Comparative Study of Game Theoretic Approaches in Distributed System

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ABSTRACT: *In this paper, we present a game theoretic framework for different type of distributed system problem like load balancing, maximizing network throughput, and dynamic network selection. This type of problem give different result depends on environment of distributed systems. We analyze different game theory approaches with their advantage and disadvantage. Finally conclude chapter with comparing Game theory model according to their problem statement.*

Keywords: Computational Grid, Game Theory, Load Balancing, Mesh Network, VANET

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1. Introduction

In recent years, heterogeneous distributed computing systems have become the main platform for the execution of distributed applications. Normally in these systems a large number of users submit their applications for the shared heterogeneous resources such as (computers, storage communication links, etc.) [1]. Thus, a distributed system can be viewed as a collection of computing and communication resources shared by active users. There is a large body of literature survey has been carried out to solve problem related distributed system. Distributed system contains various problems according to their environment and resources. This problem can be load balancing for static or dynamic environment [2] or it can be message forwarding problem in case of VANET environment [3].

Nowadays there has been interest in the use of game theoretic and market oriented models for the design and analysis of distributed systems and networking algorithms [4]. In game theory game gets form according to application where node (or workstation) acts as player for that game. Based on environment and game player decide strategy and depend on game player gets payoff. Payoffs are numbers which represent motivation of players. Payoffs can be profit, quantity, utility or continuous measure. Like in [5] coalitional game theory has been used to solve message forwarding problem where vehicle act as player for forwarding message.

2. Motivation

Our goal is to provide a formal framework for characterizing distributed system problem based on game theory. In this paper, we are observing various game theory approaches to solve different kind of distributed system related problem. Our intention is to motivate other researcher to use of game theory to solve distributed system problem. Because designing algorithm based on game is much easier approach than constructing direct algorithm model. We can create different game theories model to solve same problem and depend on behavior of system we can select best game theory.

3. Description of the Research Work

In this section we will analyze main papers with their game theory approaches to solve specific distributed system related problems. In Table 1 we have given parameter wise comparison of research paper and in section IV future scope for them. The papers which we are going to consider for our discussion as follow.

3.1 Routing Algorithm Based on Multi-Community Evolutionary Game for VANET [3]

In general, it is assumed that there are multiple communities (also refer as population) of nodes in VANET, such as taxi community and bus community. These community nodes are characterized by lack of guaranteed connectivity. The right operation of such a network requires nodes to cooperate on the level of packet forwarding. When a node wants to transmit a message to another node, the message can be opportunistically routed through relay nodes under the hypothesis that each node is willing to participate to forward. However, nodes belonging to different communities may choose selfish behavior when considering their limited resources such as memory space, energy and so on.

Therefore message routing problem has been solved by improving message forwarding technique with evolutionary game theory approach. Evolutionary game is used for the competition among nodes of same or different communities in VANET by constructing two-hop routing game.

Thus, when there only exist Population 1 or Population 2, the probability that the node receives the rewards, if it plays strategy p.

$$P'_{s,1}(x) = \frac{(1-(1-x\alpha)^m)}{mx} \tag{1}$$

$$P'_{s,2}(y) = \frac{(1-(1-y\alpha)^n)}{my} \tag{2}$$

where $X := \{(x, x-) \mid x + x- = 1\}$ and $Y := \{(y, y-) \mid y + y- = 1\}$ respectively be the set of probability distributions of Population 1 and Population 2 over the S pure strategies sample space and α is

$$\alpha = 1 - Q_\tau \tag{3}$$

In equation (3) Q_τ is the probability that the node relays the copy to the destination within time t is given by $1 - Q_\tau$ where

$$Q_\tau = (1 + \lambda\tau)\, e^{-\lambda\tau} \tag{4}$$

where λ is bandwidth between source and destination.

2.2.1 Challenges & future Scope

In reality VANET consist of number of various communalities. But in this evolutionary approach as number of community increases success probability decreases. Even if community number goes more than 2 there is drastically decrement of performance. From future perspective if we are considering evolutionary approach as solution for message forwarding problem. Then also evolutionary approach does not give us stable solution within limited amount of time. Rather as time passes, sample space of strategies in evolutionary approach increases and it leads to stable solution. But due to limitation of VANET node memory it can only store limited amount of strategy for comparison. Another approach of comparing current strategy with next random selected strategy also does not give guarantee to stable solution in minimum limited of time. On other hand Credit based approach and reputation based approach gives stable solution in limited amount of time.

2.2 On the Partially Overlapped Channel Assignment on Wireless Mesh Network Backbone: A Game Theoretic Approach [6]

In order to improve the performance of WMNs (wireless mesh networks), extensive research efforts have been dedicated towards finding means to increase the number of simultaneous transmissions in the network while avoiding signal interference among radios. In this paper Cooperative Channel Assignment Game (CoCAG) which is potential game of cooperative nature is used for maximizing network throughput.

In CoCAG game each Mesh Routers (MRs) act as player. Each player has its utility function (i.e. payoff) dependent on its own strategy and other players' strategy $U_i(\Psi)$. In CoCAG game utility of network refer as U_{NET}.

$$U_{NET}(\Psi) = U_i(\Psi) = \sum_{i \in A} M_i, \forall i \tag{5}$$

Where M_i is hop count. Network is evaluated not only by its number of links but also how efficiently these links connect the MRs towards the Wireless mesh Network Gateway (WMN-GW) called Hop count. Hop count is calculated as follow

$$M_i = k \frac{\sum_{j \in C} \frac{R}{n_j}}{h} \tag{6}$$

Where

- k is a connectivity factor set to one, if the node can indirectly reach the GW, zero otherwise.
- R is the link data rate (in Mbps).
- n is the number of interfering links.
- h is the hop count from the node to the GW

2.2.1 Challenges & future Scope

For strategy space two approaches exist namely better response and best response. Better response approach where current strategy gets compared with new random selected strategy. If new strategy giving better output than previous one then adapts new strategy else continue with old one until periodic interval over. After periodic interval it again selects new strategy for comparison. On other hand in best response strategy get selected out of strategy space which will give maximum output by considering other player strategy. Out of which better response strategy is considered while designing CoCAG game model. Even computational complexity is less in better response but time to reach stable solution is far more in better response. Nowadays time critical system demand best response for reaching stable solution. Their perspective use maximum processing to utilize resources within minimum amount of time and then release resources for another processes.

2.3 Game Theoretic Approach for Load Balancing in Computational Grids [7]

In this paper, model of the QoS (quality of service) based grid job allocation problem is considered as a non-cooperative game and for solution side it presents the structure of the Nash Bargaining Solution. To fully exploit computing resources, communication delays like constraint in grid systems, resource management and scheduling are key grid services, where issues of task allocation and load balancing represent a common problem for most grid systems. The load-balancing mechanism aims to equally spread the load on each computing node, maximizing their utilization and minimizing the average task execution time.

In this game, grid load-balancing problem has been solved using as a non-cooperative game, whereby the objective is to reach the Nash equilibrium. In this game, the players are the schedulers and each player tries to minimize its own average task completion time independently. Specifically, each scheduler calculates a strategy space r such that its average task completion time is minimized.

$$D_i = \sum_{j=1}^{m} \left[r_{i,j}.\bar{h}_j + \frac{r_{i,j}\bar{h}_j^2 \cdot \left(r_{i,j}\lambda_i + \frac{1}{h_j} - \mu_{j,i} \right)}{2\bar{h}_j(\mu_{j,i} - r_{i,j}.\lambda_i)} + e_{i,j}.r_{i,j} + \frac{b.r_{i,j}}{c_{i,j}} \right] \tag{7}$$

Equation (7) is the objective function that each scheduler aims to minimize independently where $h_j = 1/\mu_j$ is the mean of the job execution distribution and μ_j is average rate in which processor j executes tasks. $\bar{h}_j^2$ is the second moment of the distribution, and λ_i is the average arrival rate of tasks (in tasks per second) at processor j. In this model, a scheduler sends a proportion of its tasks to each processor. That is, each processor j receives tasks from multiple schedulers; therefore, λ_i is a combination of task arrivals from the different schedulers. Fraction of job I if send to processer j then it denoted by $r_{i,j}$ and in bits/s $\mu_{j,i}$ defines the computational power of processor j that is available to player i and can be estimated for each processor j.

Equation (7) object function subject to the constraints that

• Jobs must not be generated faster than the system can process them (otherwise, the queues will build up to infinity)

Paper Name → Parameter ↓	Routing Algorithm Based on Multi-Community Evolutionary Game for VANET	On the Partially Overlapped Channel Assignment on Wireless Mesh Network Backbone: A Game Theoretic Approach	Game -Theoretic Approach for Load Balancing in Computational Grids	Dynamics of Network Selection in Heterogeneous Wireless Networks: An Evolutionary Game Approach
Problem Statement	Message routing in VANET	Maximize Network Throughput in Mesh Network	Load Balancing in Grid	Dynamics of Network Selection in Heterogeneous Wireless Networks
Game Theory	Evolutionary Game	Cooperative Channel Assignment Game (Cocag) -Potential Game-Cooperative Game	Non Cooperative Game	Evolutionary Game Approach
Environment	VANET	Wireless Mesh Network	Computational Grid	Heterogeneous Wireless Network
Nature	Dynamic	Dynamic	Static	Dynamic
Protocol	Multiple Protocol	Multiple Protocol Simultaneously	Single Protocol	Multiple Protocol
Topology	Hybrid	Mesh	Hybrid	Mesh
Routing Decision	Dynamic	Dynamic	Static	Dynamic
Mapping	Many To One, One To Many	Many To Many	Many To One, One To Many	Many To Many
Control Structure	Decentralized	Decentralized	Centralized	Both Centralized And Distributed
Overall Increase In Performance	2.3%	4.6%	10%-20%	1.7%

Table 1. Comparison of Game theory model based on problem statement

• The rate of jobs sent to a processor must not exceed the rate at which jobs can be executed by the processor.

2.3.1 Challenges & future Scope

But In this approach Hostile player nature does not considered for load balancing. Hostile player nature occurs due to the different ownerships of sites in the system where each with their own interests and priorities. Therefore to evaluate this problem solution would be creating cooperative game. This game will include hostile player also by giving them some incentive to cooperate within game.

2.4 Dynamics of Network Selection in Heterogeneous Wireless Networks: An Evolutionary Game Approach [8]

The Next-generation wireless networks will give rise to a heterogeneous wireless access environment where network selection becomes crucial for load balancing to avoid network congestion and performance degradation. Hence to overcome dynamics of Network Selection in Heterogeneous Wireless Networks with different service areas to share the limited amount of bandwidth evolutionary game approach is designed.

In these evolutionary game model two approaches has discussed which are population evolution approach and reinforcement learning approach. Population evolution approach is centralized control structure where centralized coordinator maintains payoff information of all users of same area. The network-selection decision of each user is based on its current payoff and the average payoff of all users in the same area. Each user sends its payoff information to coordinator then coordinator compute average payoff as per equation (8) and broadcast result back to user.

$$\pi_i^{(a')}(x) = U(c_i^{(a')} / \sum_{a \in A^{(a')}} N^{(a)} x_i^{(a)}) - \sum_{a \in A_i^{(a')}} N^{(a)} x_i^{(a)} \quad (8)$$

where $n_i^{(a)}$ is the number of users in area a choosing network i, $c_i^{(a')}$ is the network capacity in area a' (i.e., total capacity associated with WMAN and/or cellular base station and/or WLAN access point), $A_i^{(a)}$ is the set of subareas in coverage area a'. $N^{(a)}$ denote the total number of users in area a and $X_i^{(a)}$ the proportion of users choosing network i. X denotes the vector of the proportion of users choosing different networks in all areas. While in reinforcement approach node use Q learning approach to adapt itself and take network selection decision independently.

4. Conclusion

By analyzing above papers we come with following conclusions

• In case of message Routing in VANET credit based system with incentive scheme can be considered as solution.

• For maximizing network throughput in mesh network instead of better response best response with static computation can be considered as future work.

• To overcome load balancing problem Cooperative game framework for QOS guided job allocation schemes with grid-decentralized strategy can be designed by considering hostile player nature.

• To solve the channel assignment problem creation of peer to peer network Service area similar to reinforcement learning approach can be considered for future work.

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