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Discrete event modeling of swarm intelligence based routing in network systems

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ABSTRACT

Simulation remains attractive for performance and scalability analysis and/or design of networks. This paper presents a biologically inspired discrete-event modeling approach for simulating alternative computer network protocols. This approach identifies and incorporates the key attributes of honeybees and their societal properties into simulation models that are formalized according to the Discrete Event System Specification (DEVS) formalism. We describe our approach with particular emphasis on how to model the individual honeybees and their cooperation. These models, collectively referred to as Swarm-Net, support routing algorithms akin to honeybees searching for and foraging on food. Adaptation and probabilistic specifications are introduced into honeybee (BEE) and Routing Information Protocol (RIP) routing algorithms. A set of simulation experiments are developed to show the biologically inspired network modeling with the BEE routing algorithm, as compared with the RIP routing algorithm, offers favorable throughput and delay performance and also exhibit superior survivability against network load surges. The paper concludes with some observations on the SwarmNet modeling approach and outlines some future research directions.

1. Introduction

Modeling systems that exhibit network characteristics remains an area of active research. Despite the presence of classical and contemporary methodologies, there continues to be a growing need for better models for simulating complex network systems ranging from computer systems to social societies. Existing approaches are developed using concepts and suitable model abstractions which are realized in computer programming languages. One class of simulation modeling frameworks is grounded in systems engineering and theoretical computer science whereas another class is born out of abstractions based on natural systems and their formulation in mathematics. In particular, since engineered systems must have precise and highly detailed specifications, it is important for these approaches to support formal structure and behavior specifications. For example, design of a high-speed computer network with guaranteed minimal communication latency must have blueprints that can be implemented and executed based on software and hardware technologies. In contrast, the structure and behavior of natural systems are often not fully known and do not require exact specification given their qualitative dynamics. Specification of the holistic behavior of honeybees and their colonies, for example, is formulated in terms of abstractions that are inherently inexact.

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The complexity and scalability traits of biological systems provide useful abstractions that can lead to novel modeling approaches suitable for engineered systems. Biologically inspired modeling frameworks are known to be robust, distributed, and fault tolerant [7,23]. Well-known examples are social insects such as ants, bees, and termites. The studies of these insects have been a source of inspiration for computer network researchers for many years [3,5,6,15,28,32,9,20]. However, most existing modeling and simulation frameworks that are used for simulating computer networks do not account for the social capabilities which insects possess in the presence of environmental transformation. While some recent research in modeling and simulation approaches incorporate adaptability and robustness traits of social insects, their underlying modeling constructs and simulation execution concepts are primarily conceived and devised in terms of mathematical algorithms and programming languages.

Model abstractions, and simulation techniques and tools targeted for social and biological systems are based on multi-agent modeling frameworks such as Swarm [31], Ascape [4], and Repast [24]. They typically support abstractions that lack formal modeling concepts and methods that are essential for describing complex, detailed dynamical behaviors. Lack of principles for defining detailed dynamics of computer network nodes and links and hierarchical composition of models along with separate centralized, parallel, or distributed logical or real-time simulation protocols undermines the use of these tools for simulating computer network protocols.

Another class of agent-based modeling approaches was developed based on the modularity and hierarchical concepts defined in discrete event system specification (DEVS) [37]. Agent-based DEVS modeling approaches support developing detailed network systems, such as biological and ecological systems (e.g., [35]). They are extensions of the DEVS formalism in that models can be added or removed during simulation. These approaches support different kinds of dynamic changes in a model's structure and its resulting behavior. In this paper, we developed an agent-based discrete-event modeling approach which incorporates abstractions derived from honeybees. This biologically inspired modeling approach is aimed at simulating computer network systems that can adapt successfully to unpredictable changes in the network nodes and links.

In Section 2, we briefly review DEVS formalism and some related existing modeling and simulation approaches. A description of honeybees, their social dynamics, and concepts that underlie their resiliency given changes in their own structures, those of their environment and several swarm based routing approaches are also discussed in Section 2. In Section 3, the modeling concepts from honeybees are mapped to a set of adaptable agent-based DEVS models. Section 4 presents network model specifications together with experimental models. Examples are developed in the `SwarmNet` environment in Section 5. An analysis of the simulation experiments and an assessment of the approach are also presented in this section. The paper concludes with conclusions and future directions in Section 6.

2. Background

2.1. DEVS modeling approach

Among discrete event modeling approaches, the discrete event systems specification (DEVS) [37] is well suited for formally describing concurrent processing and the event-driven nature of arbitrary configuration of nodes and links forming network systems. This modeling approach supports hierarchical and modular model construction and distributed execution, and therefore offers a basis to characterize complex, large-scale systems with atomic and coupled models. Atomic models characterize the structure and behavior of individual components via inputs, outputs, states, and functions. The internal, external, confluent, output, and time advance functions define a component's behavior over time. Internal and external transition functions describe autonomous behavior and response to external stimuli, respectively. The time advance function represents the passage of time. The output function is used to generate outputs. Atomic models can be coupled together in a strict hierarchy to form more complex models. Parallel DEVS, which extends the classical DEVS, is capable of processing multiple input events and concurrent occurrences of internal and external transition functions. The Parallel DEVS confluent transition function provides local control by handling simultaneous internal and external transition functions.

DEVS atomic and coupled models have corresponding abstract simulators. These simulators dictate how the atomic/coupled models are to be executed according to the semantics of the Parallel DEVS formalism. Computational realizations of the DEVS formalism and its associated simulation protocols are executed using simulation engines such as DEVSJAVA [1] and DEVS-Suite [25]. DEVSJAVA is an object-oriented realization of the Parallel DEVS. It supports describing complex structures and behaviors of network systems using object-oriented modeling techniques and advanced features of the Java programming language. DEVS-Suite includes extensions to DEVSJAVA such as timeview and tracking options. Distributed multi-processor realizations of the DEVS formalism have been developed using technologies such as HLA (e.g., [36]), CORBA [11,10], and Web-services (e.g., [22]). Furthermore, the DEVS models are extended with other kinds of models such as fuzzy logic [21].

2.2. Swarm routing approaches

In this section, several routing protocol approaches developed by inspiration from nature are summarized. Main concerns in such routing protocols are optimality, simplicity, robustness, convergence, flexibility, scalability, multi-path routing, reachability, and quality of service [17]. The ant colony optimization (ACO) methods have been inspired by operating