The Bio-Networking Architecture

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1. Introduction

Future networks will connect a large number of heterogeneous types of objects and services, and thus, they will be large and more complex than the current networks. The PI believes that making this future a reality requires a network that exhibits self-organization with inherent support for mobility, scalability, adaptability to changes in network conditions, and survivability/availability from massive failures and attacks. The Bio-Networking Architecture is motivated by the observation that the above desirable properties (such as scalability, adaptability, survivability and availability) have already been realized in various large-scale biological systems, and it applies key biological principles and mechanisms for designing network applications. The Bio-Networking Architecture is a new framework for developing large-scale, highly distributed, heterogeneous and dynamic network applications.

In the Bio-Networking Architecture, a network application is implemented as a decentralized collection of autonomous objects called *cyber-entities*. This is analogous to a bee colony (a network application) consisting of multiple bees (cyber-entities). Each cyber-entity implements a functional component related to their service or application and follows simple behavior rules (e.g., replication, reproduction and migration) similar to biological entities. Cyber-entities store and expend *energy* for living. They gain energy in exchange for providing their services, and expend energy for performing their biological behaviors, invoking other cyber-entities' services and utilizing resources (e.g. CPU cycles and memory space).

With support from DARPA, the PI has investigated the following key aspects of the Bio-Networking Architecture.

- Investigation of Peer-to-Peer Distributed Discovery
- Investigation of Dynamic Service Composition
- Investigation of Adaptation and Evolution
- Design and Implementation of the Bio-Networking Platform

Based on the work supported by DARPA, the PI has published a number of papers: two journal papers, nine conference papers, eighteen workshop papers, two technical papers, two standardization documents, and four papers in submission.

2. Recognition of Excellence of the Bio-Networking Architecture Research

BBC News featured an article that overviews the motivation and vision of the Bio-Networking Architecture [BBC00]. In this article, cyber-entity behaviors and adaptive network applications of the Bio-Networking Architecture are described.

One of the papers that the PI published [INMSA02] received the best paper award at the 2002 IEEE SAINT (Symposium on Applications and the Internet) conference. This is a major IEEE conference specializing in Internet applications with ten technical paper sessions, three panel sessions and 4 workshops.

Key concepts and mechanisms in the Bio-Networking Architecture are currently being discussed as a reference architecture at the Super Distributed Objects group of the Object Management Group (OMG), the largest standard making bodies for object oriented software technologies [SAS01, SSS02].

3. Recent Major Accomplishments

Peer-to-Peer Distributed Discovery. Cyber-entities require a discovery mechanism to locate specific information, cyber-entities, or users within the system. Discovery involves forwarding queries along links (relationships) between the cyber-entities in a distributed manner. The PI investigated how to structure these relationships to improve the performance and scalability of discovery, as well as the robustness of discovery to dynamic environments. In the proposed discovery mechanism, relationships are organized using similarity between cyber-entity keywords, discovery history, and feedback from users [MS02a, MS02b, Eno02, ES02]. Accomplishments in this work include design of a discovery mechanism, a discovery simulator and obtaining simulation results showing the performance, scalability and emergent properties of discovery [MS02b, Eno02].

Dynamic Service Composition. In the Bio-Networking Architecture, complex application emerges as an interaction of multiple cyber-entities. Since cyber-entities may be designed and developed independently by different designers, it is important to ensure that independently developed cyber-entities can communicate and interact to collectively provide a network application. The PI developed a set of specifications (called Loose Interface Definition) that defines cyber-entity interfaces in a loose manner so that cyber-entities with different interfaces can communicate and interact. The PI has shown that Loose Interface Definition increases the number and variety of network applications that cyber-entities can create. Accomplishments in this work include design and preliminary implementation of Loose Interface Definition [FIMS02, FS02a, FS02b].

Adaptation and Evolution. Adaptation and evolution by natural selection are among key biological concepts that the PI applies in the Bio-Networking Architecture. Analogous to a biological entity in the real world biological systems, cyber-entities follow simple behavior rules (e.g., replication, reproduction and migration). A cyber-entity invokes its behavior based on local information and interactions with other nearby cyber-entities, and thus, autonomous behaviors of cyber-entities result in network applications that adapt to changing environment. A cyber-entity also evolves in its behaviors. When a cyber-entity replicates or reproduces with another cyber-entity, diverse behavior policies are created through mutation and crossover in their behavior policies. Since an inefficient cyber-entity exhausts energy quickly and eventually dies, only beneficial cyber-entities are retained in the system, enabling network applications to adapt to changing environments. To investigate the potential benefits of adaptation and evolution in the Bio-Networking Architecture, we developed a simulator and demonstrated emergent behaviors such as scalability, adaptability and survivability in a variety of network environments [WS01, SS01, SS02a]. Accomplishments in this work include the simulator and theoretical understanding of adaptation and evolution aspects of the Bio-Networking Architecture.

Design and Implementation of the Bio-Networking Platform. The Bio-Networking platform is a middleware that provides reusable software components for deploying and executing cyber-entities. These components abstract low-level operating and networking details (e.g. I/O, concurrency, messaging and network connection management) and provide a series of runtime services that cyber-entities frequently use for performing their services and invoking their biological behaviors. Examples of these services include lifecycle management, discovery, energy management, relationship management, resource sensing and migration. Accomplishments in this work include the design and preliminary implementation of the Bio-Networking platform, as well as preliminary measurements showing the efficiency and scalability of the Bio-Networking platform [SS02b]. The design of the Bio-Networking platform has been proposed to OMG for standardizing Super Distributed Objects specifications [SAS01, SSS02].

4. Other Recent Major Accomplishments

In addition to the research efforts described in the above sections, the PI has worked on various other aspects of the Bio-Networking Architecture including behavior selection of cyber-entities, development of example applications, analysis of stability of the Bio-Networking Architecture, and authentication of cyber-entities.

Reference

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