Role Swapping in Multi-Agent Sensor Webs

Rónán Mac Ruairí [1] **and Mark T. Keane** [2]

Abstract. This paper reports on the application of multi-agent systems to the design of sensor networks. In advance of the current hardware/software capabilities of these sensor networks, we simulate a sensing network handling the detection of a contaminant, in a hostile environment, where the effective life of the network has to be optimised. By casting each sensor as an agent that can swap its role as conditions in the network change we show that networks using role-swapping, as opposed to fixed roles, can be much more effective over time. The emergent behaviour, that arises from economical local interactions, also becomes more effective as the environment for the network becomes progressively harsher.

1 Introduction

Sensor webs are a new form of instrument based on miniaturised wireless computing nodes [1] that have not, to date, relied heavily on Multi-Agent Systems (MAS) research. These instruments will eventually be deployed to operate in an autonomous fashion, possibly in inaccessible and inhospitable environments. Under these conditions, it is critically important that sensor webs prolong the battery life of their units and can adapt to the loss of nodes when particular units expire. Due to current hardware constraints and the desire to minimise the cost of individual units the first generation of sensor webs deploy simple protocols and routing strategies. However as hardware technologies evolve some sensor web applications may benefit from concepts studied in MAS.

We aim to simulate an adaptive sensor web that uses a basic agent at each node to achieve adaptable behaviour. We focus on one organisational abstraction – the role - and investigate some mechanisms that motivate agents to swap roles. Roles are generally characterised by either a set of tasks, responsibilities, and authorities or some combination of these factors and play an important part in complex systems as they help to delineate the relationships between constituent entities. For these reasons, several researchers have applied models of roles to problems such as object-orientated and agent-oriented system analysis and design [2,3].

Our prediction is that a multi-agent, sensor web with role swapping capabilities will outperform one with fixed-role agents and that this performance improvement should increase as the environment becomes increasingly harsh. We report a series of experiments to test these predictions in a simulated sensor web under conditions of varying node failure. In particular, we are interested in achieving organisation without a high negotiation or communication overhead.

The usefulness of emergent behaviour has been discussed and predicted by a number of authors (for example [6]). Sims, Goldman and Lesser [4] is most closely related to the present work. Sims et al. Report good results using negotiation to decide membership in a set of sectors. However, they use an idealised situation which assumes a global understanding of the topology to calculate utility costs for negotiation.

1.1 The Application Scenario and Roles Model

The experiments simulate a set of agent-based sensor nodes deployed in a two dimensional environment in which plumes of a notional contaminant are released. The overall instrument must strive to extend its' useful lifespan in the context of ongoing environmental pressure. In other words the instrument must maintain its functionality as individual nodes run out of energy or become damaged. To simulate this damage at every time step, zero or more nodes are selected at random, marked as damaged and take no further part in the instrument's functionality.

The agents used in this experiment are simple reactive agents which use a small set of rules to swap roles and transmit data to nearby nodes in the sensor web. Each agent has partial visibility of the environment and therefore must operate within its immediate locality. We call this locality a node's neighbourhood and define it as the set of agents within it's immediate wireless communication range (as opposed to agents reachable via message hopping). Agents are distributed randomly and so neighbourhood memberships are likely to overlap and vary in size, in fact each neighbourhood really only exists from the perspective of an individual agent. As an agent swaps a role its' neighbourhood may change according to transmission policy.

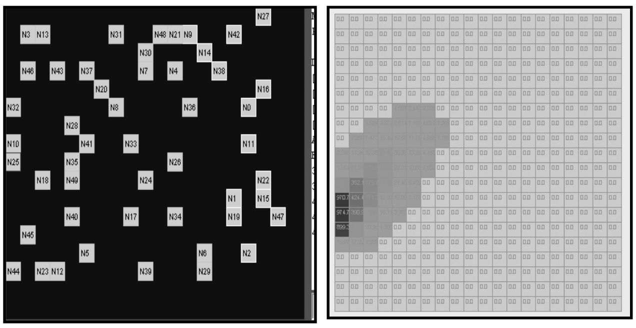

Figure 1. An example of node deployment and a map of one plume at a particular point in time.

Our system has two roles (see Table 1). The first role, the Producer, generates and transmits sensor readings to the other role, the Integrator, which in turn transmits alerts to a base station. Integrators require data from more than one Producer in order to decide if a plume exists and the base station uses a simple algorithm to count the number of unique alerts generated during an experimental run.

The roles have similar power usage profiles; however, the Producers are only active every second time step whereas Integrators are constantly active. This is set explicitly so that Integrators will have approximately twice the power requirement of Producers. Therefore, to maximise instrument life while maintaining functionality, the spatial distribution of agents in each role and their relative numbers – the ratio Producers (R_p) to Integrators (R_i) – must be optimised. As these are global

---

[1] Department of Computing and Mathematics, Dundalk Institute of Technology, Dundalk, Co. Louth, Ireland, ronan.macruairi@dkit.ie
[2] Adaptive Information Cluster, Department of Computer Science, University College Dublin, Dublin, Ireland, mark.keane@ucd.ie

properties which we cannot control directly, individual agents must monitor and optimise the following parameters:

- Their local (neighbourhood) view of the ratio ($R_p : R_i$)
- Their individual power consumption

Role:	**Producer**
Cognitive Tasks	▪ Check sensor for changes ▪ Send data changes to local Integrator(s) ▪ Assess local role needs
Communication Tasks	▪ Data transmissions to local Integrator as required (short range)
Active	▪ Every Second Cycle
Role:	**Integrator**
Cognitive Tasks	▪ Calculate local plume area ▪ Assess local role needs ▪ Generate alerts when plume area exceeds some threshold
Communication Tasks	▪ Transmit data to base station ▪ Receive data from producers
Active	▪ Every Cycle

Table 1. The Roles Model

We use an overall evaluation function, based on the instruments objectives (i.e., detect plume, extend instrument life) to gauge the success of the multi-agent sensor web. As plumes are available for detection right through to the final time step of each experimental run the evaluation criteria - useful lifespan ratio (ULR) - is calculated as:

ULR = Last Time Step Plume Correctly Detected / Total Time

1.2 Role Swapping Strategies

__Fixed Role Strategy.__ To measure the usefulness of role swapping we compared our role swapping strategy with a baseline strategy in which the agents have roles allocated randomly at deployment. In this strategy the roles remain fixed during the lifespan of the instrument. As nodes in key roles may be lost, redundancy is built in by increasing the number of nodes in these roles. The instrument's life span is essentially fixed and it will fail when some critical number of paths are broken. Through experimentation [5] we found that 88% provided the optimum role ratio ($R_p : R_i$) for this fixed role (baseline) strategy.

__Role Swapping Strategy.__ At an individual level agents will swap roles either when their own attributes (such as battery power) change, or when their neighbourhood's composition requires them to increase or decrease the ratio of a particular role:

- __*Rule 1*:__ Swap to role with lower power requirements when remaining power reaches some threshold.
- __*Rule 2:*__ Swap to a specific role when the neighbourhood ratio of that role falls below some threshold.

There is also a set of secondary rules which cause the agents to cooperate based their selected roles. All agents maintain a list of other agents in their neighbourhood and this is revised regularly so that producers are aware of local neighbourhood based Integrators.

1.3 Results and Conclusions

Both strategies were tested using 100 initial random deployments with 10 standard plumes in each of six different environmental scenarios, varying in the likelihood of node failure. The results, averaged over all runs (see Chart 1) show that with no node failure, the role-swapping strategy provides a marginal performance gain. As the environment becomes harsher the role swapping strategy outperforms the fixed-role strategy by increasing margins. In very harsh environments, where over 60% of nodes are likely to perish, the role-swapping strategy outperforms fixed roles by about 26%.

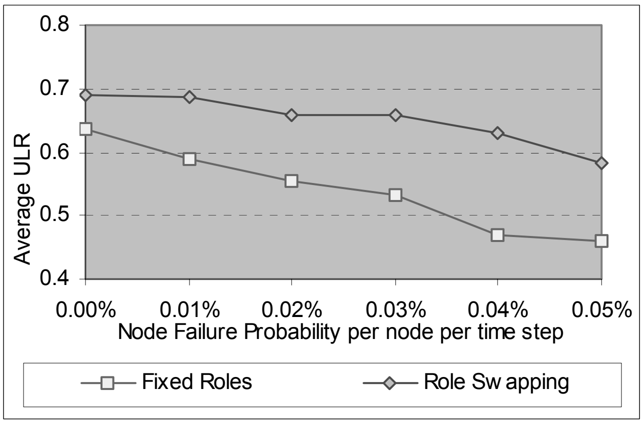

Chart 1. Comparison of role swapping strategy with baseline strategy

Overall, the general trend of the data demonstrate the usefulness of role-swapping in its realisation of positive emergent behaviour. This may be important as some applications currently conceived as being within the sensor web domain, are likely to become increasingly complex and may converge with the general MAS field. In future work more complex scenarios and role models should be examined. In this work, the rule set used by the agents to swap role was based on simple thresholds, for more complex situations further mechanisms, possibly using more involved agent architectures should be examined.

Acknowledgements

This work is funded in part by grants from Dundalk Institute of Technology to the first author and Science Foundation Ireland under Grant No.03/IN.3/I361 to the second author.

References

[1] K.A Delin & S.P. Jackson, The Sensor Web: A New Instrument Concept, SPIE Symp. on Integrated Optics, San Jose, USA, 2001

[2] E. A Kendall, Agent Roles and Role Models: New Abstractions for Multiagent System Analysis and Design, International Workshop on Intelligent Agents in Information and Process Management, Germany, September, 1998

[3] M. Wooldridge, N.R. Jennings, D Kinny, The Gaia methodology for agent-orientated analysis and design. Journal of Autonomous Agents and Multi-Agent Systems. Vol 3, 285-312,2000

[4] M. Sims, C. V. Goldman, Victor Lesser, Self-Organization through Bottom-up Coalition Formation, AAMAS'03, 2nd Int. Joint Conf. Autonomous Agents & MAS, pages 867-874, Melbourne, Australia.

[5] R Mac Ruairí and M T Keane, Simulating a Multi Agent Based Sensor Web, AAAI-04 Workshop on Sensor Networks, at AAAI National Conf. on Artificial Intelligence, San Jose, USA, 2004.

[6] A. Roli and F. Zambonelli, Emergent Behaviours in Dissipative Cellular Automata, Proc. 5th Int. Conf. on Cellular Automata for Research and Industry, ACRI 2002, Geneva, Switzerland, 2002