Self Organising Wireless Sensor Networks as a Land Management Tool in Developing Countries: A Preliminary Survey

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Abstract: This study is partly motivated by the conditions in developing nations, especially those in Africa where food consumption exceeded domestic production by 30% in the mid 90s and where 70% of the population live on farming. This production deficit which appears to be growing co-exists with a large segment of the population working in agriculture. What can self organising wireless sensor networks do to help? This overview discusses the environmental and technological challenges of seeking a solution and the socio-economic opportunities for the application of wireless technology in land management. Self organising wireless sensor networks, if implemented adequately, have the potential to target diseases given limited resources such as pesticide and fertiliser. It also has the potential of bridging spatial data gap thus empowering policy makers with more effective tools for risk assessment and decision making.

1. Introduction

The term self organisation is used to define the development of a system-wide adaptive structure and functionality from simple local interactions between individual entities. In a structure, the entities are arranged in a particular manner and interact with each other in some way. Functionality means that the overall system fulfils a certain purpose, for example, a school of small fish use a group structure to protect themselves against predators. Self organisation is about the behaviour of individual entities at a microscopic level which result in an overall system behaviour at a macroscopic level. This is called emergent-behaviour [1].

In a multihop sensor network, communication nodes are usually scattered in a sensor field with each of the scattered nodes having the capability to collect and route data via a wireless medium such as radio signals [2]. Sensor networks present a different problem for other large scale networks like the internet because of the high ratio of communicating nodes to users. Since Sensor networks exist in ratios of thousands of nodes per user, it is impossible to consider each node specially [3]. In other words the sensor network needs to be scalable especially since some nodes may be in inhospitable terrains and hence inaccessible. Secondly sensor networks must be robust and operate in very different environments with the ability to adapt to changes in the environment [2]. One such environment where the role of sensor networks is actively developing is in land management. This paper, aims to present an overview of the challenges and opportunities for the application of wireless sensor networks in agriculture. Section 2 discusses the background and motivation behind the project in conjunction with related work. Sections 3, 4 and 5 respectively consider environmental grounds for sensor networks, technological options for the application of wireless sensor networks in agriculture, and the opportunities, potentials and benefits of such a network. The paper finishes with a conclusion and thoughts for future work.

2. Background and Motivation

Ning Wang *et al* [4] present an overview of recent developments in wireless sensor technologies in the food industry. They advocate the deployment of a wireless sensor network (WSN) in agriculture because of its small size, low fixed cost and simplicity of wiring. For example, typical wiring in industrial applications has an average cost of $130-$150 per metre but employing a wireless sensor technology eliminates 20-80% of that cost [4]. This cost saving is illustrated in Figure 1 which shows that the price of wireless sensor networks is projected to fall by over 50% every 18 months. Further, Figure 2 shows the relatively small size of WSNs in comparison to other applications in monitoring.

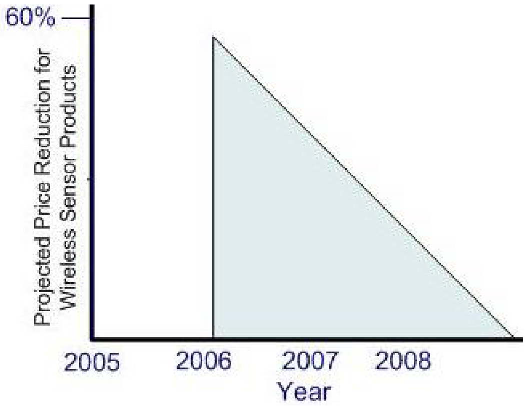

Figure 1 The projected price reduction for wireless sensor production

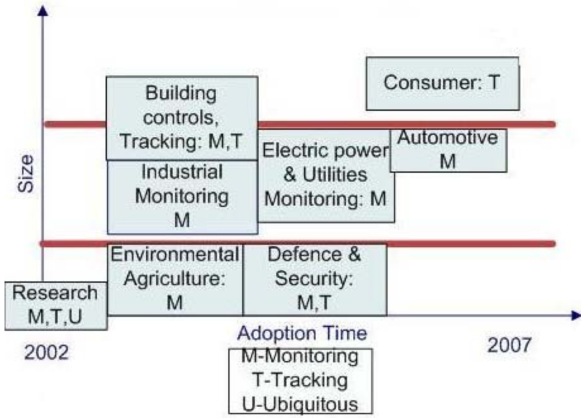

Figure 2 WSNs are relatively small in size and are currently being adopted in agricultural/environmental monitoring

In 2006, 6 – 10 million wireless devices are predicted for sale compared with just 200,000-500,000 sold devices in 2004. This proliferation is also reflected in the world wide growth in published literature dealing with the application of wireless sensor technology. Two cases below illustrate this developing trend.

In California, Beckwith *et al* designed, deployed and analysed output of a large scale implementation of a wireless sensor network in a vineyard [5]. 65 motes with a maximum of 8 hops were deployed in a planned area where no neighbour discovery features were implemented and a table driven protocol was used rather than a self organising network. Data were recorded every five minutes with a grid of sensor nodes each separated 15m from the other. Analysis of sensor data allowed the prediction of pH, titratable acids and berry weight. Using wireless sensors, Beckwith and his colleagues were able to determine a 6 hour threshold after the onset of frost when a wine maker would need to take action to deal with a weather problem.

In Europe, the Lofar Agro project is a study of precision agriculture that focuses on tailored management of a crop. This involves monitoring soil, crop and climate conditions in a field, generalising the result and providing a decision support system (DSS) for treatments or taking differential action such as real time variation of fertiliser or pesticide application. The DSS gathers information from a weather station and the wireless network. This is employed to map out a temperature and soil humidity distribution which is used to develop an effective strategy for controlling diseases such as Phytophthora [6].

3. Environmental challenges

There are further grounds for deploying WSN in Africa- including soil degradation, water scarcity and data generation for planning.

3.1 Soil Degradation

The IFDC, an international centre for soil fertility and agricultural development, reported that owing to the limitations in farming practices such as fertiliser usage, the levels of soil nutrients are declining at an annual rate of 30 Kg /ha in 85 % of African farm land [7]. Growers must then cultivate more land at the demise of wildlife and forest. Africa looses approximately $ 4 billion worth of eroded soil nutrient yearly severely damaging its ability to feed itself. This cycle of degradation was confirmed by IFDC researchers who further reported that agriculture, in conjunction with factors such as deforestation, worsen soil erosion and that if erosion rates continue unabated, the yield of some crops could fall by 17-30% by 2020. This suggests the need for monitoring using a WSN to provide a basis for policy action.

3.2 Limited fresh water

Agricultural production accounts for 70% of the world's fresh water usage and as growing population increases agricultural demands, per capita fresh water availability is declining faster than it is being replenished. This is compounded by the fact that irrigation relies heavily on ground water. For example 60% of irrigation water in Texas and 38% in California is pumped from the ground [8]. This heavy reliance on ground water for irrigation also exists in developing countries including Africa An estimated 16% of the world's crops are irrigated and 33% of the world's food is produced on irrigated land. In addition, the predicted global warming could increase world irrigation requirements by 26% to maintain current production rates [8]. This pressure on the world's water resources makes WSNs desirable and urgent.

3.3 Lack of data

Reference [9] outlines other challenges involved in assisting African countries to attain socio economic development. These include gaps in available spatial data and information, limitations in the capacity to apply new technologies to bridge spatial data gaps, limitations in the transformation of data into useful information and knowledge for governments, lack of internet and finally lack of awareness by African governments and policy makers. These problems further support the deployment of WSN.

4. Wireless Sensor Networks - Technological Options

Deployment of wireless sensor networks in agriculture is at its infancy. Currently three main wireless standards are used namely: WiFi, Bluetooth and ZigBee. Of these, ZigBee is the most promising standard owing to its low power consumption and simple networking configuration. However ZigBee standardisation is not yet complete. Some of the main obstacles in WSNs inspired by Ning Wang *et al* in [4] include:

- The limitations to power supply in a wireless sensor network
- The significant overhaul of existing IT infrastructure required if wireless sensor networks are to achieve their full potential
- The potential for the plethora of data generated by thousands of sensor nodes to overwhelm the system while providing limited value
- The reliability of wireless sensors in agriculture is unproven and is considered risky

Obviously, no unique solution for all these challenges exist however the application of wireless sensors in land management can raise awareness of the effectiveness of new technologies in the agricultural domain. The next section describes some socio-economic benefits which should encourage the search for practical solutions to some of the aforementioned challenges.

5. Opportunities

The agricultural model in Figure 3 shows some of the socio-economic benefits to farmers employing WSN technology. These include empowering the private sector, improving governance and managing diseases more effectively. Figure 3 also illustrates that the increase in GSM is mirrored by the spread of WSNs. The advent of GSM standard in the early 80s spurred the growth of mobile phone users which expanded from 1 million in the early 90s to over 2 billion by the end of 2005. Sensors and mobile phones have gone from bulky, simple and expensive devices to small, complex and cheap devices.

6. Conclusion

Despite the technological obstacles such as the incomplete standardisation of ZigBee, the application of wireless sensors in agriculture has the potential to be an economically viable replacement to wired networks. They can provide risk assessment data such as alerting farmers at the onset of frost damage and providing better microclimate awareness, say, through the use of local temperature highs. Such alerts may be useful in African farms which face annual declines in soil nutrient content due to limitations in farming practices. There is a credible future in the deployment of self organising wireless sensors in agriculture for developing countries. The next stage of this research will investigate which parts of sensor technology are applicable and useful to decision makers in the land management domain.

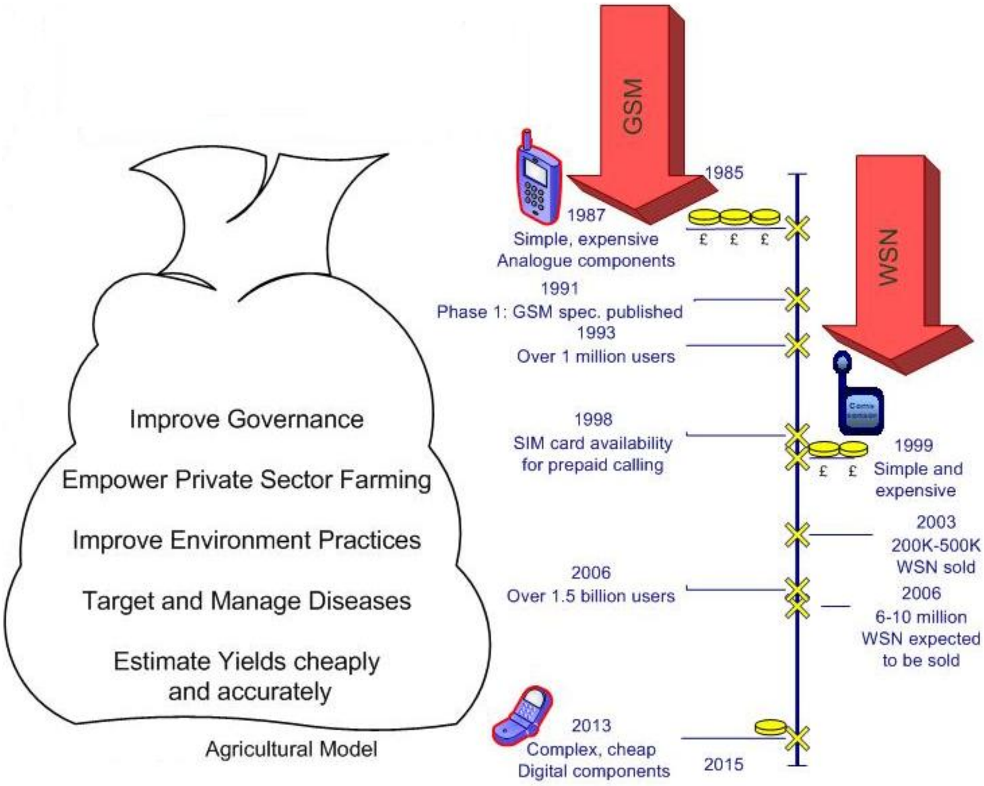

Figure 3 The socio-economic advantages of employing wireless sensors networks in agriculture and a WSN/GSM timeline

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