Stability and Control of Agent Ecosystems

Maxim D. Peysakhov
Drexel University
Department of Computer Science
Philadelphia PA 19104
umpeysak@cs.drexel.edu

Robert N. Lass
Drexel University
Department of Computer Science
Philadelphia PA 19104
urlass@cs.drexel.edu

William C. Regli
Drexel University
Department of Computer Science
Philadelphia PA 19104
regli@drexel.edu

Categories and Subject Descriptors

D.2.10 [**Software Engineering**]: Design—*Methodologies*

General Terms

Stability theory

Keywords

agents & complex systems; computational ecosystems, agents & networks: web agents, semantic web, grid, web services, P2P

1. INTRODUCTION

The problem of balancing supply and demand is not a new problem for multi-agent systems (*MAS*). Achieving a balance between the demand for jobs of a certain kind and the supply of agents to perform these jobs is critical to system performance and stability. An insufficient number of agents forces jobs to accumulate over time, preventing the system from benefiting from the parallel nature of the networked MAS. On the other hand an excessive number of agents slow the system down with unnecessary processing and communications overhead. This problem is amplified if the agent system is running over a mobile ad hoc network (*MANET*), since such networks may be composed of lightweight devices that are restricted in terms of processing power, memory, available bandwidth and battery power.

Motivation. A MANET is a challenging environment for software designers due to its unpredictable, dynamic nature. Network links can go up and down and nodes can enter and leave the network depending on a variety of factors, such as movement of hosts, terrain, weather, interference, or battery power. Agent based systems, with their runtime flexibility, can adapt to MANETs better than centralized systems [3]. This benefit comes at a cost—it is more difficult to control a decentralized MAS. Without centralized control, designers need to count on emergent behaviors.

The previous approach can be described as follows:

1. Agents collect food as a reward for completing a job.
2. Agents consume food regularly to stay alive.

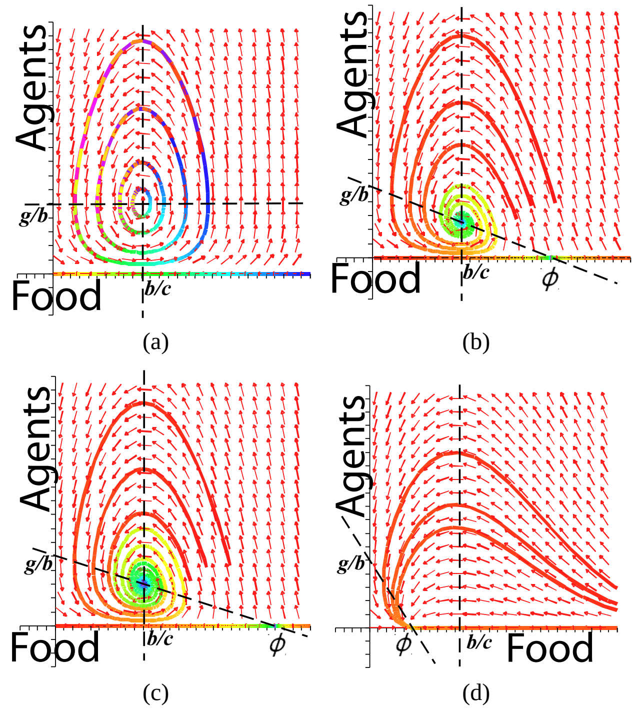


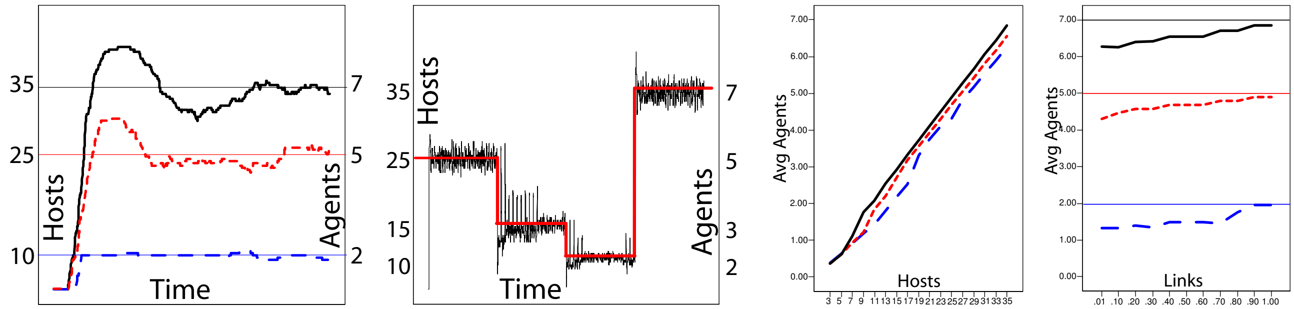
Figure 1: Phase plane analysis for: (a) neutrally stable, (b) and (c) self-stabilizing and an ecosystem with stable point at 0 agents, (d).

3. Agents that exhaust their food supply die.
4. An abundance of food causes new agents to spawn. [2]

2. FORMAL MODEL

H denotes the set of food producers, with the production rate defined by a function $F_h(t)$ for each individual producer, h, where $h \in H$. A defines the set of consumers and $f_a(t)$ is the predefined consumption function for each consumer, a, where $a \in A$. Previously, these two functions were set to constant rates, $F_h(t) = g, \forall h \in H$, and $f_a(t) = b, \forall a \in A$. The amount of food that each task can accumulate is limited by some value ϕ_h. The parameter c represents the probability that on a network of a given topology a random agent will find some amount of food. This parameter encapsulates properties of the graph and the speed of agent migration. g is the growth rate in the presence of infinite resources. This variable's influence is moderated by Φ, described below. The consumption of food by

AAMAS'05, July 25-29, 2005, Utrecht, Netherlands.



(a) (b) (c) (d)

Figure 2: The average number of agents over time for fixed (a) and variable size (b) networks. The average number of agents over network size (c) and over link speeds (d)

agents is encapsulated in b. The behavior of the system can be approximated by a system of differential equations, where $\mathscr{A}(t)$ is the number of agents, and $\mathscr{F}(t)$ is the amount of food in the system, both as functions of time, and where $\Phi = \sum_{h \in H} \phi$ is the maximum amount of food that can be stored.

$$\frac{d\mathscr{F}(t)}{dt} = g \times (1 - \frac{\mathscr{F}(t)}{\Phi}) - b\mathscr{A}(t)$$

$$\frac{d\mathscr{A}(t)}{dt} = \mathscr{A}(t) \times (c\mathscr{F}(t) - b)$$

Phase-Plot Description. Figure 1 shows trajectories for varying values of g, b, c and Φ. Some parameters, such as $\Phi = \infty$, will result in neutral stability and cyclic behavior of the system as shown in 1(a). Figures 1(b), and (c) are stable at $(\frac{b}{c}, \frac{g}{b} - \frac{g}{c\Phi})$ and unstable at $(\Phi, 0)$. Smaller values of Φ result in faster convergence to the solution point, and a greater dependence on the properties described by c. Figure 1(d) shows a stable solution $(\Phi, 0)$ with no agents.

Stability Analysis. The intersections of the isoclines produce two critical points $(\Phi, 0)$ and $(\frac{b}{c}, \frac{g}{b} - \frac{g}{c\Phi})$. Point $(\Phi, 0)$ represents the equilibrium of the system without agents present. To analyze this solution for stability, we compute the Jacobian matrix and find Eigenvalues at the solution points. By performing algebraic transformations one can see that the solution $(\frac{b}{c}, \frac{g}{b} - \frac{g}{c\Phi})$ is stable if $\Phi > \frac{b}{c}$ and unstable otherwise Figures 1(b),(c). Similar analysis at the second point shows that $(\Phi, 0)$ is stable when $\Phi \leq \frac{b}{c}$.

3. EXPERIMENTAL RESULTS

A series of experiments using a discrete event simulator confirmed the above conclusions.The agents behaved as discussed in [2] except hosts were not allowed to accumulate more than 900 food units. All of the experiments were performed on a completely connected network.

Transitional Process. The average number of agents is plotted on the Figure 2(a). The system was started with a single agent and gradually transitioned to the target number of agents marked by horizontal lines on the plot.

Dynamic Environments. The system was capable of responding to dynamic changes in the number of hosts. The number of hosts was changed from 25 to 15 to 10 and then back to 35 without restarting the system. Figure 2(b) shows the average across 15 runs (thin line) and the target number of agents at a given time (denoted by a bold step line).

The Effect of Demand on Equilibrium. As expected, the linear increase in task demand caused a linear increase in the number of agents Figure 2(c). And, as the system model predicted, the actual equilibrium point was slightly lower than the target agents to servers ratio. By increasing the maximum amount of food the host may accumulate, the equilibrium point could be brought closer to the target value, but at a price of decreased stability.

Net. Size	Perf. Band	Connection Speed 0.01	0.2	0.4	0.6	0.8	**1.0**
35	7 ±0	20.4	21.9	28.2	28.2	35.9	48.4
35	7 ±1	55.1	62.2	74.9	74.4	83.7	**94.0**
25	5 ±0	22.3	28.6	37.9	38.1	46.1	56.0
25	5 ±1	54.2	73.8	85.0	83.1	92.6	**98.1**
10	2 ±0	3.6	12.5	19.2	18.9	56.0	90.3
10	2 ±1	11.0	25.9	39.6	38.1	77.1	**100**

Table 1: Performance indexes for networks of different sizes and communication delays.

The Effect of Delays on Equilibrium. Given a final size performance band around the target value, the performance index is the percentage of time the system spent inside the band. The performance index of 94% for ±1 band is generally acceptable for most practical applications. Table 1 shows how slower network speeds from t_{min} to t_{max} affected the performance index.

Dependency between performance index and network speeds are also shown with plots of the average number of agents (Figure 2(d)). For larger networks the decline averaged 10%.

4. CONCLUSIONS

This paper significantly improves the fidelity of an ecology-based model for managing agent populations on MANETs such as the Philadelphia Area Urban Wireless Network Testbed (PA-UWNT) [1], where ecology-based agents are being used in a real-world-environment.

5. REFERENCES

[1] V. Cicirello *et al.* Designing dependable agent systems for MANETs. *IEEE Intelligent Sys.*, 19(5):39–45, 2004.

[2] M. Peysakhov, V. Cicirello, W. Regli. Ecology based decentralized agent management system. *Proc. FAABS*, 2004.

[3] E. Sultanik *et al.* Implementing secure mobile agents on ad hoc wireless network. In *Proc. of IAAI*, pp. 129-36, 2003.