Agent Oriented Routing for Wireless Sensor Networks

Leonardo Leiria Fernandes
Department of Information and Communication Technology
University of Trento - Italy
leiria@itc.it

Presented to the PhD course on
Advanced Topics in Agent-Oriented Computing
by Professor Andrea Omicini

April 28, 2007

Abstract

As the cost of electronic devices drops at impressive rates, wireless sensor networks (WSN's) are more and more seen as a useful and innovative way for humans to understand and interact with their environment. The popularity of such technology provides a vast number of new possibilities, and also many new technological challenges. One of those challenges is to provide efficient routing in sensor networks. Battery technologies do not improve as fast as electronics, and therefore energy saving is still one of the major issues on sensor networking. Multihop communication between sensors and base stations is preferred, since it saves energy to communicate in short distances only. As sensor nodes differ from traditional computing devices in several ways, routing in such networks is still a research matter.

Agent based computing is an important trend in computer science. It provides a new level of abstraction where entities called agents are autonomous in the sense that they encapsulate a thread of control. More specifically, mobile agents can be very useful in an environment such as sensor networks. As only local information is available to nodes, agents, for example, can collect such information throughout the network and come up with better solutions to problems such as efficient routing.

This document discusses the use of agent orientation in sensor networks and proposes a possible use of agents in WSN routing.

1 Introduction

Wireless sensor networks (WSN's) are a relatively new technology, but with an incredible potential to revolutionize the way people and organizations interact with the world around them. There are countless applications of the technology. In agriculture, for example, sensor networks can identify clearly where are more nutrients or irrigation needed and where not, maximizing productivity and resource utilization. Health monitoring is another application, for example a sensor network could monitor health-related data like heart rate of the elder at their own home and contact an emergency service in case of need, as well as maintaining doctors up to date with patients situation. Industries can monitor the proper conservation by measuring humidity, temperature, pressure and chemical characteristics of both products and raw materials in order to increase the quality of the productive process by taking corrective measures as soon as needed. Other applications include security, fire detection, disaster scene monitoring among many others. As the price of sensors continue to decrease this applications are expected to become more and more common and many other applications are likely to arise too.

Since sensors need to be very cheap, in order for the deployment of large quantities of them in possibly hostile or hard to reach environments to be cost-effective, and still provide some quality of service to meet the application, there is still many research to be done in the field.

Radio transmissions, for example, are one of the most energy expensive features of wireless sensor networks. The energy cost of a radio transmission is proportional to the square of the distance between sender and receiver. For this reason, such networks are usually implemented using low range communications and making the sensors to work as a multi-hop network instead of transmitting data straight from the sensor detecting the phenomena to the base station, which can be far away from the area. Even short range radio is a quite energy consuming task, so routing efficiency is a main research concern in the sensor networking field.

This document summarizes some efforts to apply agent oriented development to wireless sensor networks and also introduces a possible agent-based solution to the routing problem. The next section introduces the agent development paradigm. Afterwords, a discussion of the routing in WSN's problem is presented. In section 4 some agent oriented implementations in wireless sensor networks are discussed. And finally the proposal to the agent oriented routing is briefly introduced and some conclusions are provided.

2 Agents

Agents are defined by Wooldridge and Jennings [7] as hardware or software systems that enjoy autonomy, social ability, reactivity and pro-activeness. Autonomy means that agents operate without direct intervention by humans or other agents and have some control over their internal state. Social ability in the sense that agents should be able to communicate with other agents, and with humans in some cases, using some kind of language. Reactivity means that agents should have one or more "senses", meaning that they need to perceive one or more dynamic characteristic of its environment. And pro-activeness requires that agents should take goal-oriented initiatives, often to somehow change the environment.

Other definitions of agents are less restrictive. Franklin and Graesser [2], for example, define an autonomous agent as a system situated in an environment which it can sense and act on. Such action is taken over time, in pursuit of the agent's own agenda and so as to affect what it senses in the future.

The key word in most agent definitions in the literature is autonomy. The fact that an agent is not "run" by a user, or "called" by other agents or objects after its initialization, following its own goals and encapsulating its own control instead, is what differentiates an agent from a regular program or procedure.

Many agents have sophisticated characteristics. Learning agents, for example are able to "learn" through their experience in a way that will make them react differently to a given situation each time, trying to obtain better results based on previous results of their actions. Other agents are mobile. Mobile agents can move from one machine to another in a network, accomplishing tasks in a distributed environment.

3 Routing in Sensor Networks

Sensor networks are different from other communication networks. Usually, there is no sense in establishing a point to point connection between two arbitrary sensor nodes in the network, as is the case in traditional computer networks. Instead, the destination of all data is usually a small set of nodes called base stations or sinks in the sensor networks terminology. Often one single sink is available. In this sense, Sensor networks can be seen as converge-cast networks. In many cases nodes don't even have unique identifications.

Communication is often done through the propagation of an interest from a sink in the network and replies from the nodes that can match such interests back to the sink, as proposed in the directed diffusion protocol [4]. Nodes that provide data to the sinks are usually called data sources, or simply sources. For example, assume humidity sensors are distributed in a field and they have approximate information about their position. An interest from the sink could be a message asking about humidity on a specific area of the field. By knowing their position and the area of interest, sensors can determine if they should become a source and reply to the message or not. If a reply is sent, it could be forwarded to the sink by the reverse path through which the interest arrived.

Interests are often flooded in the network. Such flood allows nodes to keep information about which neighbors they should forward application messages to, i.e. the ones they received interest messages from.

To perform this kind of interest propagation and converge-cast in the most energy-efficient way possible is the wireless sensor networks routing problem.

4 Agents and Sensor Networks

Gan, Liu and Jin [3] propose a solution where agents are created whenever a source node decides to send a data packet to the sink. The agent is then responsible for carrying the data through the network. After reaching the destination, the agent delivers the data to the application and then dies. The agents in this scheme act in a very simple way. After arriving at a node, the agent checks a forwarding table available at the node with the possible next hops, including such nodes respective costs and energy levels. Based on that information, agents take a decision. Since energy levels are depleted as agents use a given path, future agents might take more expensive paths that happen to have more energy available, achieving some degree of load balancing. The paper also discusses a possibility of agents that negotiate and aggregate their data when they "meet" in the network, possibly becoming one single agent after such aggregation. One problem with this solution is that agents do not live more than the time it takes to transport a piece of data. All the routing information that could have been obtained by the agent is lost with it. We believe that the same solution could be achieved implementing the same logic used in the agents on each node, and making nodes simply forward data to the same node where an agent would have moved to.

Agilla [1] is an agent based middleware for agent deployment in sensor networks. The middleware provides an infrastructure for the implementation of agents that can run on top of the main operating system currently available for sensor networks, which is TinyOS. Agilla provides the infrastructure for the creation and mobility of agents. There is also a "cloning" operation that allows the agent to create a copy of itself and send it to a neighboring node. A fire detection agent based application is developed and deployed to validate the Agilla middleware.

Wang et al [6] describe a methodology for data fusion in sensor networks that is also based in agents. Data fusion is very important because it can save radio transmissions and tries to keep the richness of the data.

USAC is another agent based protocol, proposed by Padhy et al [5]. The solution was used to improve the reliability of a glacial sensor network deployed in Norway by the University of Southampton. In this approach, the agents are the nodes themselves and the agents decide not only the routing, but also when to spend energy on sensing the environment. An utility function is implemented by the agents to find out weather the collected data should be transmitted or not. For example, data with a high variance is considered more relevant than data that remains in a given range through time. Agents, based on the past, try to predict the future behavior and can decide to make more or less frequent readings of the environment based on their expectations. The routing is also decided through a cost benefit analysis. The value of the sensed information and the cost of different routes are analyzed. In this implementation, agents can even decide to send data straight to the base station, if they decide the data is worth the high communication cost. One drawback is that the solution requires nodes to know all the network topology. That is acceptable on the deployment studied in the paper, which has about twenty nodes only, but could be unfeasible on larger sensor networks.

5 Agent Routing

As shown in the previous sections, the deployment of agents in sensor networks is not only feasible, but useful. Given the previous discussion, an agent oriented routing protocol is proposed.

In the proposed solution, agents are responsible for transporting data between nodes. Agents are created when an interest is flooded in the network. As if the sink injected agents in the network to find and get the data. The agents flood the network, as the interest message would do. On this flooding phase, agents "clone" themselves when there is more than one path to be covered. Further, when an agent passes through a node, it gathers information on that node such as energy available, hop count to the sink and number of neighboring nodes that lead to the sink. The goal is that agents gather information about the topology of the network that can be used later, on the routing phase.

When agents "meet" in a node, they can also exchange information, so that agents can increase the amount of information they have about the network. Also, if both agents have information about the same part of the network, both of them can decide to keep only the more up-to-date information. In this case, timestamps would have to be collected with the information on each node, but no synchronization is required, since a local clock of each node is enough to order the events in that node. Agents can even merge into one single agent with their combined information if there is no need to keep exploring the network in more than one direction. Agent "meetings" can also include exchanging information about the latest interests of the base station, in case such interest changes.

When an agent finds a source, it gathers its data and starts acting as a routing agent. Based on all the information the agent has gathered before, it can calculate the best path to the sink in advance, avoiding regions with low energy available, for example. The advantage of this scheme compared to the one proposed by Gan, Liu and Jin [3], discussed before, is that agents can decide based on all the information they have gathered in their life (i. e. on the way from the sink to the source) instead of taking decisions based on locally available information only.

Agents that get to the boundary of the network without finding any sink can either keep exploring the network or kill themselves to save memory and the cost of being transmitted to other nodes.

After the agent delivers data at the sink, it can be informed of a new interest for data to be collected, in which case the process starts again, but with the advantage of the agent already having some topological information.

Eventually, an agent could have information about all of the network, and would only update such information when meeting other agents or visiting nodes to gather application data. For large networks, due to memory limitations, maybe it is not possible for an agent to keep information about all of the network. In such cases, agents should keep track of the most recent information. For example, having information about the last ten nodes visited can already provide a better informed decision then having only local information available.

The number of agents necessary to keep the network running is application dependent. Of course the sink can create and kill agents to deal with varying demands for information from the network.

6 Conclusion

This document discussed the use of agent oriented computing in wireless sensor networks. Brief introductions to both the multiagent paradigm and the routing in WSN's problem were provided, as well as some uses of agent orientation in sensor networks found in the literature. Also, a very high level description of a possible use of agents to accomplish an efficient routing scheme was presented. Such description lacks better detail and demands further investigation on its feasibility, design and implementation. This document is to be seen as an initial proposal of a new approach to a problem, and not as a mature research result.

References

[1] Chien-Liang Fok, Gruia-Catalin Roman, and Chenyang Lu. Mobile agent middleware for sensor networks: an application case study. In *IPSN '05: Proceedings of the 4th international symposium on Information processing in sensor networks*, page 51, Piscataway, NJ, USA, 2005. IEEE Press.

[2] Stan Franklin and Art Graesser. Is it an agent, or just a program? a taxonomy for autonomous agents. In *Proceedings of the Third International Workshop on Agent Theories, Architectures and Languages*. Springer-Verlag, 1996.

[3] Long Gan, Jiming Liu, and Xiaolong Jin. Agent-based, energy efficient routing in sensor networks. In *AAMAS '04: Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems*, pages 472–479, Washington, DC, USA, 2004. IEEE Computer Society.

[4] Chalermek Intanagonwiwat, Ramesh Govindan, and Deborah Estrin. Directed diffusion: a scalable and robust communication paradigm for sensor networks. In *MobiCom '00: Proceedings of the 6th annual international conference on Mobile computing and networking*, pages 56–67, New York, NY, USA, 2000. ACM Press.

[5] Paritosh Padhy, Rajdeep K. Dash, Kirk Martinez, and Nicholas R. Jennings. A utility-based sensing and communication model for a glacial sensor network. In *AAMAS '06: Proceedings of the fifth international joint conference on Autonomous agents and multiagent systems*, pages 1353–1360, New York, NY, USA, 2006. ACM Press.

[6] H. Qi, X. Wang, S. Iyengar, and K. Chakrabarty. Multisensor data fusion in distributed sensor networks using mobile agents. In *International Conference on Information Fusion*, pages pp. 11–16, August 2001.

[7] Michael Wooldridge and Nicholas R. Jennings. Agent theories, architectures and languages: a survey. In Woolridge and Jennings, editors, *Intelligent Agents*, pages 1–22. Springer-Verlag, 1995.