Computer Networks 53 (2009) 1760–1770

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

A simulation of an economic, self-organising resource allocation approach for application layer networks

Werner Streitberger *, Torsten Eymann

University of Bayreuth, Chair of Information Systems Management, Universitaetsstrasse 30, 95447 Bayreuth, Germany

ARTICLE INFO

Article history:
Available online 6 November 2008

Keywords:
Application Layer Network
Grid Network
Catallaxy
Self-organisation
Economic resource allocation
Cloud Computing

ABSTRACT

Application Layer Networks like Utility Grid Networks or Cloud Computing Systems, often depicted as large scale self-organising architectures using a shared infrastructure, will need innovative management approaches for controlling and matching services demand and supply. This article shows a self-organising resource allocation approach based on principles of the Catallaxy, an economic concept of F.A. von Hayek. The implementation uses a coevolutionary learning algorithm for adaptation of the agent strategy to the dynamic Application Layer Network environment. The simulation study performs a sensitivity analysis of a large scale Application Layer Network scenario with 2000 agents. A set of representative agents is selected and their evolutionary behaviour analysed.

1. Introduction

What makes Economics so attractive for computing networks is that its central research question lies in the effective allocation of resources, provided by suppliers and in demand by customers. In distributed computing environments built on computer networks like Application Layer Networks, the resources in question are processor time or storage space, while the economic actors are computers or web services [3,11].

It appears that, by just implementing markets in computing environments, the satisfying ability of economics might be viable for creating cost-effective computer architectures. However, between the mostly descriptive economic concept and the normative technical implementation lies a fundamental gap, requiring selective choice of how actors, resources, services, and markets are modelled and embedded in a technical environment.

At the moment, most of the research done in the area of Application Layer Networks focuses in particular on the hardware and software infrastructure, such that from a technical point of view, "the access to resources is dependable, consistent, pervasive, and inexpensive" [13]. Nonetheless, there are still barriers preventing the deployment of large-scaled Peer-to-Peer networks or Computational Grids.

There are several competing descriptive approaches to how economic resource allocation mechanisms work. In general, Economics is essentially all about the coordination of systems consisting of utility-maximising agents, who satisfy their needs using some mechanism for solving a distributed resource allocation problem. The effect of this mechanism is a state where prices are set, so that supply and demand is perfectly balanced, and the number of transactions is maximised [17]. All implementation attempts try either to recreate the mechanism, or to achieve the effect by using another mechanism, adding some side condition like zero communication costs or a steady environment state. Adam Smith's proverbial invisible hand [21] was a first concept of a decentralised mechanism without a coordinator, but Smith gave no implementation of that mechanism.

Economics research on self-organisation still aims at explaining the mechanism of the invisible hand, e.g. Agent-based Computational Economics [24]. Actually, there is growing interest in using self-organisation, as

* Corresponding author. Tel.: +49 921552812.
E-mail addresses: werner.streitberger@uni-bayreuth.de (W. Streitberger), torsten.eymann@uni-bayreuth.de (T. Eymann).

1389-1286/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.comnet.2008.10.020

indicated by the start of large industrial research concepts like IBM's Autonomic Computing initiative. Autonomic Computing uses a biological paradigm as a design and control metaphor, the autonomic nervous system [18].

This article presents a simulation study of an Application Layer Network based on the "Catallaxy" concept of F.A. von Hayek. Catallaxy describes a "free market" economic self-organisation approach for trading electronic services and resources, which can be implemented for realising resource allocation in Application Layer Networks (ALNs). The term ALN comprises network concepts, such as Grid and Peer-2-Peer (P2P) systems, which overlay the existing physical Internet topology. The Catallaxy concept is a coordination approach for systems consisting of such autonomous decentralised agents, and is based on constant negotiation and price signalling between agents [12]. Every individual (agent) assigns a value to service access information, and by exchanging bids for service access, the price signals carry information between individuals (agents) about the knowledge of others [14].

IBM's Autonomic Computing Manifesto describes seven characteristics, which self-adapting systems should exhibit. The core characteristics are contained in the so-called CHOP cycle of self-configuring, self-healing, self-optimising and self-protection capabilities [15]. The self-configuration property is indicated in the variation of prices when adding or removing service providers (cf. the different density regimes). The self-healing of the system is apparent in case a service provider instance shuts down or a network connection gets broken (cf. the different dynamics regimes). The application is self-optimising, in that the agents constantly attempt to change their strategies towards the maximum utility-eliciting negotiation positions, which, respectively, lay on the total supply and demand curves. The self-protection of the application finally can be reached by including security mechanisms like reputation tracking [11], which are effective in separating malicious and under-performing agents.

In ALNs, participants offer and request application services and computing resources of different complexity and value-creating interdependent markets.

In this article, the complex interdependencies are broken down into two types of interrelated markets:

(1) a service market – which involves trading of application services, and
(2) a resource market – which involves trading of computational and data resources, such as processors, memory, virtual machines or storage space.

This distinction between resource and service is necessary to allow different instances of the same service to be hosted on different resources. It also enables a given service to be priced based on the particular resource capabilities that are being made available by some hosting environment.

In such interrelated markets, allocating resources and services on one market inevitably influences the outcome on the other markets. A common approach of many other ALN market concepts is to allocate resources and services by relying on the presence of centralised resource/service brokers. However, the complex reality could turn such approaches useless, as the underlying problem is computationally demanding and the number of participants in a worldwide ALN can be huge.

The research question taken up in this article is to develop a ALN realisation of an economic concept, which describes the ability to trade (electronic) services in a decentralised fashion, a free-market economy to adjudicate and satisfy the needs of participants who are self-organised and follow their own interest.

All complex systems share common dynamical behaviours. These possible behaviours are: stability, transient instability, persistent oscillation, deterministic chaos, and random motion, which in turn are characterised by parameters of the system [5]. Depending on the values of the parameters the system shows one or several of these behaviours. The parameters characterise the communication paths between the entities in the system, the efficiency of the communication, the time delays for communication, the accuracy of response and the overall response of the entities, and the expectation of the agents.

2. Simulating a self-organising application layer network

This section describes the simulation setup and the applied strategies realising the requirements defined in the previous section. The general simulation model of the Application Layer Network presents Section 2.1 and the abstract resource allocation scheme is shown in Section 2.2. The following subsections give a detailed introduction to the discovery of service and resource (Section 2.3) and the applied bargaining strategy (Section 2.4) with its coevolutionary learning mechanism (Section 2.5).

2.1. Simulation model of the application layer network

This subsection describes the formal Application Layer Network model used in simulation environment to abstract from concrete networks. An Application Layer Network is defined by a connected non-oriented graph

$$ALN = \langle S, L\rangle$$

where $S = \{1, \ldots, n\}$ is a set of network sites and $L = \{\langle i_1, j_1\rangle, \ldots, \langle i_m, j_m\rangle\}$ is a set of links which connect sites. Each site i is characterised by

- a static *failure probability* fs_i which models the unreliability of the site s_i in sending messages to other sites;
- a triple

$$\langle CSA_i, BSA_i, RSA_i\rangle$$

where CSA_i is a set of *Complex Service Agents (CSAs)*, BSA_i is a set of *Basic Service Agents (BSAs)*, and RSA_i is a set of *Resource Service Agents (RSAs)*. In every site there can be zero or more complex/basic service agents and zero or more resource agents, that is

$$|CSA_i| \geqslant 0, \quad |BSA_i| \geqslant 0, \quad |RSA_i| \geqslant 0$$