Application of Wireless Sensor Networks (WSNs) to Oil Sands Environmental Monitoring

Leila Taheriazad, Carlos Portillo-Quintero and Arturo Sanchez-Azofeifa
Centre for Earth Observation Sciences (CEOS), University of Alberta

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Table of Contents

LIST OF FIGURES

REPORT SUMMARY

Monitoring of environmental conditions in and around oil sands developments has been underway for years. However, recent reviews have indicated the need for a more comprehensive, scientifically-rigourous and transparent monitoring program and have provided recommendations for design and oversight.

This report presents a comprehensive review of industrial applications of an emerging environmental monitoring technology called Wireless Sensor Networks (WSN). This technology consists of a series of individual wireless nodes that have the capacity to measure different micro-climatic as well as other chemical variables at costs that are significantly cheaper that current wired systems. This review describes monitoring in four main sectors: agricultural, environmental, forest, and industrial. The report reviews publications over the last 13-years; none of the case studies are from Alberta.

The report also provides a description of the establishment of a new Alberta project in which a WSN is used to monitor environmental conditions at a coal mine reclamation site. The WSN is installed at Coal Valley Mine (CVM, Central Alberta), and it represents a collaborative project between the Centre for Earth Observation Sciences (CEOS) at the University of Alberta, Alberta Environment and Sustainable Resource Development, and CVM. The system, logistical needs, and the data management system used to obtain, visualize and analyze the environmental data currently collected at CVM are described.

Given current environmental monitoring needs, plus the large areal extent of the oil sands region, wireless sensor networks have the potential to support traditional monitoring networks. The federal/provincial oil sands environmental monitoring implementation plan specifically mentions the use of remote sensing tools to enhance the monitoring system. More work is required to develop additional sensors specific to chemicals of concern in the oil sands and implement this technology in regional monitoring.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

A wireless sensor network (WSN) is a multi-hop network similar to a mobile ad hoc network comprised of a collection of independent, low-power and low-cost sensor nodes. Sensors are distributed spatially to monitor physical and/or environmental conditions (e.g., temperature, vibration, pressure, sound, light, humidity, motion or pollutants) at different temporal and spatial scales (Estrin et al. 2001, Guney et al. 2010, Johnson et al. 2009, Rashvand and Chao 2013) (Figure 1). The network requires a combination of hardware and software that is specific to the purpose (Hac 2003).

In a WSN, each node has the ability to read the detected data and send the data to a sink node through multi-hop routing (Rashvand and Chao 2013). Jiang et al. (2010) note that an important distinguishing feature of a WSN is that a number of sensors with limited resources and functions can work together to achieve a large sensing task.

Wireless sensor networks have three components that work together (Jiang et al. 2010): *sensors* (data collection, storage and transmission); *observers* (people or machines that collect and use the data); and, *sensing objects* (the subjects of data collection). Wireless sensors are compact communication devices that can be deployed virtually anywhere, in large quantities to provide detailed environmental monitoring and systems control (Cheng et al. 2013).

WSN is going to increase in popularity because it offers economical monitoring solutions for a range of issues including: traffic, pollution, medical diagnostics, disaster management, smart spaces, battlefield surveillance, precision agriculture, environmental and habitat monitoring, wildlife tracking, weather monitoring, military, and health care (Estrin et al. 2001, Haenggi 2006, Hossein Zadeh et al. 2012, Korkalainen and Sallinen 2010, Naseer 2013, Teng et al. 2008).

WSN applications in many different disciplines have evolved rapidly in recent years with significant improvements in circuit and communication devices. As such, this specific type of network is starting to move from basic laboratory applications – under controlled conditions – to field deployments under a wide range of environmental conditions (Kohvakka 2009, Zheng and Liu 2010).

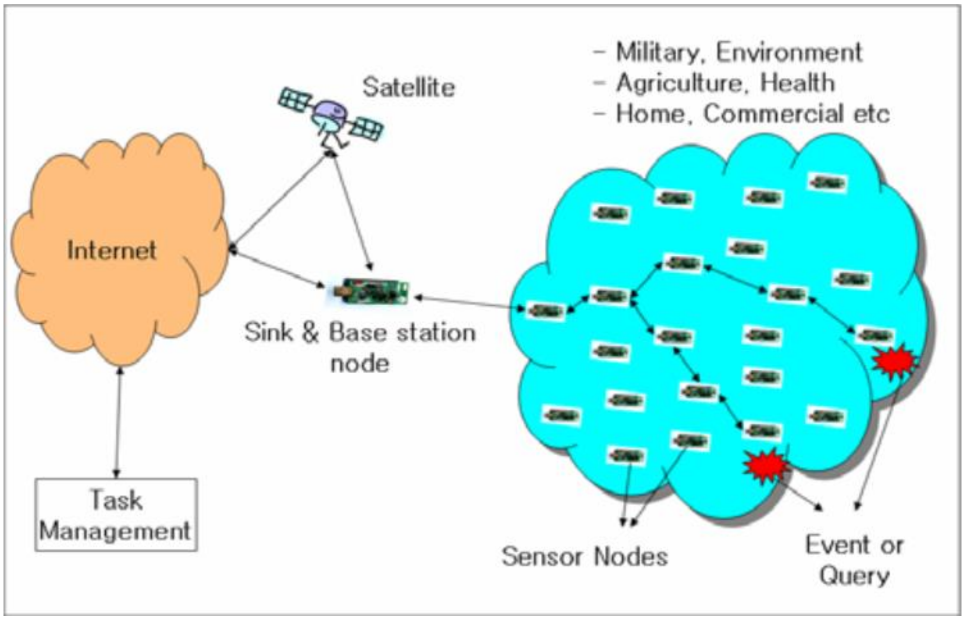

Figure 1. Wireless Sensor Network (WSN) architecture.
Figure adapted from Son et al. (2006).

1.1 Advantages and Disadvantages of Wireless Sensor Networks

Wireless sensor networks offer a number of advantages over traditional wired sensors (Chen et al. 2012, Cheng et al. 2013, Fernandez-Berni et al. 2012, Gonda and Cugnasca 2006, Hac 2003, Jiang et al. 2010, Mainwaring et al. 2002, Ruiz-Garcia et al. 2009, Sobral 2012, Zhao and Guibas 2004):

- Ease of deployment (including potential to drop from aircraft into remote and/or hazardous areas)
- Being deployed in a broad and increasing set of industries and situations for a range of purposes
- Reduced human-traffic impact in sensitive environments
- Increased safety for monitoring personnel
- No expensive and time-consuming wiring
- Large areal coverage
- Real time monitoring data
- High reliability, improved performance
- Task-specific
- Decreased maintenance costs

- Lower energy use
- Reduced downtime
- Ability to aggregate input from a variety of sensors
- Ability to link with cameras (vision-enabled)
- Ability to centralize otherwise separate controls
- Sensors can run continuously or can be scheduled for periodic data acquisition
- Sensors can be mobile (e.g., attached to farm tractors or people)
- Sensors are expendable

There are also problems that must be overcome to ensure efficiency, effectiveness and security of the network. Some of these problems arise from the assumption that the sensors will be equipped with non-rechargeable batteries and left unattended after deployment (Hac 2003, Haenggi 2006, Jiang et al. 2010, Naseer 2013, Zhao and Guibas 2004):

- Energy efficiency (power conservation)
- Limited computational power and memory
- Limited battery life
- Finite detection range for each sensor (therefore need many sensors)
- Hard to plan deployment layout in natural environments in advance
- Scalability (maintain data reliability and quality as network expands)
- Limited data transmission range (up to a few hundred metres)
- Data security (hacking)
- Must be configured for each task
- Lack of uniform standards for sensors and software

1.2 Oil Sands Monitoring Context

Monitoring of environmental conditions in and around oil sands developments has been underway for years[1] (Lott and Jones 2010). However, recent reviews (e.g., Alberta Environmental Monitoring Panel 2011, Gosselin et al. 2010, Oilsands Advisory Panel 2010) have indicated the need for a more comprehensive, scientifically-rigourous and transparent monitoring program and have provided recommendations for design and oversight (Environment Canada 2011, Government of Canada and Government of Alberta 2012, James and Vold 2010).

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[1] A search of the keyword *monitoring* in the Oil Sands Environmental Management Bibliography (http://osemb.cemaonline.ca/rrdcSearch.aspx) lists 239 references.

These reviews resulted in establishment of the Joint Oil Sands Monitoring (JOSM[2]) program, which is evolving into the Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA[3]).

The Wood Buffalo Environmental Association (WBEA) has been monitoring air quality since 1977[4] and currently operates air monitoring stations in the oil sands region measuring up to 10 air quality parameters[5]. WBEA's Terrestrial Environmental Effects Monitoring (TEEM) program monitors impacts of air emissions on natural ecosystems using a variety of tracers environmental tracers, such as chemical signatures of emission source types and stable isotopes of sulphur, nitrogen, oxygen, lead and mercury[6].

The Regional Aquatics Monitoring Program (RAMP) monitors the aquatic environment for potential effects related to industrial development[7]. RAMP monitors specific lakes and rivers in the oil sands region looking at climate, hydrology, water quality, benthic invertebrate communities, sediment quality, and fish populations[8].

The Alberta Biodiversity Monitoring Institute (ABMI)[9] is monitoring and reporting on the status (current condition) and trends of Alberta's species, habitat, and human footprint across Alberta and has recently released a report on the oil sands region (Alberta Biodiversity Monitoring Institute 2013).

The Cumulative Environmental Management Association (CEMA)[10] has also undertaken research work to support development of environmental management guidelines relative to the oil sands, some of which relates to, or relies on, environmental monitoring (e.g., Ciborowski et al 2012, Golder Associates Ltd. 2005, Matrix Solutions Inc. 2012, Monitoring Technical Task Group 2011).

Given the environmental monitoring needs identified in this section plus the large areal extent of the region to be monitored, and the capabilities of wireless sensor networks described in s. 1.1, it is evident that WSNs have the potential to support traditional monitoring networks. The federal/provincial oil sands monitoring implementation plan specifically mentions the use of remote sensing tools to enhance the monitoring system (Government of Canada and Government of Alberta 2012).

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[2] See http://www.jointoilsandsmonitoring.ca/default.asp?lang=en&n=5F73C7C9-1

[3] See http://aemera.ca/

[4] See http://www.wbea.org/air-monitoring

[5] See http://www.wbea.org/air-monitoring/continuous-monitoring

[6] See http://www.wbea.org/terrestrial-monitoring

[7] See http://www.ramp-alberta.org/ramp/design+and+monitoring.aspx

[8] See http://www.ramp-alberta.org/ramp/design+and+monitoring/components.aspx

[9] See http://www.abmi.ca/abmi/home/home.jsp

[10] See http://cemaonline.ca/

However, Diamond et al. (2013) note that the literature has many examples of WSNs concerned with physical parameters (e.g., temperature, pressure, movement, light level) as these sensors tend to be low-cost, rugged, durable and reliable, and consume little power. Chemical or biological sensors, on the other hand exhibit many of the opposite characteristics. More work is required to develop additional sensors specific to chemicals of concern in the oil sands and implement this technology in regional monitoring.

In addition to providing direct evidence of current environmental conditions, monitoring data can provide important input into a variety of environmental models (e.g., Watson and Putz 2013). The ability of WSNs to provide real-time environmental data can enhance the precision of these models. WSNs can also help improve data inputs in to research projects.

Although there is a noticeable increase in applications of WSNs to environmental monitoring, a comprehensive review of this technology with respect to its use within the oil sands industry does not exist. This report fills this gap.

1.3 Structure of this Report

The report is divided into two main sections:

1. A comprehensive review of the scientific literature that showcases the state of the art of WSN applications in different fields[11], and
2. An example of an application of a WSN to a coal mining reclamation site in Alberta.

This report was commissioned by OSRIN from the Centre for Earth Observation Sciences (CEOS) at the University of Alberta. All opinions are from the authors only and do not represent an endorsement of a specific tool or technology.

2 LITERATURE REVIEW

The section provides a comprehensive review of the technical and theoretical status of Wireless Sensor Networks (WSNs) in different sectors. Use of WSNs has become typical in environmental, health and military applications for tracking, monitoring and controlling processes and facilities. The following sections summarize current published work on WSN use in: precision agriculture, environmental monitoring, habitat monitoring, forest monitoring, industry monitoring, automation and security. Appendix 1 provides a tabular summary of the literature reviewed, including the goals and, where identified, the specific data types that were proposed or collected.

2.1 Agriculture Monitoring

The development of agricultural applications has recently attracted considerable research effort, since WSN technologies are very applicable for distributed data collection and monitoring in

[11] The report focuses on wireless sensor networks; it does not include information on the established field of remote tracking of animals (collars, etc.).

environments such as greenhouses, cropland, warehouses or refrigerated trucks. Some of these applications have been developed faster than others; for instance, monitoring greenhouses or livestock are more common than applications in farm machinery (Ruiz-Garcia et al. 2009). This section is divided into the following themes: Agricultural monitoring (emphasis on precision agriculture), pest control, viticulture, precision irrigation, farm machinery, and greenhouse monitoring.

2.1.1 *Precision Agriculture*

Precision agriculture is a management strategy that uses information technology to improve production and quality (Matese et al. 2009). The development of WSN applications in precision agriculture makes it possible to implement efficiencies, and enhance productivity and profitability while reducing inadvertent impacts on environment and wildlife. WSNs provide farmers with real time information that distinguishes differences and adjusts management actions accordingly (Ruiz-Garcia et al. 2009).

Díaz et al. (2011) developed a methodology to guide the effective development of WSN monitoring applications used in precision agriculture. The methodology divides the development process into seven stages with defined inputs, outputs and users. The authors recognized the need to enhance the integration of technical experts and end users.

Pierce and Elliot (2008) developed a regional and on-farm sensor network operating at 900 MHz to provide remote, real-time monitoring and/or control of main farming operations that increase value of targeted management practices through enhanced efficiency and efficacy. The WSN system was designed for regional-scale applications (e.g., weather networks), and for on-farm monitoring (e.g., temperature monitoring for frost protection). These two systems, one at the regional level called AgWeatherNet[12] WSN, and another at the local level called AgFrostNet, were successfully implemented in Washington State, USA. Both networks are commercially accessible to farmers (Pierce and Elliot 2008).

Akyildiz and Stuntebeck (2006) describe one of the few cases, Wireless Underground Sensor Network (WUSN), for which this emerging technology is used to monitor soil water conditions. The main goal of the project was to supply information for irrigation and fertilization in agricultural applications, and to detect the presence of toxic substances in soils. The results demonstrated that using a WUSN improved timeliness of data acquisition and processing (Akyildiz and Stuntebeck 2006).

Green et al. (2009) developed a novel wireless sensor network in the 433 MHz frequency range for measuring the temperature inside silage stacks at an early stage. They also mathematically modeled temperature variations inside a silage stack using system identification techniques. The WSN design was used to monitor temperatures in a full-sized silage stack for 53 days. The results of this study show that the wireless sensor network could possibly be used to detect silage decomposition and improve the efficacy of silage conservation systems.

[12] See http://weather.wsu.edu/awn.php for more information

2.1.2 *Pest Control*

Baggio (2005) extended the applications of WSN to fight phytophtora[13] (a fungal disease that depends on climatological conditions and can enter a field through a range of sources) in a potato field. Humidity and temperature are important factors in the development of the disease. The purpose of the system was to reveal when the crop is at risk and let the farmer treat the plants only when is really necessary (Baggio 2005).

2.1.3 *Viticulture*

WSNs have been used to manage vineyards more efficiently and automatically (Burrell et al. 2004), as well as to maximize their oenological potential (Matese et al. 2009). Beckwith et al. (2004) have shown that the total cost of ownership of a WSN in a vineyard is less than a wired network (Beckwith et al. 2004).

Matese et al. (2009) used an Advanced Vineyard Network (AVN) system to monitor and collect the micrometeorological parameters in a vineyard. The system comprises an agro-meteorological station (Master Unit located outside of the vineyard), and a sequence of wireless nodes (Slave Units) placed in the vineyard.

Morais et al. (2008) presented the possibility of a ZigBee[14]-based remote sensing network, intended for precision viticulture in the Demarcated Region of Douro, Portugal. Results demonstrated that a ZigBee-based sensor network powered by solar energy alone is possible, if the networking and power-management problems were controlled via energy consumption algorithms (Morais et al. 2008).

Beckwith et al. (2004) applied a WSN in a vineyard setting comprised of 65 nodes operating at 916 MHz, and reported results over a period of 6-months. In this study two important factors were considered: (1) heat summation and (2) periods of freezing temperatures. This application looked to find ways that a farmer could obtain a return on investment for deploying such a WSN. The results showed that in some areas wireless sensor networks deliver valuable data and provide a return on investment (Beckwith et al. 2004).

2.1.4 *Precision Irrigation*

Efficient water management is a key concern in many crop systems. WSNs have potential for monitoring the intrinsic soil spatial variability present in fields with more precision than the current systems available. Hence, the advantage to producers is a better decision-making system that allows maximizing their productivity while saving water. Maintenance cost for a WSN is lower, and installation is easier and faster, than current wired solutions (Ruiz-Garcia et al. 2009).

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[13] See http://en.wikipedia.org/wiki/Phytophthora_infestans for more information

[14] See http://www.digi.com/technology/rf-articles/wireless-zigbee for more information. Low-cost, low power consumption and self-forming are some of the advantages of ZigBee as an open and global standard for WSN.

O'Shaughnessy and Evett (2008) deployed two wireless sensor networks of infrared thermometers at a six-span center pivot irrigation system to test soil temperature. The study area was a semi-circle cropped field divided into six pie-slice sections. Three slices were irrigated manually, and three were irrigated automatically according to a time temperature threshold method. One of the networks was programmed with mesh networking firmware, and another one was programmed with non-mesh firmware. The purposes of this study were to: (1) compare mesh vs. non-mesh networking systems, (2) study the relationship between crop canopy, sensor frame, and air temperatures, and (3) explore automatic irrigation scheduling via derived data obtained from the WSN. Results indicated that the non-mesh network outperformed the mesh network; and that the data package recovery was more than 90% successful (O'Shaughnessy and Evett 2008).

Kim et al. (2008) provided a six in-field sensor station system for real-time remote monitoring of field conditions. The authors explored the use of WSNs to monitor soil moisture, soil temperature, and air temperature, as well as to control a site-specific irrigation system. The study focused on the development of WISC (Wireless In-field Sensing and Control) software designed to control a variable irrigation rate system. One of the main innovative applications of this system was the implementation of a Bluetooth wireless technology with the goals of: (1) offering plug and play deployment, and (2) reducing time and costs associated with network deployment. Constant wireless signal connectivity was gained by installing antennas at 1 m above the plant canopies, and innovative power management circuit design. In this project the concept of a low-cost wireless solution for an in-field WSN and remote control of precision irrigation was demonstrated (Kim et al. 2008).

Vellidis et al. (2008) extended a real-time, smart sensor system for measuring soil moisture and temperature that uses off-the-shelf components to design and evaluate irrigation scheduling for a cotton crop in a National Environmentally Sound Production Agriculture Laboratory[15] (NESPAL) field, located on the University of Georgia's Tifton Campus. Relatively low cost of the system allows installing a dense population of soil moisture sensors that can sufficiently show the intrinsic soil variability present in fields. The system successfully monitored soil water status and soil and air temperature in the canopy for the whole 2004 growing season, with few technical problems. The smart sensor array recorded and transmitted the data and allowed successful implementation of the irrigation scheduling protocol (Vellidis et al. 2008).

[15] See http://nespal.cpes.peachnet.edu/ for more information

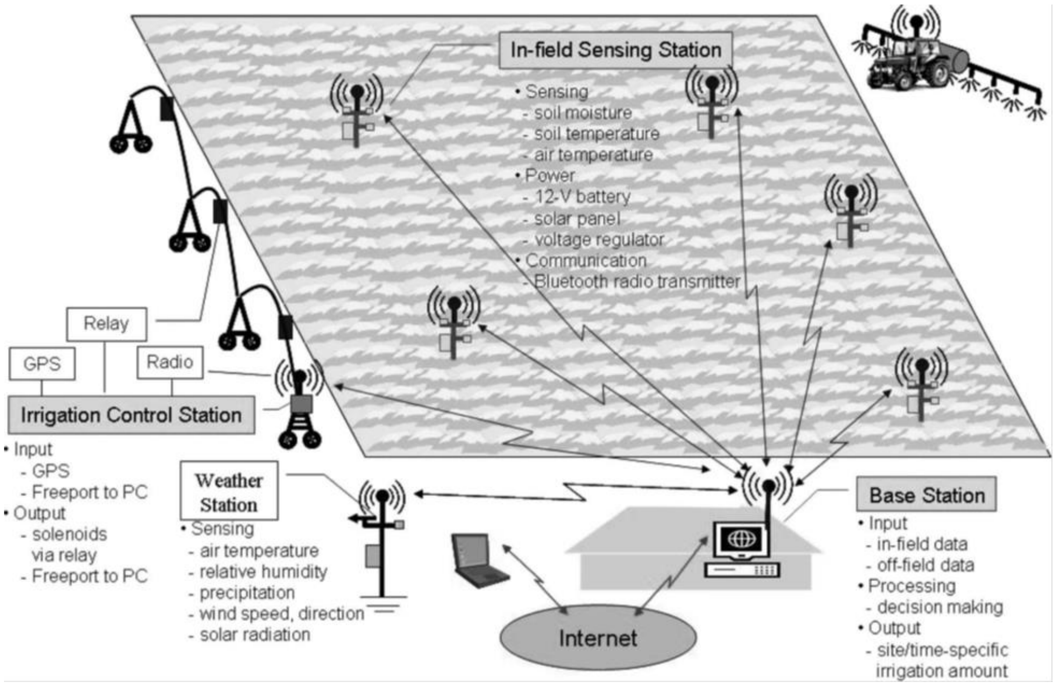

Figure 2. Conceptual system design of in-field wireless sensor network for site-specific irrigation.
Figure adapted from Kim et al. (2008).

Bogena et al. (2007) evaluated a low-cost soil water content sensor (ECH_2O probe model EC-5) in laboratory and field experiments. Results from this limited study showed that the EC-5 sensor was suitable for wireless network applications, though the temperature and electric conductivity effects on the sensor reading have to be adjusted by suitable correction functions (Bogena et al. 2007).

Ayday and Safak (2009) provided a map of soil moisture distribution by integrating WSN and GIS in their studied area. Wireless nodes with soil moisture sensors were located at prearranged locations. Geographic coordinates of these nodes were obtained with GPS. The system was used as a tool for more effective irrigation as well as to implement an alarm for soil dryness conditions.

Hwang et al. (2010) used an agricultural environment monitoring server system to collect environmental information such as luminance, temperature, humidity, and wind direction and speed, EC, pH, CO_2 and soil information via a WSN. The information is converted to a database, which is linked to images collected via CCTV and location information collected by GPS.

2.1.5 *Farm Machinery*

Applying WSNs in off-road vehicles, such as tractors or combine harvesters creates a mobile WSN. There are no commercially available systems that involve WSN, and few research studies to demonstrate the use of this technology in the field (Ruiz-Garcia et al. 2009).

Lee et al. (2002) developed a real-time yield monitoring system for a silage crop during harvesting season. This research explored the integration of a yield mapping system by means of Differential Global Positioning System (DGPS), load cells, wireless data transmission, and a moisture sensor. In the study, a silage corn yield map was created. Comparing with measurements by a platform scale, the system yielded an error in the range of 0.37% to 1.96% (Lee et al. 2002).

A study by Cugati et al. (2003) extended the use of a Bluetooth network to the application of fertilizer in real time. The data generated by the WSN were used to calculate the optimum quantity of fertilizer to be applied in a given field.

2.1.6 *Greenhouses*

The automation and efficiency of greenhouse monitoring and control are fundamental for maximum output. Sensors are essential for monitoring and control of environmental factors in a greenhouse. Implementation of WSNs in a controlled greenhouse setting is easier than in the field (Ruiz-Garcia et al. 2009). WSNs provide distributed and real-time sensing of different environmental variables inside the greenhouse (Gonda and Cugnasca 2006). Liu and Ying (2003) were the first to report the application of a WSN in the context of a greenhouse.

Gonda and Cugnasca (2006) presented a proposal for greenhouse monitoring and control by means of WSN, its benefits, challenges and future applications.

Yoo et al. (2007) presented the results of a WSN designed to monitor and control the growing of melon and cabbage in greenhouse conditions. Comparisons between the Korean Meteorological Administration (KMA) standard temperatures, and those measured by the WSN showed that the difference was up to 4.5°C and an average of 2.7°C. The authors suggested that one key element associated with the implementation of WSN in the context of greenhouse environments was the inter-calibration of sensors.

Lea-Cox et al. (2007) developed a WSN in a greenhouse that integrated several sensors measuring substrate water, temperature, electrical conductivity, daily photosynthetic radiation and leaf wetness in real-time. With this system farmers were able to obtain instant financial payback through improved plant growth, more efficient water and fertilizer applications, together with a decrease in disease problems related to over-watering.

Liu et al. (2007) reported an agricultural application of WSN in greenhouses. The network had two parts and provided real-time data on environment monitoring and remote querying. In the first part, several sensor nodes measured temperature, light and soil moisture. The second part comprised a Global System for Mobile (GSM) module, and management software based on a database running on a remote PC. The study demonstrated that Short Message Service (SMS) communication is an effective and economical key for long distance transfer of limited data.

Zhou et al. (2007) applied ZigBee-based WSN technology, using a star network topology inside a greenhouse, and a mesh topology to connect sensors deployed in a greenhouse with an off-site management system. The results of this study demonstrated the capabilities of WSN in precision irrigation and animal facilities.

More recently, Wang et al. (2008) designed a WSN system to measure temperature, humidity, dew point, soil moisture, CO_2 concentration, pH, EC and other environment parameters in a greenhouse setting. They demonstrated that nodes measure the environment parameters accurately, transfer data safely, and solve the trouble of wiring in a greenhouse.

2.2 Environmental Monitoring

Applications of WSNs to environmental monitoring have developed quickly in recent years, mostly moving from habitat monitoring, to indoor environmental measurements as well as monitoring of microclimate conditions in forested regions (Mittal and Bhatia 2010, Othman and Shazali 2012, Sanchez-Azofeifa et al. 2011). These fast migrations from conventional wired to wireless systems have been driven by a reduction in costs associated with instrumentation/node systems that in turn allows for the deployment of dense networks that cover vast regions (Vellidis et al. 2008). This capacity to cover large regions is also coupled with the advantage that these systems allow for the collection of information that can be analyzed from the onset of a network via advanced analytics approaches (Othman and Shazali 2012).

Hayes et al. (2007), Hwang et al. (2010) and Liu and Li (2012) present a few examples of how this technology has moved from basic laboratory applications to field deployments. Hayes et al. (2007) developed a WSN system for monitoring methane at a capped municipal solid waste landfill site in Ireland. In this specific case, the WSN allowed for the automatic ongoing sampling of methane over a limited area. Sensors in this study measured temperature, relative humidity, as well as various gases. The monitoring included actions such as intermittent inspection as well as constant sampling and analysis.

Liu and Li (2012) used WSNs to measure real-time environmental variables including temperature, humidity, light strength and pressure. This study showed that the WSN can quickly and accurately measure environmental variables.

The following sections presents a summary of the current available literature associated with environmental monitoring in different fields. The review considers those key papers relevant to oil sands monitoring only.

2.2.1 *Climate and Meteorology Monitoring*

Automated environmental monitoring procedures can be used in different types of climates and conditions. For example, Thienne and Margalho (2006) monitored agro-climate by analyzing WSN short-range transmission in the Brazilian Amazon Basin. They indicated that nodes located farther from a sink-aggregator had higher data loss, while nodes closer to the sink-aggregator kept their output levels. Another example of climate surveillance is flood forecast by wireless sensors, which can detect rainfall, water level and weather conditions. The sensors deliver information to a centralized database system (UDFC ALERT System)[16].

One of the first applications of WSN to look at environmental variables was developed by Hamrita and Hoffacker (2005). The authors explored the possibility of using Radio Frequency Identification (RFID) in a rapid solution to wireless real-time monitoring of soil characteristics. The prototype system was based on a commercial 13.56 MHz RFID tag. Measurements collected from the sensor showed a high correlation (greater than 99%) with those obtained using a thermocouple.

Collins et al. (2006) applied a WSN to study microclimate variations under different species of native desert shrubs in the Chihuahuan Desert, USA. To assess the data quality a simple analytical protocol, which can be programmed into sensor networks, was used. In this study three Sensor Web nodes were selected in open areas, as well as in areas below the east side canopy of different shrub species (12 nodes in total). Nodes were arranged along a 300 m transect. In this deployment, one node acted as a data relay and another one as the mother node, which was connected to a laptop that included the database and served as a gate into the system through the Internet. Sensors in each node measured soil temperature, soil moisture, relative humidity, air temperature, and light. Nighttime temperatures, winter rainfall, and nitrogen deposition were evaluated to determine the individual and combined effects of environmental change on creosote bush (*Larrea tridentate*) encroachment into grassland. Results showed that the shrub microclimate characterizations depend on the quality of the data produced by sensor networks, and that analytical procedures can be easily programmed into the network by Sensor Web, so that data quality can be evaluated through every measurement interval, and data outlines can be produced at any preferred measurement interval (Collins et al. 2006).

Thienne and Margalho (2006) presented another example of the use of WSN to monitor microclimate conditions via the INFOCLIMA project. The study demonstrated that using a WSN allowed for the collection of environmental data over longer periods and with greater frequency and resolution compared with collecting data manually. Temperature, humidity, evaporation, rain, wind, global radiation, solar brightness and ground temperature were measured. The results showed that data transferring over an ad-hoc wireless network in the Amazonian climate will affect nodes more distant from the sink.

Han et al. (2008) extended a remote, real-time, wireless sediment runoff monitoring system using wireless ZigBee mote over the period of January to February 2007 in Mission, Kansas. Two sensors and a two-layer wireless sensor network were installed to measure the soil sediment concentrations in storm drainage water (Figure 3). Two sensor stations collected and sent information to a main station. As the second base layer, the main station can collect data and connect with a cell phone system to retrieve data at a remote computer. To control data flow and wireless data transfer a “Star gate” single-board computer was used. The gateway transmitted

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[16] See http://alert5.udfcd.org for more information.

the sensor signals to an Internet server by means of the General Packet Radio Service (GPRS). Results showed that this system successfully monitored real-time sediment concentration, and that the collected information can be observed from any place with Internet access. The sensor observed the real-time soil sediment concentration and successfully transferred data to an indoor computer (Han et al. 2008).

Lengfeld and Ament (2011) examined the small-scale variability of atmospheric conditions close to the soil surface by means of WSN. The effect of the environment on air temperature, humidity, surface temperature, wind speed, wind direction, precipitation and solar radiation during the summer season over 22 days at 13 stations in western Germany was measured. The result of this study showed the data from WSNs are accurate, and also demonstrated that the WSN is a suitable tool to observe the small-scale changes in atmospheric conditions near the surface.

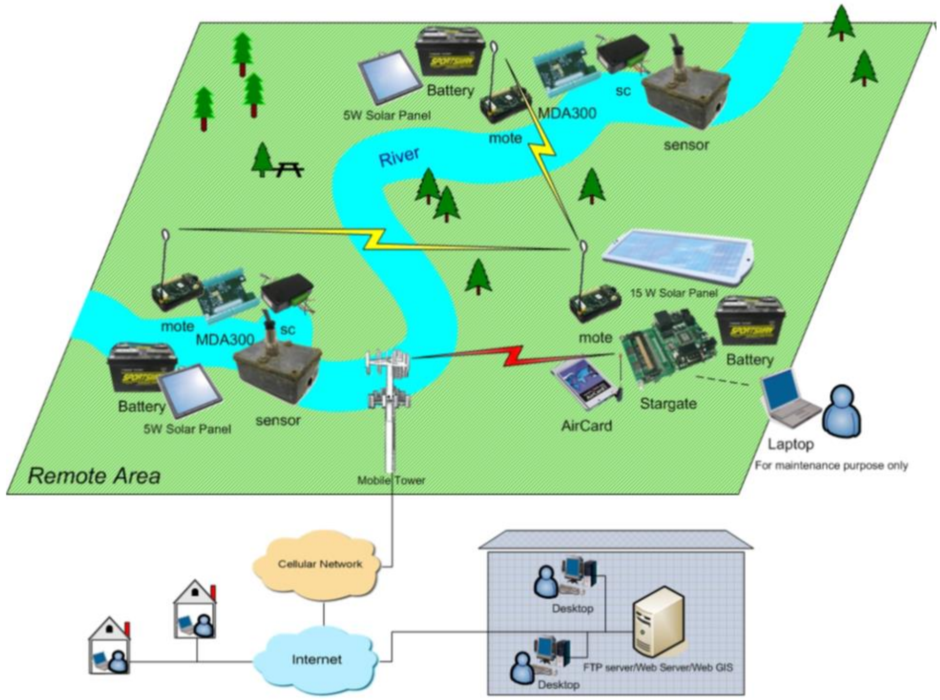

Figure 3. Conceptual pattern of a real-time sediment runoff monitoring system. Figure adapted from Han et al. (2008).

Moeser et al. (2011) deployed a Wireless Sensor Network (Snowcloud[17]) from January to May 2010 in the Sagehen Creek Experimental Field Station north of Truckee, California. The network consisted of six sensors that measured snow depth and temperature and transmitted the data by radio frequency (RF) signals to a base station. The data were converted to snow water

[17] For more information on Snowcloud see http://www.cems.uvm.edu/~ceskalka/skalka-pubs/skalka-frolik-realwsn13.pdf

equivalence (SWE). The network maintained communication for the whole period except for three days for one sensor. The authors noted that an extended sensor network could reduce data biases arising from selecting locations for standard weather stations and a sufficiently dense network could allow for extrapolation through kriging.

André et al. (2012) extended a Wireless Sensor Network to survey the impacts of climate change in agriculture in the coffee Free Air Carbon-dioxide Enrichment (FACE) project in Brazil. FACE is an experiment that has been implemented in the USA[18], United Kingdom, Germany, Japan, Australia, Italy, Denmark, among other countries, to study the effects of increasing CO_2 concentration on crops. This report describes the design and some operational features of the implementation of the FACE project in Brazil. This research showed that the wireless equipment offers no significant time delay for the system control, and it allows monitoring the changes in wind direction under a second.

2.2.2 *Air, Water and Soil Monitoring*

Applications of WSN to air, water and soil monitoring have been led by Vasilescu et al. (2005). Their study applied a novel WSN for real-time underwater monitoring of coral reefs and fisheries. The sensor network comprised stationary and mobile underwater sensor nodes. The nodes have a range of sensing abilities, including cameras, water temperature, and pressure. The optical and acoustic networking protocols are described and an experimental network and data collected in a pool, rivers, and in the ocean at Moreton Bay in Australia are presented. This study also showed the advantages of making underwater systems that have a mix of stationary and mobile nodes networked together – acoustic communication for low data rate transmission, and optical communication for high data rate point-to-point communication.

Coen et al. (2009) presented the first example and test results of a new wireless underground network system for continuous monitoring of soil water contents at numerous depths at a golf course near Almkerk in the central part of the Netherlands. Soil moisture and temperature were measured across an 18-hole golf course at depths of 4 cm and 10 cm from October 2007 to March 2008. The frequency of measurement was 15 min time interval – each sensor performed 96 soil moisture content measurements per day. This study showed the value of WSN for monitoring soil water content.

Zhang et al. (2010) presented a system capable of real-time monitoring of water quality in aquaculture based on WSN. The system was built to monitor hardware and the visualizing of data and then examine the data using expert knowledge to achieve auto control. The system gathers temperature, pH, and dissolved oxygen sensor signals by means of a sensor module, and transmits data via telecommunication. This study proved reliability and real-time capabilities for environmental monitoring of water quality (Zhang et al. 2010).

Capellaa et al. (2013) presented an application of WSNs for in-line chemical monitoring of fresh water quality that allows for low-cost and effective monitoring of nitrate concentration at the

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[18] See http://www.bnl.gov/face/ for more information

River Turia, Valencia, Spain. Results of this study demonstrated WSN applicability to analytical chemical environments, but also highlighted the benefits offered by this new technology such as arrangement, easy use, and the great quantity of data obtained.

Weimer et al. (2012) explored the problem of finding leaks at carbon sequestration sites by monitoring of CO_2 levels via a wireless sensor network (WSN). In this research a basic linear dynamic model for an advection-diffusion process is used, a model-based detection approach called the Iterative Partial Sequential Probability Ratio Test (IPSPRT) can be employed to identify and focus various leaks. Results showed that although the 2-D model is only a basic representation of atmospheric CO_2 transport, but if the desired accuracy of detection increases the improvement in performance from implementing of this strategy will increase as compared to a windowed-average approach. A test bed implementation exists and used to assess the robustness of the IPSPRT in the presence of common WSN errors and failures.

Chen et al. (2012) applied a portable wireless sensor to monitor the volatile organic compound concentrations at a personal level in real-time, collecting environmental toxics data every three minutes. The sensor sensitivity to aromatic, alkyl, and chlorinated hydrocarbons was high, with a resolution as low as 4 parts-per-billion (ppb). Higher exposure of hydrocarbons was detected in high traffic outdoor areas, inside remodeled rooms or close to chemical-emitting products, and in man-made disasters. These field tests not only validated the efficiency but also proved WSN capability to provide previously unavailable temporal and spatial toxicant data.

Ramesh (2014) designed and deployed a wireless sensor network for detection of landslides (Figure 4). In this study a practical system consisting of 50 geological sensors and 20 wireless sensor nodes was deployed in Idukki, an area highly prone to landslides in the southwestern region of Kerala State, India (Figure 5). Vast amounts of data such as relative humidity, rainfall, soil pore pressure and movement, together with other geological, hydrological and soil features were collected over three years. This system had the ability to run real-time data over the Internet, and also to issue warnings ahead of time using a three level system (Early, Intermediate and Impending).

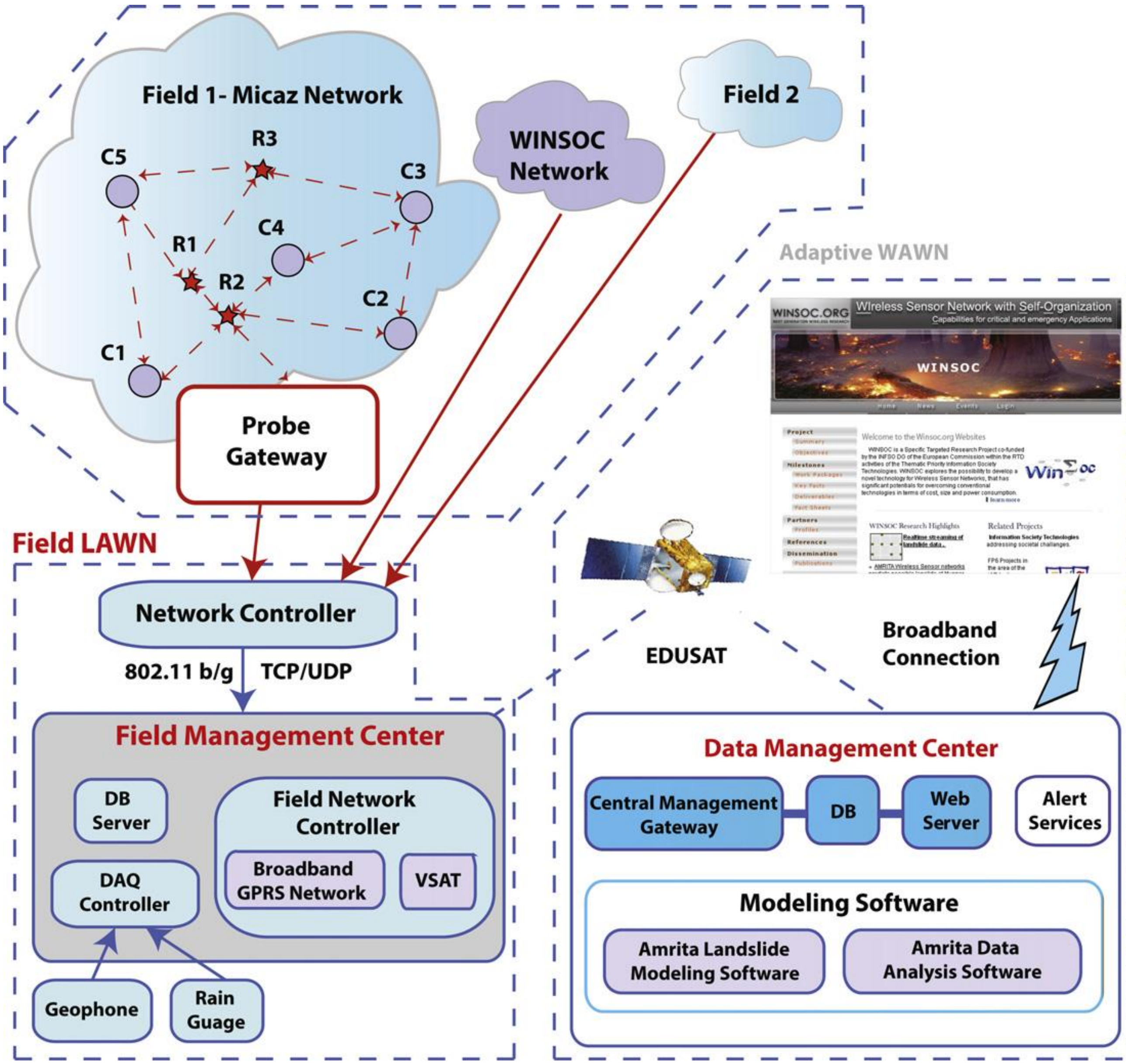
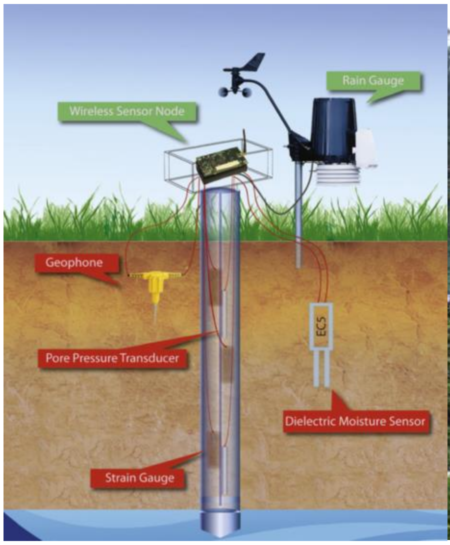
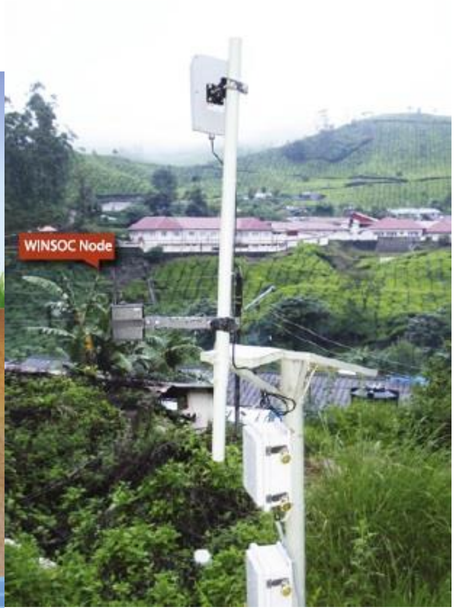


Figure 4. Wireless sensor network design for landslide detection. Figure adapted from Ramesh (2014).



a)



b)

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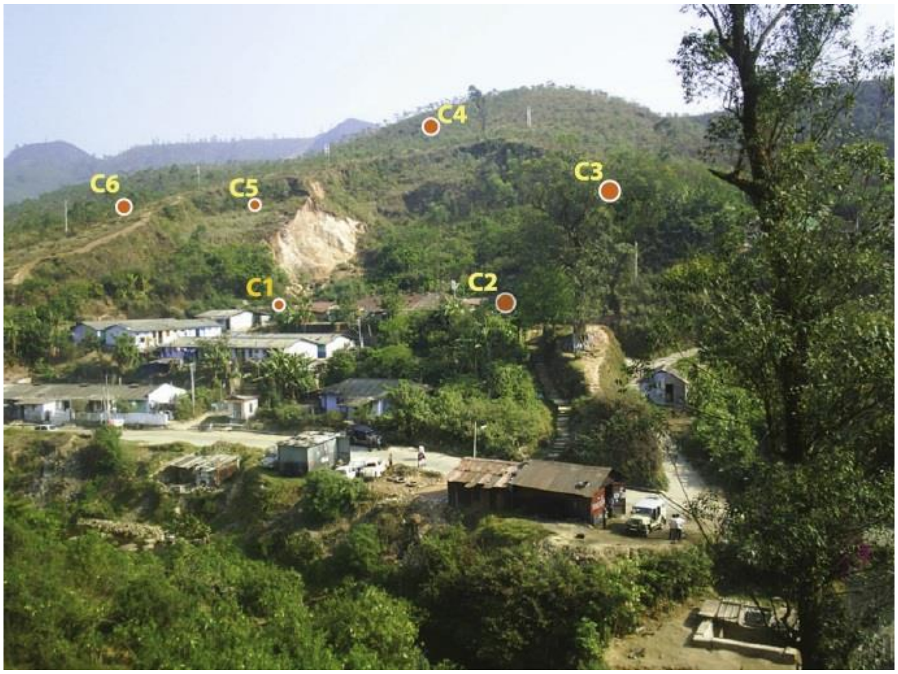

Figure 5. Multi sensor Deep Earth Probe (DEP).
b) Field deployment of WINSOC[19] node with miniature antenna, c) Deep earth probe deployment locations at the Anthoniar Colony Site, Munnar, Kerala, India.
Figure adapted from Ramesh (2014).

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[19] See http://www.geoconnexion.com/articles/winsoc-project-advances-wireless-sensor-networks for more information.

2.2.3 *Habitat Monitoring*

Sensor networks show a significant advance over traditional invasive techniques of habitat monitoring. Sensors can be installed at the beginning of the breeding season or other sensitive period (in the case of animals) or when plants are dormant or when the ground is frozen (in the case of plant studies). In addition, WSNs can be used for monitoring inaccessible areas like small islets where it would be unsafe or unwise to repeatedly attempt field studies. Mainwaring et al. (2002) have suggested that WSN placement may be considered a more economical method for leading long-term studies than traditional personnel-rich methods.

One of the most cited scientific publications on the use of WSN for habitat monitoring was produced by Mainwaring et al. in 2002. The authors deployed an initial prototype network at the James San Jacinto Mountains Reserve (in Idyllwild, California) to monitor seabird nesting environment that was later fully deployed off the coast of Maine. The full deployment consisted of 32 nodes on a small island. Environmental monitoring data were then streamed live to the web. Barometric pressure, relative humidity and temperature were measured. The result of this experience guided the development of a habitat monitoring kit.

Another example of the use of WSNs for habitat monitoring was published by López et al. (2009). The authors developed a WSN to monitor pH, NH_4^+ and temperature in a fish farm in Spain. Two different types of modules were designed: A sensor module that included pH and NH_4^+ sensors and the wireless module. The sensor module gathered and transmitted the data to the wireless module via a 9,600 b/s asynchronous wired communication.

This application serves to recognize important areas of further work in data sampling, communications, network retasking, and health monitoring.

2.3 Forest Monitoring

Gilman et al. (2005) deployed a WSN to monitor the redwood trees in Sonoma, California. This specific network was designed to explore the complex environmental dynamics of the microclimate surrounding a coastal redwood tree. Nodes measured air temperature, relative humidity, and photosynthetically-active solar radiation over 44 days in the life of a 70-metre tall redwood tree, at a frequency of every 5 minutes and every 2 metres spacing between nodes at the tree. The WSN provided the potential to expedite the state of science by enabling temporal and spatial monitoring of large volumes.

Ghosh et al. (2014) developed an inferential framework for modeling soil moisture in the Duke Forest, Orange County, North Carolina (35°52′N, 80°00′W) from March 18, 2009, through December 8, 2009 by using wireless sensor networks. In this study, a wireless sensing and relay device network (WiSARDnet) was used in16 sites in Duke Forest. Soil moisture was measured every two hours at each site. This study has shown the ability to integrate soil moisture sensor network data with measurements from a portable time domain reflectometer (TDR) device. A nonlinear state space model was formulated in this research.

Yu et al. (2005) deployed a WSN for real-time forest fire detection. The purpose of this model was to instantly sense and forecast forest fires. Sensor nodes collected temperature and relative humidity data, which were sent to their respective cluster nodes that collaboratively manage the data by creating a neural network. The neural network estimated an index of the probability for the weather to cause a fire. The simulation results have shown that in-network processing method is efficient to decrease communications between sensor nodes.

Son et al. (2006) developed a Forest-Fire Surveillance System (FFSS) based on WSNs in South Korea. The FFSS consists of WSNs, a middleware program, and a web application monitoring program. The WSNs detect temperature, humidity, and smoke. In addition the FFSS was able to detect the heat that allows it to send an early alarm in real time when a forest-fire happens. The middleware and web application analyze the data.

Bayo et al. (2010) presented the development of a wireless sensor network for monitoring forest conditions to detect and avoid forest fires. Critical meteorological parameters like high temperatures, low relative humidity and lightning storms raise fire forest chances. Therefore in this study important factors such as environmental temperature, barometric pressure, light intensity (solar cycle), smoke, relative humidity, soil moisture, and temperature and humidity were detected by sensors at different tree heights, depending on terrain topography.

Sanchez-Azofeifa et al. (2011) presented two case studies from tropical forests of using WSNs for environmental monitoring at the Parque Natural Metropolitano, Panama and at the Mata Seca State Park in Minas Gerais, southeastern Brazil. The WSNs were mounted in forest plots at three different successional stages: early (10 years recovery after pasture abandonment), intermediate (30 years of recovery), and late (no records of clear-cutting for 50 years). Leaf temperature in Panama and Photosynthetically Active Radiation (PAR) at high temporal resolution in Brazil was measured to evaluate this new technology. The results demonstrated that some of the recorded temperatures in Panama were significantly above the critical environmental thresholds for tropical environments. Furthermore, PAR results from Brazil demonstrated that this technology is useful as a tool to evaluate the importance of light patterns on ecosystem succession as a result of regional land use/cover change process.

Aslan et al. (2012) developed a framework to apply a wireless sensor network collecting temperature and humidity data in forest fire detection and monitoring. In this system, when there is no fire, the sensor network is not very effective in detecting and connecting several sensory data. But when there is a fire hazard, the network functions in an emergency mode and detects and communicates as fast as possible. This study showed that the system can provide both effective and efficient function: using less energy without reducing the rapid reaction capability. Also the study demonstrated that season, environment, and weather adaptation can significantly decrease WSN energy consumption.

Fernandez-Berni et al. (2012) extended a vision-enabled wireless sensor network node for the reliable, early on-site detection of forest fires over 4 years. A new framework is defined by integrating ground detection systems, and WSN-based monitoring systems to gain early detection with better dependability. These two key components have been combined into a model vision-enabled WSN node. The results of the field examinations, comprising the assigned burning of a 95×20-m shrub plot confirmed the high degree of dependability of this method in terms of both successful early detection and a very low false-alarm rate.

Bouabdellaha et al. (2013) presented a comparison between two forest fire detection approaches (Canadian – Fire Weather Index and Korean – Forest-fires Surveillance System) using a real experimental method. The results proved the Canadian system is adapted to local climate. The Korean technique is less accurate than the Canadian one. The study demonstrated the effectiveness of the Canadian method in terms of energy efficiency and algorithmic complication compared to the Korean one.

2.4 Industrial Monitoring

WSNs are widely used in the oil and gas industry. Hostile land, remote places and severe weather are usual obstacles to proper monitoring (Sobral 2012).

Safety and efficient operation in the oil and gas industry depends on continuous monitoring and management of a variety of parameters, such as pressure, temperature, vibration, gas, fire, equipment condition, container level, gas leakage, object speed, mechanical stress, etc. in a range of environment conditions. WSNs decrease maintenance and set-up costs and reduce unexpected system devastation, giving the opportunity to access and control remotely in dangerous locations (Sobral 2012). Specifically, by eliminating the need for cables, installation and operating costs decrease, and allow for installations in remote locations.

The most common applications in the oil and gas industry are associated with monitoring of real-time process control, safety, maintenance and manufacturing performance (Sobral 2012).

In this section we summarize the use of WSNs in refineries and oil and gas industry. Jang et al. (2008) discuss the application of WSNs to monitor temperature and light in industrial buildings.

2.4.1 *Remote Monitoring*

Using sensors in industrial plants and engineering services is required to ensure product quality and efficient and safe operation (Krishnamurthy et al. 2005). Remote monitoring capabilities help oil and gas companies address new regulatory and production requests. Some examples presented in the literature regarding oil and gas remote monitoring applications include (Sobral 2012):

- Reservoir level monitoring
- Equipment condition based monitoring
- Pipeline pressure relief valve monitoring
- Refinery pressure relief closure monitoring
- Monitoring offshore (marine locations) and wellhead automation are mainly corrosive and need serious maintenance.

2.4.2 *Safety Monitoring*

During oil discovery and refinery operations, many types of toxic gases such as ammonia (NH_3), hydrogen sulphide (H_2S), and sulphur dioxide (SO_2) are produced as products or by-products of different chemical processes. The potential for industrial leaks, especially H_2S leaks, that can affect humans and ecological systems is an ongoing concern (Chao et al. 2008, Reiffenstein et al. 1992, Sobral 2012). Therefore, monitoring H_2S is considered an important application of WSNs for oil and gas exploration companies (Chao et al. 2008, Sobral 2012).

Krishnamurthy et al. (2005) designed an Industrial Sensor Network focusing on preventative equipment maintenance using vibration signs collected via sensors to predict equipment failure. Two experiments were performed: the first was in a semiconductor construction plant, and the second onboard an oil tanker in the North Sea. The purpose of this study was to validate the prescriptions for industrial environments and estimate the effectiveness of the sensor network architecture. Results demonstrated that additional abilities in the sensing platform allowed a simpler and more effective overall system design. Adequate RAM removed the need for external intelligence and buffering to the sensor board, therefore decreasing complexity, cost, and total energy. This study showed that predictive maintenance is a viable application of WSN. The cost analysis of several solutions shows that sensor networks can provide high quality information at a relatively low investment in setting up and operation (Krishnamurthy et al. 2005).

Johnstone et al. (2007) designed and deployed a wireless sensor network in a petroleum facility at College of North Atlantic, Cove Campus, Newfoundland. The network consisted of four nodes and an aggregator. This research focused on a heterogeneous sensor network in an industrial area where data rates and latency were key issues for a successful running of the system. In addition analysis of environmental noise in an industrial plant has been presented. The results showed that sensor networks for an industrial environment have stable supplies of latency, throughput and channel access (Johnstone et al. 2007).

Dalbro et al. (2008) developed a heterogeneous network for underwater monitoring of oil and gas production, and to either avoid or detect oil and gas leaks, as well as to improve the production flow and well production. Two ultrasound and infrared light nodes were used for wireless communication. The mixture of ultrasonic/optical networks as supplements to wires, guaranteed redundancy for vigorous and continuous communication of the status of subsea oil and gas fittings. This study used tiny IR wireless motes (Moteiv Tmote Sky Type) and ultrasonic transceivers. Results showed that, for sub-sea applications, Tmote nodes with Micro-Electro-Mechanical Sensors (MEMS) can be connected to other Tmotes in a wireless sensor network, either by applying old-style radio frequency (RF) communication or alternatively by ultrasound or light connection.

Akhondi et al. (2010) applied WSNs in refineries, petrochemical plants, underwater development facilities, and oil and gas platforms to monitor the production process, to either avoid or detect health and safety issues or to develop production. Such a network was used to remotely monitor pipelines, natural gas leaks, corrosion, H_2S, tool condition, and real-time tank status. The result have shown the data collected in this system allows new opportunities in plant function and provides innovative ways that help the oil, gas and resource industries to improve platform safety, optimize operations, avoid problems, standing errors, and decrease operating costs (Akhondi et al. 2010).

Obodoeze et al. (2013) extended WSNs and actuators in industrial automation efforts, especially to control and monitor safety of crude oil pipelines in the Niger Delta region of Nigeria. In this study deployment and control architectures for automating monitoring and reporting of oil and gas pipelines that have been vandalized were implemented. This study specifically helped in detecting biometric characteristics of the suspected pipeline thugs that eventually led to their capture and prosecution.

Carlsen et al. (2008) deployed a WSN at the Gullfaks offshore oil and gas facility in the North Sea to predict production stops caused by pressure drops in well pipes. For this specific problem a wireless temperature sensor network was selected to predict the loss of flow from a well. The result of this study demonstrated that the WSN enabled fast, relatively inexpensive and reliable detection of lost flows, therefore enabling quick action to re-establish flow. The WSN has provided almost 100% reliability with an acceptable latency (<2 sec). These results show that WSNs are completely capable of strong and reliable connection in the severe environment of offshore platforms.

3 IMPLEMENTATION OF A WIRELESS SENSOR NETWORK FOR MONITORING FOREST REGROWTH IN RECLAMATION SITES AT COAL VALLEY MINE, ALBERTA

The project presented in this section is part of a large partnership between the University of Alberta and the Government of Alberta (Albert Environment and Sustainable Resource Development, ESRD) to showcase the implementation of WSNs at the provincial level in a series of conditions and environment. Tecterra Inc., as part of it Proof of Concept University driven Projects (UNI), provided funds for this field deployment.

In conjunction with ESRD and Coal Valley Resources Inc. (Sherritt Coal International), the Center of Earth Observation Sciences (CEOS) designed and implemented two wireless sensor networks for measuring microclimate variables in conifer forests around the Coal Valley Mine (CVM) site (located few kilometres from Robb, Alberta). The WSN’s main objective is to compare microclimate variables between old growth forests and forest regrowth to support the development of a tool to enhance reporting of reclamation site status.

The proposed system is based on two main technologies:

1. WSN technology, which will provide the necessary data with high spatial and temporal resolution, and without the need for in-field, manual data collection, and
2. A Geomatics/Internet-based technology embodied in the Enviro-Net portal (www.enviro-net.org) which will offer data mining techniques and algorithms for data visualization, quality control and analysis of the ground-based data obtained using WSN systems.

3.1 Field Deployment

3.1.1 *Study Area*

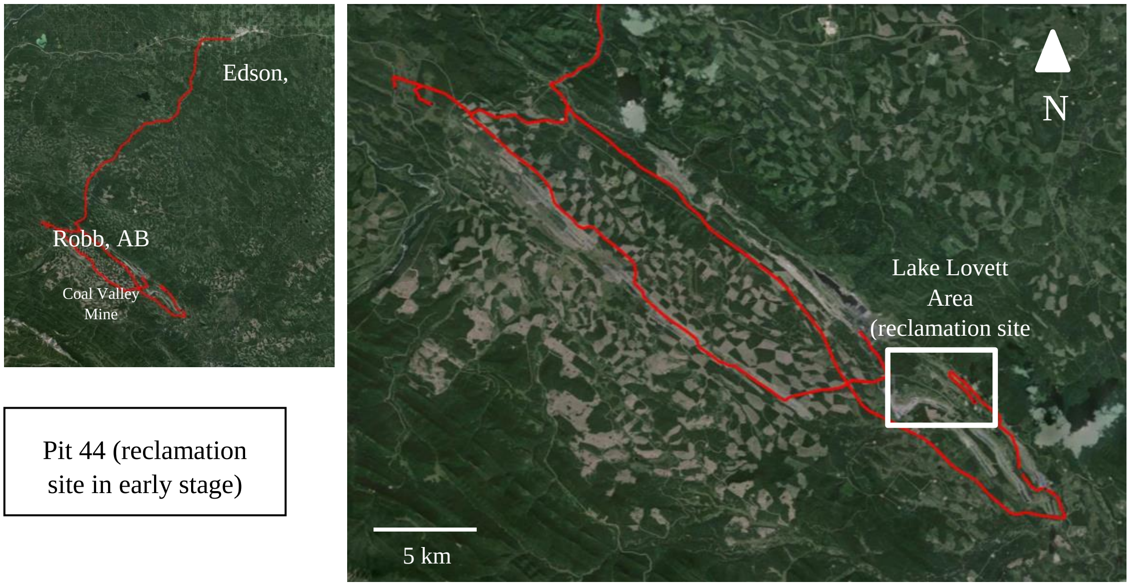
A preliminary field visit was made on June 13, 2013 with the aid of ESRD and Coal Valley Resources, Inc. to assist in designing and planning the WSN. We surveyed major vegetation/land cover types, checking accessibility and potential site conditions (e.g., level of ecosystem composition, structure and ecological succession) for WSN deployment (Figure 6). The natural vegetation in the area is dominated by coniferous forests composed of *Pinus contorta* Loudon (lodgepole pine) with ericaceous shrubs and feathermosses. *Populus tremuloides* Michx. (aspen) and mixed *Pinus* and *Populus* stands with herbaceous and deciduous shrub understories sometimes occur on south aspects and the crests of knolls (Russell and La Roi 1986, Strong 2000).

Reclamation plans for major disturbances such as coal mines typically involve contouring of the post-development landscape, placement of cover soil, fertilizing, and seeding with a mixture of legume and graminoid species. In subsequent years, shrub and tree seedlings may be planted to promote the development of different forms of vegetation. Other reforestation techniques involve transplanting plugs taken from an undisturbed forest floor to a disturbed area. The plugs contain the LFH horizon, upper mineral soil horizon, vegetative propagules and seeds which, when transplanted, can spread and colonize the disturbed area (Naeth et al. 2013).

During the field visit two areas were selected to deploy WSNs: (1) Old growth conifer forest, and (2) Forest regrowth through reforestation techniques in a reclamation area.

3.1.2 *Design of the WSN for Microclimate Monitoring*

The WSN implemented at CVM consists of a set of 8 nodes (a portable datalogger able to collect and store data from various sensors). Each node is equipped with a photosynthetically active radiation (PAR) sensor, a soil moisture sensor and a temperature and relative humidity sensor (Figure 7). Each node stores data in the internal memory and is powered by two Lithium AA batteries. Currently, the data stored are accessed through remote connection with the network using a Base Station. Wireless connection with this base station in the field allows simultaneously configuring the 8 nodes, and downloading the data collected from one single point. Microclimatic data are currently measured at high temporal resolution (every 10 min) allowing detection of the events or factors that control vegetation productivity and regrowth during the reclamation process. The data collected can also be used to calculate the fraction of intercepted PAR, vapour pressure deficit (VPD) or other derived variables. At the reclamation site, this system will allow monitoring changes in photosynthetic productivity and plant productivity during the process of vegetation regrowth. In 2014, the CEOS team will establish remote communications to this data aggregator through a cellular modem system.



Lake Lovett forest restoration site

Lake Lovett Old Growth forest site

Figure 6. Coal Valley Mine field site.
GPS track and reclamation sites surveyed in CVM site (Red Line) on June 13, 2013.
Photos of the old growth and the reclamation site selected for the WSN deployment around Lake Lovett.

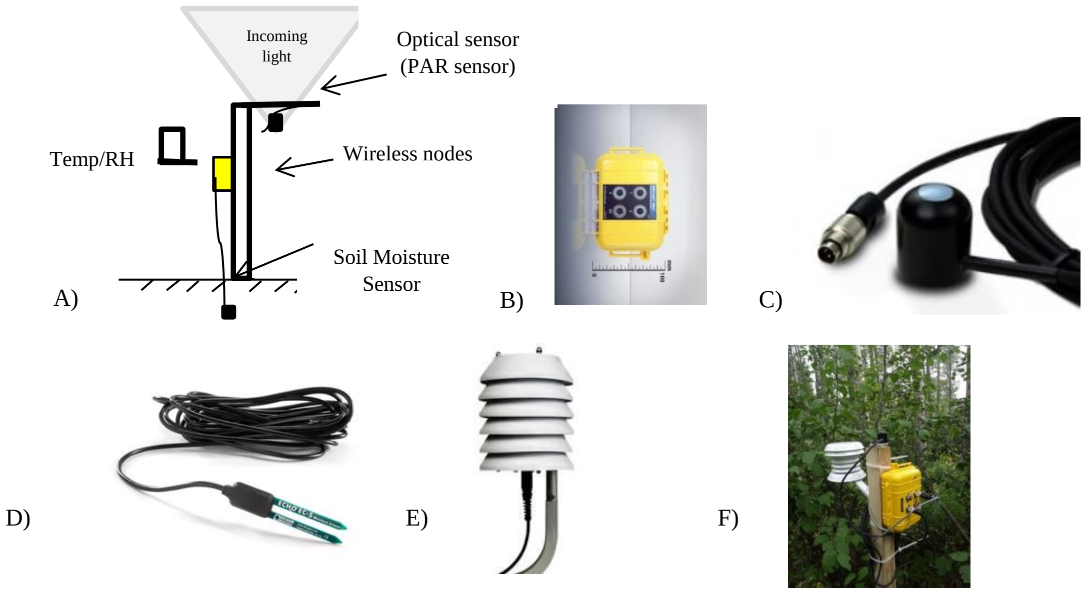


Figure 7. Nodes and sensors for environmental monitoring.
(A) Example diagram of nodes and sensors mounted on a 1.5 m wood post for measuring incoming and reflected solar radiation in a grassland
(B) Wireless node that logs and transmit environmental data collected
(C) PAR sensor
(D) Soil moisture sensor
(E) Temperature/humidity sensor
(F) Example of a single Wireless Node deployed in the field.

3.1.3 *Full Deployment of WSN in the Lake Lovett Reclamation Site*

The slopes around the Lake Lovett reclamation site are populated by 3 to 5 metre conifer trees planted during reclamation in a matrix of grasslands and surrounded by old growth conifer forests. This area can be used to measure and compare environmental aspects (microclimate dynamics) of a late-stage reclamation site to an old growth conifer forest.

In the reclamation area, a total of eight nodes were located 20-m apart from each other within continuous vegetation cover. The same was done for the old growth conifer forest area. A single node, with the same sensors, was deployed in an open area to have an independent measurement of incoming PAR, soil moisture and temperature/relative humidity outside the forested areas. The deployment took place in September 2013 (Figures 8 and 9).

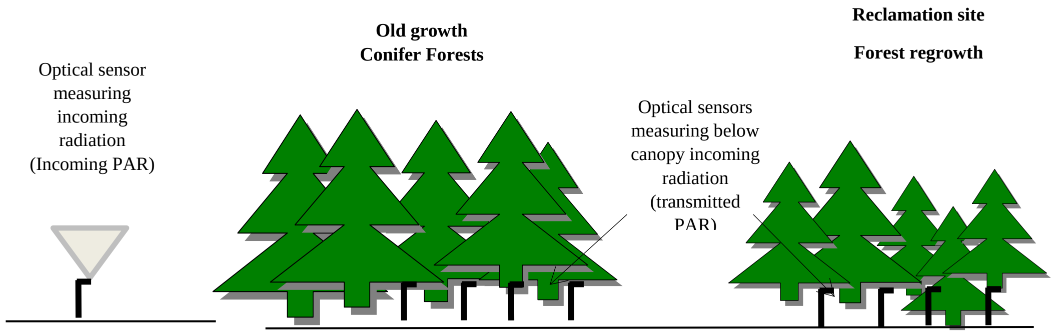


Figure 8. Design of wireless sensor networks at Lake Lovett at CVM site.

Figure 9. Wireless sensor nodes deployed at Lake Lovett at CVM site.
Old growth forest (left) and forest regrowth at reclamation site (right).

Overall, the sensor deployment at CVM required the installation of 17 nodes with sensors, each one tied on a wood post secured firmly in the ground up to 50 cm of its length. The transportation and deployment of the WSN took a maximum of 6 hours in the field. The equipment needed for the deployment consisted of:

- 17 wood posts (1.5 m height)
- 17 Microstrain nodes
- 17 Temperature/RH sensors
- 17 PAR sensors
- 17 Soil Moisture probes
- Tools for installation of nodes

- Field GPS and Laptop.

In terms of logistics, the deployment and the maintenance of the WSN was carried out by a team of graduate students and staff under the supervision of the Principal Investigator, Dr. Arturo Sanchez-Azofeifa. Data collection and battery replacement of the nodes is being performed every four months. However, batteries can last up to 8 months. The CEOS will also install a Fixed Data Aggregator at the site in 2014 with remote connection capabilities through a cellular modem. This will allow remote access; configuration and data download capabilities from the CEOS at the University of Alberta in Edmonton and from here to our government and industry partners.

3.2 Data Access and Analysis (Enviro-Net.Org)

Once the collected data are downloaded from every node in the field to a field laptop, they are immediately uploaded to the Enviro-Net site. The Enviro-Net portal (www.enviro-net.org), hosted by the CEOS at the University of Alberta, offers data mining techniques and algorithms for data visualization, quality control and analysis of the ground-based data obtained using WSN systems (Figure 10). Enviro-Net is designed to allow the user to visualize field data without pre-processing and offers tools to visualize trends and patterns in the information collected. The use of Enviro-Net is restricted (fee for use) and customized for users and their specific wireless sensor network dataset.

4 CONCLUSIONS AND RECOMMENDATIONS

In recent years, wireless sensor networks have evolved as one of the most discussed and actively studied areas in network research with important applications to medical diagnostics, disaster management, smart spaces, battlefield surveillance, precision agriculture and environmental and habitat monitoring. This report presents a comprehensive review of industrial applications of this emerging technology.

- The development of WSN applications in precision agriculture makes it possible to increment efficiencies, productivity and profitability while reducing inadvertent impacts on environment and wildlife.
- WSNs can be used to manage vineyards more efficiently and automatically as well as to maximize their oenological potential.
- WSNs can provide distributed and real time sensing of different environmental variables inside the greenhouse.
- WSN technology for greenhouse control seems to be a promising application area.
- WSNs have big potential for monitoring the intrinsic soil spatial variability present in fields with more precision than the current systems available. Maintenance cost for a WSN is lower, and installation is easier and faster, than current wired solutions.
- Using a WSN allows for the collection of environmental data over longer periods and with greater frequency and resolution compared with collecting data manually.

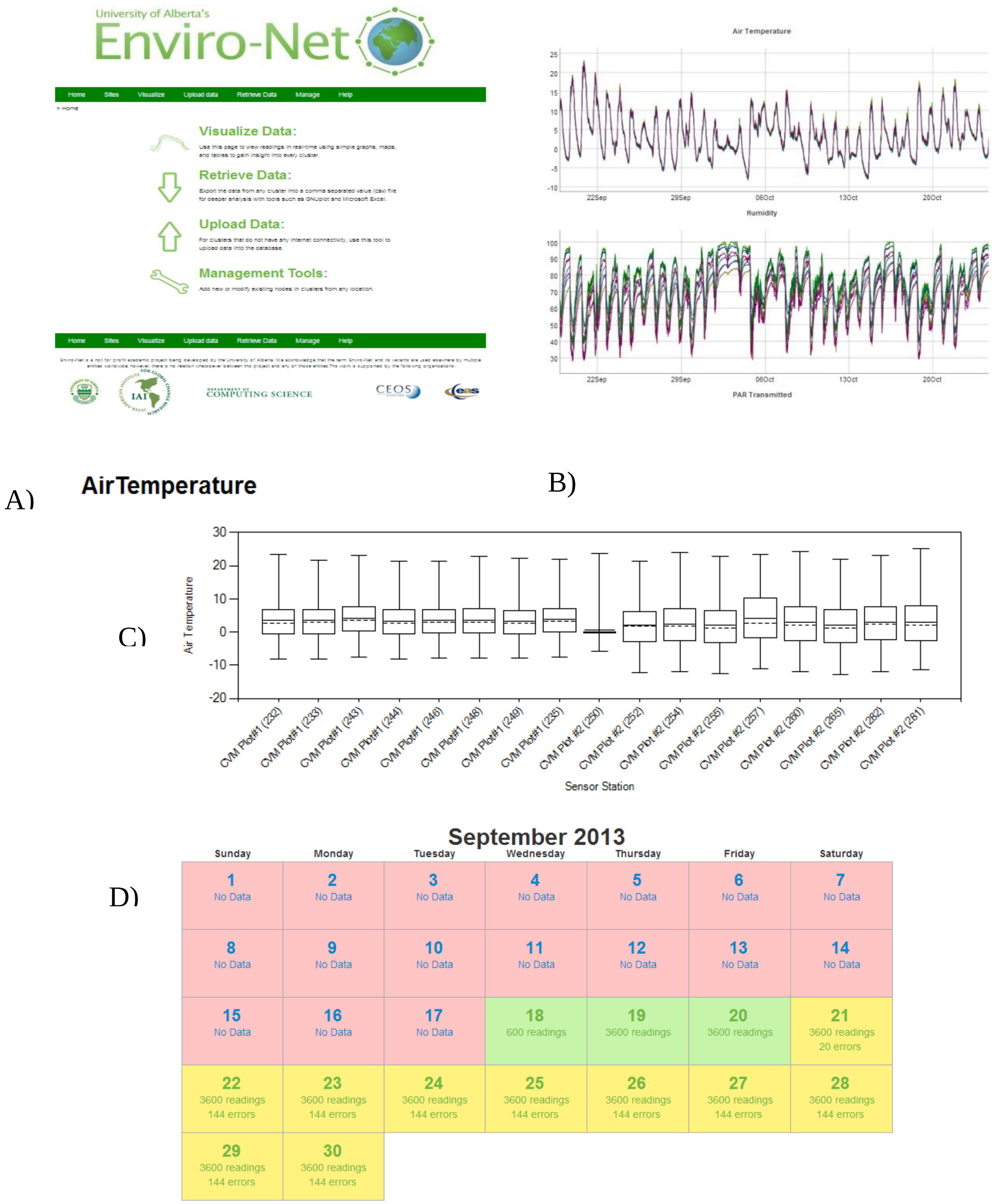


Figure 10. Enviro-Net webpage.

(B) Home Page

(B) Time series of temperature and relative humidity from WSN

(C) Box plots comparing humidity between nodes in different networks in CVM (Plot #1 vs. Plot #2)

(D) The data availability visualization tool allows analysis of quality and time range of the dataset

- WSN is a suitable tool to observe the small-scale changes in atmospheric conditions near the soil surface.
- WSN is applicable to analytical chemical environments, furthermore using this new technology has some benefits such as arrangement, easy use, and the great quantity of data obtained.
- Sensor networks show a significant advance over traditional invasive techniques of habitat monitoring.

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6 GLOSSARY

6.1 Terms

Actuator

A device that puts something into automatic action or starts something working.

Aggregator

A part of network which aggregates the data from other nodes and sends the collected data to the end user.

Distributed Data Collection

Act of collecting data from sensor nodes in a distributed fashion.

Heterogeneous Network

A network that includes different devices and computers and connecting these devices with different operating systems.

Latency

It is a time interval between the motivation and response of some physical variation in the system being observed.

Macroscope

The sensor network macroscope gives the possibility to develop the state of science by supporting dense temporal and spatial monitoring of huge sizes.

Middleware

Middleware in computer science is a common term for programming and it provides programs written for specific database to access other databases.

Multi-hop Network

A network consisting of multiple segments separated by routers; every time you cross a router it's a 'hop' from one network segment to another. *Multi-hop* would indicate you have crossed several routers to reach your destination.

Neural Network

In computer science it is a system which is modeled based on the human brain and nervous system.

Node

In networks system a node is a point of each device that communicates each other.

Real-time

The actual time that a process occurs.

Sensor

A device that measures detects and responds to some physical input such as motion, light, heat, pressure, moisture, or other environmental features.

Sensor Node

In a wireless sensor network is a node that performs some process and collects the data sensory and connects with other nodes in the network.

Sink Node

The sink is the node that access to the entire network and all the information which is collected by the sensor nodes are sending to sink node to proses and performs.

Wireless Sensor Network

Is a network that comprises of spatially distributed separate sensors to monitor environmental conditions such as temperature, moisture, pressure, etc.

6.2 Acronyms

AVN	Advanced Vineyard Network (see NAV)
CEOS	Centre for Earth Observation Sciences
DGPS	Differential Global Positioning System
FACE	Free Air Carbon-dioxide Enrichment (a program to study the impacts of the CO2 concentration increasing on crops)
FFSS	Forest-fires Surveillance System
FWI	Fire Weather Index
GIS	Geographic Information System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile
IPSPRT	Iterative Partial Sequential Probability Ratio Test
IR	Infrared
KMA	Korean Meteorological Administration
NAV	Network Avanzato per ilVigneto – Advanced Vineyard Network
MEMS	Micro-Electro-Mechanical Sensors
NESPAL	National Environmentally Sound Production Agriculture Laboratory (a unit of the University of Georgia’s College of Agricultural and Environmental Sciences)
OSRIN	Oil Sands Research and Information Network
PAR	Photosynthetically Active Radiation
RAM	Random Access Memory
RF	Radio Frequency
RFID	Radio Frequency Identification
SEE	School of Energy and the Environment
SMS	Short Message (or Messaging) Service
VPD	Vapour Pressure Deficit
WINSOC	Wireless Sensor Networks with Self Organization Capabilities
WISC	Wireless In-field Sensing and Control

WSN	Wireless Sensor Network
WUSN	Wireless Underground Sensor Network

6.3 Chemistry

EC	Electrical Conductivity
CO_2	Carbon dioxide
H_2S	Hydrogen sulfide
NH_4^+	Ammonium, the monovalent ion formed from ammonia.
pH	The acidity or alkalinity of a solution, soil, etc.
ppb	parts per billion

APPENDIX 1: Summary of Papers Reviewed on Application of Wireless Sensor Networks (WSNs)

This table summarizes the goals and, where identified, the specific data types that were proposed or collected. It is evident from the table that the most commonly-collected data are temperature, humidity, soil moisture, electrical conductivity, and solar radiation. These are all important factors for oil sands environmental monitoring. Additional data that are less frequently mentioned but are also useful for oil sands applications include: movement, level, CO_2, hydrocarbons, nitrate, and ammonia.

Area	Year	Authors	Location	Goal	Data
Overview	2001	Estrin et al.	…….........	Instrumenting the world	
Overview	2003	Hac	…….........	Network design	
Overview	2004	Zhao and Guibas	…….........	Constraints and challenges	
Overview	2006	Haenggi	…….........	Opportunities and challenges	
Overview	2008	Teng and Dong	China	A survey of available tools for developing wireless sensor networks.	
Overview	2009	Johnson et al.	Ireland	A comparative review of wireless sensor network mote technologies.	Humidity, temperature and light Barometric pressure, acceleration/seismic activity, acoustics, magnetic fields and GPS position
Overview	2009	Kohvakka	Finland	Medium access control and hardware prototype designs	Acceleration, air pressure, humidity, illumination, infra-red, magnetic field, geographic position, and temperature
Overview	2010	Guney et al.	Turkey	Programming formulations	
Overview	2010	Jiang et al.	……............	Introduction to WSN	
Overview	2010	Korkalainen and Sallinen	Finland	A Survey of RF-propagation simulation tools for wireless sensor networks.	
Overview	2010	Zheng and Liu	China	A survey on the topology of wireless sensor networks based on small world network model.	
Overview	2012	Hossein Zadeh et al.	Canada	Optimal base station positioning	

Area	Year	Authors	Location	Goal	Data
Overview	2013	Cheng et al. 2013	…..............	Scheduling systems	
Overview	2013	Naseer 2013	…..............	Energy efficiency and security	
Agriculture	2002	Lee et al.	USA	Silage yield monitoring system.	Weight, moisture
Agriculture	2003	Cugati et al.	USA	Variable rate fertilizer application	
Agriculture	2003	Liu and Ying	………	Greenhouse monitoring and control	
Agriculture	2004	Beckwith et al.	USA	Vineyard management	Temperature
Agriculture	2004	Burrell et al.	....	Vineyard production	
Agriculture	2005	Baggio	Netherlands	Crop risk (phytophtora) management	Humidity and temperature
Agriculture	2006	Akyildiz and Stuntebeck	USA	Irrigation and fertilization Soil toxins	Soil water
Agriculture	2006	Gonda and Cugnasca	Brazil	Greenhouse control	Temperature, humidity, solar radiation, CO_2
Agriculture	2007	Bogena et al.	Germany	Evaluation of a low-cost soil water content sensor	Soil water
Agriculture	2007	Lea-Cox et al.	USA	Greenhouse water and fertilizer control	Substrate water, temperature, electrical conductivity, daily photosynthetic radiation and leaf wetness
Agriculture	2007	Liu et al.	China	Greenhouse monitoring	Temperature, light and soil moisture
Agriculture	2007	Yoo et al.	Korea	Greenhouse monitoring	Temperature
Agriculture	2007	Zhou et al.	China	Greenhouse irrigation control	Temperature, humidity, light, pH, EC, soil humidity
Agriculture	2008	Kim et al.	USA	Irrigation system control	Soil moisture, soil temperature, and air temperature
Agriculture	2008	Morais et al.	Portugal	Vineyard management	Soil moisture content, soil temperature, air temperature, relative humidity and solar radiation

Area	Year	Authors	Location	Goal	Data
Agriculture	2008	O'Shaughnessy and Evett	USA	Automatic irrigation scheduling	Soil temperature
Agriculture	2008	Pierce and Elliot	USA	Regional and on-farm wireless sensor networks	Standard weather variables include air temperature, relative humidity, dew point temperature, soil temperature at 20 cm, rainfall, wind speed, wind direction, solar radiation and leaf wetness
Agriculture	2008	Vellidis et al.	USA	Scheduling irrigation.	Soil moisture and temperature
Agriculture	2008	Wang et al.	China	Greenhouse monitoring	Temperature, humidity, dew point, soil moisture, CO_2 concentration, pH, EC and other environment parameters
Agriculture	2009	Ayday and Safak	Turkey	Irrigation management and soil dryness warning	Soil moisture
Agriculture	2009	Green et al.	Denmark	Silage management	Temperature
Agriculture	2009	Matese et al.	Italy	Vineyard management	Micrometeorology
Agriculture	2009	Ruiz-Garcia et al.	………	Review of wireless sensor technologies and applications in agriculture and food industry	
Agriculture	2010	Hwang et al.	Korea	Agricultural environment monitoring server system	Luminance, temperature, humidity, and wind direction and speed, EC, pH, CO_2
Agriculture	2011	Díaz et al.	Spain	Method development	
Environmental	2002	Mainwaring et al.	USA	Seabird nesting habitat	Barometric pressure; relative humidity and temperature
Environmental	2005	Hamrita and Hoffacker	USA	Assess RFID technology	Soil temperature
Environmental	2005	Vasilescu et al.	USA	Coral reef and fishery monitoring	Water temperature and pressure Cameras

Area	Year	Authors	Location	Goal	Data
Environmental	2006	Collins et al.	USA	Microclimate variability	Soil temperature, soil moisture, relative humidity, air temperature, and light Nighttime temperatures, winter rainfall, and nitrogen deposition
Environmental	2006	Thienne and Margalho	Brazil	Agroclimate monitoring	Temperature, humidity, evaporation, rain, wind, global radiation, solar brightness and ground temperature
Environmental	2007	Hayes et al.	Ireland	Landfill methane monitoring	Temperature, relative humidity, as well as various gases
Environmental	2008	Han et al.	USA	Sediment runoff monitoring	Sediment concentration
Environmental	2009	Coen et al.	Netherlands	Golf course water management	Soil moisture and temperature
Environmental	2009	López et al.	Spain	Fish farm management	pH, NH_4^+ and temperature
Environmental	2010	Mittal and Bhatia	India	Environmental monitoring	
Environmental	2010	Zhang et al.	China	Water quality monitoring for aquaculture.	Temperature, pH, and dissolved oxygen
Environmental	2011	Lengfeld and Ament	Germany	Local-scale variability of near-surface temperature and humidity	Air temperature, humidity, surface temperature, wind speed, wind direction, precipitation and solar radiation
Environmental	2011	Moeser et al.	USA	Snow water equivalence estimation	Temperature, snow depth
Environmental	2012	André et al.	Brazil	Impacts of climate change in agriculture	CO_2, wind, air temperature, air humidity, rain, barometric pressure, solar radiation
Environmental	2012	Chen et al.	USA	Personal exposure to volatile organic compounds	Aromatic, alkyl, and chlorinated hydrocarbons

Area	Year	Authors	Location	Goal	Data
Environmental	2012	Liu and Li	China	Application of wireless sensor networking in environmental monitoring	Temperature, humidity, light strength and pressure
Environmental	2012	Othman and Shazali	Malaysia	Review of applications for environmental monitoring	
Environmental	2012	Weimer et al.	USA	Leak detection at carbon sequestration sites	CO_2
Environmental	2013	Capella et al.	Spain	In line river monitoring	Nitrate
Environmental	2013	Diamond et al.	………	Overview of on-going projects with an emphasis on environmental sensing	Ammonia, acetone, benzene, chloroform, pentane, organic solvents, phosphate, NO_2, NOx, O_3, CH_4, CO, CO_2, H_2S, NH_3
Environmental	2014	Ramesh	India	Detection of landslides	Relative humidity, rainfall, soil pore pressure and movement, together with other geological, hydrological and soil features
Forestry	2005	Gilman et al.	California	Microclimate surrounding a coastal redwood tree	Air temperature, relative humidity, and photosynthetically-active solar radiation
Forestry	2005	Yu et al.	China	Real-time forest fire detection	Temperature and relative humidity
Forestry	2006	Son et al.	South Korea	Forest-fire surveillance	Temperature, humidity, smoke and heat
Forestry	2010	Bayo et al.	Spain	Early detection and monitoring of forest fire	Environmental temperature, barometric pressure, light intensity (solar cycle), smoke, relative humidity, soil moisture, and temperature and humidity

Area	Year	Authors	Location	Goal	Data
Forestry	2011	Sanchez-Azofeifa et al.	Panama Brazil	Tropical forest monitoring	Leaf temperature –Panama Photosynthetically Active Radiation (PAR) – Brazil
Forestry	2012	Aslan et al.	Turkey	Forest fire detection and monitoring	Temperature and humidity
Forestry	2012	Fernandez-Berni et al.	Spain	Early forest fire detection	Smoke (visual)
Forestry	2013	Bouabdellaha et al.	Algeria	Forest fire detection	Temperature, light, acceleration, humidity, and pressure
Forestry	2014	Ghosh et al.	USA	Forest soil monitoring	Soil moisture
Industrial	1992	Reiffenstein et al.	Canada	Toxicology of hydrogen sulphide	H_2S
Industrial	2005	Krishnamurthy et al.	USA	Predict equipment failure	Vibration
Industrial	2007	Johnstone et al.	Canada	Petroleum plant monitoring	
Industrial	2008	Carlsen et al.	Norway	Predict well production stops	Pressure
Industrial	2008	Chao et al.	....	Human and ecological health	H_2S
Industrial	2008	Dalbro et al.	Norway	Underwater monitoring of oil and gas production	Motion
Industrial	2008	Jang et al.	USA	Building monitoring system	Temperature, light
Industrial	2010	Akhondi et al.	Australia	Avoid or detect health and safety issues Develop production	H_2S
Industrial	2012	Sobral	Brazil	Wireless sensor network for oil and gas industry	Level, pressure, flow, temperature, alarms and signals Valve angle
Industrial	2013	Obodoeze et al.	Nigeria	Control and monitor safety of crude oil pipelines	Biometric characteristics

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