Proposing a Method of Network Topology Optimization in Wireless Sensors in Precision Agriculture

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Abstract

In this paper we are going to propose a new way to build a wireless sensor network which is based on measuring the field's electrical conductivity, staying away from the classic network grid implementation. Furthermore we are going to explain the way a typical WSN works, which are the pros and cons and the technical characteristics, as well as how electrical conductivity can influence our decision to build the WSN topology and the advantage of this approach comparing to the typical ones.

Keywords: Precision Agriculture, Wireless Sensor Networks, Electrical Conductivity

1. Introduction

Precision Agriculture refers to the use of an information system for the within-field management of crops. This basically means to add the right quantity of fertilizer to the right time and to the exact location within certain cultivate extend of ground. In fact we treat every part of the crop in different way and not as a whole part. The use of precision agriculture techniques gives agronomists the potential to apply new and continuously developing technologies which help to manage better the production. Some of these technologies are the GPS, GIS, Remote Sensing, Variable Rate Technology, Machine Controls and Smart Sensor Arrays and the WSN technology.

1.1 WSN Technology

A number of sensors which will be placed appropriately and will cover the whole filed are required for a WSN to function. These sensors can be programmed to record measures like temperature and humidity when we want them. All the data which are collected from the sensors, using a wireless multi-hop routing technology, end up in a gateway which transfers them to the end user through wireless network, internet or LAN.

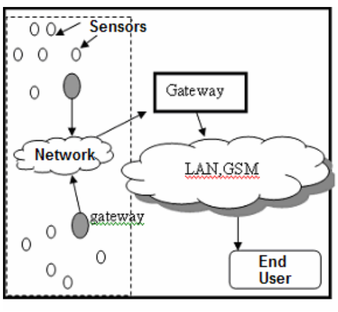

Figure 1 : A Wireless Sensor Network

1.2 The advantages from applying a WSN in the field

The benefits which arise from the application of precision agriculture technique come up from the precision in the irrigation quantity, the use of chemurgy only in the appropriate field areas, the control in the quantities of the fertilizer, the exact definition of the semination and crop. More over the use of appropriate quality of seed depending on the field conditions, water control, the optimum quantity of seed semination and spending less money on agriculture scientists and consulting firms are factors that WSN has a direct impact. In addition with WSN we have:

- Ability to observe for long periods of time crop state.
- Direct, exact briefing of the field state and ability to interfere in case of an emergency.
- Distant decision making
- Analytical information storage in order to create a case record of the field crop.
- Friendly Graphical User Interface with the monitoring system.
- Potential to make exact evaluation of new crop methods and techniques.

2. Materials and Methods

Precision Agriculture is mainly based on the management of the field's differenciality. The differentiality in the production is defined from the variability in the field structure, the organic matter, the level of saline and the level of water. In order to treat the field in different ways we should produce detailed management field maps which depict this differentiality. The production of these management maps can give us evidence, in an indirect way, of how to build the topological diagram of the WSN. The maps will act as a criterion based on which we could pass from the classic grid implementation to a more sophisticated diagram.

2.1 Management Zones

The field management zones are smaller parts of the field which show certain variability from each other and each of them needs different management treatment and tactics. The criterion to create the management zones is not only one and is not always fixed. The categorisation depends on several factors which the agronomists decide that are capable to do so, for example humidity, organic matter or agile. In figure 2 we discern 4 management zones each of which have individual characteristics.

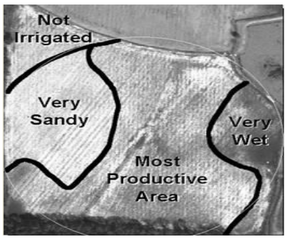

Figure 2: Management Zones

The size of the zones depends on the ability of the agronomist to differentiate them according to measurements. So there is no rule to state the size of a zone. Moreover the shape of the zones depends on which essence we measure and form the variability in the zones. However the zones should be clearly detected.

2.2 Electric conductivity and Veris System

The Electric Conductivity is a measurement of easiness with which electric current goes through the soil. It mainly depends from the presence of salts and the constitution of soil in sand, clay, organic substance and water. Regions with the same EC values belong in the same territorial type with a great probability and thus management maps construction can be done based in EC measurements.

According to so far research, the measurements of electrical conductivity are mainly influenced from humidity. This means that each time the levels of humidity change within the field we should not re-design the network because these levels change respectively for all the field and the management zones remain the same as before and so network diagram does not change either.

One of the most known systems for measurement of electric conductivity in real time is Veris 3100. The provision brings a GPS receptor so that each measurement is recorded precisely and collected in a central unit. For each area scanned with Veris a data file is produced including each measurement with the coordinates of the point that the measurement was taken. The data can be represented in a graphic mode so that regions with similar characteristics can be categorized, distinguished and clearly seen. This requires processing of data from specialised software of geographic information system (GIS).

2.3 Topology efficiency

We use the apove approach for the segregation of field in management areas with the use of Veris, so that we can avoid the grid concretisation. We place a number of sensors which will completely cover our informative needs from the aspect of data that should be dispatched, so that we have a complete picture for the total field.

We apply the following methodology for the optimal placement of sensors:
1. Scanning of all extent with the system Veris.
2. Explicit segregation between zones.
3. Registration of points in the field which can cause problem in the communication between the nodes.
4. Placement of nodes in points in which communication is achieved and which will give central measurements for each area.

In a real field in which cotton is cultivated in the region of Karditsa and with extent of 50 acres, we followed the above methodology in the management zones created by Veris system in a work done by Athanasios Markinos of the Department of Agriculture Crop Production and Rural Environment of University of Thessaly. By using the Veris 90cm measurement, the 50 acres field is segmented in five distinguishable zones.

Our simulations are done using the two following network topologies.
- Using grid topology we need 56 sensors with 32m vertical and horizontal distance.
- Using the proposed methodology we use 17 sensors with medium distance between sensors 34,8m.

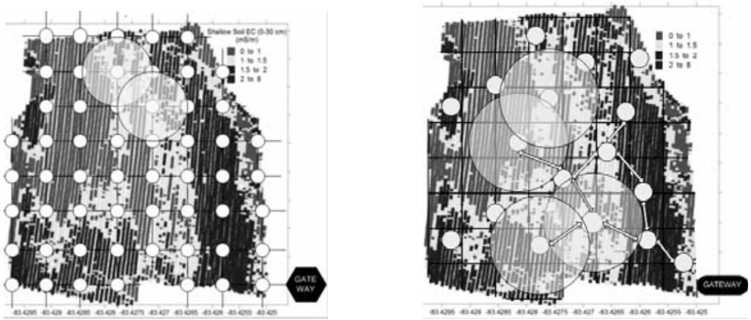

Figure 6: Grid Topology & Optimal nodes placement

Our simulation was done in Prowler, which is an event – based simulator, a framework based to TinyOS / NesC. Based on Prowler simulator, we used Rmase as a base platform to run the simulations.

The coverage distance for each node depends on the node and RF technology. We didn't want to put the nodes at the maximum coverage distance for more power efficiency. The medium distance of 35m results from distances of nodes that have the possibility of communication between them. Clearly there is a trade-off between the number of nodes used (lower cost) and the network robustness.

The reduction in the number of sensors that is required in the cotton cultivation, reaches 70%. This ratio occurs when we only use the absolutely necessary nodes to cover the management zones. In a more robust solution, we can use some extra nodes in key communication positions in the field, but we safely avoid the expensive grid solution.

A key point in the design of our network is receiving under consideration factors as scattering and the absorption and weakening of signal that depend each time from the type of the cultivation, the height of leafage as also hillocks and pieces of machinery in the field, while we should also consider sources of electric noise as cables of high voltage. Other factors are still the technology of sensors that will be used and real climatic conditions that prevail in the region.

One drawback of our topology proposal is that for specific nodes we have more power consumption in comparing with the grid topology. All sensors we use are greatly responsible for their zone through their measurements and they work in higher tension than the sensors used in a grid topology.

Results

Rmase provides a set of performance metrics for comparing different routing algorithms, including latency, throughput, success/loss rate, energy consumption/efficiency, and network life-time predication. The simulation time is calibrated.

Latency: Time to send a message from source to destination. For any destination, if n packets have arrived, latency for that destination is given by Si di/n, where di is the latency of the ith packet. The latency of the network is then averaged by the number of destinations.

Throughput: Number of messages per second received at destination. The throughput of the network is the sum of the throughputs from all destinations.

Success Rate: The total number of packets received at all the destinations vs. the total number of packets sent from all the sources.

Loss Rate: Number of lost packets vs. the total expected number of packets for that destination. Measures quality (e.g., more dropped messages result in lower sensing resolution).

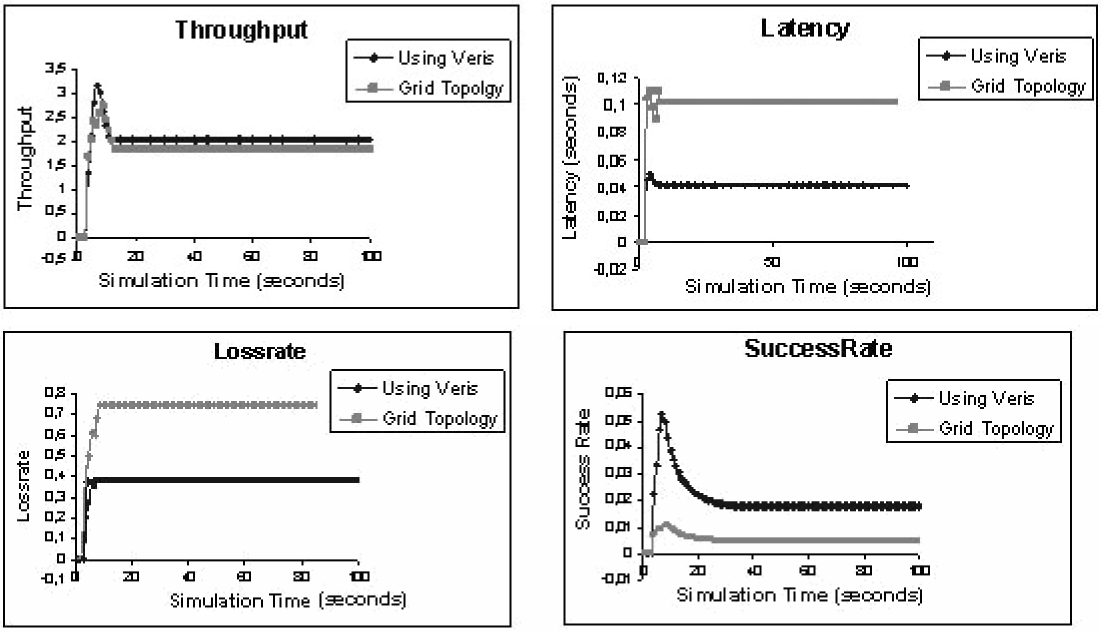

Figure 7: Simulation Plots using Rmase

Applying the methodology that we propose we have dramatic reduction in the number of sensors needed. The reduction in the number of sensors that is required in our real example in the cotton cultivation, reaches 70%. This is directly translated in a rapid direct reduction in the cost of concretisation and maintenance. In our particular example with cost of sensors 100€ we have reduction in the cost of concretisation 3900€.

Using a de facto grid topology substantially we do not receive under consideration factors such as scattering and multi path reception.

An other advantage is that because the humidity of the ground is altered proportionally in all the field influencing the prices of conductivity uniformly, the management zones remain immutable. This means that we do not need to re-design the topology of the network. In our experimental field the management zones have remained inalterable for 5 years.

Because the number of sensors is decreased, maintenance of the network is easier.

Finally, we do not fill the extent with sensors, with result easier harvest and seeding.

Discussion

Our aim is the real concretisation of the WSN in the specific field in the very near future. Mica or Mica-like motes will be used. We also aim to use technologies other than Veris, and take locally conductivity measurements and so obtain the maps needed.

We closely collaborate with the Department of Agriculture Crop Production and Rural Environment of University of Thessaly to make a complete comparison of humidity and temperature measurements taken from data loggers, which take ground measurements and use wires to send all data in a central unit. As a next step we aim to verify this system with WSN concretisation.

Conclusions

Precision Farming and WSN applications combine an exciting new area of research that will greatly improve quality in agricultural production, water management and will have dramatic reduction in cost needed. Furthermore, the ease of deployment and system maintenance opens the way for the adoption of WSN systems in precision farming. Using the proposed methodology, in finding the optimal sensor topology, we contrive to lower implementation cost and thus make WSN a more appealing solution for all kinds of fields and cultivations.

Acknowledgements ??

References

Jason Lester (Spring 2003), System Architecture for Wireless Sensor Networks, Hill University of California, Berkeley

Eiko Yoneki, Jean Bacon (September 2005), Technical Report A survey of Wireless Sensor Network technologies: research trends and middleware's role, University of Cambridge

Kevin C. Kahn, David E. Culler (April 2002), Ad Hoc Sensor Networks A New Frontier for Computing Applications, Intel Corporate Technology Group

Virginia Tech, (August 2002), Precision Farming: A Comprehensive Approach,, Publication Number: 442-500

Spyridon Fountas (1998), Precision farming, Cranfield University, MSc thesis

P.C. Kikiras1 & D. Drakoulis, The European Approach to Augmented Satellite Based Positioning Systems and their Application in Precision Farming

M. Shamsi (1999), Design and Development of a Date Palm Harvesting Machine, Ph.D. thesis. Cranfield University.

Calvin Perry (2005) Variable-Rate Irrigation", University of Georgia Biological & Agricultural Engineering and NESPAL Tifton Campus

George Vellidis (2005), A Real-Time Smart Sensor Array for Scheduling Irrigation in Cotton, NESPAL – National Environmentally Sound Production Agriculture Laboratory

J. Burrell, T. Brooke, R. Beckwith (2004), Vineyard Computing: Sensor Networks in Agricultural Production,Published by the IEEE CS and IEEE ComSoc 1536-1268/04

Aline Baggio (2005), Wireless sensor networks in precision agriculture, Delft University of Technology – The Netherlands

Wei Zhang, George Kantor, Sanjiv Singh (2003), Integrated Wireless Sensor/Actuator Networks in an Agricultural Application, Carnegie Mellon University

E. D. Lund, C. D. Christy, P. E. Drummond ,Practical applications of soil electrical conductivity mapping, Veris Technologies, 601 N. Broadway,, USA

Athanasios, Markinos (May 2006), Using Veris to produce management maps, First Conference on Precision Agriculture Implementations, University of Thessaly Volos

K. P. Ferentinos, T. A. Tsiligiridis, K. G. Arvanitis (July 2005), Energy Optimization of Wireless Sensor Networks for Environmental Measurements, Informatics Laboratory, Agricultural University of Athens