Wireless sensor networks for precise Phytophthora decision support.

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Background.

Precision Agriculture provides the optimal treatment for each production unit that can be distinguished and which can be individually treated in an efficient way. This agricultural practise is based on detailed information on the status of crops and soil. Most of this information focuses on techniques like soil mapping, yield mapping and remote sensing, which cover the spatial domain with more or less spatial resolution. The information is incidentally sampled and is therefore valid at the time the observations are made. Some of the processes like fertilization and especially crop protection require frequent updates in information. Sensor systems that are continuously present can deliver such information.

Several research groups and companies are working on the development of “Smart Dust”. “Smart Dust” stands for a sensor, a processor and a means of communication that will be packaged into a few cubic millimetres in the future. It is expected that these devices will be available in six years at a cost of around one dollar apiece, although downsizing might not have reached the intended level at that time. Such wireless sensor systems can form a dense network and provide the possibility for continuous monitoring of relevant parameters in a dense grid for a reasonable price.

In the Netherlands, high capacity communication and processing infrastructure is being developed for the LOFAR astronomical observation system (www.lofar.org). This system is based on a new generation Low Frequency Array telescope, which is made up of a large number of small antennas spread over an area with a diameter of 350 km. These antennas are coupled in real time by the communication infrastructure. Precision agriculture is, together with geophysics one of the other disciplines that can make use of this infrastructure spread over the rural area.

Objective.

Research started to investigate the possibility of wireless sensor networks in agriculture and particularly that of microclimate monitoring with presently available wireless sensor technology. At the same time architecture will be developed to incorporate wireless sensors in an agricultural ICT infrastructure. The research objectives are:

1) to design an architecture for decision support systems in agriculture, based on wireless sensor networks as an extension of a rural communication infrastructure,
2) to investigate the distances over which radio signals will propagate in a crop canopy under varying conditions,
3) to determine accuracy of localisation techniques for sensor networks and
4) to obtain first results on micro climate monitoring.

Requirements.

The first application focuses on measuring the microclimate of a potato crop to deliver detailed information for the next generation of decision support systems for *Phytophthora* control. This involves measuring temperature and relative humidity in the crop canopy. As a reference for the present generation *Phytophthora* DSS systems, a meteorological station will be realised by means of wireless components.

Energy availability is one of the limiting aspects for wireless senor networks. Processing on the motes, especially the communication has to be done by energy saving procedures and protocols.

In spite of the fact that the location of the sensors can be determined during placement, a positioning method is good to verify the origin of the obtained information.

Materials and methods

Environment.

A communication infrastructure is under development by the LOFAR astronomy project. This consists of a high bandwidth glass fibre network based on existing infrastructure which is extended towards the test site for the astronomy antennas in Exloo in the north east of the Netherlands. At this site, a container houses the AD converters of the astronomical antennas and provides a gateway to the fixed network. Central in the information infrastructure is the glass fibre backbone with a 768 gigabit/s throughput in the centre, a central server and an IBM Blue Gene super computer with 43 TFlops processing capacity.
In the area of the test-site, many starch potatoes are grown and one of the fields was selected for the experiments with the wireless sensor network in 2005.

Design and development of the architecture.

Design and development follows common methodology used for ICT projects. After formulation of requirements, the major processes are identified and described as use-cases, the data to be collected and processed is described as classes and deployment of the data processing and –storage over the hardware components is described in the architecture. Interfaces for data exchange between the different components are formulated.

Development of the wireless sensor network component is based on the commercially available MICA2DOT processor radio platform (NN, 2003) and the equivalent TNOdes developed by TNO in the Netherlands.

Already developed software components like TinyOs and a Medium Access Control (MAC) Layer, developed by the Delft University of Technology are used as much as possible. (van Dam en Langendoen, 2003)

Experiments on radio wave propagation.

During the 2004 growing season experiments were set up to measure radio propagation over varying distances in a potato crop grown in Wageningen. For this experiment the Mica2Dot mote processor radio boards (NN 2003) are used. They are equipped with a Chipcon CC1000 radio's operating in the 433 MHz band. The standard $\lambda/4$ monopole antenna was used and protruded through the enclosure, based on the work by Polastre (2003). In this experiment no energy saving communication protocols were used and 7200 mAh lithium batteries were just enough to cover the duration of the experiment.

The CC1000 radio has a built in Received Signal Strength Indicator (RSSI) which results in an analogue output signal. The output current is inversely proportional to the received signal strength and measured by a 10 bit A/D converter. This measurement can be converted to engineering units as specified in the manual (NN 2003) by the formula:

$$RSSI(dBm) = -51.3 * V_{RSSI} - 49.2 \qquad (1)$$

Environmental weather conditions are measured at the experimental site by two temperature sensors, two relative humidity sensors and a rain gauge. T and RH were measured in the canopy and just on top of the canopy. As back up, data is available from the Haarweg weather station, a few kilometres from where the experiments took place.

A laptop computer is used as the base station and communicates with the nodes in the field through a node mounted on the MIB510 programming board (NN 2003). An omni-directional Diamond X 400 antenna with 11.7dB gain was used for the base station node.

The base station and the node software were developed by Whitehouse (2002) and written in an open source development environment for wireless sensors, called TinyOS. The programme orders each node in the field to sequentially send 30 messages while the other nodes listen. They measure the received signal strength of each message and store the results in the memory. When all nodes are done, they are requested to send the results to the base station. We used the highest available transmitting power during the experiment.

In the potato field of 154 by 105 meters, thirteen nodes were employed and arranged in two rows, 16.5 m apart. The mutual distance between the nodes in the rows was 3.0 m. The nodes were placed in the bottom of the valleys between the ridges with an average height of 0.25 m. The top of the antennas had a height of 0.295 m.

Results.

Architecture

The *Phytophthora* application was developed with a general architecture for agricultural applications of wireless sensor networks in mind. The following components, visualised in Figure 1, are highlighted.

Infield part.

The infield part ensures that the sensor values are collected. In our application the most important sensor values are T and RH. They are measured by a Sensirion sensor (NN2), which has its own processor and is calibrated by the manufacturer. It provides values in an I2C like manner to the node processor. Values are measured every minute and communication occurs every ten minutes. A Medium Access Protocol developed by the Technical University in Delft (van Dam & Langendoen, 2003), is implemented for transmitting the sensor values and forwarding the messages of neighbouring motes. Sensor readings are provided with a mote specific time stamp. For coding of the sensor values, the Process Data Elements of ISO11783 part 11 are used and extended. The messages for the wireless infield part follow the methodology of ISO11783 Part 7. Mote addresses are fixed in our application.

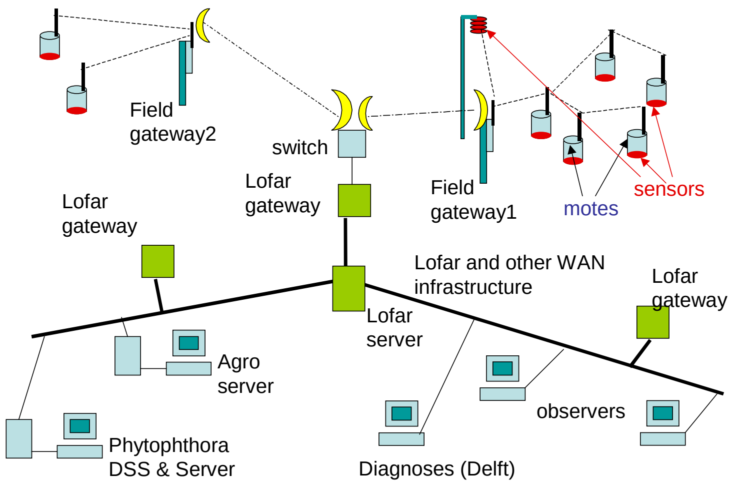

Figure 1. Main components for the LOFAR_Agro Phytophthora application.

Field Gateway.

A Stargate single board computer, equipped with a 400MHz X-Scale processor is located at the side of the field (NN, 2004). All messages are routed towards a field gateway with software for collecting the sensor data. The gateway is responsible for converting the mote specific time stamp to a time stamp on UTC basis. It also adds additional task information that the motes are unable to identify like the field it is working in, the person responsible for the session, when the measuring session started, etc. An important part in our experiment, but also for future use, is the gathering of information on network performance. The source of any problem should be known before sending someone into the field in case of malfunction. Data is stored in the gateway and sent to the data Warehouse on request. XML files following the ISO11783 Part 10 standard are used for data communication with the data warehouse. It was shown that this standard fulfilled all requirements, except for certain Process Data Elements representing meteorological variables, which are not part of the most recent draft version. Point to point communication to the LOFAR gateway is realised by a wireless Wifi connection and uses directional antenna's to cover the distance of a few hundred meters.

The Lofar Gateway and server.

The LOFAR gateway provides access to the LOFAR Infrastructure and the LOFAR server controls access by legitimate users.

Agro Data Warehouse

The Agro Data Warehouse (ADW) collects the data from the field gateway over the wide area communication system. XML files are processed with procedures already developed for data exchange with tractor mounted task controllers. The reliability of data is verified by comparing readings with neighbouring sensors and from the same sensor in the time domain. Correction of sensor values by calibration tables is done in the data warehouse. In the future corrections will be done within the sensors themselves.
The data warehouse checks authorisation of applications that request data and provides this data following the earlier mentioned XML methodology.

Phytophthora decission support system.
The decision support system has the function of entering general crop and field data, which can be stored in the ADW.

The DSS component generates a new recommendation on Phytophthora prevention, as soon as a new weather forecast becomes available. The actual information on microclimate in the potato crop obtained from the ADW is used to make spatially differentiated estimates on susceptibility for *Phytophthora* development. This results in spatially variable recommendations for prevention. Based on the generated information, estimates will be made on savings in fungicides that can be realised in theory and practice.

Observer system
During the experiment in 2005, it is possible for the public to follow development of the micro climate in the experimental field by means of a web application..

Radio wave propagation.
The antenna's used in the 2004 experiment protruded from the enclosure, which was identified a weak spot in the protection of the electronics assembly against the environmental conditions. A protective cover for the antenna and a watertight connection to the enclosure solved the problem.

Three measurement sessions were carried out in the potato field;

- a short indicative session in June with only two modes that were placed at different distances in the same lane. The potatoes canopies were not fully developed.
- two 14-day sessions in July and August following the described arrangement. At both times there was a closed canopy, but first signs of maturity in August resulted in reduced crop height.

The measurements resulted in 0.8 million successful range measurements, though about one percent of the data showed a very high standard deviation (SD) between the 30 or less received messages from each series of 30 transmissions. It was not possible to pinpoint which of the four programmes used in the data collecting process was responsible, so the SD was used to indicate corrupted data and they were excluded from further analyses.

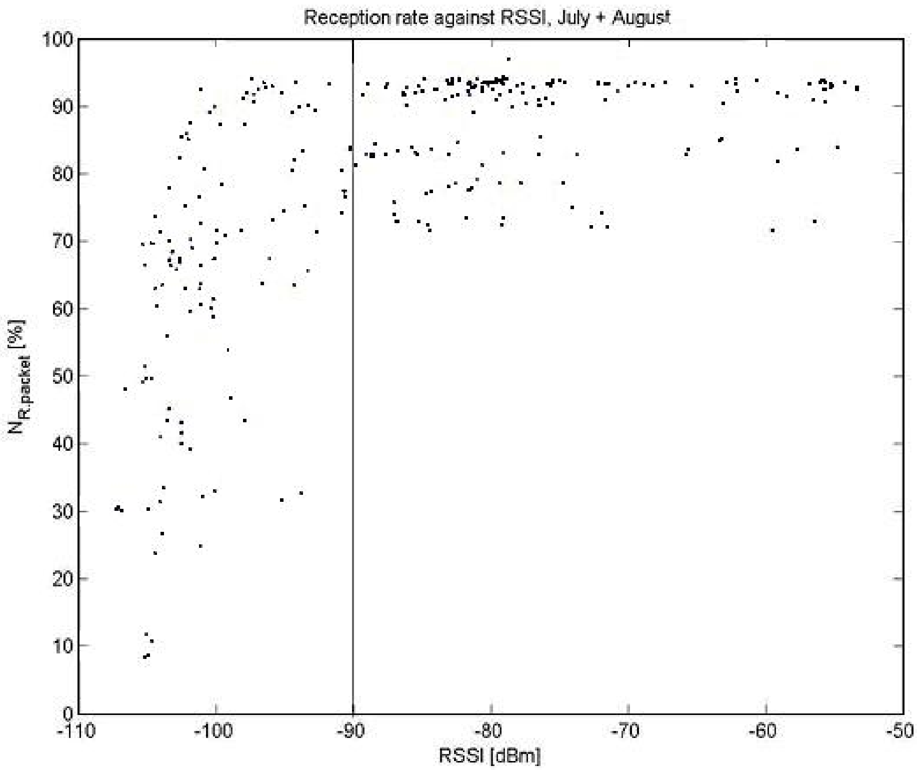

Figure 2. The percentage of received packets as function of the measured signal strength

Figure 2 shows the percentage of received packages as function of the measured radio signal, which indicates that below a radio strength of -90 dBm there is a considerable loss of messages. These results are somewhat poorer than those obtained by Alippi and Vanini (2004), who suggest -100 dBm as the threshold. In Figure 3, radio strength as function of transmission distance shows that reduction in signal strength follows a logarithmic trend as is indicated by theory (Parsons, 2000). Depending on the development of the crop, a strength of -90 dBm is achieved at 11 to 25 m. This is much shorter than the distance that can be reached following the plain earth propagation equation (Parsons, 2000), which gives a distance of 78 m for the radio and antenna specifications. The difference indicates the weakening by the crop canopy. The weakest signals are measured in July, when the total crop canopy is fully developed.

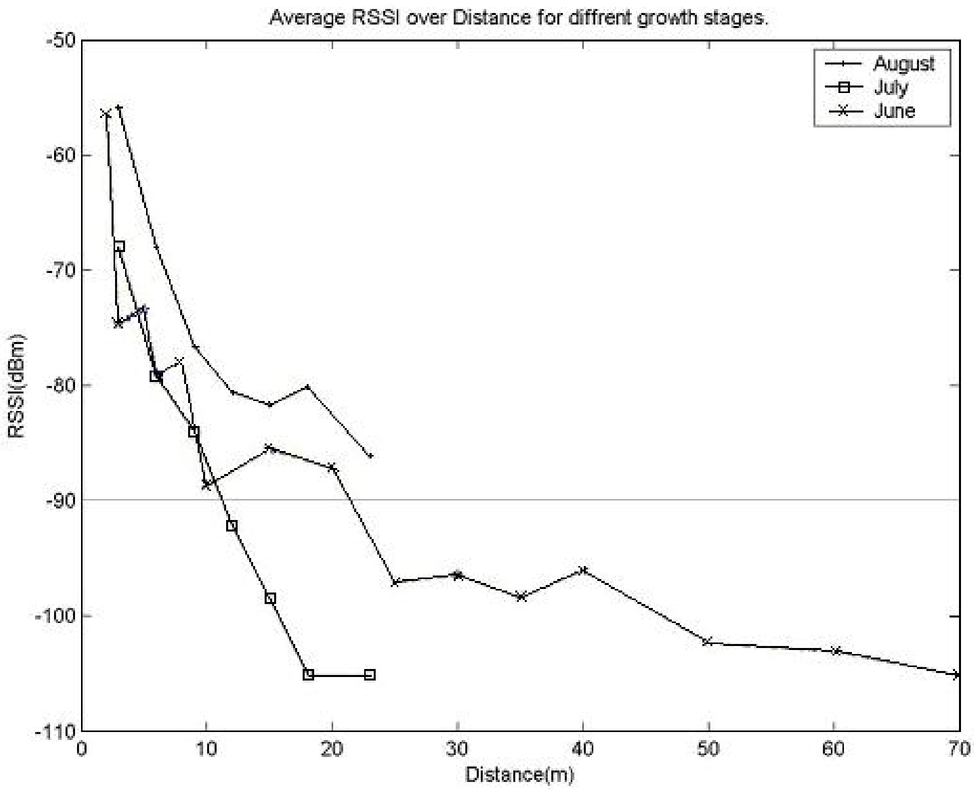

Figure 3. Measured received signal strength as function of transmission distance. Averages for three experimental periods.

The course of the signal strength shows a clear diurnal pattern, which corresponds with changes in temperature and relative humidity. The better radio reception is measured during higher relative humidity and the best reception, as shown in Figure 4 is during and short after a rainfall period. Linear regression analyses showed a clear relation between signal strength and relative humidity, but residuals show a diurnal course, which up to now cannot be clearly explained.

Conclusions.

<u>Architecture.</u>

Packaging of wireless sensors will form a major challenge for the coming years. They must protect the electronics against a range of weather conditions, but their form must also allow efficient employment and deployment.

An available energy saving MAC protocol is used for wireless communication, however there is an urgent need for a standard in wireless sensor networks in agriculture. Different manufacturers will operate in the same wave bands. As this might cause interferance between networks, non agricultural applications also, there is a need for an overall standard in respect of physical, data link and network layer. Zigbee or its base IEEE802.15.4 are examples of such standards. Requirements from agricultural applications should be drawn up and proposals for standards checked on them. Self-configurable addresses as used in ISO11783 should replace the fixed addresses we use in this experiment, but the address space of ISO 11783 of one byte will not accommodate future wireless sensor networks. The higher application-oriented layers should follow existing agricultural standards as closely as possible, so that management systems do not care whether the information comes from implements, fixed farm installations or wireless sensors.

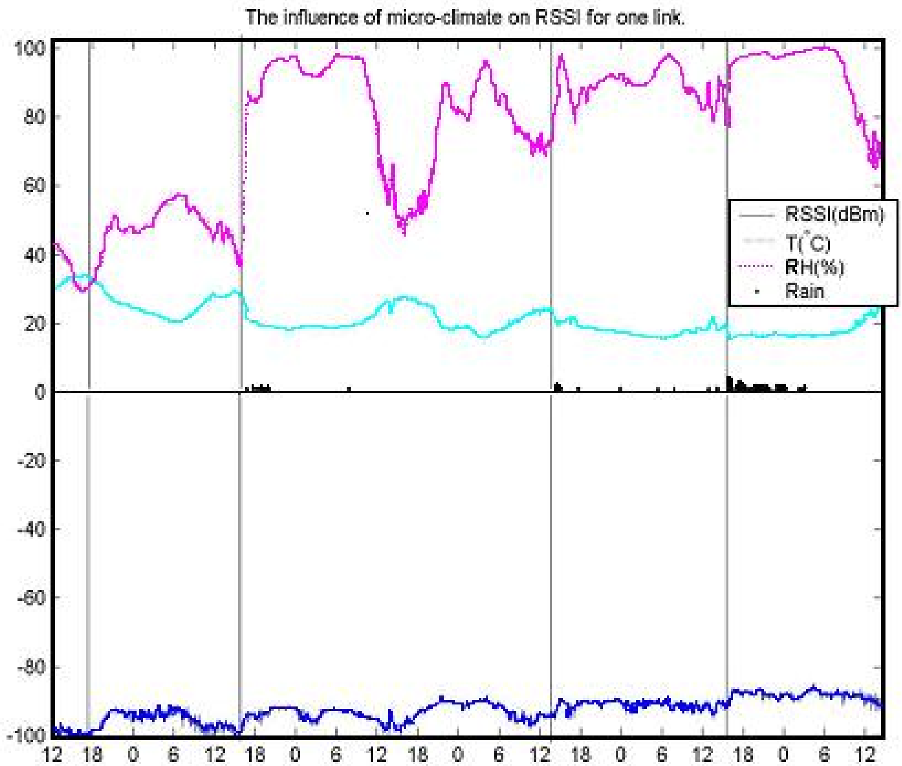

Figure 4. Course of the measured signal strength under varying environmental conditions.

Uniformity in standards is realised in our experiment by implementing ISO11783 the field-gateway as a TaskController and realising the data interchange with the Agro Data Warehouse as a ISO11783 TaskFile as specified in part 10.

Radio propagation

Experiments in a potato crop showed a clear influence of canopy development and mutual distance on the strength of radio signals. Reliable communication is possible with Mica2Dot motes operating in the 433 MHz band up to a signal strength of -90 dBm. This is achieved in a well-developed crop at a distance of around 11 m.

This shows that we will need around 100 radios per hectare to have reliable communication over the whole field. As not all crops will cover the associated cost by improved yields or reduced inputs, we look for alternative methods of mote employment that result in higher antenna positions with respect to crop canopy during the 2005 season.

The influence of weather conditions on signal strength requires some further investigation.

Outlook

The field experiment of 2005 will, when resources allow, be extended with wireless sensors that measure soil moisture, ground water table and leaf wetness. Available sensor technology will be extended with a TNOde for integration in the wireless sensor network.

Implementation of a part of the ISO11783 network protocol provides the possibility of dynamic address claim and allows in the future flexible placement of additional sensors in an already established network.

"Smart Dust" or wireless sensor networks can play a major role in future Precision Agriculture and Precision Livestock farming systems. Wireless sensors can, apart from monitoring the growth environment in open and closed crop production, also be used to monitor batches of produce during transport and storage. On animals they can be used to measure different variables as indication for health status and welfare.

A number of challenges are still present:

- Development of a standard that cooperates with wireless applications outside agriculture.
- Packaging of motes which serve the agricultural task, but is also cheap to manufacture and cheap to deploy.
- Energy supply
- Make them so robust that they can be employed by farmers.

References

Alippi, C. and Vanini, G. 2004. Wireless Sensor Networks and Radio Localization: A Metrological Analysis of the MICA2 Received Signal Strenght Indicator. In proceedings of the First IEEE Workshop on embedded Networked Sensors, Tampa, USA, 16 November, 2004

NN 2003. MPR-Mote processor radio board MIB – Mote Interface / Programming Board User's Manual. December 2003. Crossbow Technology, Inc. San Jose CA USA.

NN 2004. Stargate Developers guide. Rev A February 2004. Crossbow Technology, Inc. San Jose CA USA.

Parsons, J. D. 2000. The mobile radio propagation channel. John Wiley & Sons.

Polastre, J. R. 2003. design and implementation of wireless sensor networks for habitat monitoring. Master thesis, University of California, Berkeley. 2003. http://www.cs.berkeley.edu/~polastre/papers/masters.pdf

Van Dam, T. V. and Langendoen, K. 2003. An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks. *The First ACM Conference on Embedded Networked Sensor Systems (Sensys'03)*, Los Angeles, CA, USA. November, 2003.

Whitehouse, C. D. 2002. The design of calamari: an ad-hoc localization system for sensor networks. Master thesis, University of California, Berkeley, 2002. http://www.cs.berkeley.edu/~kamin/pubs/whitehouse02calamari.pdf