**Introduction**

Temperate forests cover about 6% of the Earth's total land surface. Other than tropical forests, temperate forests experience all four seasons, including winter. For wildlife and plant life to survive, the temperature must range between -30̊ C to 30̊ C. Due to the theory about the effects of global warming, temperate forests stand the risk of substantial temperature increase above 30̊ C during summer, and substantial temperature decrease below -30̊ C during winter, which pose a threat to wildlife and plant life. To begin to address this issue, monitors have to be set up in these remote forests. These monitors will consist of temperature sensors which will periodically record temperature readings. Due to how vast temperate forests are, robots will be required to implement this monitoring system.

**Challenges**

Attempting to implement the system in a forest brings up some challenges. One of the main challenges that may occur when designing this system is addressing the vastness of the forest. How big the forest is (in square miles) determines how many RF radios will be needed for wireless communication. It also determines how many temperature sensor stations and mobile robots are needed. Also physical obstructions in the forest can communication. Another factor that comes into play is the terrain of the forest, which limits the robots’ ability to travel throughout the forest and may also affect wireless communication. Weather and its effects on the design components is also a main concern. Wildlife and plant-life interference with the system should also be considered. There are also no electric outlets in a forest so a reliable power source for each component is an issue.

**Requirements and Constraints**

Based on some of the challenges that may arise, the design should have these minimum requirements:

1. Each mobile robot must be designed with traction power wheels for maneuvering the terrain.
2. Each temperature sensor station and mobile robot will include an overhead enclosure for weather protection.
3. Each component in the system will be battery powered. Each component should be operational for the duration of three months before needing a replacement.
4. The system will be designed for temperate forests no bigger than 100,000 sq. m
5. Components will only be operational during summer and winter months for energy saving and maintenance purposes.

**System Design**

1. Sensor Network Architecture

The sensor network infrastructure will be in the form of multiple networks. Due to the vastness of the forest, a network will be implemented in different regions of the forest. Each network will contain a temperature sensor station consisting of a temperature sensor and an Xbee Zigbee radio for wireless communication. The Xbee radio operational temperature and humidity conditions are -40° C to 85° C, 0-95% humidity non-condensing, so it will be suitable for this application. Both the temperature sensor and Xbee radio will be driven by a physical computing platform containing a microcontroller. In the network there will also be an Xbee radio set as a router connected with a wireless device with a much larger bandwidth than a regular Xbee radio. This wireless device will consist of a cellular radio capable of connecting to the internet. By connecting to a cellular tower, it will be able to connect to the internet. This will be the gateway in the network. It will be placed as close as possible to the edge of the forest to a secluded area.

Each network will be implemented with a mobile robot. The robot will travel from the communication range of the temperature sensor to the communication range of the gateway to relay information to the internet. Each robot will have an Xbee to collect data from the sensor and relay the information to the gateway. The sensor that will be used for this system is the TMP36 temperature sensor.

1. Performance Specifications

The temperature sensor is operational at a voltage input of 2.7V to 5.5 VDC. It uses a less that quiescent current of 50µA, the current that is used when it is on but not operational. It also uses 0.5µA maximum shutdown current. The Xbee radio is operational at a voltage input of 2.1V to 3.6 VDC. The power cost to broadcast is 1.25 mW and the current used to broadcast is 40mA. Current used to receive data is 38mA and current used in powering down, or sleep mode is less than 1µA.

For the physical computing platform used to implement the temperature sensor station, the microcontroller used will be the ATmega328, which is operational at a voltage of 5V. All components of a sensor station will be battery powered. As stated in the requirements, all components need to be operational eight hours a day for three months. That is equivalent to about 672 hours of operation. The wattage use of the sensor, Xbee radio and microcontroller is about 1.81W. To produce power for that long period of time, a 12V battery that produces 244 Ampere per hour is required. The gateway will require power usage similar to a laptop computer. Combined with the power from the Xbee radio, power usage should be about 68.28 Watts. A 48V battery that produces 2290 Ampere per hour should suffice.

For communication, Xbee radio frequency band is 2.4 GHz and has a communication range 120 meters. Radio Frequency rate at this range is 250 Kbps. The wireless radio found in the gateway will be similar to one found in a cellphone. Whatever the frequency band is of the cell tower will be the frequency band of the gateway. For example, if the cell tower is a Sprint cell tower, the gateway frequency band would be 800MHz, 1900MHz and 2500MHz. The average communication range of a cell tower is a maximum of about 8046.7m (due to terrain). Considering physical obstructions like trees and hills, the gateway will be at the most 7232.03m away from the cell tower. The communication range of the gateway must be 6437.36m.

The temperature sensor has a scale factor of 10 mV/ ̊C, with an accuracy of ±1°C at +25°C and ±2°C over −40°C to 125°C operational temperature range. The sensor provides a 750 mV output at 25°C. The low output impedance of the TMP36 and its precise calibration simplify interfacing with an Analog-to-Digital Converter. The ATmega328 has a 10-bit ADC, which is equivalent to about 4mV/bit. For transmission between Xbee radios, data quality will be maintained using Retries and Acknowledgments to confirm reliable data delivery. Although data being transmitted and broadcasted in this system is not confidential or sensitive, the option of security is provided by Xbee. A 128-bit AES (Advanced Encryption Standard) encryption is available. To avoid collision on the same network, each sensor station and robot respectively will have its own PAN ID to broadcast so the data will be unique to that mote. The gateway will use an encryption protocol that is used by most cellular wireless modems when transmitting data to a cell tower.

When the gateway receives data from a robot, and the gateway relays the information to the internet to update the database, there are two main issues that need to be considered: The accuracy of the sensor and the time the data is received by the gateway. When a temperature reading from a specific sensor is received from the robot, there is a chance it will be 2̊ C less or greater than the original value. Also when the data is received by the gateway from the robot, the value is not in real time, due to robot having to travel from the communication range of the sensor station to communication range of the gateway. Knowing the time each robot takes to travel from its sensor station to the gateway and its speed will help determine what time the temperature reading was received by the robot. It is also the user’s discretion to be aware that the temperature values sent to the internet may have a ±2 ̊C error.

1. Information Management System

All the data collected from the gateway will be sent to a remote database hosted on ‘sensornetworks.engr.uga.edu’. Two tables will be used to organize the data. The first table will keep track of how many motes are in the system, their 64-bit addresses, and which a description to identify each mote. The second table will be a data log for data being sent from the gateway. Each log that is inserted in the data log will identify which mote the data came from with a ‘mote id’ field, the 64-bit address of that mote, the sensor reading from that mote, and a data log id to keep track of the order data is added to the table. It will be a one-way conversation between the gateway and the database, meaning the gateway will not receive or utilize information from the database. Data gathered from the data will only be used for database purposes.

When a log is added to the datalog table in the database, for user purposes it will be added to an html web page hosted on ‘sensornetworks.engr.uga.edu’. The website will contain a Homepage, which shows the title of the sensor system, a link to an Overview page, which gives an introduction to the problem, and the objective of the sensor system to fixing that problem, and a Temperature Reading link, which shows the user a table of temperature readings of each mote. The table on the website will update right after an update on database is made.

**Sensor Testing**

1. Sensor Accuracy

Getting the correct sensor value required some calibration. After taking in the analog input from the sensor, the voltage had to be converted to ̊ F reading, then sent from the router to the gateway.

1. Network Performance and Limitations

Communication between XBee router and gateway works. There was some issue with packets containing data being displayed on the gateway as another random integer value. This was mostly likely caused by a logical error in the bit shift operations of the data packets. One limitation of the network was having multiple XBee routers on the same PAN ID. For some reason when multiple routers were on the same PAN ID broadcasting in communication range, data packets would not reach the gateway. This is fine for testing purposes, since if the system was implemented in the real world, none of the sensor motes containing routers would be in communication range of each other.

1. User Experience

The website showing temperature readings of a temperate forest will be mainly for people who are interested in the fluctuation of temperature of the forest and its effects it may have on the environment. These may include environmentalists, scientists, or possibly hikers. There are no functionalities on the website to allow the user to request information. The website is strictly for viewing updated temperature readings of a temperature forest.