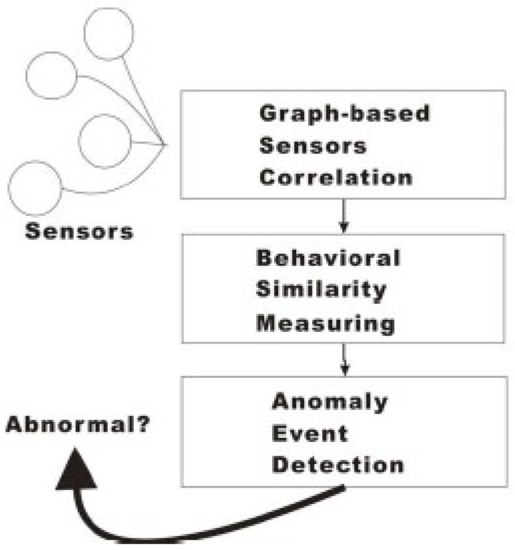
1) Weather monitoring stations
2) Motion Sensors in Lights and Electrical Appliance control in a building
3) Security System in a building
4) Parking lot sensors to determine which parking lot is open (The National Institute of Standards and Technology)
5) Traffic Sensors to monitor and report traffic

And many more can be added to the list.

Based on its use, a sensor network can be broadly classified into 4 major parts.

1) Networks to determine a parameter and perform various actions on it. Like find the average temperature of a region, or find the min and max temperature of an area
2) Predict the value of a particular attribute, for eg, predict the speed of a car or temperature in an area based on interpolated data
3) Track a particular object, for eg track the enemy tank in an area
4) Classify an object based on sensors, eg trucks, cars etc in a toll booth

In all these systems, the most important part is to relay this data to the concerned system in order to take suitable action. For eg, In case of the enemy tank, it is important to inform the authorities about the breach. In general the sensor networks can be used to identify problems as follows


Sensors
Graph-based Sensors Correlation
Behavioral Similarity Measuring
Anomaly Event Detection
Abnormal?

(Lee & Mao, 2009)

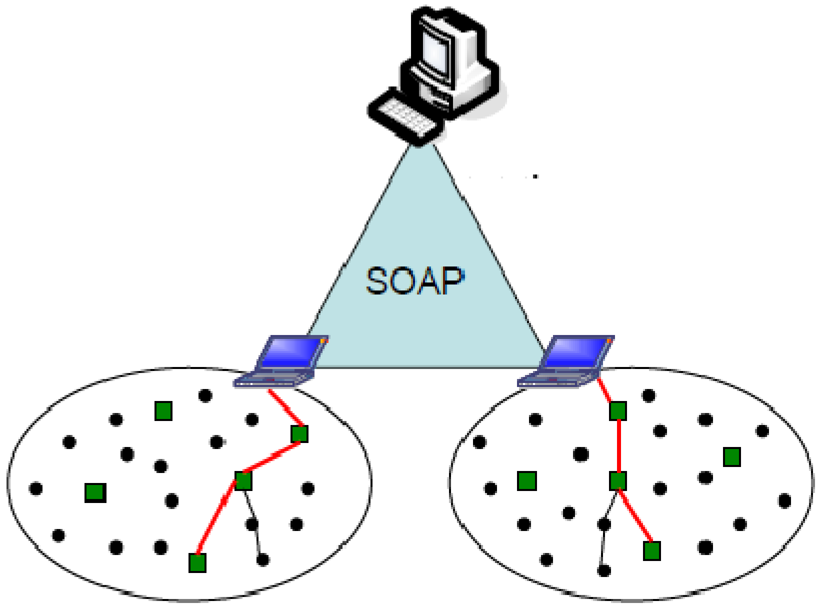
As seen in the above paper, there are several ways of detecting an anomaly using the sensor networks as well. However, for the sake of the project, this is not very important and perhaps is a great future work for the project.

Based on requirements, the network can be designed accordingly. These requirements can change. Some of the common requirements in a network include

1) Low power use
2) Large number of nodes to support
3) Network Self Organization
4) Querying ability
5) Limited availability of resources

Architecture

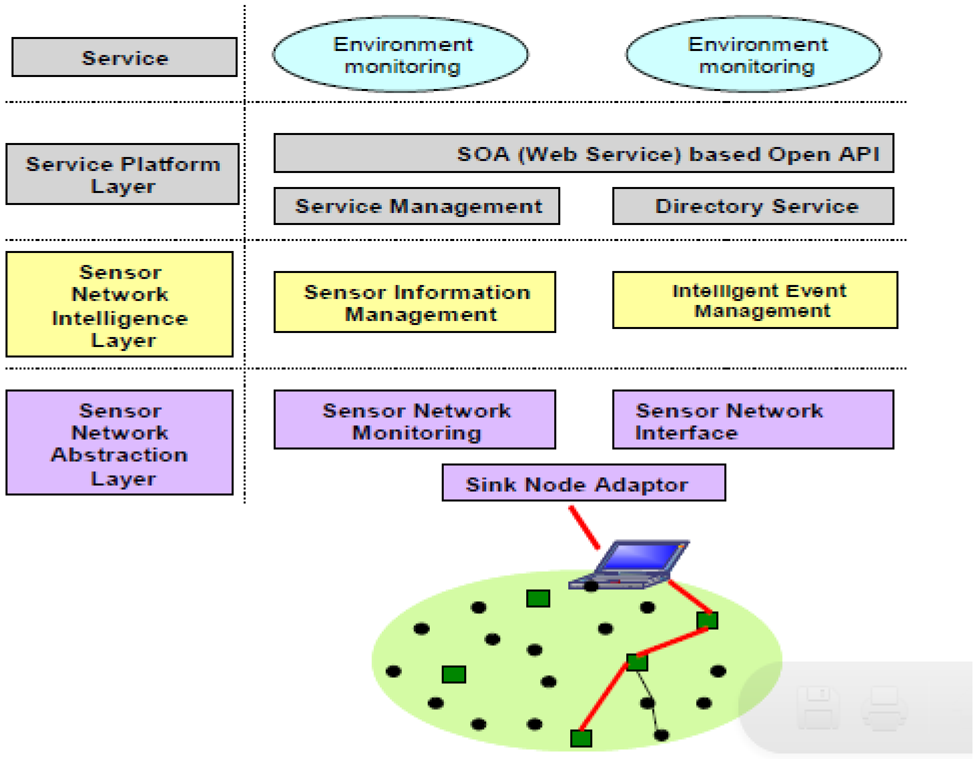
As discussed in (Lan, Qilong, & Du, 2008), the basic architecture for a Sensor Network is as follows



(Lan, Qilong, & Du, 2008)

The nodes form the end sensors while the ones directly connected to the system forms the base station. There are multiple connections which may denote a hierarchy of base stations or in some cases shared base stations.

A more detailed structure of the stack can be seen in the diagram below.


Service
Environment monitoring
Environment monitoring
Service Platform Layer
SOA (Web Service) based Open API
Service Management
Directory Service
Sensor Network Intelligence Layer
Sensor Information Management
Intelligent Event Management
Sensor Network Abstraction Layer
Sensor Network Monitoring
Sensor Network Interface
Sink Node Adaptor

(Lan, Qilong, & Du, 2008)

As seen from the diagram, each network can be divided into layers like the ISO's OSI model. Each layer has its own working and is kept independent of the next layer of abstraction. This involves a low level of coupling and a higher level of cohesion. I have tried to keep the same in the various modules of my program.

Since the diagram shown above is strictly for environmental networks, the implementation is not strictly similar to the one shown above, but as a general thumb rule, I have tried to follow the guidelines established in the application above.

Sensor Network Abstraction Layer: The main idea of this layer is to communicate with the network and have an interface for the layers above. This layer hides the complexity of the underlying network which is an objective of our problem as in the problem statement.

Sensor Information Management Layer: This layer is used to collect all the information sensed by the various sensors and maintain it in a central location. This may involve a database backend or a flat file data storage. If the Sensor Network Abstraction Layer has been implemented properly, this layer is just another application and hence is not any different from a desktop application.

SOA / Open API: This is used to expand the current application to new levels of abstraction. This will ensure that future applications can make use of our application without demanding any special privileges or rights in the application in a way which is secure and useful at the same time.

Service

This is the top level of our project which involves the data processing.

I believe that in order to ensure a good architecture, the fundamental must be strong. Hence most a great deal of effort has been spent in the first part of the project which is the Sensor Network Abstraction Layer. Around 60% of the entire code revolves around this layer of the code. (Baeg, Park, Koh, Park, & Baeg, 2007)

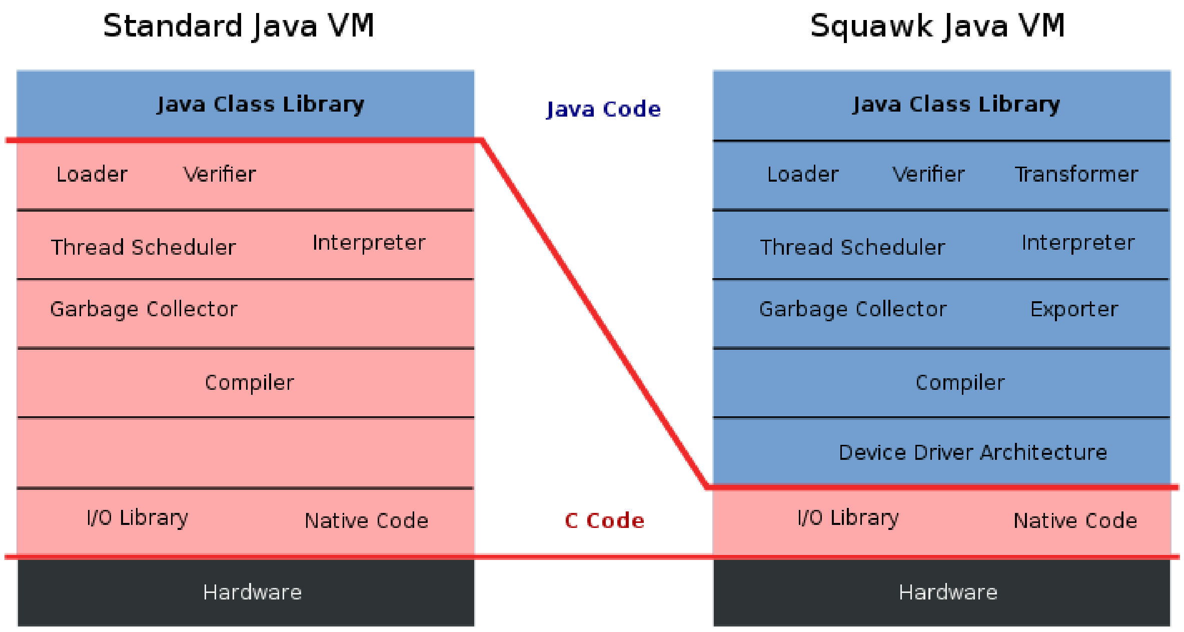
Infrastructure based networks are generally made up of a set of sensors which communicate with a central device. The central device is the one which is generally connected to the rest of the world, however this is not a requirement. If the case is different, the inner intricacies are generally abstracted away from the user.

Sensors

Sensors are usually small thin devices with limited computation capacity deployed only to perform limited tasks. Because of their limited computational limitation, the actions deployed to the sensors has to be planned keeping in mind a lot of factors.

SUN Programmable Object Technology

Sun Spot sensors are a product of the Sun Microsystems. (Wikipedia Sun Spot) . These devices are built on the IEEE 802.15.4 standard. These devices run the Squawk Virtual Machine on them which is a virtual machine for java.



(Wikipedia Sun Spot)

As seen above. The Squawk Virtual machine has all its layers and a stack of its own which runs on top of the device and provides an abstraction for the end programmer. Hence the programmer can write programs in Java and deploy them over the sun spot devices and expect them to run as they would on their systems.

The Spot devices have their own API which is programmed using java programs and the internal systems can be queried using this API.

Sun provides a diverse development environment where in programs can be written in an environment of choice by the user and later deployed to the devices. These devices can be connected to the system with the use of a USB cable and hence be programmed. The programs are then deployed using ANT Build Scripts to the individual devices. The same is applied for the base station. The base station however runs closely with the VM on the system, and hence runs a regular Java VM.

The program can be divided into two parts

1) Spot App: The app which is deployed on individual Spot sensors which works on the Squawk VM and sends data to the Base station. This app has a limitation with respect to access, computational and other issues. For eg this program cannot access specific objects or resources which are designed to operate only on certain machines. This VM

also cannot run native applications. This program needs a cable connection in order to be deployed, but once deployed, it can work on radio technology without a cable connection.

2) Host App: As mentioned earlier, this is a part of the Sensor Network Abstraction Layer of the program. This ensures that the top level applications such as the web server have a direct access to the sensors without bothering about the complexity or the changes in the underlying sensors (Baeg, Park, Koh, Park, & Baeg, 2007)

   This is the part of the program which runs on the base station. This is like any other Java program and hence has fewer limitations. This can also communicate with the internet and other services. Since the base station works closely with the system, it needs a connection all the time it is running. The host app can be run in two modes.

   a. Dedicated Mode: In this, only one VM is launched on the Host Machine and this hosts the base station as well as the running app. Hence the target sensor is just one radio hop away from the app. Here only one app can run at a time

   b. Shared Mode: In this, two VMs are launched by the Host machine. One VM hosts the app while the other hosts the base station. In this, the base station is 3 radio hops away from the target sensor. The major advantage of this kind of a communication is that the base station can be shared by multiple applications running on the host machine.

      The main disadvantage being that the PAN id of the device cannot be changed at run time.

Tools Used for Development

1) Netbeans : Netbeans is an IDE used for programming in Java. It is primarily used for Swing and GUI programming. It adds various features such as intellisense auto complete for code and the ability to add external Jars, compilation, deployment, etc. Since netbeans is widely accepted and used, it sticks to the standards of the Java community. The Netbeans modules provided by Sun Spot make it easier to create and deploy projects on the sensors.

2) ANT : To give a background of ANT, I would like to go back in the days of C++ where in dependancies and other support files used to create a problem. Makefiles were introduced for this reason. Each make file had a list of files which were to be compiled along with the main program in order for it to work.

Bringing this concept to Java, ANT provides the same functionality. All the dependancies are coded into XML files and the ANT scripts run the JDK compiler and deploy the various files

It is not a requirement for the project to be in Java. It has been tested successfully on C/C++ projects as well. But Java remains to be the popular technology. Furthermore, specifying of classpaths, environment variables etc can be done using the ANT Scripts

Important files

- Build.Properties – for user defined properties. Contains classpath and other user variables
- Build.xml – main build file
- Project.xml – Contains netbeans project information

3) Solarium: This is a tool provided by the Sun Systems which helps in setting up sensors and / or virtual SPOT sensors for communicating with the system. It is also used to perform various activites like

   1) Updating the sensor firmware
   2) Find out information about a particular sensor like its version, battery life, serial no etc
   3) Find out links between networks
   4) Administer a network at a physical level

4) Visual Studio 2010: This was used primarily to create the Front end part of the project. The front end page was in ASP .NET which requires a .NET Backbone. Visual Studio is the preferred tool used for this development. While many options are available, Visual Studio 2010 is the latest version and is used

5) SQL Server 2008 Management Studio: The Database forms the backbone of the project. The Database can be complicated to create and design. Luckily SQL Server 2008 provides a lot of tools for development which can help in making this process simpler. These include creating Diagrams, schema and designing table. SQL Server also has its own front end for entering and manipulating the values in the database tables

6) Microsoft Project: Project Management is an important aspect of any project and in order to do so, we need various tools which can help us in all the processes. These can

include allotting resources, dividing tasks, using CPM Pert techniques or estimating timelines. It is very important to track changes with respect to the tasks. Microsoft Project provides us with all these functionalities and reporting capabilities to create reports which can improve the productivity of any project.

7) SVN: Since this project is huge and has many contributors, it is important to have a proper version control in place. The Google Code SVN seemed to be a perfect fit for these needs. It involves installation of a small plugin in the IDE (Visual Studio or Netbeans) and setting up an account on the Google code Project.

8) Rational Rose : This was used as a UML tool for documentation purposes. Creating Sequence, statechart, Class and Use Case Diagrams.

Each of the technologies and its application will be discussed in detail in the later sections of this document

SPOT Sensor Application

Sun Spot Background

As discussed above, the Sun Spot sensors work on the Squawk Virtual Machine which supports j2ME. Hence many applications running java can be run on this machine. Most of the internal tools are available as an API for the programs and these programs can work with this API. Out of all the tools available the important ones are

1) Temperature Transducers: These can fetch the temperature of the surrounding in Celcius or Fahrenheit. This is implemented using a polymorphic reference to the ITemperatureInput interface in the com.sun.spot.resources.transducers.ITemperatureInput pakage. In order to get the value of the temperature, we first need to create a solid instance of the ITemperatureInput interface. We can use the Resources.lookup method to do the same for us.

2) Light Sensors: Like the Temperature Sensors, the light sensors can be used to sense the light incident on the sensor. They are a part of the ILightSensor interface and can be used in the same way as the temperature sensors.

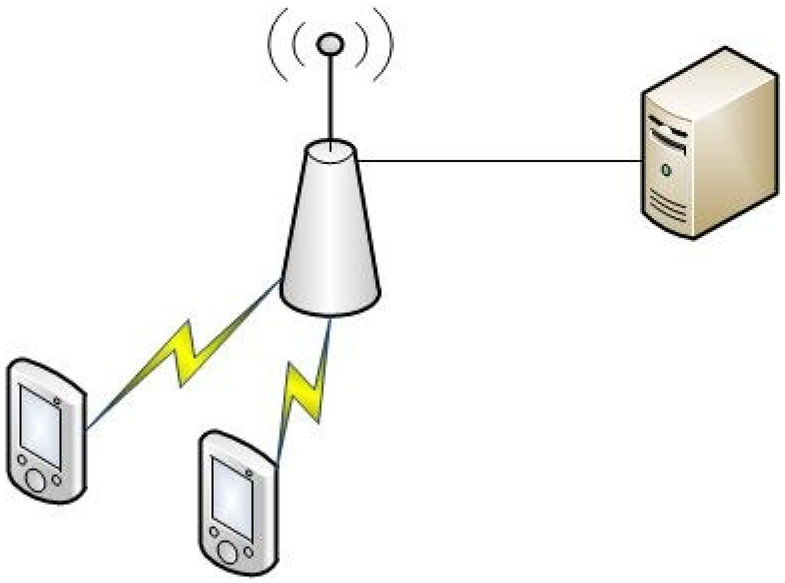
3) TriColorLED Display: Since there is no display on the sensors, the only way of signaling and having an output for debugging is through the LEDs which are present on the sensor.

4) Accelerometer Sensor: This will report the inclination of the sensor. This value can be used to sense motion, wind, velocity etc.

5) IAT91 Timer : This is an internal timer which can be used by all the applications for keeping time in their programs. While even the Date class is supported by the timer, Date is synchronized by the base station. This on the other hand will work independently

Communication

Communication takes place between the base station and a spot sensor, or a sensor and another sensor (adhoc). This happens due to the fact that each of the sensor works on a fixed frequency and the base station is programmed to accept this frequency. This frequency is pre established by the sender and the receiver. SPOT allows various channels for communication each with a different frequency in order to ensure that two different networks do not interfere with each other. This can be done using different Pan ID.



As seen from the figure, each spot device is connected to the base station which is connected to the server which hosts the host app. The sensors relay their signals to the base machine and thus work independently. Since each sensor has its own app running on its Virtual Machine, it becomes difficult to keep track of which all sensors are active in the current network and synchronize their work. Hence I had to write a module for establishing their connection. Each Sensor can be identified by its IEEE address which is printed on each sensor device. This is a 48 bit dotted decimal address and resembles the Ethernet Mac address in functionality. Hence every target sensor has a unique IEEE address.

Data and Messages are exchanged between the sensor and its host app in the form of Packets. There are two types of connections which can be established.

- Radio / Datagram Connection
- Radiostream Connection

Datagram Connection:

This is a connectionless protocol in which data is sent asynchronously from one end and received by the receiver. Hence there is no guarantee of packet loss or delay. In order to ensure delivery, external mechanism has to be put in place. Hence this is used when time and packet size is an important issue Datagram connection is the connection of choice.

```
DatagramConnection recvConn = (DatagramConnection)
Connector.open("radiogram://:100");
recvConn.receive(dg);
```

```
String answer = dg.readUTF();
```

(Sun Microsystems)

As can be seen the communication can then proceed in the form of UDP communication like any other socket program. There is a list of all different type of data that can be transferred in the form of datagrams. There is support for all the primitive data types as well as string and other data. There is support for Data Serialization, however since J2ME does not support automatic serialization, the externalizable interface is the only possible way to do so.

A major advantage of Datagram connection is the fact that it allows broadcasts. Hence if the application uses broadcast messages, this is the best way to go.

Radiostream Connection

This is a connection oriented protocol aimed at emulating the TCP connection in conventional network communication. As with TCP, it involves a guaranteed delivery of packets and hence is more reliable. This is a 3 step process which involves setting up and breaking down the connection. Once the connection is established, data transfer can commence in a way similar to streams in Java.

```
DataInputStream dis = conn.openDataInputStream();
DataOutputStream dos = conn.openDataOutputStream();
```

As shown above, streams are set up to transfer data. One of the disadvantages of this kind of a connection is the fact that broadcasts are not possible, since they do not use 802.15.4 ACK.

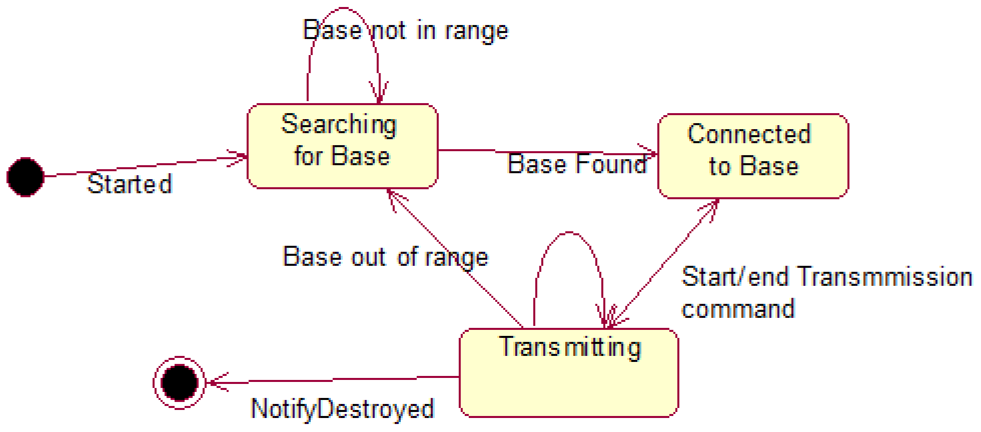
In both the above communication protocols, it is necessary to use a port. This could be any number between 0-31. However, the port must be agreed upon by the sender and the receiver in order to achieve proper communication.

Broadcast Messages

As seen above, Broadcast Messages do not have 802.15.4 ACKs and hence cannot be supported by the radiostream protocol. Hence the only way to achieve this service is through the Datagram protocol. Broadcasts do not have a fixed size and can be any data with certain restrictions. The maximum permissible size of a packet for broadcast is set to 1260 bytes of payload. However, broadcast is not recommended beyond 200 bytes due to fragmentation issues. As per the Sun Documentation, broadcast frames broken into 2 fragments are generally reliable, however those broken into 3 or more fragments generally experience packet loss. Being connectionless, it is generally not advisable to do so. If such a situation is unavoidable, a 20 ms pause between packets ensures keeping up the reception.

Structure of the Transmitter

As seen above, the application works on the transmitter. When the application is started, it may or may not be in the range of the base station. However, it may go into the range once it is started. Hence, the first state in which the app starts is to search indefinitely for the base station. I have used the Telemetry Demo as a reference from the Sun Microsystems samples to build this application. Certain classes are used while some others are based on ideas presented in various samples.



State Chart: Transmitter setup

The above state diagram explains the states which the transmitter can be in briefly. One thing worth noting is that the base station can go out of range and the transmitter will then automatically go back to the searching for base state. This functionality has been added keeping in mind that the transmission is not always reliable.

In order to achieve “Plug and Play” functionality in the sensors, I took a key out of the Sun Spot Telemetry Demo Sample provided with the sensors.

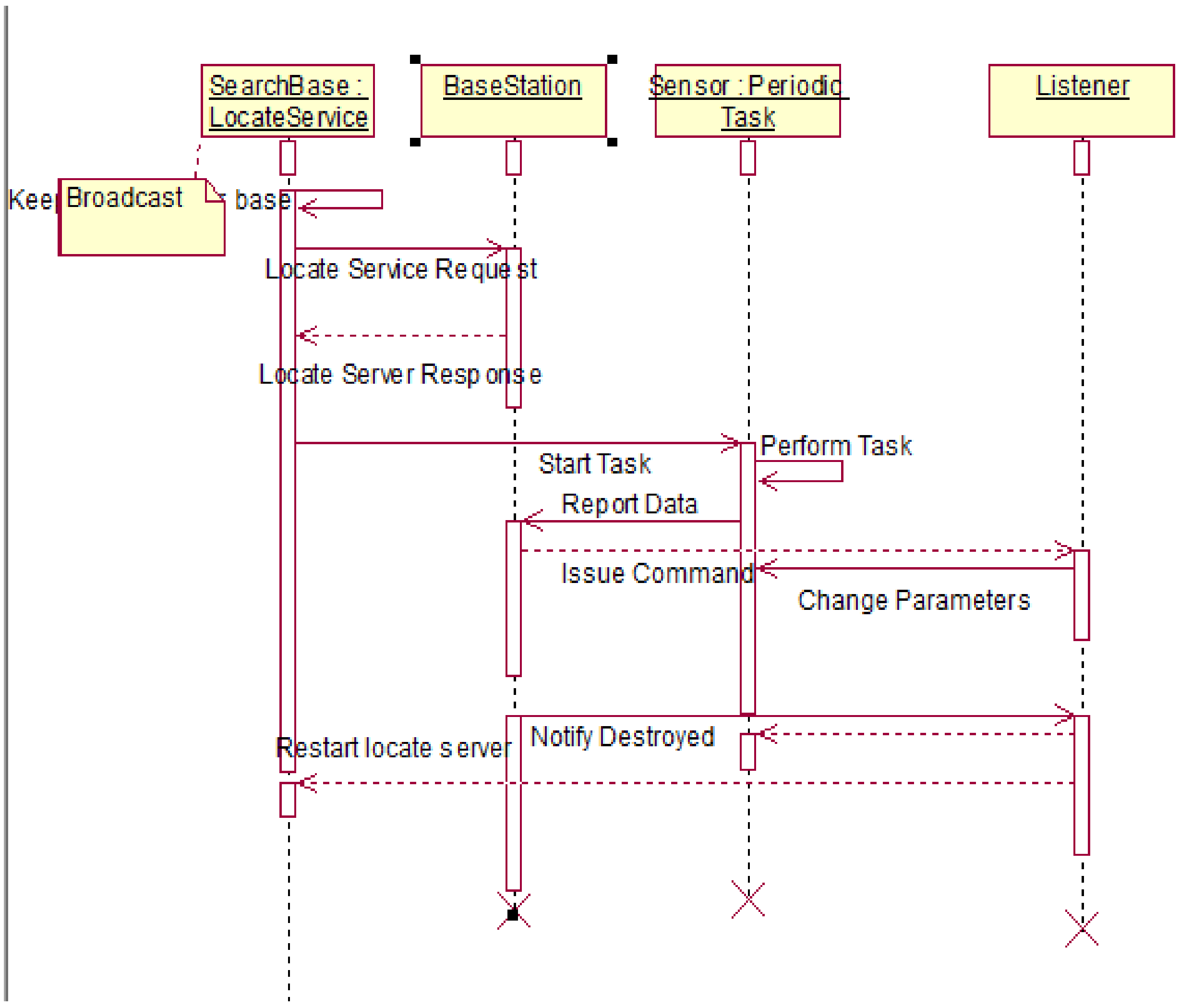
Algorithm for Initiation of Communication

Register handlers

While(true){

```
    Wait for base station
    If(Base Station found){
        Send frame
        Start Periodic task
    }
    Else
        Continue;
}
```

These actions can be better explained with the sequence diagram as below.



Sequence 1: For SPOT sensors

So in detail,

1) The base first broadcasts a Display Server Restart frame.
2) The spot first broadcasts a frame with the header (Locate Server Request).
3) The base responds to this request with a Locate Server Response Header
4) The base then establishes connection and sends the Get temperature frame which is a command to start the periodic task
5) The periodic task sends back regular frames with the Get Temperature reply frame.

The type of frames which can be sent are as follows.

Header Type	ID
Locate Display Server Request	1
Display Server Restart	2
Display Server Quitting(NotifyDestroyed)	3
Blink Leds	10
Ping Request	9
Ping Response	110
Message Response	111
Get Temperature	114
Get Temperature for Network	116
Get Temperature Reply	115
Get Temperature Network Reply	117
Get Gui Info	118
Get Gui Info Reply	119
Set Period	120

All the packet headers are stored in the org.sunspotworld.demo.PacketTypes.java file and implemented as an interface as constants and hence any class which wants to refer them can implement this interface.

Listeners

In order to implement it as an observer observable model, I followed the technique used in the sample program by having a listener for each command.

The process is 3 fold.

1) Each class which is capable of handling any type of command from the above table will first register itself with the

2) Once registered, the adapter will add the object reference to a list.

3) The handle method as per the interface will be called for every object in the list for that particular event.

Periodic Task

The periodic task abstract class Is used to implement any process which can act as a daemon on the spot sensor (Sun Microsystems). This is a class which has been provided by Sun Microsystems in their sample code. Every implementation of the task implements a multiton pattern in a way. This is made to ensure that not more than 3 timers are used. Every implementation of the multiton will have a few methods.

Components

- Timer: This is a set of 3 universal timers whose tick will determine the period for repetition of the task
- Task: The activity to be performed on each task
- TaskPeriod: the time interval in between two ticks
- ServiceName: A more descriptive name to the process
- Priority: priority in a realtime environment

Temperature Class:

This is a concrete implementation of the periodic task which sends back the temperature and light readings to the base station.

Host Application

The host app is the Desktop version of the module. The main aim of this app is to enter the readings recorded by the spot sensor into the database. This app has been written in Java as well to match the SPOT device application. In order to maintain autonomy, this app has the ability to support multiple sensors and does not require any particular device to be preconfigured as long as the sensor and the receiver agree on the protocol. As with the transmitter, the Telemetry Demo sample has been used as a reference in many places to create this application.

Spot Listener

This is the main thread of the application. It is a continuously running process. Every new thread forks off from this thread. The algorithm is as follows.

```
While(true){
    If (Incoming spot request)
        Fork()
        If(new spot device)
            Register in the database

        Initiate handshake protocol
        Start collecting data
        Display panel with data

}
```

Handshake

1) This is the first communication which happens using the Radiogram protocol(Asynchronous).

2) If a SPOT sensor comes in the range, it sends a request by first sending a Locate Server request.

3) The host app then compares the type of the arriving packet with the packet types headers.

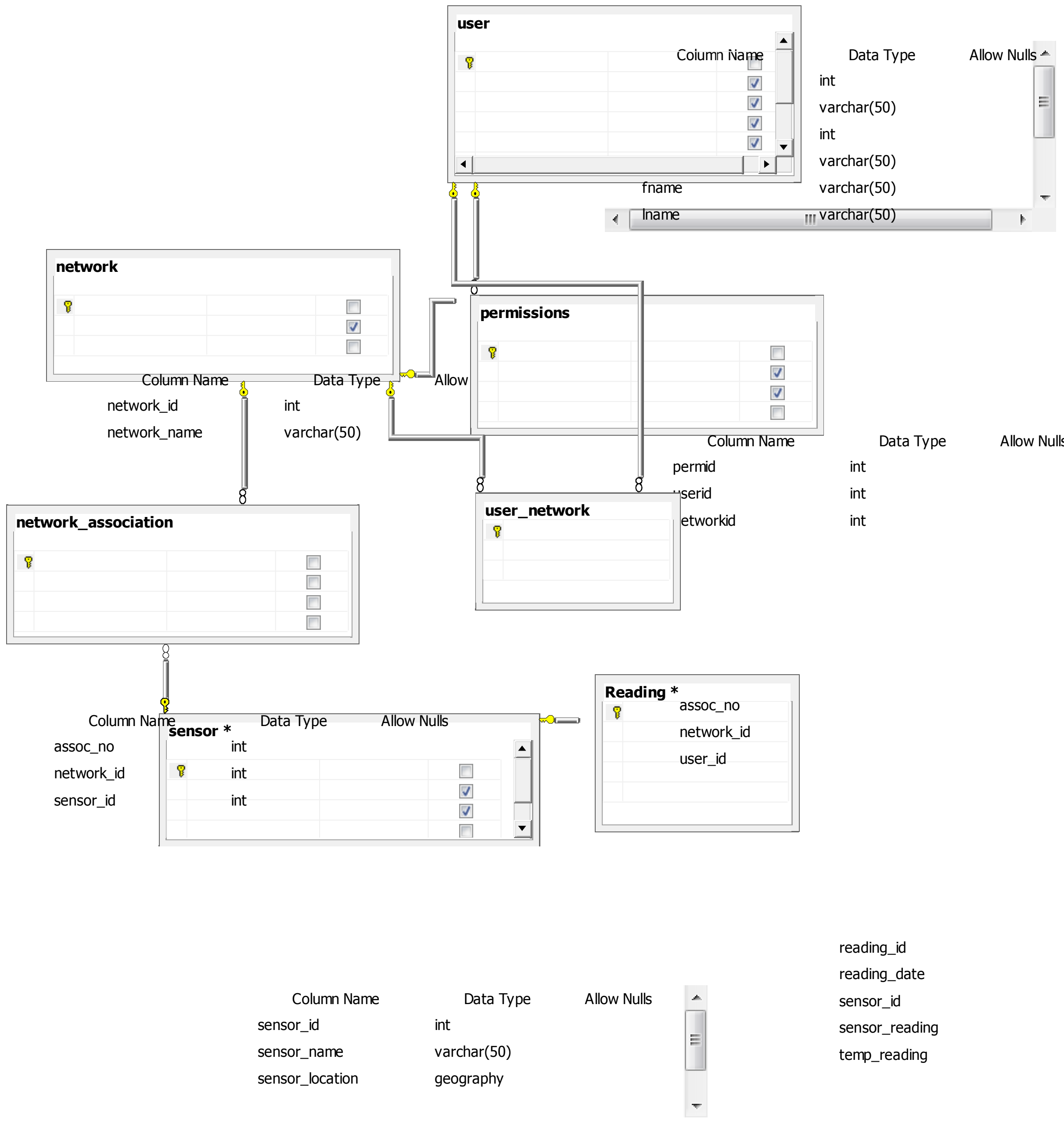
4) If it is indeed a locate server request, it replies back with a Display Server Available response

5) It then starts the listener with its own address

As seen above, all new spots are plug and play. Like the spot device, even the host app has an observer-observable pattern. Hence it has its own listener. It shares the packet headers from the spot app. It can issue a few commands to the spot app which includes

Set Period	Set the period for the sampling
Get Temperature	Get the temperature reading(Force a sample)
Send Data	Send a packet
Ping	Similar to a TCP Ping request
Blink	Blink all LEDS 10 times

Once a new spot has been connected to, the SPOT starts recording its readings, in the database. The Database Design is as follows:


user
Column Name
Data Type
Allow Nulls
int
varchar(50)
int
varchar(50)
fname
varchar(50)
lname
varchar(50)
network
Column Name
Data Type
network_id
int
network_name
varchar(50)
Allow
permissions
Column Name
Data Type
Allow Nulls
permid
int
userid
int
networkid
int
user_network
network_association
Reading *
assoc_no
network_id
user_id
Column Name
sensor *
Data Type
Allow Nulls
assoc_no
int
network_id
int
sensor_id
int
reading_id
reading_date
sensor_id
sensor_reading
temp_reading
Column Name
Data Type
Allow Nulls
sensor_id
int
sensor_name
varchar(50)
sensor_location
geography

Database Description :

The Sensor Table:

This is the table which holds all information about sensors , mainly the location, IEEE address and the name assigned to it. The IEEE address and the id is assigned by the system. However, for it to be fully functional, the location must be updated manually by the user in the web interface.

Reading:

This is where readings are logged in. This is a 3 dimensional table in the sense, it is temporally sensitive

User:

This is the table for storing information about the user. This may include his personal details and information related to the system. As per the business rules, one user may be concerned with a number of networks which in turn may have a number of sensors in it. The hierarchy is maintained in the database.

Network:
This is a group of sensors which are combined together as a network. This may not be tantamount to the fact that all sensors share the same base station. In fact the current business rules permit the association of multiple sensors from different networks to the same network by providing an abstraction layer. It also means that sensor may be a part of multiple networks.

Web Interface

The web interface is an ASP .NET interface which sits on top of the existing database. This provides a flexible interface for the users to access and modify the parameters related to the sensors, and also to obtain various visualizations on the data. This is another way of interacting with the sensors remotely. The web interface provides the flexibility achieved by the application with the added advantage of being accessible remotely.

The web interface could be divided into various pages as follows:

1) Register.aspx

   This page is used to initially register a user in the system. Each network is a function of a user and hence the user is the top level class in this case

2) Login.aspx

   The name is self explanatory. Once registered, the user can login securely into the network. Behind the scenes, this is the page which will eventually set the sessions for a successful login

3) AddSensor.aspx

   As mentioned before, in order to make a sensor available on the map, it is essential to register a sensor. This can be achieved using this page. This page provides the map where the user can register the sensor at a particular location.

4) Visualization.aspx

   This is the page where the user can get charts on the statistics of the network.

5) Map.aspx

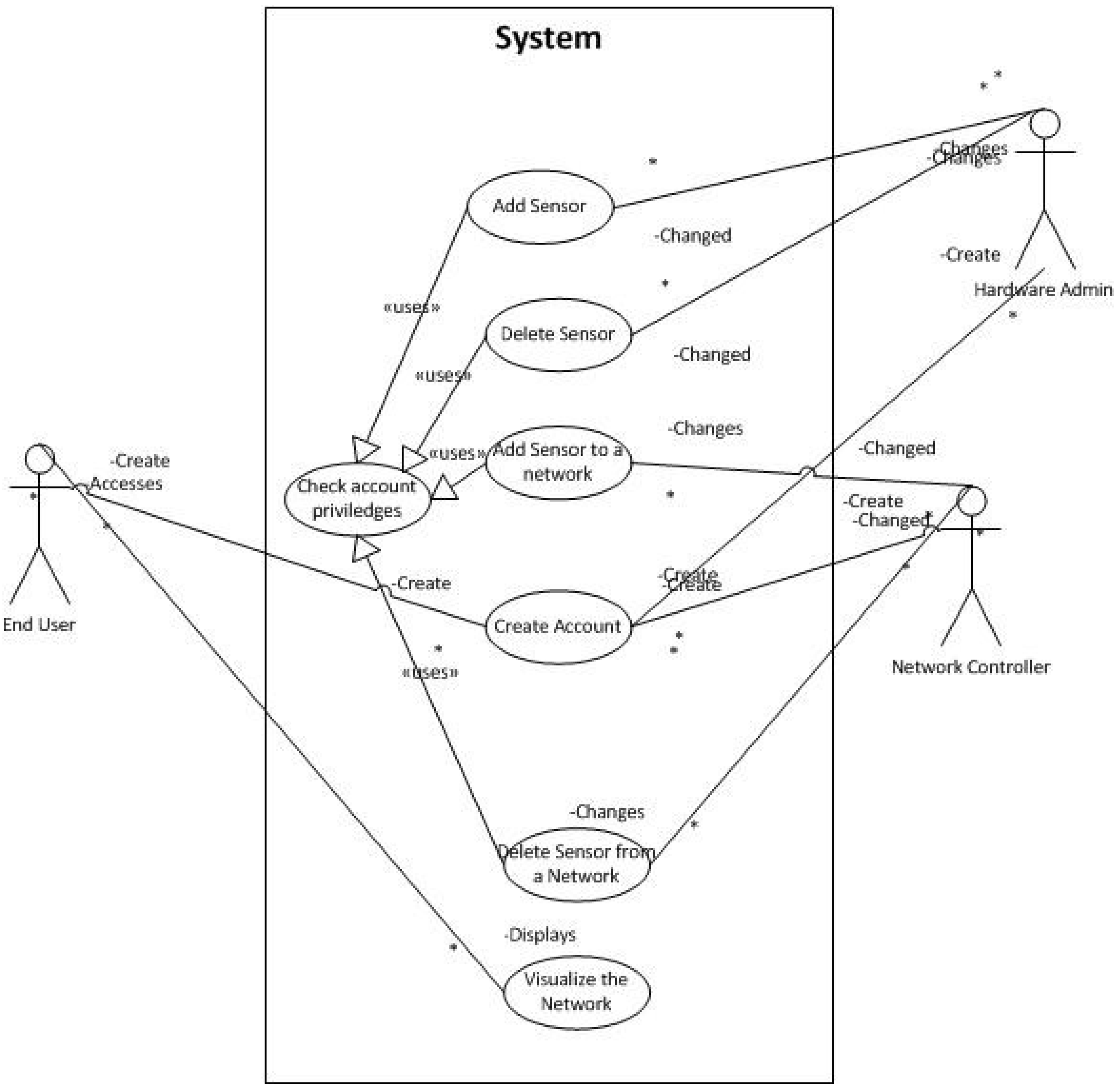
   This is the page where the user sensors are shown on a GIS map.

User:

As seen from the database, each user may be interested in a series of networks. These networks in turn could have a collection of sensors. Hence the sensors have an indirect association with the user.

Structure:

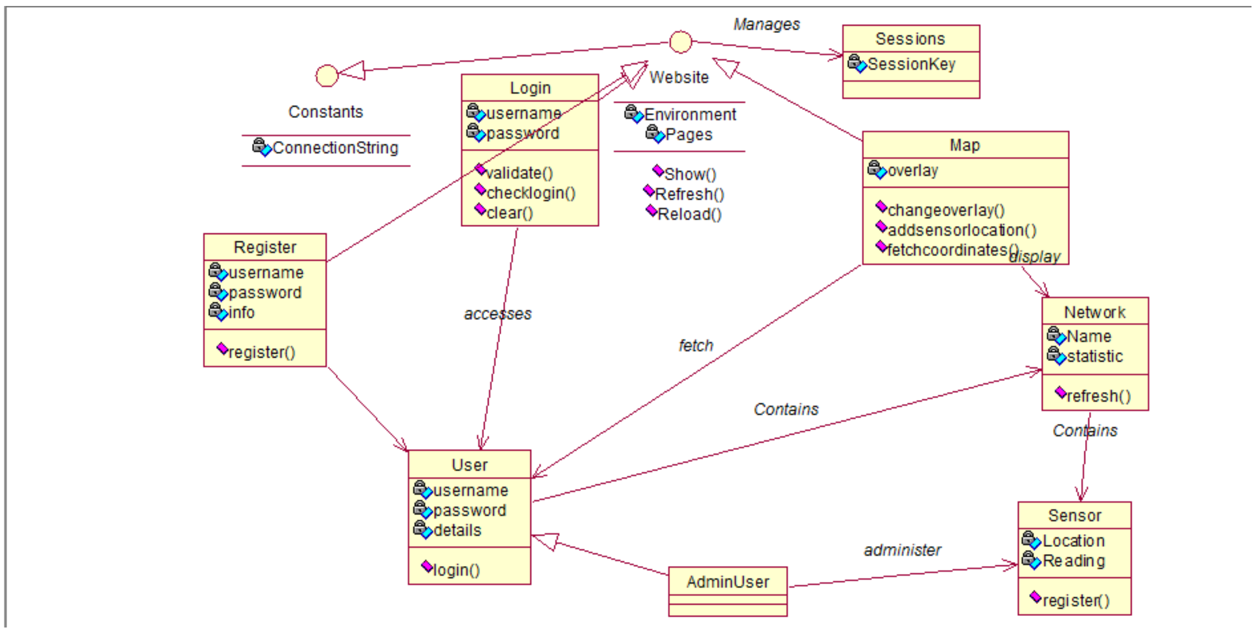
The use case diagram below will describe the functions better



Use Case as in Proposal 1

The use case diagram points out the hierarchy present in the users. This is also visible in the class diagram as presented in the later part of the document.

The structure of the C# application can be better explained by the class diagram as shown below.


Manages
Sessions
SessionKey
Constants
ConnectionString
Login
username
password
validate()
checklogin()
clear()
Website
Environment
Pages
Show()
Refresh()
Reload()
Map
overlay
changeoverlay()
addsensorlocation()
fetchcoordinates()
display
Register
username
password
info
register()
accesses
fetch
Network
Name
statistic
refresh()
Contains
Contains
User
username
password
details
login()
administer
AdminUser
Sensor
Location
Reading
register()

GIS and Maps

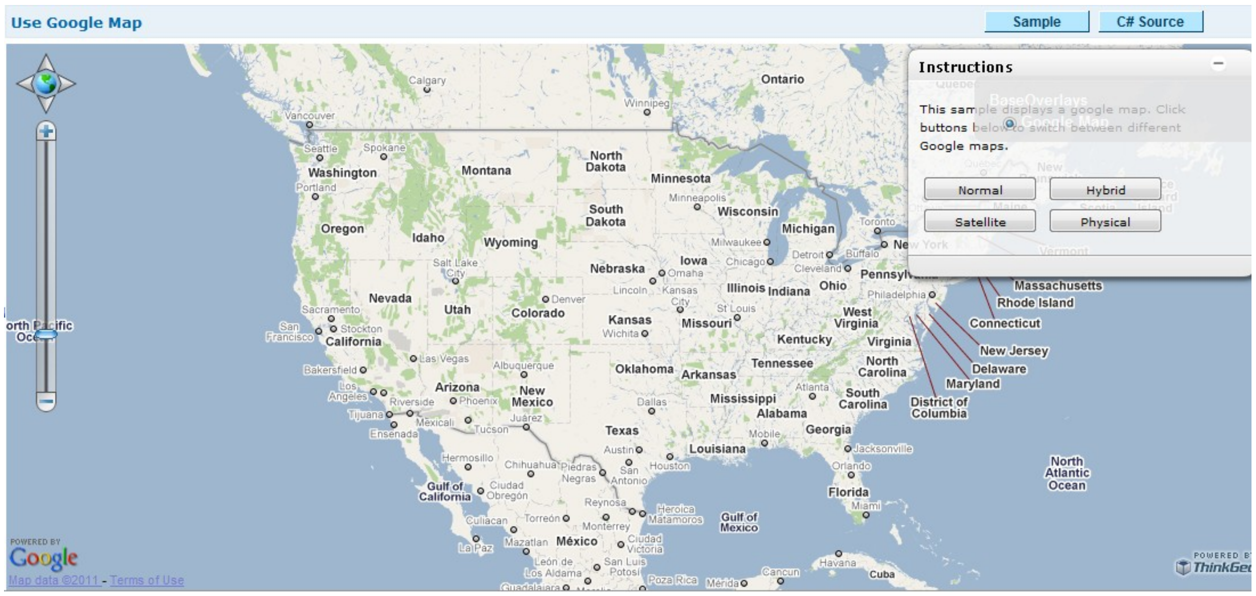
Background and Need in the Project:

As seen in the proposal, one key aspect of the project is visualization. Visualization helps us in making better decisions with respect to the data. Along with Data Mining, presenting this data in a more user friendly way and reducing the need for imagination is one of the key elements of the project. This involves representing the Data in a more efficient manner. This is where the GIS module comes into the picture. The GIS module is a very standardized way of projecting the sensor locations on a global map in order to paint a clearer picture in front of the user. Doing so will help monitor the various networks and immediately identify problems or solutions if any from the map. The map also helps in extending the project by making the various geographic parameters in a system. One example of this extension would be to extrapolate weather conditions in regions where sensors are not present by means of their proximity to actual sensor locations. While this is not a part of this project, it is a possible future development for the project and not a huge leap from its current status.

Think GEO Application Programming Interface:

Instead of Re-Inventing the wheel, I decided to make use of existing libraries to implement this module and concentrate on the Spatial Data Storage, and implementation of this. For this purpose, as proposed earlier, I made use of the Think Geo Web Edition with Ajax. (Think Geo Software, 2011). A look at the samples provided gave me a good idea for its implementation in my project.

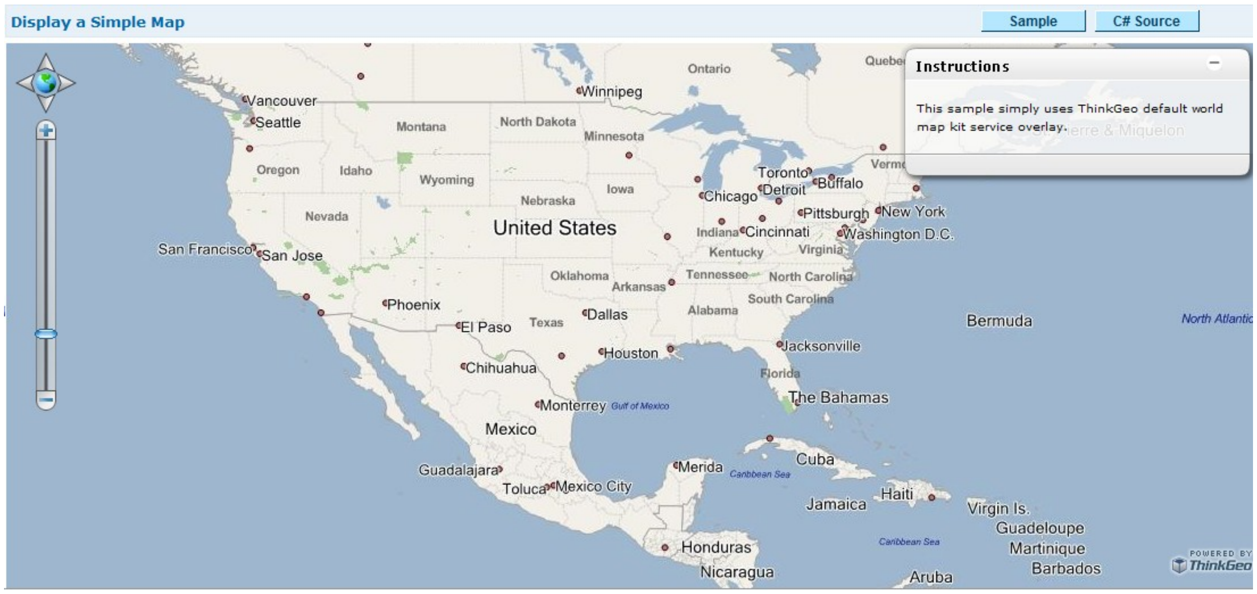
The API provides a map overlay. It has the ability to add a custom overlay such as Google Maps API or Bing Maps or use their own overlay.



This sample displays a google map. Click buttons below to switch between different Google maps.

(Think Geo Software, 2011)

As seen above the overlay can be added to the MAP implementation in order to have a custom implementation. From the project point of view, the user can have a familiar Google Maps Interface for the application while maintaining the data which is provided by our application. For the purpose of the project however, I have preferred to use the regular overlay for the sake of simplicity.



This sample simply uses ThinkGeo default world map kit service overlay.

(Think Geo Software, 2011)

Basics of GIS Programming

The main idea behind GIS is that data and visualization are stored separately. Hence, we store information along with metadata in the database and this data is rendered at runtime based on the other parameters. One of the most common way of storing spatial data is in the form of SQL Geography objects. (Microsoft Corporation, 2008)

This data type provides the capability to store semantically information related to all geography objects on the map in the form of

- Point
- LineString
- Polygon

  And many more

For the sake of the project, we are only concerned with the Point Datatype. All these structures are based on the OGC Specifications. (Ryden, 2005)

Point:

As with Geometry, a point is a dimensionless entity which can denote a single quantized place on the map. A point is made up of a variety of parameters, but the most common way of representing a point on a global map is with the help of its **Longitude** and **Lattitude**.

Since both Raster as well as Vector Formats are supported, I preferred going for the Raster implementation given the fact that the Point is the most commonly used entity in the project.

Shapes:

While this is not a part of the project, I thought of sharing information about this for future purposes. In order to have a shape shown on the map, it is possible to define these spatial shapes as a part of an .SHP file which can then be accessed by the map.

SRID: Each map is identified by its SRID. In this case, I have used 4326 as the SRID. This is just a number randomly generated which is unique.

Geography: The begin geography and end geography are commands which limit the start and end of the geography declarations

Running the Application

Starting the base station

The first thing to do in this case is to start the base station. This is done by first building the host application and then in the directory with the build.xml

- Ant host-compile
- Ant host-run

The device will then automatically choose the mode to run(Shared base or Isolated). If all goes well, the program then enters a loop where in it will keep listening for SPOT sensors to connect. It is worth noting that if there is already a sensor in range, it will connect at this instance

Compiling Sensor App

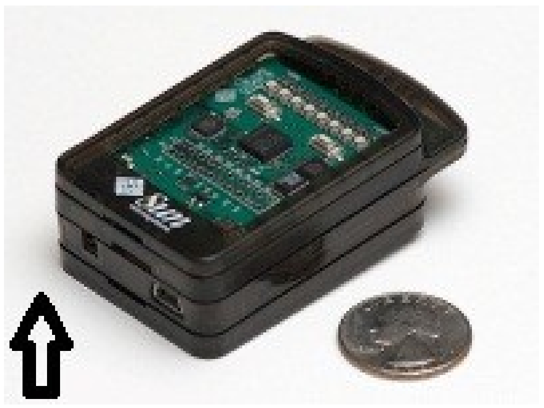
This app will be deployed using ant scripts as well. In order to compile the application we use

- Ant compile
- Ant deploy

If there is a specific sensor that we need to deploy this application to, we can use it as one of our environment variable. So that is done as

ant -DremoteId=0014.4F01.0000.0F2A deploy (Sun Microsystems, 2008).

Once the application is properly deployed on the sensor, we are free to start connecting it to the main program. This is done by restarting the sensor.



This can be done by pressing the button as shown in the figure. Once pressed, the first LED in on the device will first start by turning RED. This is an indicator that the device has started and is currently looking for a host. This LED will subsequently turn yellow when it initiates the connection process which has been described earlier and then turns green when a successful connection has been established with the host app. This is an indicator of a successful connection. In any of the steps if there is an error, it will be visible with either the

LED not turning green or there being an error on the Host application side. Once connected, the application will now start sampling the temperature and reporting it to the host app which in turn will start recording these readings in the database.

If this is the first time this sensor has been used with the Host app, we need to specify the location. All the other registration fields are filled in automatically by the application.

Web Interface

The web interface can be run by setting up an IIS Server and running the SensorNetworksUI project in it. The default.aspx page will decide the best start point for the program. In most cases the start.aspx will be the first page.

If a user is not registered, he has to register using the registration form provided in the register.aspx page. After filling in the data, the user can then access the various controls in the program which include adding and deleting sensor locations amongst others. It is worth noting that the web interface will also need the database running and the connection string provided to the correct SQL Server. It will also need all user privileges.

Operations:

Having talked about the service platform layer, we now come to the topmost layer in the stack. This is the service layer. The service layer defines the various operations which can be performed over the network and the sensors. We have already studied a few operations in detail before. But I would like to add a few operations in this section as well.

They can be broadly divided as follows

User Setup Operations:

These include registering, setting up and logging in of the user. The authentication as of now is not encrypted, but this can be thought of as a future addition to the project when it is implemented in the real world. The validation and summary is implemented using the controls provided by Microsoft .NET .

For the reason of flexibility, I chose to not use the login user wizard control

Temporal Operations:

These include the operations which are performed over sensors in a temporal sense, which include the data in the previous timestep and the current. These operations are used on individual sensors and provide us with details of the same. The operations are statistical and are useful in extrapolating data, or guessing the status of the sensors.

I have implemented 2 such operations.

Chart: This is used to plot the graphs of various trends in the sensor data such as light and temperature. These are plots which include line, box and other common graphs implemented using the Microsoft controls.

Outlier Analysis: This is another way of testing the sensors. In most of the cases, outliers are not just a nuisance but unacceptable. It is sometimes difficult to analyze outliers since they may indicate trends and are very specific to the sensor and its current trend. The system provides a basic mechanism for analyzing outliers.

According to Central Limit Theorem, the mean of a sample will always be distributed normally. (Charles Grinstead)

Here, we define the sample as a section of the temporal readings which we find to be out of sync with the rest of the data. The hypothesis testing is performed over this sample over the population (the entire set of readings) to test for the mean and standard deviation. In case of a pass, we add this sensor to the non outliers section of the list. Otherwise, we add it to the list of outliers.

While this is a basic way of doing so, it is indeed a powerful way of analyzing outliers.

Group Operations:

These operations are those which are performed over a set of sensors together (generally over a network) to find basic parameters of these networks. These include

Parameterless operations: such as Mean, Median, Mode, Min, Max, Standard Deviation and other parameters of the networks which will indicate the statistical parameters which can be used for other complex statistical calculations

One Parameter Operations: These are operations which include operations performed on certain values such as Rank, finding out the quartile, percentile, decile etc of the sample data. These operations can help other complicated operations on the data. The Rank operation will find the rank of our parameter if it were a part of the sample data.

Probability Based Operations: These are operations which make use of probability to predict certain parameters. For eg, if we have to find the probability of a particular reading to be a part of a particular system based on probability, we can use some of the distributions to do so. The currently supported distributions include the Normal Distribution and the Uniform Distribution which will predict the probability of a value in the distribution.

Special Installation Instructions:

Netbeans:

The project can be opened directly in Netbeans. Make sure you open it as a project. The ant build scripts will import all the jar files. It is also required to have the Microsoft JDBC Drivers installed. The user.classpath value should be set in the /hostapp/build.properties file to include the path to the sqljdbc.jar file

Visual Studio

The program uses 3 different libraries which need to be installed prior to use.

1) Think Geo Web Edition (Ajax supported): http://thinkgeo.com/
2) NMath Statistics Suite : http://www.centerspace.net/
3) NMath Math Suite: http://www.centerspace.net/

These three libraries and its dlls should be included with the Visual Studio .sln file in order to run the application.

Troubleshooting

1) The base station gives an error – No Base station found
    a. Check if the Base Station is connected
    b. Check if the user has admin privileges
    c. Check if another application is using the base station
    d. Run Solarium and check for the properties
2) The File is locked
    a. Check if another process has access over it
    b. Try Restarting Netbeans or Eclipse if using it
    c. Try Restarting the System if nothing works since it could be a daemon process
3) Spot Sensor does not connect
    a. Check the batteries
    b. Check to see if the running frequencies on the base and the host are the same
    c. Check if the appropriate program is installed
4) Database is not accessible
    a. Check to see if the Drivers are installed
    b. Check to see if the jtds jar files are in the classpath. This is set in the build.properties file as discussed earlier
    c. Since the application uses trusted connection, the jtds path should be in the environment variable – java.library.path.
5) IIS Server fails to start
    a. This is generally due to a conflicting port or a server.
6) User cannot login
    a. This is generally due to a database failure
    b. Check to see if the SQL Server is accessible
7) Think GEO API doesnot show up

   a. Check to see if the trial period is still active
   b. Check to see if the right browser is installed

8) Google Maps Overlay is giving errors
   a. Google Maps sometimes change their Javascript Library address.
   b. Updating to the right location should fix this error

Testing and Analysis

As with any problem, the outcome is the most important aspect. Since the problem is complicated, various situations can lead to several different outcomes. It is the duty of the programmer to analyze all these outcomes. Depending on the circumstances, the system can either give a satisfactory result or handle exceptions gracefully. There are cases when we expect exceptions and in such cases they should be projected to the user gracefully.

Sr No	Test Case	Remarks
1	Sensor is started but Base Station is not Broadcasting	Waits for the base station by showing the orange indicator periodically changing to red indicating that it keeps searching for a base station periodically
2	Base Station is started but no sensor is in range	The base station waits listening for spots
3	SPOT Sensor is now in range	The base station recognizes the spot and starts its function by popping out a new window
4	A new SPOT Sensor is added to the network without any configuration changes	This is efficiently recognized by the system and a new admin window is opened by the system
5	One of the sensor stops broadcasting	The Base Station tries broadcasting frames till the sensor comes back in the network. This is one place where the application could improve in the future
6	The base station stops responding	The sensors lose their connection. If the base station has responded by having the notify destroyed, the base station start searching for a new station
7	The database is not functioning	A Database Connection error

		is thrown, since the sensor is not in a level where it can make a decision in such a situation
8	No user is present in the database	The network still keeps broadcasting and recording readings since the user may be added to a particular network at a later stage
9	Sensor is restarted	The Network will make the readings based on timestamps. In such cases the spacing might change affecting parameters such as Standard Deviation but other parameters such as mean and variance are still kept intact
10	A user is added with no networks in his account	The user is given access to no networks which is equivalent to not being present and as expected he is given access only once networks are assigned to him
11	A user is given access to networks	These networks and their functions show up on his web interface
12	User is trying to view the map for whom he has no access	Since the Map is password protected at loading time, it is impossible for such a situation to arise
13	A Sensor is present but not shown on the map	This is typically when the GIS location is not updated in the database. This is a drawback of the sensors due to their lack of Geo Sensing Capacity
14	Sensor Network hangs due to unknown reasons	In this case the sensor cannot send out packets with a recognized header. Hence their value is not counted in the calculations. This is still a problem but mitigated to its lowest extent
15	Exception is thrown at the web interface	The exception is very abstract

		however due to separation of the UI and the model, the exception only affects the target user but the system remains intact
16	Change in frequency of the base station	This can be only changed in non shared mode. There is no run time option to do so and if done has to be a pre planned notion since it has to be done explicitly
17	Sensor with a different frequency comes into the network	Since the running frequency is different from the base station, it is as if the sensor is invisible and will keep searching for the base station. The only way to find the base station Is if it is changed to work at a common frequenct
18	Blink Command is issued	All the LEDs on the sensor will blink 10 times to indicate a successful command

There were many other cases which were run successfully to ensure that the program was to the best of my knowledge bug proof. However as with every operation there may be bugs which passed all these tests and will be fixed in the subsequent releases.

Result

The application was run on May 3rd 2011 from 2-30 pm to 4- 30 pm for testing and analysis. The test cases were as above. However, I feel that the basic description of its working is also worth mentioning.

1) The application was able to start off successfully on the system on the execution of the ant host-run command in the ./HostApp folder. The host application then went into individual or shared mode as per the availability of resources. In either mode, it kept listening for new spot devices to connect on port 43 which was the specified port for the application.

2) The SPOT app was first deployed using the ant deploy command. The SPOT was then restarted using the button and then its behavior was observed. The application ran within 5 mins of the restart. As expected the application began to search for an available base station upon restarting and once found it initiated the handshake protocol which was described in the previous text. At the successful completion of the handshake protocol, I was able to see the successful LED pattern

3) The most important phase was when the connection took place since this was the place where there was a high chance for an error. However, the connection was established gracefully. The host app made entries in the database for a newly discovered spot device or just reconfigured itself for the older ones.

4) The readings were taken once the connection was established. As programmed, both the light as well as the temperature readings were taken by the application and stored in the Reading table in the database. These readings mentioned the timestamp at the time of recording (Not entering) hence making the system more accurate.

5) The Web Site was the final piece of the puzzle but in no means the smallest since it constitute to almost 70 % of the entire application. The web site pulled out details from the database and displayed various tools for the end user to perform his operations on. The website ran on port 58213 of the localhost for testing purposes.

6) The Statistic engine was up and running and able to perform various computations and calculations

7) The GIS Maps were able to show the overlay and the various locations perfectly on the global map which was the icing on the cake. The Bing Maps however had bugs with them and hence I decided to let go off the idea.

Future Work

This project lays a foundation for many new projects. While this is a very general and open field, there are many topics and projects which I felt would be great additions to my current project but for the sake of staying focused, I could not include in the current project. I have mentioned a few which come to my mind along with a very brief description of the same.

1) Distributed Sensor Network:

    - The whole time, we operated on the principle that each sensor should be connected to a base station remotely and then the level of abstraction issued by this made it possible to have multiple networks. However, it sometimes is a good idea to have a network which is inherently decentralized as discussed. (Ketel, Dogan, & Homaifar, 2005). The advantages of using a distributed system need not be reemphasized, but the reliability gained by such an approach is worth a mention

2) Extrapolation using GIS

    - The main advantage of GIS is that the geographic semantics can be mapped to the system. Distance between two points is an important feature which can be efficiently obtained from the GIS System. This distance can be used effectively to calculate the temperature of any point on the map. This can be done by having a weighted sum of the actual values to estimate the temperature at a point.

3) Cell Phone Interface

    - As the title says, instead of extending the concept to websites, it will be even more handy if a cell phone app(Android or Iphone or other smartphone) were to be created in order to access the system.

4) Automatic GPS Sensing

    - This is more of an issue with the sensors. Their inability to sense their location makes us add an extra step of configuring sensors. However these sensors have to be stationary as a result. If the sensors are able to sense their location in the future, it may be possible to incorporate such a thing in the future technologies to come. (Yu, Choi, Park, Lee, Jin, & Kim, 2008)

5) Use of Neural Networks to predict results

    - The part of data collection has already been successfully executed. Now more effective and accurate techniques for data prediction can be used to effectively predict the outcome of various questions. Neural networks is one such approach. (Guan & Li, 2007)

(Microsoft Corporation, 2008)

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