Base Station Design and Architecture for Wireless Sensor Networks

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Abstract

Wireless Sensor Network (WSN) systems are an invaluable tool in agriculture. Currently these systems are good at reporting and logging data, though newly available WSN systems also provide features to control irrigation and other environmental parameters. The crux of this work is making the data useable and actionable for the grower as well as the framework behind it. A stable framework is necessary for the system to gain acceptance among growers, and to guarantee long term use. A secure framework is also needed for WSN based irrigation control and for remotely accessible user interfaces.

This paper describes a WSN base station implementation that is deployed at over a dozen agricultural sites examining all key components including the base software, base to node communications, user interfaces, and data storage. After discussing the base station design the user interface that has evolved with constant feedback from growers and researchers will be presented. This system is a fully featured base station that enables growers and researchers to maximize the benefit from their WSN system.

Key words: Wireless Sensor Network, WSN, base station, design, control

1. Introduction

Wireless Sensor Networks (WSN's) are becoming an invaluable tool to growers. The ability to monitor environmental and crop conditions in real time has allowed growers to decrease costs while improving crop quality (Lea-Cox, 2011). However in order for growers to recognize these benefits they must be able to interpret, understand, and act on the data provided by the WSN. This paper focuses on the base station component of the system, i.e., the part in which data is collected, viewed, and transformed into useful information for the end user. Other key components such as sensing needs and node development are discussed in depth by Kohanbash et al. (2011). An overall network diagram is shown in Fig. 1.

Base stations are often thought of as just a central component that is used to gather data from distributed nodes. This approach allows advanced users to control their crop, it has a very steep learning curve. We take a different approach that focuses on creating a system that is easy to learn, easy to use, and makes it easy to generate actionable that can be used to improve growing conditions. This system also allows for configuring irrigation at the node level from a centralized interface.

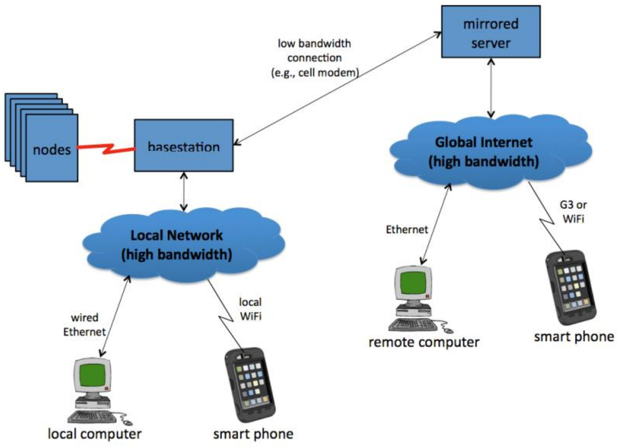

FIGURE 1: Wireless Sensor Network

2. Base Station Design

2.1. Hardware

In our system, the base station consists of two main components, the computer and the radio. The computer is typically an inexpensive laptop that runs Ubuntu Linux. It is important to note that while most systems are using laptops with relatively small memory requirement the easiest way to improve system performance is by upgrading to a faster computer. This system supports several radio modules including the Digi DigiMesh 900 MHz and 2.4 GHz modules and the Digi XSC radio operating at 900MHz. For most cases the Digi XSC radio is utilized for its simplicity as well as for the 900 MHz operating frequency which has better range and better foliage penetration characteristics. The other radios provide features such as multi hop networking and alternate operating frequencies. It should be noted that prior work (Valada et al. 2011) has developed and implemented a multi-hop networking algorithm optimized for WSN's that can be used with the Digi XSC radios.

2.2. Software

The base station software system has four primary components: the database, the base module, the user interface, and the Grower Tools module. The glue for the entire system is the SQLite3 database. SQLite3 was chosen for the fast read times associated with a file based database. Database efficiency is very important since users need to query large amounts of data (for example to create a chart). Many database optimization methods are not effective for this application. All of the data is stored in its raw form and conversions are applied as users access the data.

The base module is responsible for all node communications. This module gets data from the nodes and inserts it into the database followed by sending any newly modified node parameters to the node. The base module is written in Perl which provides a full scripting language to help parse data from the nodes.

The next component is the user interface. The user interface is designed using the Ruby on Rails (RoR) web framework. This RoR framework provides direct database access and allows for an object oriented approach to the data. For example to get data from the database a call such as "Data.last.convert" will return the most recent data entry and convert it from raw units to proper units. Another benefit to RoR is that the entire interface is a web site and is commonly configured for remote access.

The last module is for running Grower Tools. Grower Tools are derived data products that require processing; some of these tools include Vapor Pressure Deficit, Dew Point, and water use predictions made using plant specific physiological models. The Growing Tools are handled by a Ruby utility called Rake. A conventional RoR application is event driven and responds to user actions such as mouse clicks and keyboard commands. Rake allows for scripting while having full access to the methods defined in the RoR application. The Growing Tool application runs every five minutes to check if any Growing Tool needs to be run as each tool has its own run frequency. The reason for checking this every five minutes is to reduce the load on the database.

The Growing Tool interface is modular and allows for the easy introduction of new Growing Tools. Each tool consists of a database record with the input and output units of the model defined and the directory where the model script (Fig. 2) is located.

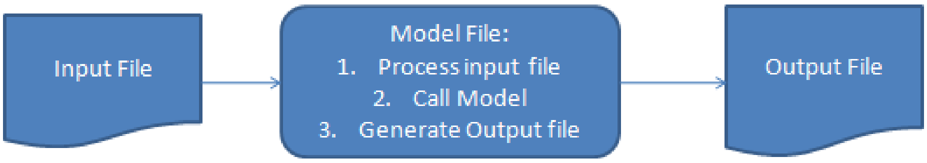

FIGURE 2: Model Component Flow

When a user creates a model instance the Growing Tool system automatically generates an input XML file based on the units that the model wants from the nodes that are selected, runs the model script, and reads in the output file (Fig. 3). The output file is then loaded into the database where it can be plotted in a chart or used to control irrigation.


```
<model_input>
    <model_id>1</model_id>
    <model_name>petunia</model_name>
    <version>1.2</version>
    <flow_rate>2</flow_rate>
    <sample_rate>5</sample_rate>
    <last_run_time></last_run_time>
    <last_irrigation_time>1308824059</last_irrigation_time>
    <last_irrigation_volume>12</last_irrigation_volume>
    <units>time,umol/m2/s</units>
    <data>1308824159,600;1308824259,400;</data>
    <meta_data>1306721010</meta_data>
</model_input>
```

```
<model_output>
    <model_ID>1</model_id>
    <version>1.2</version>
    <model_name>petunia</model_name>
    <units>ml,time</units>
    <time>1309276672</time>
    <output_values>160.721,0.0212</output_values>
</model_output>
```


FIGURE 3: Sample input and output files

2.3. Communications

A node to base station communication protocol was developed with Decagon Devices to provide secure and reliable operations. In order to keep everything in a 64KB window for radio transmission efficiency and to create a more secure system, all of the data is transmitted in binary and not using ASCII characters. CRC checksums are used to verify packet integrity, and a confirm delivery protocol ensures that each message is received by the base station from the nodes. Certain commands such as manual irrigation commands have a twofold confirmation procedure where the base station first sends the request, then the node confirms it, then the base confirms the nodes confirmation in order to ensure reliability. If there are node parameters that need to be updated the base will include a flag in the confirmation packet that alerts the node to not go to sleep and wait for the configuration updates. This method helps to conserve battery power by minimizing the awake time of the node/radio. The protocol has successfully been implemented and tested on both commercially available Decagon wireless data loggers and CMU research WSN nodes.

3. User Interface

The user interface is arguably the most important part of this system as it allows the growers to use the data and derive maximum benefit from this system (Kohanbash et al. 2011). Some of the features in the user interface include the spatial view (Fig. 4), the chart view (Fig. 5), and the irrigation page (Fig. 6).

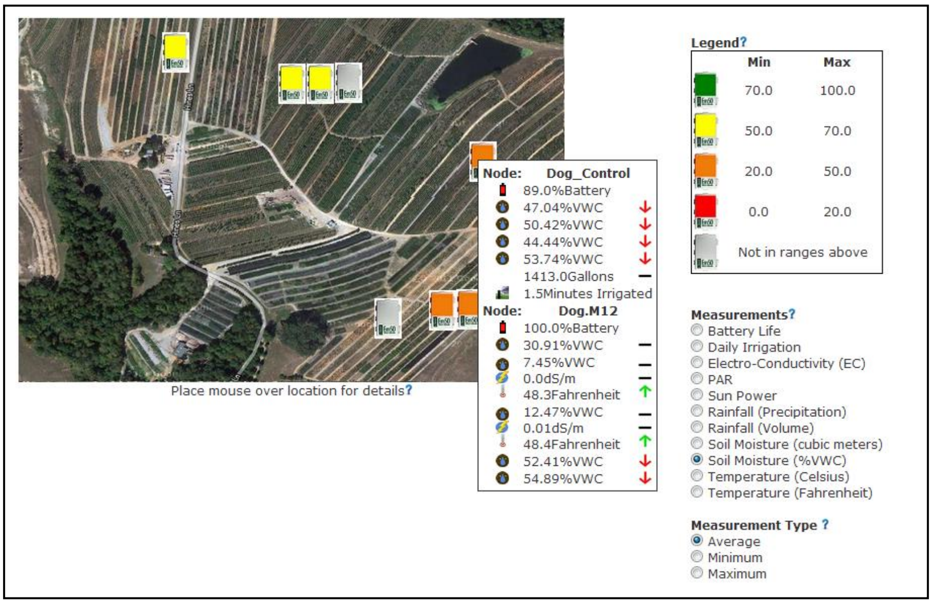

FIGURE 4: Interface home screen with spatial data view

The spatial view (Fig. 4) is the first page that users see when they access the base station interface. This view allows users to see the state of various node locations with a quick glance. The images can be set to display different settings by using the list at the bottom right of the page. By simply moving the mouse over an image the user can see more detailed information as well as the current trend for that measurement.

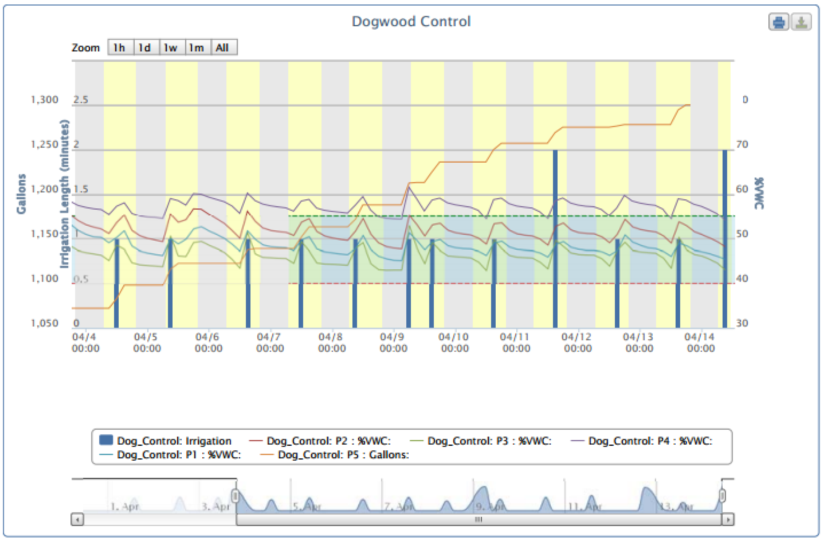

FIGURE 5: Interface chart showing temporal view. This example chart has blue bars for irrigation events, and yellow/gray bars for day/night.

The chart page (Fig. 5) provides a time series view of the data for examining trends or prior data. This page allows the user to plot data from any node and from any growing tool. Users are able to set regions that are shaded to help monitor if the values are staying in the proper range. The daytime and nighttime hours are shaded in alternating colors to further help the user understand the data. This chart allows the user to instantly change zoom levels so that a user can choose the area of interest with ease.

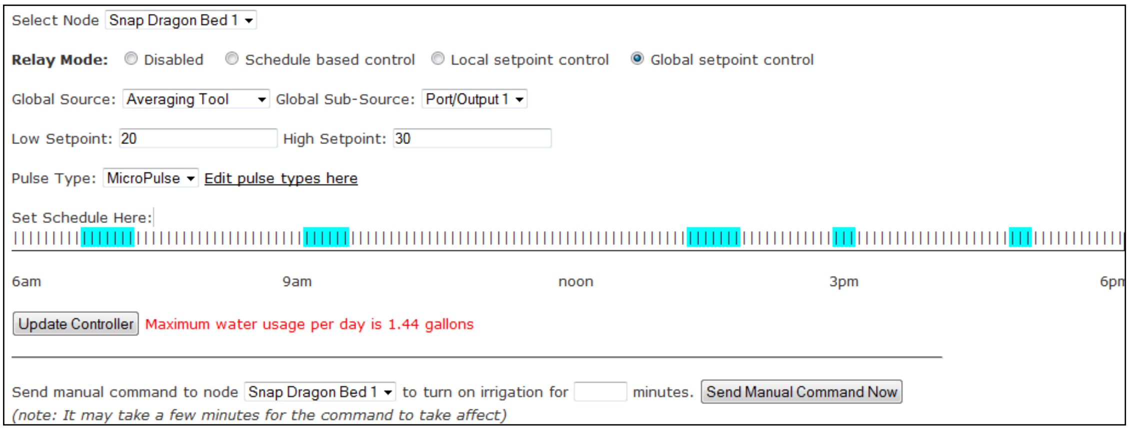

FIGURE 6: Irrigation configuration page.

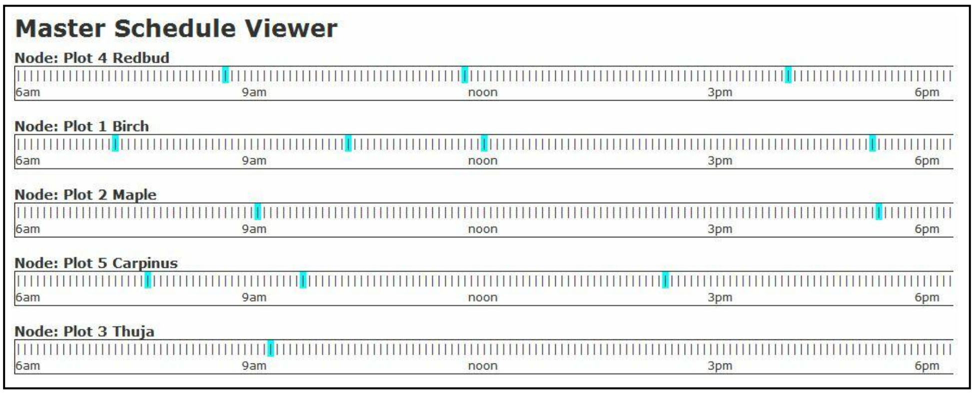

FIGURE 7: Irrigation master schedule viewer page. Growers can see all schedules to help coordinate proper resource utilization.

The irrigation page (Fig. 6) allows the user to control what irrigation method (Lea-Cox, 2011) each node should use, what schedule it should use for irrigation, as well as send manual irrigation commands to the nodes. This enables the grower to monitor and control irrigation of specific regions all from a central remotely accessible location. Other tools further enhance the irrigation experience such as the master schedule viewer (Fig. 7).

The user interface also has other tools such as data exporting, sensor calibration configuration, user/group controls, mouse over tooltip support throughout the interface and a node configuration tool. By providing the user with easy to use tools and out of the box functionality, the learning curve is reduced while the productivity and benefits are increased.

4. Conclusions

4.1. Conclusion

This design has proven to be very effective at providing reliable data handling and node communications. Additionally, this work has developed a user interface that is easy to use and provides growers with the tools to make intelligent data driven decisions. Providing a flexible user interface enables users of various levels to use the system successfully.

For more information on this project please visit *http://www.smart-farms.net* to learn how to save water, increase efficiency and to reduce environmental impacts.

4.2. Future Work

There is still significant work to be done to improve the usefulness of WSN's for sensing and control agricultural settings. The first area of work needed is the development tools to maximize the actionable results that requires less grower effort and training than the existing techniques. Another key area for future work is to continue to add features to the user interface. For example this system demonstrates a spatial view of data, however expanding that to a 3D spatial view showing sensors at different depths would be very informative to growers and researchers trying to understand factors such as sub-surface water movement and canopy temperature/humidity conditions.

5. Acknowledgments

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