

Consensus-based Estimation Protocol for Decentralized Dynamic Load Balancing over Partially Connected Networks

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Abstract—A novel consensus-based protocol is developed for estimating the load information at nodes in a distributed computing system operating over a partially connected communication network. The challenge in such estimation process arises from the existence of tangible delays in the exchange of information, and the fact that loads are dynamic since nodes continue to execute their loads while the estimation process is ongoing. The protocol utilizes the concept of trust weight that each node has about any other node, based on the number of hops in between, to periodically form an updated estimate of the loads of the other nodes. The probability of consensus at any given time as well as the probability density function of the time to the first consensus are analytically characterized and used to determine the best instant for executing a dynamic load balancing (DLB) action. Detailed Monte-Carlo simulations of the average completion time of a workload by a distributed system under different system configurations are presented and discussed. The results suggest a range of time for executing the DLB over which satisfactory average completion time is achieved. The results also provide insight on the effects of network connectivity and the frequency of communication on the DLB performance.

Index Terms—consensus-based estimation, distributed computing, partially connected network, load balancing, trust-weight

I. INTRODUCTION

Distributed computing systems (DCSs) offer an efficient and inexpensive way to process workloads composed of a large number of independent tasks in a cooperative manner. The completion time required to execute a workload on a DCS is mainly dependent on the distribution of tasks on the computing nodes as well as their individual processing power. As computing nodes in the system process tasks, some nodes may be overloaded while other nodes may run out of tasks, thereby becoming idle. To avoid such scenarios that defeat the purpose of cooperative computing, load balancing (LB) techniques are used [1] so that the system resources are utilized optimally, and consequently the workload completion time is minimized. Specifically, the goal of LB is to give every computational node its fair share of the workload so that ideally no node becomes idle prematurely before the entire workload is completed. The LB problem belongs to a more general class of problems in resource allocation. These problems appear not only in DCSs but also in routing in

wireless networks, telecommunications, and other problems in computer science and operational research [2]–[4].

From the perspective of the type of system information (online vs. off-line) used by the DCS to perform task redistribution, LB can be categorized as either dynamic or static [5]. In dynamic load balancing (DLB), the current state of the DCS is utilized to redistribute tasks across nodes. From the perspective of the structure of the decision-making process, on the other hand, there are two methods to pursue DLB in a DCS: centralized and decentralized. In the centralized DLB [6], a central coordinating node fuses the global load information of the DCS and conducts appropriate LB decisions. For the decentralized DLB [7], [8], no such central coordination exists; nodes execute DLB autonomously based on their own local estimates of the loads at other nodes. The estimation is facilitated by a process of information exchange among the nodes that accompanies the DLB process. Decentralized DLB is a more useful approach for many distributed systems, such as wireless sensor networks and cloud computing, because it alleviates the dependence on a centralized control node that can make the system vulnerable to its failure.

The performance of decentralized DLB also relies vitally on the accurate estimation of the load at each node. As nodes exchange information, they form their own individual estimates of the loads across the DCS based upon the received information, which can be local or global. When a DCS operates over a partially connected network, where nodes communicate over multiple hops, the information exchange is not as effective as that in the scenario for which a fully connected network is utilized. This is because of the presence of tangible delays in communication, especially between distant nodes, that deem the information dated. Furthermore, the frequency of information exchange is equally important in forming accurate estimates of the loads at the nodes. Due to bandwidth or energy constraints in certain practical distributed systems such as wireless sensor networks [9], the frequency of information exchange can be limited. We emphasize that both communication delays and infrequent load-information exchange affect the quality of estimates of the load at each node. This is because nodes continue to process tasks during

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