A Market-based Pricing Scheme for Grid Networks

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Abstract. This paper presents a new market-based pricing scheme which aims to improve the link load balance in Grid networks. Simulation results show that the proposed scheme achieves a better link load balance and, thus, improves the network's robustness and stability. At the same time, the scheme increases the network's effective capacity as it enables to accommodate more new services. The results show that the proposed scheme leads indeed to a more efficient usage of network resources.

Key words: Pricing, market model, load balance, Grid networks

1 Introduction

Despite the fact that traffic management engineering mechanisms have been investigated both in the area of Internet-based communications [2] as well as in thea area of Grid computing (cf. [3], [4], [5], [6]), the use of economic means for traffic management in Grid networks has received little attention so far. Existing mechanisms mainly focus on traffic optimization from the end user's perspective rather than from the network provider's perspective. Hence, they may not lead to an optimal result from the network point of view. For example, a main drawback of [3] is the dynamic migration of individual, on-going services from one *node* or *link* to another without considering the concurrent Grid services' behavior, which can cause new bottlenecks in the network and – even worse – it may lead to unexpected ping-pong migration in some cases. Moreover, [1], [7], and [8] focus on balancing the load in terms of CPU and memory resources only.

In order to achieve an optimal balance of the traffic load which is benefical for the network provider as well as the network user, this paper proposes a new approach which aims to manage the traffic of Grid networks through economic means. Our contribution is a simple method for balancing the network traffic through a market-based price adjustment scheme.

The rest of this paper is organized as follows: Section 2 presents the proposed pricing scheme, while Section 3 shows and discusses the results of the simulations that have been carried out to show the improvements of the proposed scheme. Finally, Section 4 concludes this paper.

2 Pricing Scheme

The proposed economic traffic management approach is to introduce a logical pricing component in every network domain which is in charge of determining the final link price according to the link load. The network is considered as an overlay network among different participants in a Grid, denoted as peers. It is assumed that metering points are located at each peer which detect and report the current link load to the pricing component in a periodic manner. Based on the information collected, the pricing component decides on the link prices, which shall reflect the current link load fluctuation and finally lead to a balance of the load on all links of the network.

The market-based pricing scheme balances the link load via an adjustment of the link price to provide an incentive to peers to select a path or link with a light load rather than one with a high load. The link price will increase, if the link load is higher than the average level or decrease, if it is lower than the average level.

A path is composed of one or more links for each pair of peers. Each link can be used to transfer data for several other peers. Figure 1 shows an example for a specific source peer (peer 1) and target peer (peer 4) for which there are two potential paths.

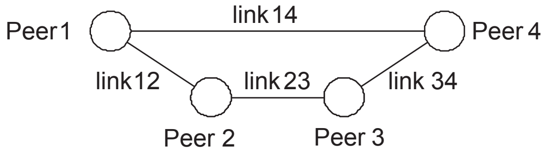

Fig. 1. Path sets for a specific connection from Peer 1 to Peer 4: Path 1 = {link 14}, Path 2 = {link 12, link 23, link 34}

A feasible path solution space can be provided by any routing algorithm. The link resource is modeled as a set $G(V,E)$ which is composed of peers and links. V is the set of the peers, $|V| = n$ is the number of peers, E is the set of links, $|E| = m$ is the number of links. A detailed step-by-step description of the price adjustment algorithm follows:

1. Assuming that the peer α competes or shares the bandwidth in the path P_α which is composed of M links ($M < m$), r_1,r_2,...,r_M is the set of resources; the resource allocation vector is represented as $x = \{x_1, x_2, ..., x_M\}$; the corresponding price of the path is $\bar{p} = \{p_1, p_2, ..., p_M\}$, in which p_1,p_2,...,p_M is the price of the links on the path. The basic link price p_{base} as well as the link price adjustment step p_{step} has to be determined by the network provider.

2. A utility function describes the satisfaction of a peer with the available resources and their link prices. It is assumed that the feasible solution space is determined before the calculation of the utility function, i.e. the credits owned by a peer is enough to cover the data transmission. The utility function of the transferring path of peer α is defined as follows:

$$U(x) = Min\{(x_i/X) \cdot (C/c_i), i \in P_\alpha\},$$

   where X and C are average remaining link throughput and average link price respectively; x_i is the remaining throughput of link i; c_i is the price of link i, P_α is the data transferring path of peer α.
3. According to the result of the routing method, the feasible solution of a set of data transfer paths is determined as $B(\bar{p}) = \{x : \bar{p} \cdot x \leq \omega\}$, where ω is the total credits of the peer or the amount of credits that the peer wishes to pay for the given service and $\bar{p}$ is the price vector of the corresponding path (or links).
4. For those target peers with enough credits it is more likely to have more than one potential path for the data transfer from their corresponding source peer. It is assumed that the size of $B(\bar{p})$ is K. Obviously K cannot be less than zero. When $K = 0$, it means that the peer doesn't have enough credit. If $K = 1$, there is only one potential path $\tilde{p}$ for the service delivery. If $K > 1$, the following procedure will help to select the final path from the potential path set. Before going into the detailed procedure, the potential paths are listed in the order of decreasing utility function:

$$\boldsymbol{U} = \{U(x_1) \geq U(x_2) \geq \ldots \geq U(x_K), x_i \in B(\tilde{p}), 1 \leq i \leq K\}.$$

   Instead of simply selecting the path with the highest utility function as the final path, a *persistence factor* is introduced to avoid ping-pong effects in some cases where many peers select one specific link and shift to an another link simultaneously. In this way, each peer will choose the path with the highest utility function with a high probability and it still has the possibility to select the path listed at a lower position in the sequence.
5. The demand function is defined as $\Phi(\tilde{p}) = \{U(\tilde{p})\}$. The total resource demand of link i is the accumulation of the demand of each peer interested in the link i: $d_i(\tilde{p}) = \Sigma_{\alpha \in A} \Phi_i^\alpha(\tilde{p})$, where in $\Phi_i^\alpha(\tilde{p})$ is the resource demand of peer α in the link i under the current price vector $\bar{p}$. A is the set of the peers being interested in link i.
6. The definition of the over-demand function is that the difference between the total resource demand and the supply of link i at the current price $\bar{p}$, i.e. $Z_i(\tilde{p}) = d_i(\tilde{p}) - S_i$, S_i is the remaining capacity of the link i; For all the $i \in E$, if $|Z_i(\tilde{p})| \leq \varepsilon$, in which ε is a predetermined small enough value, the traffic control based on the market model reaches the balance in price vector $\bar{p}$. As long as the resource demand of the link changes, the link price will make a response, i.e., the link price will decrease if $Z_i(\tilde{p}) < 0$ or increase when $Z_i(\tilde{p}) > 0$.

7. After the update of the link price, step 2 to step 6 will be repeated. Finally, the iteration round with the highest total utility value will be chosen as the final result and the price of each link in that round will be set as the final link price.

Of course, in order to guarantee QoS for all services no over-demand or overload is permitted, i.e. the link load or link utilization, normalized by the link capacity, cannot be larger than one.

3 Simulation and Evaluation

In order to verify how much the proposed scheme improves the network resource utility, simulations have been carried out and results are compared with those of the shortest (direct or one hop) path scheme (OSPF).

In order to achieve convincing simulation results, Monte Carlo simulations have been carried out. The network scale is ranging up to 340 peers. It is assumed that each peer can reach any other peer through a direct path or via one relay peer. For the sake of simplicity, only paths with no more than two hops or links were considered.

The traffic requests and link loads have been generated randomly. The initial link prices were proportional to a link's current (background) load. A maximum of 100000 simulation runs were carried out in order to obtain a stable simulation result for all Monte Carlo simulation cases.

The average link load variation of the whole network was chosen to analyze the performance in a quantitative manner. Ideally, in a robust network all links have almost the same if not identical level of load, i.e. the variation of the link load sequence is zero. A larger difference between link loads will lead to a larger variation of the link load sequence. Therefore, a smaller variation value indicates a more robust and stable network.

As it can be seen from Figure 2, the market-based pricing scheme outperforms the OSPF scheme in terms of network link load balance, since it reduces the average link load variation ranging from 20% to 50% based on the number of peers in the network.

Moveover, the average link load with the proposed scheme is higher than that of the OSPF scheme when the network peers are less than 200, which shows that the price adjustment scheme improves the network resource utilization. In addition, the network's effective capacity is increased. As Figure 3 shows ten percent more services can be accommodated in the network when the number of peers is larger than ten.

Finally, the computational complexity of the proposed pricing scheme has been measured by the time consumption of the price adjustment algorithm. As expected, Table 1 shows that the computational complexity of the scheme increases with the increasing number of peers within a network.

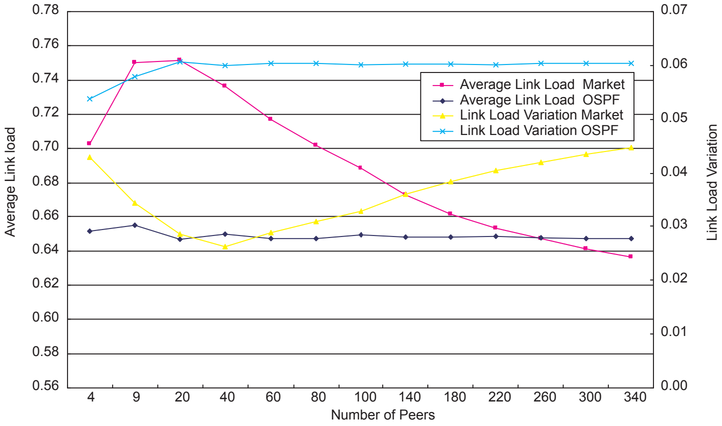

Fig. 2. Performance comparison of the market-model based pricing scheme with OSPF in terms of link load variation and average link load

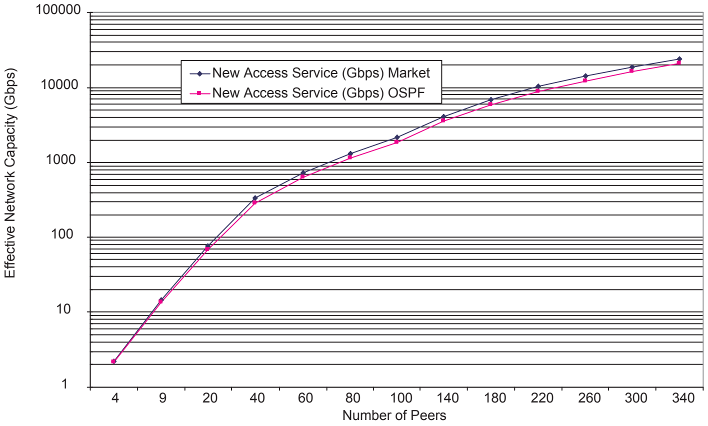

Fig. 3. Performance comparison of the market-model based pricing scheme with OSPF in terms of effective network capacity

Table 1. Time consumption of the proposed pricing scheme

# Peers	10	50	100	150	200	250	300
Time (sec.)	0.00375	0.0228	0.17	0.5706	1.4044	2.7874	4.8874

4 Conclusion

This paper presented a market-based pricing scheme for Grid networks. Simulation results show that the proposed scheme improves the network's robustness and stability. This is due to the fact that the average link load variation is reduced compared to the OSPF scheme. Furthermore, the pricing scheme increases the network resource utilization as it allows to accommodate more services compared to the OSPF method. The average link load with the proposed scheme is higher than that of the OSPF scheme when the network peers are less than 200. Moreover, the simulation results show that ten percent more services can be accommodated in the network when the number of peers is larger than ten.

Future work aims at extending the simulations with more hops between peers and improving the scalability of the proposed scheme by dividing the network into multiple domains.

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