The Bio-Networking Architecture
Bi-weekly report #7 (Sep. 2, 2002): Adaptation and Evolution

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Introduction:

Adaptation and evolution through natural selection are among the key biological concepts that the PI applies in the Bio-Networking Architecture. As described in the bi-weekly report # 5 (submitted on Aug. 5, '02), a cyber-entity (i.e., a mobile agent like service component in the Bio-Networking Architecture) invokes its behavior (e.g., replication, reproduction and migration) based on local information (such as resource availability of local and/or nearby nodes) and interactions with other nearby cyber-entities. When a cyber-entity replicates or reproduces with another cyber-entity, evolutionary mechanisms in the Bio-Networking Architecture modify the behavioral policies in a new offspring cyber-entity. By natural selection through generations, only beneficial cyber-entities are retained in the system, enabling network applications (composed of multiple cyber-entities) to adapt to changing network environments.

New Achievements:

In the bi-weekly report # 5 (submitted on Aug. 5, '02), the PI evaluated the natural selection and evolutionary mechanisms applied in the Bio-Networking Architecture in a relatively static and homogeneous environment. Since then, the PI has extended the simulator to support a variety of new simulation scenarios that involve user migration, different resource costs at different nodes, and dynamic network topological changes. Using the extended simulator, the PI has obtained simulation results and observed that cyber-entities successfully evolved in such dynamic and heterogeneous environments.

Evolution in a Dynamic and Heterogeneous Network Environments

Using the newly extended simulator, the PI examined how cyber-entities evolve and adapt to a dynamic and heterogeneous network environments. As described in [TS02], each behavior policy of a cyber-entity is implemented as a weighted sum of behavioral factors that determines when to invoke a behavior (e.g., reproduce, replicate, migrate and die). The behavioral factor weights are modified by evolutionary mechanisms with possible mutation and crossover in order to generate cyber-entities that are more efficient and well adapted to the environment.

In the following simulations, cyber-entities are given four migration factors: request rate factor, resource cost factor, population density factor, and wander factor as listed in Table 1.

Factor Name	Description
Request Rate Factor	Encourage the cyber-entity to migrate toward requesting users
Resource Cost Factor	Encourage the cyber-entity to migrate toward a cheaper resource cost node
Population Density Factor	Encourage the cyber-entity to migrate away from a node where the population density of cyber-entities is high.
Wander Factor	Encourage the cyber-entity to randomly chose the node to migrate to (to explore to find new requesting users on the network)

Table 1: Migration Factors

In addition, we assume in the following simulations that there is only one user on a 5×5 mesh topology network and that the user randomly migrates between nodes once per hour. This user issues 80 requests per second. The other parameters such as resource cost and energy reward for service are the same as those presented in the bi-weekly report # 5 and are summarized in Table 2.

Parameter Name	Value
Platform resource cost	1 energy unit per second
Platform service cost	100 energy unit per service
Cyber-entity request processing time	0.2 second per user request
Reward from user	10 energy unit per service

Table 2: Simulation Parameters

With a cyber-entity whose migration factor weights are all set to 1.0, the PI performed two sets of simulations; a set of simulations where the evolutionary mechanisms are turned off, and another set of simulations where the evolutionary mechanisms are turned on.

Table 3 summarizes the simulation results. As seen on this table, evolutionary mechanisms of mutation and crossover improve the energy gain of a cyber-entity, the average waiting time (i.e., the average time between the issuing of a service request by a user and the provision of the requested service by a cyber-entity), and the average hop count (i.e., the average distance between a requesting user and a cyber-entity that processes the request.)

	Avg. Energy Gain per Sec.	Avg. Waiting Time	Avg. Hop Count
Evolution off	630.426	3.9977	0.0261
Evolution on	772.258	0.0263	0.0045

Table 3: Performance Comparison in a 5×5 Mesh Topology Network

Figure 1 shows how the weights of four migration factors change during the course of simulation. In this figure, the vertical axis indicates factor weights of a cyber-entity who dies at the simulation cycle shown in the horizontal axis. This figure shows the weight of the migration request rate factor always takes the highest value compared to other factor weights, indicating that cyber-entities evolved toward becoming responsive to user migration and successfully adapted to the dynamic environment.

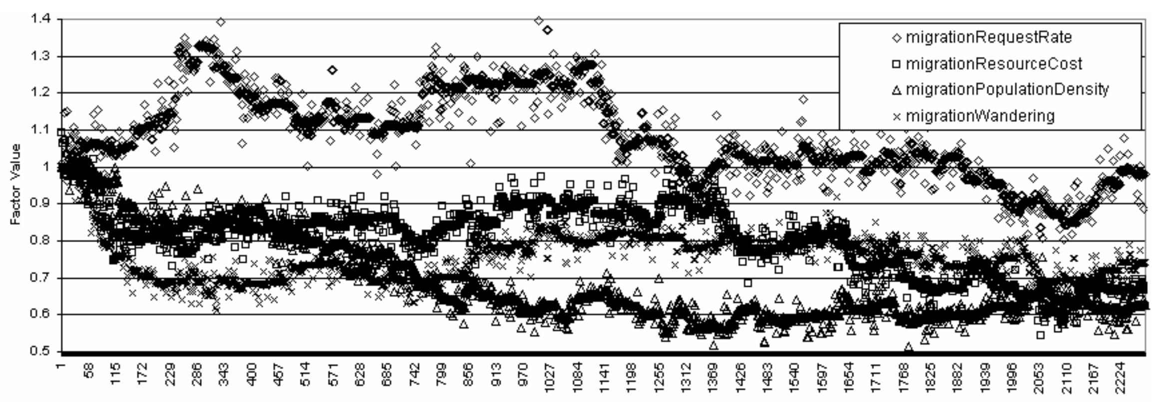

Figure 1: Factor Weight Changes

Reference

[TS02] T. Suda, T. Itao, M Matsuo, "The Bio-Networking Architecture: The Biologically Inspired Approach to the Design of Scalable, Adaptive, and Survivable/Available Network Applications," The Internet as a Large-Scale Complex System, Ed. K. Park, 2002.