Traffic Forecast in QoS Routing

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Abstract

Facing some major challenges, QoS routing solutions can be classified into two categories, state-dependent and time-dependent, according to their awareness of future traffic demand of the network. This article examines both mechanisms under different traffic loads by selecting representative algorithms and studying their behaviors closely, and concludes that state-dependent mechanism has congenital shortcoming of adapting itself to the changes of traffic demand. The analysis of our observations reveals the importance of traffic forecast in the QoS routing context, yet traffic forecast is another open research area that needs further investigation.

1 Introduction

With the increasing versatility of the Internet services, such as Web, multimedia services and virtual private networks (VPNs), more quality-of-service (QoS) support is expected from the Internet and its routing protocols. Meanwhile, from the network operators' perspective, administrative policies, performance requirements, load balancing and scalability are becoming more important in operational networks and thus in the Internet routing. Under this circumstance, for years, people have been seeking for more optimal solutions on Internet routing under a dynamic environment, which includes network resources (supply) and network traffic (demand).

The focus of this article is to provide an analysis of QoS routing, including difficulties and proposed mechanisms. Simulations on some state/time-dependent mechanisms are conducted and reported. It is concluded that the state-dependent approach has limited ability to optimize networks under different traffic demands. Hence, traffic forecast is advocated in QoS routing, and its output is valuable for time-dependent mechanism.

1.1 Challenges of QoS Routing

There are some routing standardization efforts basically addressing the same set of problems, namely supporting QoS and optimizing overall network performance. These standards are:

- Integrated Services (IntServ) [1]
- Differentiated Services (DiffServ) [2]
- Multi-Protocol Label Switching (MPLS) plus Traffic Engineering (TE) [3,4]

In short, QoS routing are facing some primary challenges [5]:

- *Stability and Scalability*. When multiple resources are allocated and deallocated, high frequency of state updates is required to avoid instability and route flapping [6,7], but it does not scale well due to its high communication overhead for large networks.
- *Robustness*. Routers always get state updates with delays, and there is no guarantee that resource information is accurate and up-to-date. Route computation and routing decisions should be robust enough based on imprecise states [8].
- *Routing Cost*. Processing state updates, implementing techniques related to robustness issue, and conducting QoS routing (an NP-Complete problem [12]) introduce considerable computational cost [9,10]. Contrastively, QoS requests expect highly responsive services.

1.2 Assumptions

When the QoS requirements are considered in the Internet, the behavior of IP network becomes more like connection-oriented, since certain amount of resources has to be assigned to specific QoS requests. To simplify our description of scenarios, connection requests are used as examples in the rest of the paper. The situation of connectionless requests is similar in our context.

Let N be the number of source-destination pairs, then the traffic demand can be expressed as $D=[d_1\ d_2 \ldots d_N]$.

1.3 Performance Evaluation

Given a set of LSP (Label Switched Path) requests, a good QoS routing algorithm will minimize the average number of hops that those LSPs traverse, and to minimize the maximum link utilizations. These two metrics can be compromised within a nonlinear objective function [18], though it remains the ISP's judgment to decide which factor is more important according to specific requirements. In this paper, the value of the objective function is regarded as the level of network-wide performance. Moreover, for a given traffic demand matrix D, the value of the objective function for any routing algorithms is bounded by an optimal value (i.e. the lowest value), which can be computed if the nonlinear function is differentiable convex [19].

1.4 Rearrangement of Traffic Flows

A naive thought is trying to approach optimal points when the traffic demand is changing in real-time. The underlying barrier of this thought is due to traffic rearrangement, which means some flows have to be rearranged in terms of explicit routes and their assigned bandwidth. Rearrangement causes service disruption and significant signaling overhead to proceed with minimal disruption. The cost of rearrangement increases dramatically as rearrangement becomes frequent.

2 State vs. Time-Dependent Mechanism

A QoS routing algorithm works like this: Upon the arrival of a routing request, the algorithm either selects a route that satisfies the QoS requirements without degrading the overall performance much or rejects it. If the QoS algorithm accepts the request, corresponding network resources are reserved on each link of the route during the period. Note that there is usually more than one route that can meet the request, and the best one or the one that is good enough is desired for network performance. If a routing algorithm that is able to find the optimal route for every request knowing neither history nor future traffic demand. This is called *state-dependent* mechanism, while the one with history or future knowledge is called *time-dependent* mechanism [11].

State-dependent mechanism is ideal but hard to design. First, it faces all challenges mentioned above, no matter it is designed as Pre-Computation Routing [13,14] or On-Demand Routing [15,16,17]. In particular, pre-computing paths for all possible QoS requirements [13] is extremely processor and memory consuming, as it has no idea about the future demands.

Second, there is a *rearrangement dilemma* in case of state-dependent mechanism. Suppose it can approximate an optimal point according the current state. After a few minutes when new LSP requests come in, it has a high chance to rearrange existing user flows in order to keep the same level of performance. On the other hand, if fewer rearrangements are needed, it has to stay away from the optimal points. Again, the dilemma partially stems from the ignorance of future traffic demand.

3 Time Dependent Widest Shortest Path (TDWSP)

When D_{peak} is given, an optimum solution is calculated and part of its output ingressed from node 1 is shown in Fig 1. For each ingress, the preplanned network is a directional subnet without loops. Besides all 20 trees (one per node), the remaining bandwidth of the whole network constitutes another network.

TDWSP is a variation of WSP, but it knows the future demand at D_{peak}. For a request of bandwidth *bw* from *s* to *d*, the pseudo code for the TDWSP is as follows:

```
initialize preplanFreeBw
if bw < preplanFreeBw(s,d) {
  do WSP on preplannedNet
  if failed {
    do WSP on remainingNet
  } else {
    preplanFreeBw(s,d) = preplanFreeBw(s,d)- bw
  }
} else {
  do WSP on remainingNet
}
```

source	destination	demand (Mbps)
1	2	43
1	3	111
1	4	11
1	5	62
1	6	21
1	7	14
1	8	7
1	9	55
1	10	8
1	11	22
1	12	122
1	13	14
1	14	10
1	15	3
1	16	86
1	17	74
1	18	26
1	19	52
1	20	107

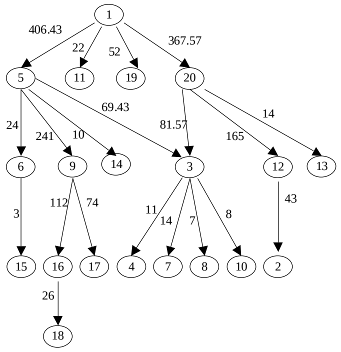

Figure 1. Traffic Demand and Preplanned Network

4 Simulations

Simulations are conducted on a 20-node network with 37 bi-directional links including OC-3, OC-12 and OC-48. The topology and traffic demands were obtained from an ISP in North America. Performance of SPF, WSP and Shortest Widest Path (SWP) is compared with respect to the objective function value (Fig. 2). LSP requests used in simulations are randomly generated in the range of 1-3 Mbps (only integer values are used) until certain D is reached. Traffic demand is normalized to its maximum possible value that the network can handle.

The difference between the state-dependent algorithms and the optimal is not large, mainly because the network was well designed. A time-dependent QoS routing, TDWSP, was devised to show the value of forecast. TDWSP outperforms WSP at almost all load levels, especially when the traffic load is < $D_{peak.}$ As shown in Fig. 2, the setting of D_{peak} does not make much difference on performance. More simulation results reveal that the performance of TDWSP is not sensitive to the position of forecasted traffic demand.

5 Generalization of the Simulation Results

Image a surface which consists of all optimal points for all legitimate vector D in an $N+1$ dimensional space. Fig. 2 is only one of the cross-sections of this space passing the origin. Whatever QoS routing algorithm is used, a point representing the performance of the network is moving within a surface[1] as traffic demand D changes. In general, if a state-dependent algorithm performs well when D is close to the origin in the space, then a time-dependent variation of this algorithm can also perform near optimally when D is close to D_{target}, where D_{target} is configurable.

Research [20,21] shows that Internet traffic exhibits some type of daily usage patterns and is predictable in a high aggregation level. So the orbit of this movement is limited in an area of the surface. Our results suggest that a good prediction of the orbit may help QoS routing yield good routing performance.

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[1] Strictly speaking, it is not a surface. Most routing algorithms are sensitive to the order of LSP requests, so the value of objective function may vary in a range for every given *D*.

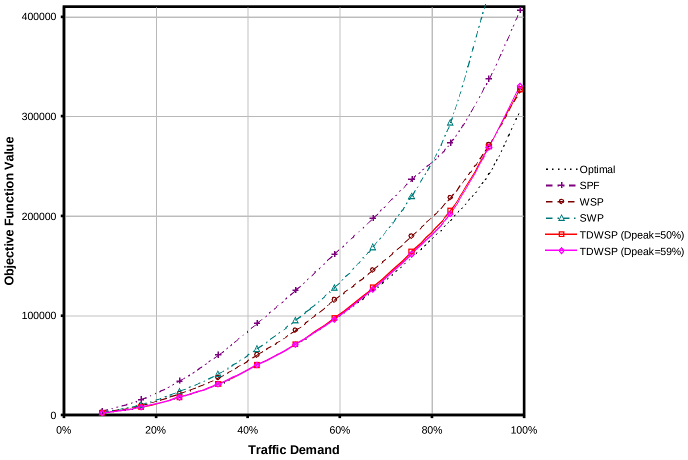

Figure 2 Network Performance with Different Routing Algorithms

6 Advantages of Time-Dependent Mechanism

Now the challenges mentioned in the beginning of the paper are reexamined in the context of time-dependent mechanism. Use TDWSP as an example, both WSP and TDWSP are algorithms without rearrangement. In TDWSP the forecasted traffic matrix D_{peak} is fixed and its optimal solution is computed offline in advance. For most LSP requests that the TDWSP expects, ingress router can make routing decision just based on preplanned *local* information. Only when unexpected requests come in, TDWSP uses WSP algorithm on the remaining network. The existence of this *fast path* can mitigate all those challenges we discussed before.

The advantage of time-dependent mechanisms also can be applied to algorithms with rearrangement. A time-dependent algorithm swinging among 2 or 3 typical traffic demands *D* could be feasible if these demands are structurally different and if there is a practicable way to do the rearrangement.

We argue that the QoS routing problem could be decomposed into two orthogonal sub-problems: traffic forecast that deals with the dynamic aspect, and optimization that deals with the static aspect. Though both sub-problems are not easy to answer, the insight of the dynamic Internet traffic is necessary and valuable to solve the QoS routing problem.

7 Conclusion

From both simulation and analysis, we illustrated the inherent disadvantages of state-dependent mechanism, rooting from the lack of traffic prediction. We further explained the benefits of traffic forecast in time-dependent mechanism in light of its positive impact on performance. If we consider the fact that current operational networks normally are running in a predictable traffic pattern, the role of traffic forecast in QoS routing becomes more useful.

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