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A new generalized particle approach to parallel bandwidth allocation

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Abstract

This paper presents a new *generalized particle* (GP) approach to dynamical optimization of network bandwidth allocation, which can also be used to optimize other resource assignments in networks. By using the GP model, the complicated network bandwidth allocation problem is transformed into the kinematics and dynamics of numerous particles in two reciprocal dual force-fields. The proposed model and algorithm are featured by the powerful processing ability under a complex environment that involves the various interactions among network entities, the market mechanism between the demands and service, and other phenomena common in networks, such as congestion, metabolism, and breakdown of network entities. The GP approach also has the advantages in terms of the higher parallelism, lower computation complexities, and the easiness for hardware implementation. The properties of the approach, including the correctness, convergency and stability, are discussed in details. Simulation results attest to the effectiveness and suitability of the proposed approach.

Keywords: Bandwidth allocation; Generalized particle (GP); Distributed parallel algorithm; Computer networks; Dynamical process

1. Introduction

1.1. Related work

Well-known approaches to network resource allocation include: (1) Lagrangian multiplier approaches including Kelly's [1–3] and low et al's [4–7]; (2) ant colony optimization approaches [8,9]; (3) Max-Min fairness and progressive filling algorithm [10].

The Max-Min fairness algorithm has been widely used in digital networks. It allots the bandwidths as equally as possible to all the users under the existent transmission conditions. Although the Max-Min algorithm is easy to realize, it always gives rise to a lower availability of network bandwidth resources. Recently, algorithms based on a utility function were proposed to optimize the flow control in networks. The flow control algorithms proposed by Kelly and Low et al. manage to dynamically control the data transmission rates of source nodes in networks so that the global utility of all the source nodes may be maximized. Algorithms based on a utility function can usually acquire a comparatively higher network resources availability with a certain proportional fairness. But based on centralized flow control, they are not easy to realize.

Ant colony optimization (ACO), which uses distributed control, is a novel technique for solving hard network optimization problems. ACO is based on stochastic search procedure. Their central component is the pheromone model, which is used to probabilistically sample the search space. ACO belongs to the class of meta-heuristics, which are approximate algorithms used to obtain good enough solutions to hard combinatorial optimization problems in a reasonable amount of computation time. Notwithstanding its theoretical interest, this algorithm has unknown empirical performance and requires much computation time.

In this paper, we propose a generalized particle (GP) approach, which is based on hybrid energy functions. GP has overcome the main deficiencies and retained the advantages of the well-known approaches mentioned above, as follows:

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- It is easy to realize.
- It acquires a comparatively higher network resources availability.
- It controls dispersedly.

1.2. Motivation and contribution

The aim of this paper is to explore a different approach to dynamical optimization of network bandwidth allocation. We consider factors such as competition, cooperation among network entities, congestion, metabolism, breakdown of network entities, and market mechanism between the demands and service. Based on these factors and past studies in this field, a generalized particle model (GP) for network resource allocation is proposed. The GP model algorithm takes into account all the factors just mentioned and has a good prospect in practice because it has lower time complexity.

We have proposed the *crossbar composite spring net* (CCSN) approach in Ref. [11]. CCSN takes the *elastic net* (EN) as its simplest case but can overcome EN's main deficiencies for problem solving in multi-agent systems. A CCSN consists of numerous springs coupling agent nodes, with each spring having its own time-varying force-deformation properties to represent various social interactions among the agents. These composite springs have more flexibility than EN's uniform isotropic band.

Based CCSN, we

(1) study further the particle characteristics of nodes in a spring net;
(2) extend the force properties of different composite springs to different forces on particles in the GP model and study the kinematics and dynamics properties of GP such as the evolutionary mechanism, learning and particle interactions;
(3) study distributed and parallel algorithms for GP and their application in networks.

The GP approach can also overcome many limitations of the CCSN approach:

(1) In a CCSN, since the types of springs representing social interactions between two agents are finite, it is possible that some types of social interactions cannot be represented by appropriate springs.
(2) Even though the problem nodes in a CCSN can move, they do not have autonomous self-driving forces to embody their own autonomy and personality of entities.
(3) GP improves the situation by introducing the piecewise linear functions for every node (particle) so as to obtain better performance for problem solving.
(4) We prove the suitability, correctness, convergency and stability of the GP approach are proved, whereas only the correctness of the CCSN approach has been proved.

1.3. Organization

In Section 2, the generalized particle approach is introduced. In Section 3, the model for the bandwidth allocation problem is given. The parallel computing architecture and the algorithm for GP are highlighted in Section 4. In Section 5, we present the GP model and its many interactions. In Sections 6 and 7, the evolution and the properties of GP are addressed, respectively. In Section 8, we give the simulation results. Finally, conclusions are drawn in Section 9.

2. Generalized particle approach

The GP approach takes the CCSN as its simplest case but can overcome the CCSN's many deficiencies. The GP model consists of numerous particles and forces, with each particle having its own dynamics equations to represent network entities and each force having its own time-varying properties to represent various social interactions among network entities. These particles and forces have more flexibility than CCSN's composite springs and nodes. A particle in GP can move along a specific orbit under the exertion of a composite force. GP extends the composite springs and nodes of CCSN is four ways:

(1) Each particle in GP has an autonomous self-driving force, to embody its own autonomy and the personality of some network entity.
(2) The dynamic state of every particle in GP is a piecewise linear function of its stimulus, to guarantee a stable equilibrium state.
(3) The stimulus of a particle in GP is related to its own objective, utility and intention, to realize the multiple objective optimization.
(4) There are a variety of interactive forces among particles, including unilateral forces, to embody various social interactions in networks.

GP will essentially be based on two particle-fields, entirely different from the CCSN approach which is oriented to sequencing problems in multi-agent system.

3. Bandwidth allocation model

In networks, a path is an end-to-end relation among nodes, and is mapped the resulting split flows between the source-destination pair. The channels are route trees representing a set of paths between pairs of nodes.

We examine how best to allocate the bandwidth of a link between competing unicast and multicast traffic. We consider the scenario with a given number of links, a given number of paths, and different bandwidths allocated by each link among the channels (source-destination(s) pairs). For this study, we make several assumptions:

(1) There is knowledge in every network node about every flow through an outgoing link.