27 Wireless Ad Hoc Sensor Networks

Wireless data communication for agricultural purposes relies on: one or more sensors of environmental data (temperature, humidity etc.); a signal conditioner; an analogue to digital converter; a microprocessor with an external memory chip; and a radio module for wireless communication between other sensor nodes and/or a base station (Popescu 2007).

One of the first wireless networks for agriculture was built for the Dutch Lofar Agro research project (Visser 2005). It consisted of 150 sensor boards (based on the Mica2 Crossbow wireless sensor platform) deployed in a field for gathering temperature and humidity data (Popescu 2007). The data received by the sensors was handled by a microprocessor implementing the TinyOS operating system, and transmitted via radio in the 868/916 MHz band to a field-gateway and from there via Wi-Fi to a personal computer for data logging (Popescu 2007). Since then there has been considerable interest in using ad hoc wireless networks for automatic data acquisition in agricultural enterprises.

Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) have developed a series of devices for agricultural wireless network systems. These devices incorporate: a Nordic radio with a range of over 1 km that operates on the 433- MHz or 915-MHz band; an integrated solar battery charging circuit; and an extensive range of sensors (Wark, *et al*. 2007). Their system also incorporates a real-time clock chip to reduce microcontroller overheads. Their system was also based on the TinyOS operating system (Wark, *et al*. 2007).

In precision agriculture, various parameters including soil moisture and soil temperature vary dramatically. Off-the-shelf irrigation controllers are not effective in managing water applications under these circumstances; however an irrigation management system based on wireless sensor networks can better respond to high resolution water application requirements (Mafuta, *et al*. 2013).

27.1 Network Configurations

Early computer networks could be divided according to their underlying topology. They loosely divided into: a star connected system; a bus connected system; or a ring connected system. The star connection is the oldest topology for networked systems (Parker 2000). The star arrangement uses point to point links from peripheral network nodes to a central machine (Parker 2000). In the bus configuration, the network nodes are connected onto a long bus as a series of tee junctions (Parker 2000). The ring system, as the name suggests, has a central ring bus onto which the nodes connect (Parker 2000).

There are no wired infrastructures or cellular networks in ad hoc wireless networks (Li 2003). Different configurations are possible; however many systems use wireless nodes with omni-directional antennae. Any transmission from a node can be received by any node within its vicinity. It is also possible to use directional antennas to directly link fixed nodes (Li 2003). Each mobile node has a transmission range. If the signal from one node can not be directly received from a second node, the data message must be communicated through multi-hop wireless links by using intermediate nodes to relay the message (Li 2003). Consequently, each node in the wireless network also acts as a router, forwarding data packets for other nodes (Li 2003).

Wireless ad hoc network have their own special characteristics and some unavoidable limitations compared with wired networks. Wireless nodes are often powered by batteries and have limited available storage memory (Li 2003). Data transmission from a wireless node can be received by several neighbouring nodes. This can cause interferences (Li 2003). Unlike traditional static communication devices, the wireless nodes are often moving during the communication process (Li 2003).

Several data routing options can be used in ad hoc networks. Most routing systems require pre-knowledge of the destination node's physical location. Compass Routing forwards data via other nodes such that the angles among the neighbouring nodes to the destination node are the smallest possible (Li 2003). Greedy Routing transfers data based on the shortest possible overall transfer distance rather than calculated transfer angles (Li 2003).

Many ad hoc networks in agricultural systems have limited power resources; therefore consideration needs to be given to minimising the power needed to transfer data. This can be achieved in several ways. Firstly, the data should be as information dense as possible. This usually requires some pre-processing of the data before transmission. For example, calculation and transmission of means and standard deviations, rather than transmitting raw data reduces the size of data being transmitted. Secondly, when a wireless network has a sufficient density of nodes, only a small number of them need to turn on at any given time to forward data traffic (Chen, *et al.* 2002).

27.2 Open Source Platforms

Several commercial wireless systems have been developed; however for small scale experimental systems, a number of open source platforms have are available. Two options include the Arduino and the Raspberry Pi.

27.2.1 Raspberry Pi

The Raspberry Pi is a credit-card sized computer that plugs into a TV (or monitor) and a keyboard. It is a capable little computer which can be used in electronics projects, and for many of the things that a desktop PC does, like working with spreadsheets, word-processing and games. It can also play high-definition video (Anonymous 2014b). The Raspberry Pi can support a complete operating system such as Linux and can be programed in languages like Scratch and Python (Anonymous 2014b).

The Raspberry Pi platform also supports various add-ons, including wireless adaptors that support wireless connectivity.

27.2.2 Arduino

Arduino is a tool for making computers that can sense and control other devices. It is an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. Arduino can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs (Anonymous 2014a). The Arduino platform supports plug in devices called shields, including the Xbee, Wireless SD and Cellular mobile devices.

The Xbee shield allows an Arduino board to communicate wirelessly using Zigbee (Anonymous 2014a). The module can communicate up to 100 feet indoors or 300 feet outdoors (with line-of-sight). It can be used as a serial/USB replacement or it can put into a command mode and configured for a variety of broadcast and mesh networking options (Anonymous 2014a).

The Wireless SD shield allows an Arduino board to communicate wirelessly using a wireless module. It is based on the Xbee module, but can use any module with the same footprint. The module can communicate up to 100 feet indoors or 300 feet outdoors (with line-of-sight) (Anonymous 2014a).

The Cellular Shield allows the Arduino to access a mobile telephone network, providing simple messaging systems (SMS), *Global System for Mobile* Communications/ *General Packet Radio Service* (GSM/GPRS), and *Transmission Control Protocol/Internet Protocol* (TCP/IP) functionalities (Anonymous 2014a). The cellular module requires a SIM card (pre-paid or straight from an existing mobile phone) and an antenna. Data can be sent using “Serial.print” (Anonymous 2014a).

27.3 Mobile Telephone Networks

The *Universal Mobile Telecommunications System* (UMTS) is a third generation mobile cellular system for networks based on the GSM standard. UMTS uses wideband code division multiple access (W-CDMA) radio to offer a broad range of data and communications services. The technology described in UMTS is sometimes also referred to as Freedom of Mobile Multimedia Access (FOMA) or 3GSM. If sufficient coverage is available, using the mobile telephone network as part of an ad hoc wireless sensor network provides greater range than can be achieved using low power wireless links alone.

As an example, a sensor system for testing wood condition contained three sensors: one audio sensor; one temperature and humidity sensor; and a temperature and pressure sensor. All these sensors were integrated into Arduino Mega 2560 and 1280 boards. A programme was written to collect readings from the sensors on an hourly basis and sends them to a remote place as an SMS text message using a mobile module with the Arduino board (Turnbul, *et al.* 2012).

27.4 Power Supply

Most ad hoc networks used in agricultural systems operate from batteries. The capacity of these batteries depends on the number of sensors attached to the node, the sampling frequency, and the amount of data being transferred. Because networks can be costly and data has real financial value, power reliability becomes critical. This implies that battery power needs to continually topped-up whenever possible. Part of the data stream should also include battery status so that power supply issues can be identified early. Usually photovoltaic cells are used to charge the batteries during daylight hours.

27.4.1 Available Solar Energy

Photo-voltaic solar collectors convert sunlight into direct current electricity. The use of solar energy has many advantages. In the field, it is a clean, quiet and reliable energy source. About seven million households around the world use solar hot water systems. In remote areas, without a connection to a public energy grid, solar energy is used for heating water and generating electricity.

The average solar power density falling onto the upper atmosphere, otherwise known as the solar constant, is 1353 ± 20 W m^{-2} (Howell, *et al.* 1982). Depending on the wavelength, much of this radiant power penetrates the atmosphere (Drury 1998). Analysing a sun-ray (Howell, *et al.* 1982), based on the geometry displayed in Figure 27.1, reveals that the solar power incident on a horizontal plane at the earth's surface on a clear day is:

$$I_r = \frac{1353}{r^2}\tau_s^{\frac{1}{\sqrt{1-\frac{R_e\cos^2(\alpha)}{R_e+A}}}}\left[\sin(\xi)\sin(\psi)+\cos(\xi)\cos(\psi)\cos(\zeta t)\right] \tag{27.1}$$

Where Ir is the incident radiation power at the earth's surface (W m^{-2}), r is the distance from the sun to the earth (m), τ_s is the transmission coefficient of the earth's atmosphere, R_e is the earth's mean radius (m), A is the mean thickness of the atmosphere (m), a is the solar altitude (Radians), ξ is the Geographic latitude (Radians), ψ is the Solar declination (Radians); ζ is the Angular velocity of the earth's rotation (Radians s^{-1}), and t is time (s).

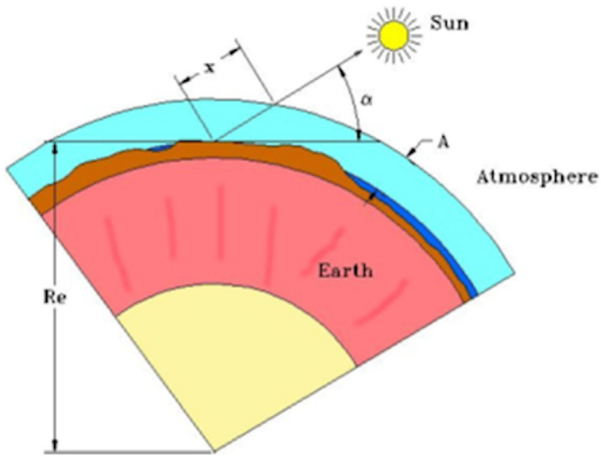

Figure 27.1: Geometry of a solar ray pathway through the Earth's atmosphere.

Blewitt (1973) and Howell, *et al.* (1982) show that the solar altitude (a) may be determined using:

$$\alpha = \sin^{-1}\left[\sin(\xi)\sin(\psi) + \cos(\xi)\cos(\psi)\cos(\zeta t)\right] \qquad (27.2)$$

Atmospheric transmittance (t_s) is about 0.7 for a clear day (McMullan, *et al.* 1978, Studman 1990, Sturman and Tapper 1996) and much less on cloudy days.

Spencer (1971) has developed a set of equations to describe some of the important parameters for calculating solar power unavailability. The distance from the earth to the sun, in astronomic units, can be calculated using:

$$\frac{1}{r^2} = \begin{Bmatrix} 1.000110 + 0.034221\cos(\theta) - 0.001280\sin(\theta) \\ -0.000719\cos(2\theta) - 0.000077\sin(2\theta) \end{Bmatrix} \qquad (27.3)$$

Solar declination can be calculated accurately using:

$$\psi = \begin{Bmatrix} 0.006918 - 0.399912\cos(\theta) + 0.070257\sin(\theta) - 0.006758\cos(2\theta) \\ +0.000907\sin(2\theta) - 0.002697\cos(3\theta) + 0.00148\sin(3\theta) \end{Bmatrix} \tag{27.4}$$

where $\theta = \frac{2\pi(n-1)}{365}$ is the "orbit angle" of the earth about the sun for the n^{th} day of the year.

Ideally, the solar absorber should track the sun in such a way that its surface is always perpendicular to the sun's rays. In practice, this is expensive to implement. Consequently, fixed non-tracking absorbers are commonly used in solar heating systems. More consistent year-round performance can be achieved when a fixed solar absorber is tilted toward the equator in such a way that it is in a plane parallel to the earth's axis. This implies that the tilt angle of the absorber should be equal to the local geographic latitude of the system. The basic arrangement of a tilted absorber is shown in Figure 27.2.

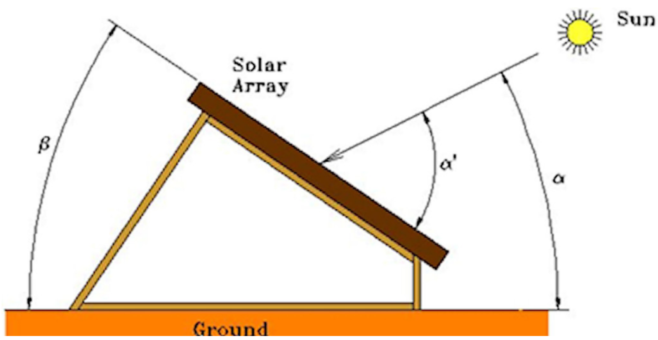

Figure 27.2: Geometry of a tilted solar absorber.

When this is done, equation (27.1) becomes:

$$I_r = \frac{1353}{r^2}\tau_s^{\frac{1}{\sqrt{1-\frac{R_e\cos^2(\alpha)}{R_e+A}}}}\left[\sin(\xi-\beta)\sin(\psi)+\cos(\xi-\beta)\cos(\psi)\cos(\zeta t)\right] \tag{27.5}$$

Because $\xi = \beta$, equation (27.5) reduces to:

$$I_r = \frac{1353}{r^2}\tau_s^{\frac{1}{\sqrt{1-\frac{R_e\cos^2(\alpha)}{R_e+A}}}}\left[\cos(\psi)\cos(\zeta t)\right] \tag{27.6}$$

Figure 27.3 shows the effect of using a tilted collector on year-long solar power absorption.

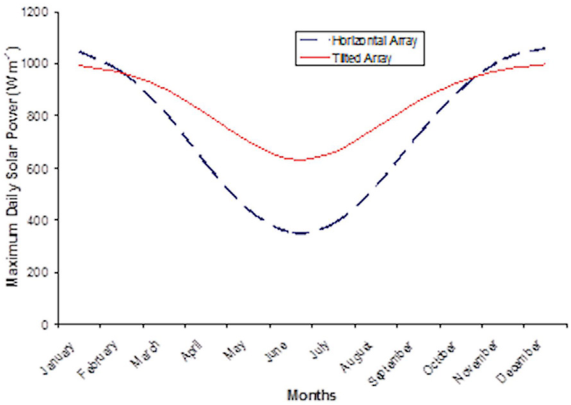

Figure 27.3: Effect of tilting the absorbing surface on solar performance throughout the year at 36o South latitude.

In addition to this ray intensity there is also a diffuse component of solar radiation due to atmospheric scattering. The US Department of Energy (1999) suggests that the diffuse component of solar radiation can be approximated by:

$$I_{diff} = \frac{676.5}{r^2}\left(1-\tau_s^{\frac{1}{\sqrt{1-\frac{R_e\cos^2(\alpha)}{R_e+A}}}}\right)\left[\sin(\xi)\sin(\psi)+\cos(\xi)\cos(\psi)\cos(\zeta t)\right] \quad (27.7)$$

Therefore the total solar radiation intensity can be defined by:

$$I = I_r + I_{diff} \quad (27.8)$$

Power supply is an ongoing issue for data acquisition. Various methods of harvesting energy from stray RF have been developed (Aguilar 2012). One of the earliest examples of this strategy was the RF-ID system where the ID chip harvests its energy needs from the RF reader during a scanning process. The next chapter will explore RF-ID systems.

References

Aguilar, A. 2012. RF Energy Harvesting. Unpublished thesis. University of Cincinnati,

Anonymous. 2014a. *Arduino*. http://arduino.cc/

Anonymous. 2014b. *Raspberry Pi*. http://www.raspberrypi.org/

Blewitt, M. 1973, *Celestial Navigation for Yachtsmen*, 5th edn, London: Edward Stanford.

Chen, B., Jamieson, K., Balakrishnan, H. and Morris, R. 2002. Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks. *Wireless Networks*. 8(5): 481-494.

Drury, S. A. 1998, *Images of the Earth: A guide to Remote Sensing*, 2nd edn, Oxford University Press.

Howell, J. R., Bannerot, R. B. and Vliet, G. C. 1982, *Solar - Thermal Energy Systems, Analysis and Design*, New York: McGraw-Hill.

Li, X.-Y. 2003. Topology control in wireless ad hoc networks. *Mobile Ad Hoc Networking*. 175-204.

Mafuta, M., Zennaro, M., Bagula, A., Ault, G., Gombachika, H. and Chadza, T. 2013. Successful Deployment of a Wireless Sensor Network for Precision Agriculture in Malawi. *International Journal of Distributed Sensor Networks*. 2013: 1-13.

McMullan, J. T., Morgan, R. and Murray, R. B. 1978, *Energy Resources*, London: Edward Arnold.

Parker, C. 2000, *Understanding Computers: Today and Tomorrow*, Fort Worth: The Dryden Press.

Popescu, V. 2007. Wireless Data Communication in Agricultural Engineering. Trends and Practical Experiments. *Proc. Research People and Actual Tasks on Multidisciplinary Sciences*. Lozenec, Bulgaria

Spencer, J. W. 1971. Fourier series representation of position of the sun. *Search*. 2(5): 172.

Studman, C. 1990, *Agricultural and Horticultural Engineering*, Wellington: Butterworth's Agricultural Books.

Sturman, A. P. and Tapper, N. J. 1996, *The Weather and Climate of Australia and New Zealand*, Oxford University Press.

Turnbul, C., Brodie, G., Thanigasalam, D. b., Farrell, P., Kealy, A., French, J. and Ahmed, B. 2012. *Final Project Report - Investigate control of in-situ termite and decay protection and control using microwave technologies*. University of Melbourne

US Department of Energy. 1999. *WIMOVAC Macroclimate Module*. March, 2004. http://face.das.bnl.gov/Modelling/newpage9.htm

Visser, O. W. 2005. Localisation in Large-Scale Outdoor Wireless Sensor Networks. Unpublished thesis. Delft University of Technology, Faculty of Electrical Engineering, Mathematics, and Computer Science

Wark, T., Corke, P., Sikka, P., Klingbeil, L., Ying, G., Crossman, C., Valencia, P., Swain, D. and Bishop-Hurley, G. 2007. Transforming Agriculture through Pervasive Wireless Sensor Networks. *Pervasive Computing, IEEE*. 6(2): 50-57.