The internet of things – wireless sensor networks and their application to forestry

Karen Bayne, Samuel Damesin and Melissa Evans

Abstract

Small wireless sensor networks (WSNs) have the potential to change the way forests are managed in the future. Already used widely in agricultural and horticultural situations to monitor and control production, what basis do they have as a tool for the modern forest manager? We propose that WSNs could enable a transformation in the way forests are managed in future, by collecting and relaying key management data in real time, as well as helping to better understand complex relationships within forest ecosystems. However, forested environments pose some challenges to deployment, such as reduced signals from vegetation, loss of connectivity and the scale-up factors.

What is the internet of things (IoT)?

The basic concept behind the IoT is interconnecting devices to an information network like the internet to enable advanced services. This applies to potentially anything from components of machines (such as harvester heads, tyre pressure for trucks) to cell phones and wearables. The internet is used as a way to transfer information between devices and computer systems. The information is often not publicly available, rather only accessible to the manufacturer/service provider or product owner.

What is a wireless sensor network (WSN)?

A WSN is a group of sensors, connected and communicating with each other to form a network without using wires or cables. The sensors often measure environmental (such as weather) or physical (e.g. diameter) data for various applications: fire detection, integrity of buildings or planes, or traffic monitoring etc. In order to make the information that is collected available, a WSN is usually connected to a local computer network or the internet. Such machine-to-machine (M2M) communication involves direct communication between devices whereby IT systems gather, collate and analyse the data transmitted, presenting it in a way that allows users to make an appropriate response to what is received.

When data can be sent and received from sensors connected to the internet and placed on everyday objects, WSNs and the IoT become fundamentally complementary and related. Those concepts are impacting and reshaping almost every industry and will potentially transform current forestry practices. It is estimated that there are 6.4 billion connected objects today and that number is expected to grow to 20 billion by 2020 (Gartner, 2015).

Figure 1 represents a WSN example in an agriculture environment. Three sensors (often called nodes or motes) are measuring various pieces of information about the environment and communicating wirelessly through a gateway. The base gateway receives the messages, stores them, and transfers the data to an online database. The information collected by the sensors now becomes easily accessible via the web for further analysis.

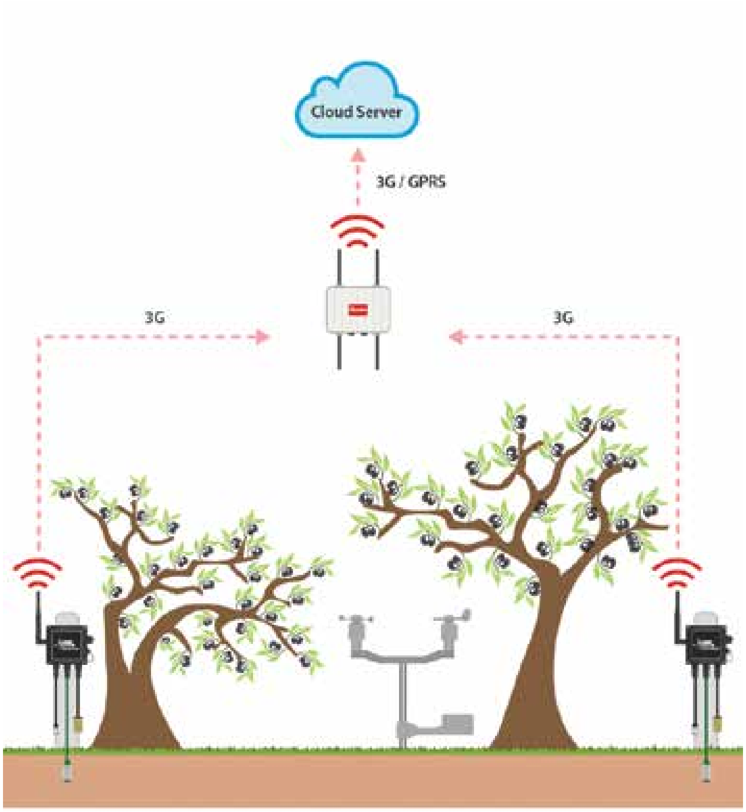

Figure 1: Orchard application of a WSN. Source: Libelium

Why use a WSN?

A WSN uses a range of sensors in autonomous networks that can record and manage data, and allows for optimisation modelling so that decision-making can occur at a much faster rate. In forestry, those concepts are to a certain extent already used. However, these technologies are becoming more affordable, reliable and practical, enabling additional opportunities and greater impacts for our industry.

One of the major reasons for using a WSN is to improve management practices, in particular, to enable real-time control of the environment and a quick response to environmental conditions that need a change in management and/or improvements to growing conditions. The most important benefit of a WSN is the ability to communicate data in real time, within a network, and through predictive analytics take actions to adjust or modify the environment accordingly. That the network does not rely on wired cables, but can gather and send the data via the internet to an office PC in a remote location, allows less physical monitoring and downloading of data.

Another benefit of the network is the ability to look at interactions between the various data streaming in real time from a range of sensors. The ability to automate when machinery and facilities become operational, and when they can be on stand-by, allows for optimised processing, minimised redundancies and reduced energy requirements leading to cost savings. The information produced by these sensors can be used to monitor (such as sensing the environment or the use of equipment), allowing operators to better analyse the situation and make informed decisions and take action. It can also be used to control (e.g. shutting off a machine or turning a light on) and optimise (take the best action for each circumstance) systems. This therefore enables the implementation of autonomous systems, which are able to understand the situation they are facing and take the most appropriate action, following a set of defined rules and without direct human intervention.

Sensor nodes are becoming more affordable, and being wireless they can be placed in any location without the need for cable runs. They have been adopted heavily for certain industries. For instance, the use of WSNs in tank farms and warehouses is now ubiquitous due to increased precision in automatic switching technologies and better sensitivity from detection sensors. In parallel, the rise in cell phone usage and coverage allows mobile devices to be used to alert people to changes within a network system without the need to be confined to an office, so systems can be monitored and adjusted remotely. Various types of sensors are available and they vary in readiness for deployment in the field, scalability and cost (Bagula, 2015).

A large number of WSNs are employed for environmental monitoring of crop and plantation growing conditions (such as temperature and humidity, and soil moisture and soil temperature). Also one of the more common crop management monitoring processes conducted today is in the estimation of leaf area index of crops as a precision agricultural tool to measure plant growth rates (Qu et al., 2014a, b).

Other common uses for WSNs include: machine surveillance and preventive maintenance, medicine and health care, intelligent buildings and bridges, traffic monitoring (flow and congestion control) along with monitoring parking capacities in parking buildings, and precision agriculture. The main uses of WSNs in agriculture today include: irrigation, pest control, fertilisation, animal and pasture monitoring, horticultural orchard, nursery and greenhouse management, and viticulture (Rehman et al., 2014). Conditions within nurseries, orchards and greenhouses, along with barns for farm animals and milking sheds, can all be monitored and controlled to both determine the optimum conditions for production, as well as controlling the conditions to ensure levels are kept to the optimum in a more efficient manner. WSNs can be employed to measure humidity, temperature and light, and detect the risk of frost, possible plant diseases and soil humidity levels. In most cases the use of WSNs becomes cost-effective with high-value crops, where the survival and growth rates of each individual plant are critical for business success.

Potential applications of WSNs in forestry

Given the complexity and inter-relationships present within forest ecology, IoT sensors could enable a major transformation within forest management. The ability to not only measure and manipulate a few key variables, but to monitor many variables in real time and over the rotation period, could enable new relationships and critical indicators to be identified. A long-term ecological research project at a Harvard University forest site (Harris, 2015) has been taking environmental measures since 1988, moving to monitoring by WSNs in 2010. The sensors now capture sound data in the forest to detect the exact timing of first cricket emergence each season, along with spring bud burst dates.

Linking atmospheric and climate measures with these events has enabled improved ecosystem modelling and forecasting of likely forest change under different climate change scenarios. Similar sensor applications for the commercial forestry sector could be in monitoring growing conditions, customised monitoring and optimisation of soil nutrient levels and micro-climate effects, enhancing tree survival, and predicting diseases, extreme weather events or fire. Other applications could be in optimising milling operations, harvesting or transport, by closely monitoring raw material, product, machine or equipment usage. Opportunities can also be expanded to derived secondary products (such as furniture, milled lumber) or packaging both through monitoring production, as well as storage conditions and location throughout the delivery chain.

There are potential applications further up the value chain such as sawmilling and in-service monitoring of timber products. Machinery would be able to obtain and incorporate upstream information into operational decision-making, while passing on new information to downstream processing equipment and operators. Hansen and Leavengood (2016) see this ability as a missing link in the ability to send the right tree or board to the right processing facility, and efficiency gains may drive investment into improved optimisation and scanning equipment.

Sawmills are already using sensors and wireless scanners (e.g. the Rold Vosk sawmill in Denmark), but connecting them together into a real-time network will aid information flow throughout the mill, product traceability and production optimisation within a mill setting (Hansen & Leavengood, 2016). ARETAS sensor networks (www.aretas.ca) already offer WSNs for fluid and noxious gas level monitoring in wood processing mills.

WSNs can also be integrated with a data storage service to collect and store information gathered from sensors on-board an unmanned aerial vehicle (UAV). UAVs are becoming more commonly deployed to collect aerial imagery and LiDAR data from ground plots. They could be used not only for crop monitoring, but also fauna detection and fauna damage to native forest areas (Melin, 2016), as well as detecting timing of pollen and bud burst. Alternatively, UAVs can be regularly deployed to collect data from remote WSNs, negating the need for an internet connection port at the site in order to transit the data over the internet. Badescu and Cotofana (2015) employed a UAV to send the node signals, rather than using a ground-based sink, and placed antennas above the canopy from the nodes. This aimed to prevent ground reflection and vegetation attenuation impacts common in heavily stocked settings.

The deployment of sensor units will also require progress to be made in data management systems, particularly the ability to quickly access historical stand information (such as fertiliser application, temperature, soil and moisture levels) at any given time. This is to understand the inter-relationship between actions taken in the past and local climatic conditions on resultant yields.

Progress to date with WSNs in forests

There are numerous groups in New Zealand and worldwide studying and deploying WSNs in agriculture and also investigating orchard and forestry applications. The main issue being researched is the ability to prolong the battery life of the network and develop energy-efficient nodes. Other issues being researched include:

- Attenuation impacts due to ground cover and canopy heights – several authors have worked on algorithms or technologies to account for this
- Optimisation of sensor positions within the network area and calibration for accuracy of sensors
- Empirical models to account for vegetation attenuation and shadowing effects
- Optimising the balance between data acquisition and transmission rates
- Working on node failure and nodal bottleneck issues.

One of the earlier uses of WSNs proposed was in forest fire monitoring, which comprises either monitoring humidity and temperature within the forest or else detects smoke and early fire outbreak. There are a number of papers outlining networks and how these could be used for this purpose. Although a research team (Hartung et al., 2006) developed a FireWXNet system that incorporated both long-range wireless technology with short-range wireless sensor networking, and deployed it at a prescribed burn, this was not operationalised in the forest. WSNs have also been used to monitor and track animals and poachers in conservation reserves (Badescu & Cotofana, 2015).

Additional work is required before WSNs can be deployed commercially at scale in a forest environment. Most of the studies at this stage are either simulations or aiming at improving communication in difficult environments. Scale-up has a lot of issues to take into account, and studies are trialling algorithms and new methods to account for the forest environment and scale-up capability. Wireless communication is highly impacted by obstacles (in the forestry context ground, undergrowth, canopy, tree trunks), so careful planning is required to define the best sensor placement. Ideally the sensor's antenna should be placed in an open environment, and with the line of sight to ensure the best possible communication link. Undergrowth and distance to canopy are also worth considering.

Some environments will be better suited than others from a communication and battery life point of view. Lithium batteries are strongly affected by temperature – WSNs are therefore not ideal for hot arid environments. Areas like nurseries, where sensor antennas can be placed above the canopy, provide better access to solar energy so should have a longer lifetime as well as better wireless coverage. We can expect difficulties and limitations in a remote mature stand with undergrowth. Combining various wireless technologies with repeater towers and using a combination of frequencies may allow communication efficiencies and prevent signal dead zones (Harris, 2015). A small compact sink and gateway is preferable to prevent interference with farming operations and reduce the risk of theft – equipment should be inconspicuous.

Although the life of a WSN is usually determined by battery life and the time to first sensor node failure, like all technology there is a limited lifespan for the gear and it requires maintenance and in some cases replacement. Some sensors will eventually fail and others may become dislodged. It will be of little value if the network is compromised due to these events, so fail-safe routing is required.

Growing capability at Scion

Scion's Complex Systems team purchased a WSN from Libelium (see photos) and they have been scoping possible applications for such technology to be trialled. Communication uses the XBee-PRO DigiMesh 2.4 network protocol, which operates within 2.4GHz. Other communication protocols exist, like ZigBee, and they have their own strengths and weaknesses. Most of the current systems are working with bands ranging from 900MHz to 5GHz. It is recommended to consider conditions in which the WSN will operate, as well as the operational requirements (range, power availability, frequency of data collection, accessibility of the site etc), in order to choose the best technology and system for a particular application. Some technologies (such as DigiMesh) offer key features like self-healing and self-discovery, making it ideal for remote environments like forestry.

Scion has undertaken some initial trials on the Libelium units, testing their communication reliability and battery duration (see photos). The results to date appear promising for forestry applications. Previous studies showed that communication coverage in a forested environment is affected by the height of the sensors, the position on the trunk and vegetation (Gay-Fernandez, 2010). Our study showed that it is possible with current technology to have a working network in a mature pine forest with nodes installed more than 200 m apart. It is expected that the working range can be even further increased, which may enable a wide range of potential applications.

Access to a power source and battery capacity are other important factors for enabling WSN adoption, especially for forestry and any outdoor application. Our study showed that the configuration of the network plays a key role in power consumption. WSNs, like the one we tested, offer features like support for sleeping nodes, which allow the network to be configured to sleep for a defined period of time. This is critical for battery dependent networks to increase operational life. Our tests showed that battery life can range from weeks to years, depending on the frequency of the sleeping patterns (from minutes to hours). External power sources like solar panels greatly improve the operational life of a WSN.

Scion plans to deploy the unit in a series of forest applications over the coming two to five years, and investigate options to best extract the data, focusing on accessing this as close to real-time streaming as possible. Feedback suggests that forest owners are interested in using this technology to keep track of weather, the whereabouts of staff in their forest blocks, traffic, as well as issues to do with tree health. Implications downstream for forest management and operations from the new technology applications will also be further scoped with industry.

Installation of the Libelium WSN set up in a forested environment

Conclusion

WSN technology is an emerging science field for forestry and an initial trial has proven the technology is operational in a mature pine environment. The installation of sensors in a forested environment offers a number of possibilities. For such technology to be more than just the latest research tool, progressing the development of WSN feasibility and data monitoring for New Zealand forestry requires their application in situ through a series of use cases. It appears the strongest potential use cases to be explored for real-time data monitoring would include:

- Soil moisture and soil temperature monitoring, potentially with pest and disease and fertiliser uptake sensors in nursery beds and at the forest establishment phase in cutover
- Nutrient monitoring in forest streams and riparian zones, as well as real-time turbidity sensors and upstream rainfall sensors
- Monitoring of movement and location of large mammals (and people) within a forested area
- Improved real-time and localised weather monitoring.

Three key concurrent development phases are required to progress WSNs for commercial forestry application. First, the initial stage will involve physical feasibility testing of the technology in a use application, and improving sensor communication, data collection techniques, and developing required algorithms for data analysis. Second, at the same time, management requirements and potential changes in operations and impacts to the sector from commercial deployment of WSN in forestry businesses will need to be determined. There are several international research groups already working on WSNs in a forestry setting, so the third phase of enhancing New Zealand's networks with other research groups and technology suppliers who are investigating WSN technology and data capture for forestry operations will serve as a potential catalyst in progressing implementation of WSNs for New Zealand forestry.

References

Badescu, A. and Cotofana, L. 2015. A Wireless Sensor Network to Monitor and Protect Tigers in the Wild. *Ecological Indicators*, 57: 447–451

Bagula, A. 2012. *Applications of Wireless Sensor Networks*. Accessed 13 June 2016 at http://wireless.ictp.it/wp-content/uploads/2012/02/WSN-Applications.pdf.

Gartner. 2016. *Gartner Says 6.4 Billion Connected 'Things' Will Be in Use in 2016, Up 30 Percent from 2015*. Stamford, Connecticut, USA, 10 November 2015. Accessed 30 June 2016 at www.gartner.com/newsroom/id/3165317.

Gay-Fernandez, J.A., Garcia Sánchez, M., Cuinas, I., Alejos, A. V., Sanchez, J. G. and J.L. Miranda-Sierra. 2010. Propagation Analysis and Deployment of a Wireless Sensor Network in a Forest. *Progress in Electromagnetics Research*, 106: 121–145.

Hansen, E. and Leavengood, S. 2016. Will the Internet of Trees Be the Next Game Changer? *MIT Sloan Management Review*, 17 February 2016. Accessed 14 March 2016 at http://sloanreview.mit.edu/article/will-the-internet-of-trees-be-the-next-game-changer/.

Harris, M. 2015. A Web of Sensors Enfolds an Entire Forest to Uncover Clues to Climate Change. *IEEE Spectrum*, 26 February 2015. Accessed 12 August 2016 at http://spectrum.ieee.org/green-tech/conservation/a-web-of-sensors-enfolds-an-entire-forest-to-uncover-clues-to-climate-change.

Hartung, C., Han, R., Seielstad, C. and Holbrook, S. 2006. FireWxNet: A Multi-Tiered Portable Wireless System for Monitoring Weather Conditions in Wildland Fire Environments. *Proceedings of International Conference on Mobile Systems, Applications and Services (MobiSys'06)*. Uppsala, Sweden, June 2006, 28–41.

Libelium. 2016. *The Future of Farming Through the IoT Perspective*. White Paper from Beecham Research and Libelium Corp, London (UK), Zaragoza (Spain), released 5 July 2016.

Melin, M., Matala, J., Mehtätalo L., Suvanto, A. and Packalen, P. 2016. Detecting Moose (*Alces alces*) Browsing Damage in Young Boreal Forests from Airborne Laser Scanning Data. *Canadian Journal of Forest Research*, 2016, 46(1): 10–19. DOI 10.1139/cjfr-2015-0326.

Rehman, A., Abbasi, A., Islam, N. and Shaikh, Z. 2014. A Review of Wireless Sensors and Networks' Applications in Agriculture. *Computer Standards and Interfaces*, 63: 263–270.

Qu, Y., Fu, L., Han, W., Zhu, Y. and Wang, J. 2014a. MLAOS: A Multi-Point Linear Array of Optical Sensors for Coniferous Foliage Clumping Index Measurement. *Sensors*, 14: 9271–9289.

Qu, Y., Zhu, Y., Han, W., Wang, J and Ma, M. 2014b. Crop Leaf Area Index Observations With a Wireless Sensor Network and its Potential for Validating Remote Sensing Products. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 7(2): 431–444.

Karen Bayne is a Senior Scientist, Samuel Damesin a Business Analyst and Web Developer, and Melissa Evans a Research Leader Computer Science at Scion. Email: karen.bayne@scionresearch.com.