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Coexistence of various topology aggregation methods in a hierarchical network

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Abstract

Quality of Service (QoS) routing methods are expected to replace existing routing protocols in future QoS-based data networks. QoS routing allows the selection of feasible paths for connections requiring QoS support. A good QoS routing method should efficiently utilise networking resources and the overhead involved in spreading information about resource availability should be low. Topology aggregation has been proposed as a method to reduce this overhead and allow scalability to large networks. It is used in the PNNI routing protocol which has been standardised for ATM networks.

There are several aggregation methods proposed by researchers. PNNI does not restrict aggregation to only one technique, stating only that: "the symmetric star topology is used as the 'default node representation'" [1]. This paper explores the performance of PNNI routing when various aggregation methods coexist in a single network with two hierarchical levels, within a game-theoretic framework. It is shown that in such a scenario typical aggregation methods can give a rise to a "tragedy of the commons". Improved performance is shown to result after adopting a new rule governing the manner in which state information is shared.

1 INTRODUCTION

Quality of Service (QoS) aware routing algorithms are complex and demanding. There is a wide variety of proposed solutions to the problem of selecting a path with specific QoS requirements – a comprehensive survey can be found in [2].

This paper considers source link-state QoS routing, which can be used by PNNI [1] or the extended version of OSPF [3]. In such an architecture the source router selects a route based on information about network resources provided by link state advertisements and information about QoS requirements carried within set-up requests. Link state information is flooded or broadcast using a spanning tree to ensure that all routers process the same topological and state information. There are two methods which reduce communication overhead: update policies [4, 5] and network topology aggregation [1].

Update policies control the frequency of link state advertisements so that only important changes in the link state are advertised.

Topology aggregation is used in hierarchical networks. It maps the detailed topological information about group of nodes into a compact representation. Therefore it reduces not only the amount of state information but also the amount of memory and time required to compute paths. So topology aggregation is considered a key concept to achieve scalability of QoS aware models in the Internet.

Both update policies and topology aggregation result in inaccurate state information being maintained by the routers [6], which usually has a negative impact on the path selection process [5]. However it has been shown [7] that topology aggregation can have positive influences and can increase stability of route selection by decreasing traffic oscillations.

In this paper we consider a two level hierarchical network and consider the effects on routing performance of having a variety of aggregation methods coexisting in the network.

2 AGGREGATION METHODS

A lot of attention has been devoted to the problem of the most accurate representation of an aggregated topology with one or more QoS constraints [8, 9]. The most commonly used aggregation methods are these proposed for ATM networks [10]: symmetric star, full-mesh and complex node representation. The symmetric star provides little information and full-mesh is not scalable; the complex node representation provides a tradeoff between these two methods. The complex node representation is usually created by reducing the number of edges of the corresponding full-mesh topology [10]. For example the t-spanner [11] is a compact representation which features a minimal difference between the complex node and its original full-mesh representation.

In this paper we consider only one QoS metric – the available bandwidth, since the aggregation of multiple metrics is a difficult task [8, 9]. We assume that accurate information about the number of hops is also provided using a full mesh representation [7], since some algorithms also require information about the number of hops. Because the information about the number of hops changes infrequently, thus precise advertisements only slightly increase the overhead.

Since PNNI does not restrict aggregation to only one technique, defining only the symmetric star topology as the default node representation [1], we assume that several aggregation methods can coexist in one hierarchical network at the same time. In this paper we assume that three aggregation models coexist:

exact representation – when a group of nodes is abstracted using a full mesh representation or another form of compressed full mesh which allows the original full mesh to be recreated;

fine representation – when only information about average resource availability (mean available bandwidth) is abstracted using a symmetric star representation;

coarse representation – when a group of nodes is configured not to advertise information about its resources availability or sends such advertisements very infrequently.

3 AGGREGATION STRATEGIES

The Internet is administered by many entities which often operate without any coordination and behave in a greedy manner [12]. Game theory is a suitable tool which can be used to model such a competitive environment [12, 13, 14].

The aggregation of network topology information can also be viewed as a competitive game. This is a valid approach in the case of an internetwork which is a coalition of networks administered by separate entities. Each administrator can choose a different aggregation method based on the selected strategy. We assume that administrators of each peer group do not cooperate and select one of the aggregation methods according to a preferred strategy. We also assume that each administrator can change his aggregation method to improve peer group performance.

For the three aggregation methods considered in this paper we have three corresponding strategies:

friendly strategy – when the peer group administrator is willing to share state information with other peer groups to allow the most accurate path selection to be performed. So it uses an *exact representation* of the aggregated topology.

social strategy – when the peer group administrator is willing to share state information with other peer groups but also wants to hide details, to protect its resources from being used excessively by others. Thus it uses a *fine representation* of the aggregated topology.

selfish strategy – when the peer group administrator does not want to share any state information with other peer groups. So it uses a *coarse representation* of the aggregated topology (in this case we assume that only information about the number of hops is provided).

In todays Internet network operators usually have mutual agreements and configure their networks according to them. Such agreements may define the aggregation methods to be used. Thus administrators may not be free to choose his/her strategy without invoking penalty clauses in the agreements. However, such agreements are subject to periodic review upon which an administrator may opt for a new strategy. The question arises as to which strategy should be written in to such agreements. Therefore in the following we consider a scenario when various aggregation methods can coexist in a network and administrators may choose various strategies.

4 GAME RULES

In our experiment the peer group administrators play a game. The rules of each game are simple:

- ▷ During each game there are only two strategies (aggregation methods) available to peer group administrators.
- ▷ All peer groups enter the game using the same strategy.
- ▷ Each administrator seeks to improve the performance of his peer group by changing his strategy.
- ▷ Only one peer group can change its strategy at a time. This peer group, know as opportunist, is chosen randomly from the set of requesting peer groups.
- ▷ The simulation is run until the blocking probability of the opportunist stabilises. A new opportunist is then selected.
- ▷ If the new strategy was beneficial for the opportunist it continues using it; otherwise it reverts to the previously used strategy (aggregation method).
- ▷ The game is continued until no administrator wants to change his strategy.

5 ROUTING MODEL

We consider a network with two hierarchical levels and which uses link state QoS routing. Within each peer group information about available bandwidth is advertised using a flooding mechanism or a spanning tree to all peer group members. The frequency of such advertisements is controlled by the link state update policy (in our experiments we use a threshold based policy controlled by a *hold-down* timer). Only abstracted information about available bandwidth is advertised to other peer groups using one of the aggregated representations described in the previous section. We also assume that this process is controlled by the update policy, but that no hold-down timer is applied to advertisements of aggregated information. So it is disseminated immediately if the change in available bandwidth is significant (i.e. if the threshold is crossed). Finally we assume that upon a change in topology the hop count information is advertised precisely to other peer groups.

Upon receiving a route request the source router algorithm computes a path according to the hierarchical information it possesses. If the reservation along a chosen path can be realised, the request is accepted, otherwise it is rejected. In this paper we do not consider crankback or rerouting of flows over alternative paths.

We consider two approaches to QoS routing:

Load distributing approach - which aims to balance the offered load over the network using link costs expressed as a convex function which increases with the link utilisation [15]. As an example of this approach we have chosen the *shortest-distance path* (SDP) algorithm [16], which computes the least cost path, where link cost is inversely proportional to available bandwidth.

Resource conserving approach - which minimises resource consumption by the use of min hop paths. As an example of this approach we have chosen the *widest-shortest path* (WSP) algorithm [16], which selects the path with the highest residual bandwidth from the set of min-hop paths.

Since topological information is inaccurate we assume that link pruning is disabled for both approaches [4, 5].

6 PERFORMANCE EVALUATION

In this section we compare the performance of routing algorithms on a two-level hierarchical network, where different aggregation methods can coexist.

6.1 Network Model

In our experiment we use a randomly generated network with two hierarchical levels as shown in Figure 1. This was created using the GT-ITM software [17]. It has $N = 48$ nodes grouped into 8 peer groups and $L = 72$ links. All links are bidirectional, and $L_1 = 60$ links with capacity $C_1 = 45Mbps$ are used to connect nodes within peer groups while $L_2 = 12$ links with capacity $C_2 = 155Mbps$ are used to interconnect peer groups.

6.2 Traffic model

The requests arrive at each node independently according to a Poisson distribution with rate λ and have exponentially distributed holding times with mean value $1/\mu$. The requested amount of bandwidth is uniformly distributed over the interval:

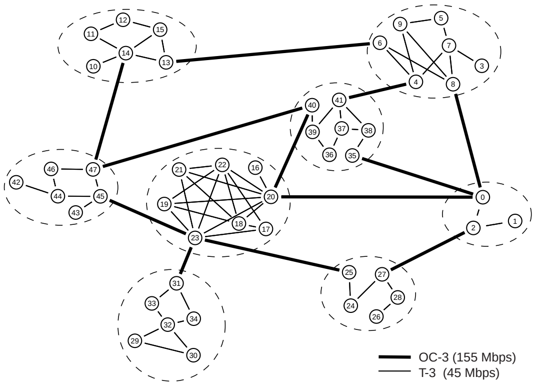


Figure 1: The two level hierarchical network used in our experiment

$[64kb/s, 6Mb/s]$, with mean value $B = 3.32Mb/s$. If N^a nodes in the network generate the traffic, the load offered to the network is [5] $\rho = \lambda NBh'/\mu(L_1C_1 + L_2C_2)$, where h' is the average shortest path distance between nodes, calculated over all source-destination pairs (for our simulation: $N = 48$, and $h' = 3$). In our experiment we adjust λ to produce the required offered load and fix the mean connection holding time at 180sec.

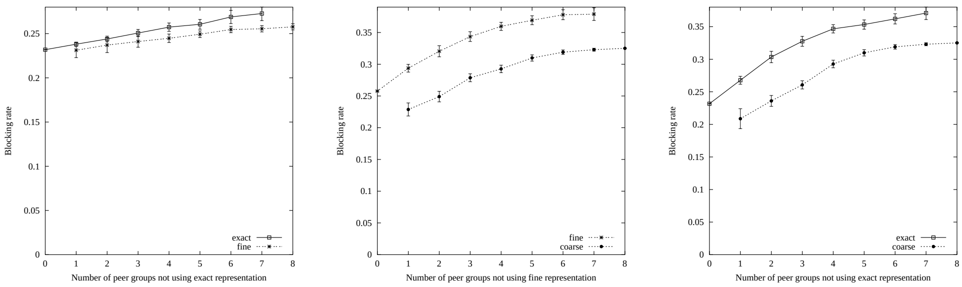
6.3 Results

In our experiment we evaluate the routing performance of the network with two hierarchical levels when a number of aggregation methods coexist. We compare the performance of peer groups employing different aggregation methods using the *blocking rate*.

In each part of our experiment we compare different aggregation strategies in pairs. Each game is repeated 50 times and we present here the average results obtained with a 95% confidence interval.

The graphs which were obtained show the payoffs of each strategy. Therefore we can use them to deduce the equilibrium point of our aggregation game.

Although we have studied two routing algorithms, we present the results only for the load distributing approach as represented by the shortest-distance path (SDP) algorithm, since the choice of the strategy will be the same regardless of which of the routing protocols is used.



(a) exact and fine (b) fine and coarse (c) exact and coarse

Figure 2: Blocking rate observed by peer groups when exact, fine and coarse aggregations coexist

6.3.1 The most beneficial strategy

In Figures 2(a), 2(b) and 2(c) we can observe all possible two element combinations of the three considered strategies.

As we can see in Figure 2(a) when the friendly and social strategies coexist, peer groups which use the social strategy benefit from not advertising exact information. A given peer group is better off not to use the exact representation, regardless of the number of peer groups adopting the friendly or social strategies. This is because peer groups which advertise their state information in detail are preferred during route computation and carry more traffic than other peer groups, so nodes from these peer groups experience higher blocking rates. So the dominant strategy is the social strategy, which does not advertise exact information. In a dominant strategy equilibrium, all peer groups will choose to use fine representation.

If a similar analysis is applied to a mix of fine and coarse representations (see Figure 2(b)) or exact and coarse representations (see Figure 2(c)) we can observe that the dominant strategy is not to advertise state information at all. The selfish strategy discourages other peer groups from routing their traffic through the selfish peer group, which results in only light traffic traversing such peer groups and hence a low blocking rate experienced by its nodes. Therefore in a dominant strategy equilibrium all peer groups behave in a selfish manner and do not advertise state information.

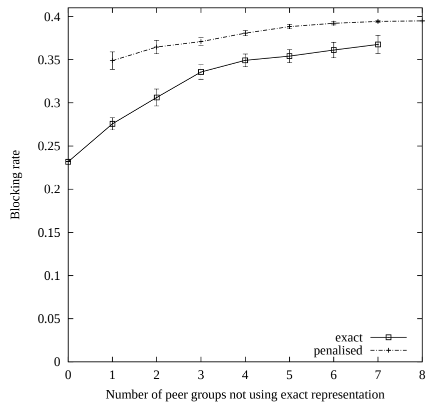


Figure 3: Blocking rate observed by peer groups when detail and penalised non-social aggregations coexist

6.3.2 The socially correct suggestion

The choice of selfish strategy as dominant strategy makes every peer group worse off. The individually rational actions lead to a situation where no peer groups advertise state information. To protect the network from such behaviour we propose that peer groups using the friendly strategy should not advertise state information to peer groups which do not share such information with them. So friendly peer groups should be only friendly to each other while they should act selfishly to other peer groups. We call this the conditionally friendly strategy.

If such a modification is made we observe in Figure 3 that conditionally friendly peer groups experience better performance than those peer groups which do not share state information (which we call penalised). Such a modification results in a situation where the dominant strategy is to advertise the state information and to behave in a friendly manner. Thus in the dominant strategy equilibrium all peer groups use the conditionally friendly strategy.

Therefore, if the proposed modification is used, the dominant strategy is to use the exact representation. So the dominant strategy equilibrium is when all peer groups share state information. Without this modification there is a strong motivation for peer groups not to share and to behave in greedy manner.

7 CONCLUSIONS

The Internet is administered by many entities which often do not cooperate and are prone to behave in a greedy manner. Game theory can help us to understand the complicated rules which apply in such scenarios. This paper considers topological aggregation when various aggregation methods are allowed to coexist in a network. We believe that it can be treated as a noncooperative game where peer group administrators can change their topology aggregation method so as to optimise the performance of their peer groups.

We have shown that if the exact and coarse aggregation methods coexist with the same privileges, it leads to “the tragedy of the commons”. Peer groups wishing to minimise blocking rates stop advertising state information. However, since other peer groups behave in the same way no peer group shares state information with any other and so poor route selection is performed at each router.

To protect the network from such behaviour we propose to advertise state information only between peer groups willing to reciprocate. In such a case the dominant strategy is to behave in a friendly manner and in the dominant strategy equilibrium point all peer groups share their state information with others. The results obtained suggest that without such strict rules for topology aggregation, performance degradation caused by selfish behaviour will ensue.

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