ENVIRONMENTAL MONITORING WITH WIRELESS SENSOR NETWORKS

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Abstract: A architecture framework is presented for wireless sensor networks (WSN) designed to capture and monitor micro-climates in a crop field. WSN are rapidly improving their place and performance in the automotive industry and for agricultural, industrial and environmental monitoring. Uptake of this technology can also be seen inmany other application areas. Recent developments and advances in wireless technology as well as affordability give rise to this emerging field in the realm of Precision Agriculture (PA). Vineyard monitoring is an emerging application field in PA. This paper presents an architecture framework for developing a WSN and gives a brief overview of hardware components needed to build wireless sensor nodes.

Keywords: Wireless Sensor Networks (WSN), Precision Agriculture (PA) and Vineyard Monitoring

1 INTRODUCTION

Wireless Sensor Networks (WSN) have been the subject of research in various domains over the past few years and deployed in numerous application areas. WSN is seen as one of the most promising contemporary technologies for bridging the physical and virtual world thus, enabling them to interact. A WSN is composed of a number of sensor nodes, which are usually deployed in a region to observe particular phenomena in a geospatial domain. Sensor nodes are small stand-alone embedded devices that are designed to perform specified simple computation and to send and receive data. They have attached to them a number of sensors gathering data from the local environment that is being monitored. WSNs have been employed in both military and civilian applications such as target tracking, habitant monitoring, environmental contaminant detections and precision agriculture [3][4].

The work described in this paper is a realisation of a concept outlined in Eno-Humanas project [1]. It is a system for gathering (sensing) and analysing climate, atmosphere, plant and soil data. It is specifically designed for micro-climate analysis in vineyards and other agricultural/horticultural environments. This research has produced and is further developing a prototyping in order to demonstrate how state-of-the-art devices could be used in precision viticulture as a management tool to improve crop yield quantity and it is assumed, crop quality.

2 WIRELESS TECHNOLOGY

WSN technology eliminates connectors, provides safe/flexible connectivity, improves resources sharing, easy installation and mobility. The other advantage is that these systems require a low micro power levels, thus it can last for longer period of time [7]. Two major protocols are used in wireless networking, IEE 802.15.4 and ZigBee stack. The ZigBee network stack sits on top of IEEE 802.15.4 standard Medium Access Control (MAC) and Physical (PHY) layers (Refer to Figure 1). MAC and PHY layers define the RF and communication components between other devices. ZigBee stack contains the network layer, an application layer and security service provider (SSP) [8].

These protocols have their own limitations and advantages. The main limitation for the both protocols is low data rate (narrower bandwidth). Therefore these protocols are suitable for low data transmission applications.

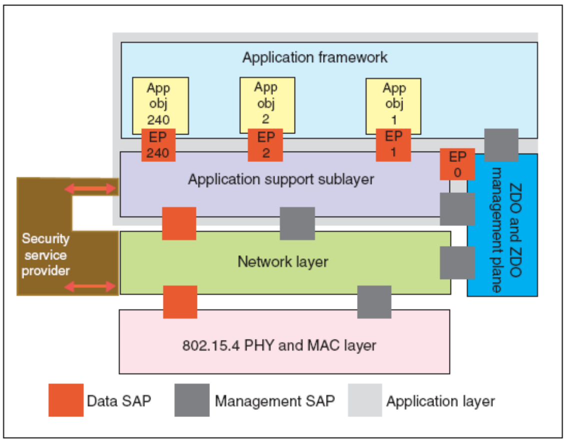

Figure 1: ZigBee stack layer adapted from [5]

As shown on Figure 2, as the data rate is increased the power consumption, cost and complexity of the system increases geometrically. Since moisture detection system is located remotely, power consumption needs to be minimal, preferably battery operation for end of product life. Moreover sensor data does not require wide band-width. Therefore as illustrated in Figure 2, a suitable protocol for small sensor network is ZigBee [8].

2.1 Wireless Network Topologies

Three main network topologies used in wireless net-working are point-to-point, star and mesh networks (re-fer to Figure 3). Each of these topologies has their own ad-vantages and disadvantages in different applications.

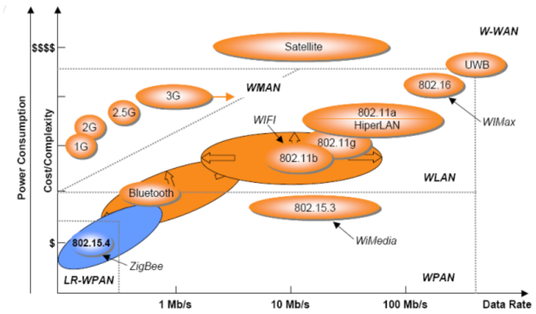

Figure 2: Standard technology map adapted from [7]

Their main difference is the use and behaviour of net-work components.

2.1.1 Point-to- point

Point-to-point is the simplest topology and mostly used to replace single communication cable. Point-to-point network can work adequately, when two end points are located close to each other [9].

2.1.2 Star topology

Star topology is also known as a point-to-multipoint wireless system. This system is usually based on IEEE 802.11 or Bluetooth communication standards. This system has one main base station, which controls the communication with all the other end nodes. The reli-ability of this network depends on the quality of the RF link between the coordinator and each of the end nodes. The main problem with this system in industrial applica-tions is the difficulty finding a suitable place for the central controller in order to communicate which each end node [9].

2.1.3 Mesh topology

Mesh topology is also sometimes called a peer-to-peer system. This system is an ad hoc multi-hop system. Mesh networks are based on the ZigBee protocol, which means each node can be used to send and receive data. In this manner, network consists of multiple redundant communication paths, which can be used in event of node failure. Therefore, data will reach its destination reliably, via the intermediate nodes (Refer to Figure 3) [9].

The mesh network has three important properties: Self-Configuring, Self-Healing and Scalability. A ZigBee mesh network configures itself automatically. The net-work identifies new nodes and automatically includes them in the network. Moreover, if one node fails the network re-routes the message through an alternative path. According to the ZibBee mesh network standards, it can support up to 65,536 network nodes (clients) [9].

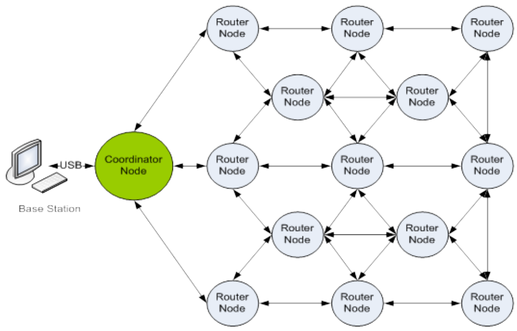

Figure 3: A mesh network topology applied in a vine-yard monitoring application

3 MODELING THE EFFECTS OF CLIMATE CHANGE

The WSN ability to simultaneously capture and relay real time data for analyzing the variability in climate change and its effects on plant physiology is significant for different grapevine varieties. This is because model-ling the relationships between climate variability re-quires both data on the cause and effects recorded with-out any time discrepancies. Complexity in the models increases with spatial information combined with other environment related parametric variables. It is assumed that in combine with one another this variable set will correlate with grape and consequently wine quality.. Gaining more insights into natural systems and their functioning including climate change involves many complex dynamic and diverse processes with nonlinear interactions that pose huge challenges to modellers [6].

A wireless network such as the one discussed herein will enable the vineyard management to decide on the kind of measures (i.e., sprinkler system, gas/ turbine heaters/ helicopter and a schedule) required for example, to pre-vent frost damage to the crops. Further details on the frost prediction and wireless sensor network issues could be found at [10]. Modelling macro-micro climate change effects has begun in this project with the use of WSN data obtained from vineyards located in three continents. This enables observations of the variability in global climate change across the continents using prediction model values provided by NASA and other institutions.

The models and results will be used in a comparative analysis on climate change effects on viticulture, especially its variability and its influence on grapevine “cultivars“ or varieties and wine quality, such as aroma, colour and mouth feel as climate change effects on viticulture is described to be dramatic and varying across the globe significantly.

4 THE WSN ARCHITECTURE

The proposed WSN system [2] consists of sensor nodes located in critical locations within vineyards for collecting weather, atmospheric and environmental data as well as plant related data such as leaf wetness and sap flow. Figure 4 shows the system architecture consists of three layers namely, mote layer, server layer and application layer.

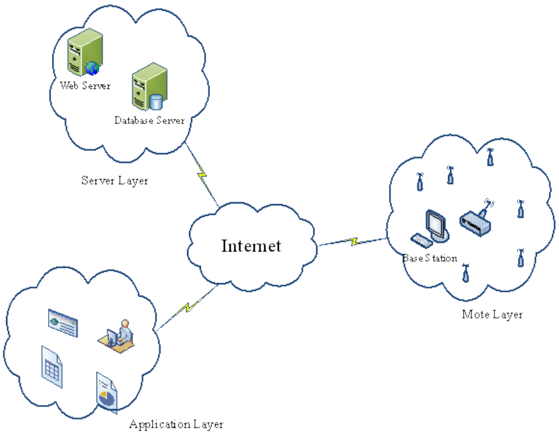

Figure 4: A schematic view of WSN architecture

Mote layer: This layer consists of all the wireless sensor nodes and a Base Station (BS). Each node has one or more sensors plugged into the hardware device with a transmitter, power supply (usually a small battery) and microcontroller. The nodes are distributed over an area of interest uniquely arranged as required provided the distance between the sensor devices does not exceed the maximum communication range. Therefore, energy optimized routing becomes essential. Data transmission from sensor nodes to the BS depends on application maybe continuous, event driven, query-driven or hybrid. In continuous approach, data is transmitted to the BS periodically according to predetermined intervals. In query and event driven models, data is transmitted when an event takes place or query is generated from the BS. The Hybrid model uses combinations of these approaches to transmit data from sensor nodes to the BS. Various types of routing protocols such as data-centric, hieratical and location-based protocols are available [6].

Server layer: Data are sent to the data server from the BS through the internet. Two main tasks performed by data server are to:

1) obtain and process data from the BS.

2) populate database with WSN data and enabling the application layer to access WSN data.

The server layer also deals with on-time data delivery from the BS and generates alarm when an undesirable event takes place.

Application layer: This layer allows users of the system have remote access to WSN data using web browsers. This provides a powerful tool to visualize real-time WSN data and compare data from various nodes. In addition, the BS can be accessed remotely to modify sensor nodes’ configurations.

5 IMPLEMENTATIONS

To achieve objectives described in Eno-Humanas project [1], a WSN prototype was designed and developed for gathering and monitoring environmental data within vineyards. Both hardware and software were designed and built by researchers at Auckland University Technology (AUT).

5.1 Hardware design

WSN hardware can be divided into two main components namely, coordinator node and router node. For both node types one wireless plug-in module is used. The plug-in board is based on CC2431 wireless micro controller. This microcontroller has on chip 2.4GH wireless radio, 128KB in-system programmable flash and hardware based location awareness. Figure 5 below shows the controller unit, which has Printed Circuit Board (PCB) antenna, on-bard power and all the I/O ports are connected to two headers.

Sensor nodes used are small low-cost, single-chip device which have their own built-in micro-processor. These nodes can automatically set up an ad hoc wireless communication network with other motes that are within range (up to100 m). These nodes are small battery powered devices allowing wireless communication capabilities (Refer to Figure 7). Sensors may be configured to send data to the BS in following manners:

Periodically: sensor node sends data according to predetermined intervals.

Event-based: sensor node stars sending data when a specific requirement is met. For instance, there may be no need for sending data to the BS unless temperature drops below a certain threshold in frost prediction task.

In this study, data are sent to the BS periodically at varies intervals for different sensors. In addition, an ultra light minicomputer with wireless communication capability is used to receive sensed data from sensor nodes. The BS also can be accessed remotely via internet to upload sensor data to the main off-site server.

In order to create a wireless sensor network, ZigBee wireless protocol based CC2431 micro controller is used. This microcontroller has on-chip 2.4GH wireless radio, 128KB in-system programmable flash, hardware based location awareness and much more other useful features. Figure 5 shows the main controller unit, which has Printed Circuit Board (PCB) antenna, on-bard power and all the I/O ports are connected to two headers.

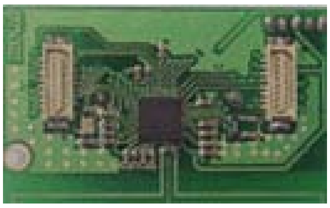

Figure 5: Wireless controller plug-in board

5.1.1 USB coordinator node

The coordinator is used to collect the information from the network and transfer the data into the computer via USB port. This board is powered through the computer USB power supply. Once data is received from the network, sensor data is transferred to the RS232 to USB converter. The converter sends the RS232 data to the computer via USB port (Refer to Figure 6).

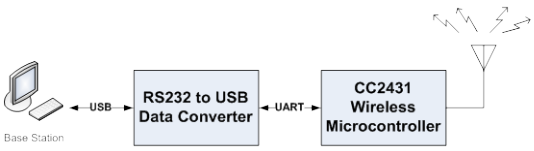

Figure 6: Base station with coordinator node

Every time new node is connected to the network, coordinator will identify the node and issues the new node with an IEEE address. During the communication between these nodes, coordinator identifies each node with the IEEE address.

5.1.2 Sensing router node

The router node can be divided into two main modules; sensor module and wireless module as shown in Figure 7. The CC2431 controller module collects the sensor readings via Analogue to Digital Converters (ADC) and transmits the data to the USB coordinator dongle via mesh network. The sensor unit is powered via 4x1.5V AA battery pack. Due to limitation on flash memory, raw data is sent to the BS without any processing. The BS converts ADC reading into appropriate values by using conversion factors.

The sensor module comprises six different environmental sensors namely pressure, leaf wetness, sunlight, humidity, temperature, and soil moisture.

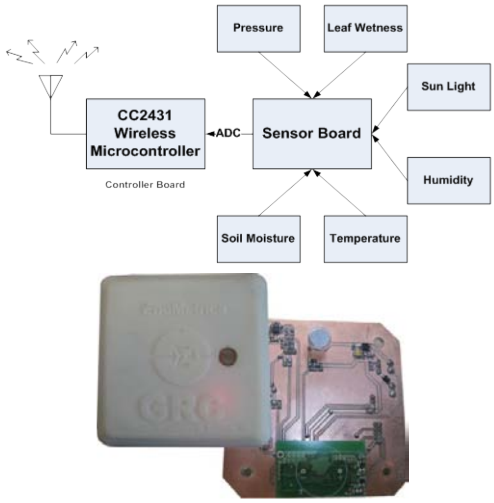

Figure 7: Router node with environmental sensors

5.2 Software Implementation

A graphical user interface designed to manage sensor nodes communication, data logging and server upload. It also provides a dashboard for displaying sensor readings and derived parameters such ad dew point (Refer to Figure 8). Historical data displayed in grid and graphical formats which can be customized to provide better visualisation of logged data.

Figure 8: Graphical user interface for displaying WSN data

Sensor modules can be added as required. Data that are collected at predetermined intervals or at specific times are transmitted through the network elements to a main computer or controller

4.3 Online web monitoring

A web application was developed enabling users to interactively access the WSN data over the internet. It allows live monitoring and visualization of climate, atmosphere, plants and soil data from each vineyard (Refer to Figure 9).

Figure 9: Live web monitoring of Awarua vineyard's environmental data

6 DISCUSSION

Power and resource management are two main issues that needed to be taken into consideration. In this implementation, one way to achieve this is to incorporate a low level controller that facilitates for more sensors and computational power. The higher level controller will handle the ZigBee mesh networking, and request the data from the low level controller. The main task for the low level controller is to collect data from the sensors and process the data for suitable format and send it the high level controller on demand. The low level controller will be responsible for the sensor power management.

7 CONCLUSIONS AND FUTURE WORK

The paper investigated the recent advances in remote wireless sensor devices, and how WSN of these devices could be combined with the internet and used in vineyard operations, such as management decision making, by monitoring weather, atmospheric, environmental conditions and plant physiology, and also for online display of climate information at larger scales, such as regionally within a state and cities in the Asia Pacific Region.

In order to improve the data management TinyOS real time system can be deployed. TinyOS tiny data base system can be used to temporary store the data within the network. Power management can be improved by introducing renewable energy sources, such as solar and wind energy to charge the batteries. The down side to this approach is that the cost of the node will increase significantly. But long term sustainability and life-time without any servicing will increase considerably.

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9 REFERENCES

[1] Sallis, P.J., Shanmuganathan, S., Pavesi, and L., and Jarur, M., "A system architecture for collaborative envi-ronmental modelling research", International Symposium on Collaborative Technologies and Systems (CTS 2008), Eds., Waleed W. Samari and William McQuay, A publication of the IEEE, New Jersey, USA. ISBN: 978-1-4244-2248-7, Irvine, California, May 19-23 2008 pp 39-47.

[2] Ghobakhlou, A., Shanmuganthan, S., and Sallis, P. , "Wireless sensor networks for climate data management systems.", In B. Anderssen et al. (eds) /18th IMACS World Congress - MODSIM09 International Congress on Modelling and Simulation/, 13-17 July 2009, Cairns, Australia. ISBN: 978-0-9758400-7-8. pp. 959-965.

[3] Camilli, A., Cugnasca, C. E., Saraiva, A. M., Hira-kawa, A. R., and Corrêa, P. L. From wireless sensors to field mapping: Anatomy of an application for precision agriculture Computers and Electronics in Agri-culture Volume 58 , Issue 1 (August 2007) Pages 25-36, ISSN:0168-1699.

[4] Xianghui Cao, Jiming Chen, Yan Zhang, and Youxian Sun (2008) Development of an integrated wireless sensor network micro-environmental monitoring system. ISA Transactions, Volume 47, Issue 3, July 2008, pp 247-255.

[5] Garcia R.R. Understanding the Zigbee stack. pp. 1-2, 02/01/2006 (Freescale Semiconductor Inc.).

[6] Ankur Suri, S.S. Iyengar, and Eungchun Cho Ecoinformatics using wireless sensor networks: An Overview. Ecological Informatics, Volume 1, Issue 3, November 2006, pp 287-293.

[7] Jose D., Gutierrez A. IEE Std. 820.15.4 Enabling Pervasive Wireless Sensor Networks. Innovation Centre, pp.2-54,2005.

[8] Egan D. The emergence of ZigBee in building auto-mation and industrial control. Computing & Control Engineering Journal, pp. 14-19, April-May 2005 16(2).

[9] Wheeler A. ZigBee Wireless Networks for Industrial Systems - White Paper. 2006 [cited 04/09/2007]; Avail-able from: http://www.microcontroller.com/Embedded.asp?did=149

[10] Sallis, P., Jarur, M., and Trujillo, M. Frost prediction characteristics and classification using computational neural networks. In Australian Journal of Intelligent Information Processing Systems (AJIIPS) volume 10.1, 2008 (ISSN 1321-2133) pp50-58. Also published in M. Kppen et al. (Eds.): ICONIP 2008, Part I, LNCS 5506, 2009. Springer-Verlag Berlin Heidelberg 2009. pp. 1211-1220.