The Bio-Networking Architecture
Bi-weekly report #13 (Nov. 25, 2002): Adaptation and Evolution

PI: Tatsuya Suda (suda@ics.uci.edu)
University of California, Irvine, http://netresearch.ics.uci.edu/bionet/

Introduction:

Adaptation and evolution through natural selection are among the key biological concepts that the PI applies in the Bio-Networking Architecture. In the Bio-Networking Architecture, a cyber-entity (i.e., a mobile agent that implements service) invokes its behavior (such as replication, reproduction and migration) based on its local conditions (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 mutate the behavioral policies in a new offspring cyber-entity. Through natural selection over 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:

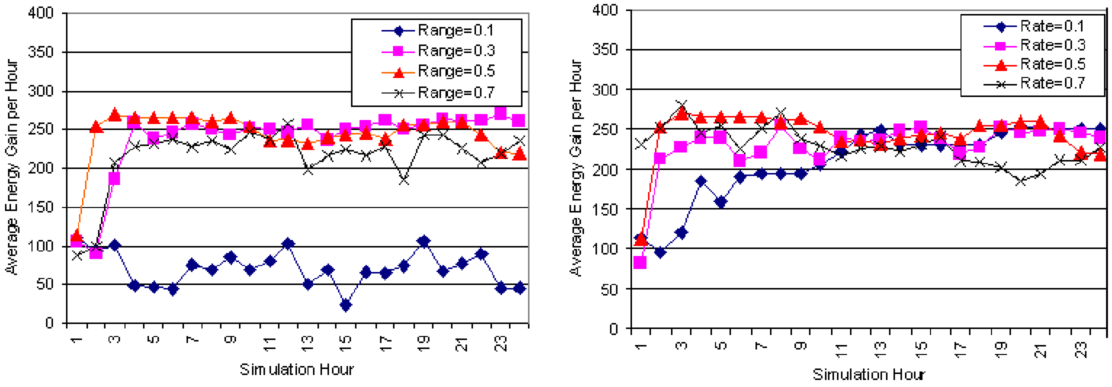
In the bi-weekly report # 7 (submitted on Sep. 2, '02), the PI evaluated the evolutionary mechanisms in the Bio-Networking Architecture in a dynamic network environment where users move, a network topology changes and resource costs are heterogeneous over different network nodes. In the report #7, the PI observed that evolutionary processes take a significantly long time, especially as the network environment becomes more complex and dynamic. Since then, in order to accelerate the speed of evolutionary processes, the PI has examined the effect of changing various parameters in evolutionary mechanisms. Based on the observations made from the parameter tuning simulation results, the PI has designed adaptive mutation control mechanisms and evaluated them through simulations.

Parameter Tunings to Accelerate Evolutionary Processes:

In replication and reproduction, mutation occurs at each factor weight probabilistically at the rate of *mutation rate*. (See the bi-weekly report # 7 for detailed explanation of factor weights.) In mutation, each factor weight is subject to the random change within a certain range (i.e., within a certain percentage of the parent's factor weight) called *mutation range*. Since the speed of evolution crucially depends on the mutation rate and range, the PI has first examined the impact of varying these two parameters on the speed of evolutionary processes.

First, simulation is performed in a relatively static environment: (1) there are 25 nodes on a 5×5 grid topology network, (2) eight users exist on different nodes with a constant service request rate ranging from 2 to 10 requests per second, (3) each node charges a cyber-entity 5 energy units per second for computing resources, (4) a cyber-entity processes one request every 0.2 seconds, and (5) a cyber-entity obtains 10 energy units in exchange for processing a user request. One cyber-entity is initially placed on a randomly selected node with a reproduction request rate factor weight set to 0.2 and with four migration related factor weights all set to 0.1. These are the same factor weights as those presented in the bi-weekly report # 7.

Figure 1 shows two simulation results, indicating the typical effect of varying mutation parameters on the energy gain per hour. Figure 1 (a) shows the energy gain when varying the mutation range, while Figure 1 (b) shows the same when varying the mutation rate. Mutation rate is set to 0.5 on Figure 1 (a), and mutation range is set to 0.5 on Figure 1 (b). These simulation results show a potential trade-off between the speed of the evolutionary processes and the resulting performance (i.e., energy gain). In Figure 1 (a), for instance, the mutation range of 0.5 quickly adapts the cyber-entities to the network environment (and the energy gain reaches stable point quickly). On the other hand, mutation range of 0.3 leads to slower adaptation but the higher energy gain. This is because a higher mutation range is initially required to explore possibly fit offspring while a higher mutation range can potentially drive offspring cyber-entities away from a stable operating point. Near a stable operating point, the smaller mutation range is preferred for fine-grained tuning. This observation still holds for the simulation results shown in Figure 1 (b).



(a) **(b)**

Figure 1: **The Effect of Varying Mutation Parameters on the Energy Gain**

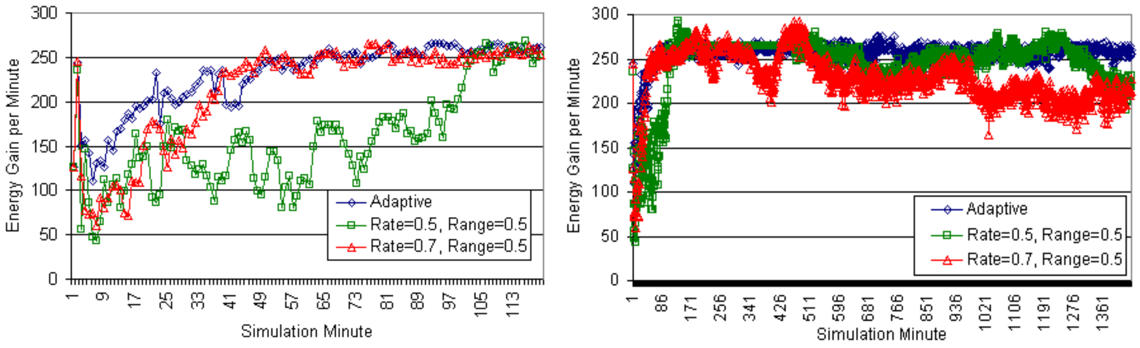
Adaptive Mutation Control:

To address the trade-off observed in Figure 1, the PI has designed and is currently evaluating adaptive mutation control mechanisms where a cyber-entity autonomously adjusts the mutation range and rate during the course of simulation. The designed mechanisms also eliminate the need for manually finding a set of suitable parameter values through parameter tunings.

The first and simplest mechanism that the PI designed is a deterministic mechanism, where a cyber-entity decreases the mutation rate and range as the simulation progresses. This mechanism is implemented in the simulator and evaluated under the same simulation environment as that used in Figure 1. Simulation results are shown in Figure 2.

Figure 2 compares the speed of evolutionary processes when the deterministic adaptive mutation control mechanism is applied. Simulations are done with the two parameter sets, (1) rate = 0.5 and range=0.5, and (2) rate =0.7 and range=0.5. Note that the second set of parameter values allowed the quickest adaptation in Figure 1. Figure 2 (a) depicts the average energy gain for the first 120 simulation minutes, which corresponds to the first 2 simulation hours in Figure 2 (b). (Figure 2 (a) shows the first 120 minutes, and Figure 2 (b) shows entire simulation results.) Figure 2 (a) shows that the deterministic adaptive mutation control quickly maximizes energy gain. The average energy gain with the deterministic adaptive mutation control mechanism reaches 260 energy units after 66 simulation minutes and remains stable until the end of the simulation.

In addition to the deterministic adaptive mutation control mechanism where mutation parameter values decrease in proportion to the elapsed simulation time, the PI has designed and is currently investigating other mechanisms (e.g., a fitness-based adaptive control mechanism) to accelerate the evolutionary processes.



(a) **(b)**

Figure 2: Comparison of the evolution speed and obtained performance