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New Routing Metrics in QoS Network[1]

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Abstract: Providing end-to-end quality-of-service (QoS) guarantees is important in packet networks. The key issue is how to determine the feasible path that satisfies a lot of QoS constraints. In order to improve the service performance for real-time multimedia applications, we propose two new routing metrics (i.e., hop and bandwidth) in constraint-based path selection (CP). In this paper, we study the path selection under two QoS constraints. One is additive (i.e., delay), the other one is concave (i.e., bandwidth). We compare the performance of hop-bandwidth-based path selection (HBP) with that of delay-bandwidth-based path selection (DBP), which is the most usually used in CP. Besides analytical results, we run simulations to demonstrate the efficiency of the proposed routing algorithm. Simulation results show that HBP provides not only low end-to-end transmission delay but also low network cost.

Keywords: QoS, Path Selection, Hop, Delay, Bandwidth

1 Introduction

Today, mission-critical Internet is required to provide quality-of-service (QoS) guarantees in multimedia applications. Most of these applications have multiple QoS guarantees in terms of delay, bandwidth, packet loss ratio and energy consumption, etc [1-5]. In order to satisfy the QoS guarantees, researchers focus on providing several QoS-based network frameworks [6-10]. The key issue is how to select a feasible path that satisfies the application's requirements, for example, cost, delay, and reliability, etc. The constraint-based path selection (CP) problem has been extensively researched. In order to find the path providing the QoS guarantees, researchers have proposed several mechanisms, such as mixed-metric-based path selection (MMP) [11,12], multi-additive-metric-based path selection (MAP) [13-25]. However, these mechanisms are not widely deployed in Internet. The reasons are as follows.

First, one important issue in MMP is that the resource reservation can be supported by the mixed metric. MMP uses a predefined function to compress various network information (e.g., delay, bandwidth) into a single value (a mixed metric). Path selection is based on the mixed metric. For example, a mixed metric $f(p)=\frac{B(p)}{L(p)\times D(p)}$. p represents a path. $B(p)$, $L(p)$ and $D(p)$

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represent bandwidth, loss probability and delay, respectively. A path with larger $f(p)$ is better than that with smaller $f(p)$. Obviously, the network information (i.e., bandwidth, loss probability and delay) cannot be obtained directly from the he mixed metric. Therefore, it is difficult to know whether the QoS requirements are satisfied.

Second, although the network information can be easily obtained from the multiple additive metrics in MAP, the problem of finding a path subject to two or more additive metrics is NP-complete [1]. Many heuristics and approximate solutions for MAP, e.g., k-shortest-paths approach [19, 26, 27] and the constrained Bellman-Ford algorithm (CBF) [28, 29], have been proposed. However, the time complexity of these algorithms is too high especially in large network [24]. For example, the complexity of CBF is $O(e^{\alpha N})$ which grows exponentially with the number of nodes N [28]. MAP problem can be solved by pseudo-polynomial-time algorithms [20], in which the complexity depends on the value of the largest link weight and the size of the network. However, if the link weight value has large resolution, these algorithms have high complexity. In order to control the time complexity, ε-optimal approximation algorithm [30-32] is proposed at the expense of degrading the performance. ε-optimal approximation algorithm can minimize the cost of a selected feasible path. However, the algorithm complexity is proportional to $1/\varepsilon$. When ε has a small value, this algorithm is impractical. In Ref. [20], Jaffe proposed a different approximation algorithm for MAP problem based on Lagrange relaxation. Jaffe developed a linear cost function $l(p)$ with link weights (i.e., $l(p) \triangleq \alpha_2\omega_1(p) + \alpha_2\omega_2(p)$). α_1 and α_2 are two positive numbers. ω_i $(i = 1,2 \ldots)$ is a link weight. The algorithm aims to minimize the cost function in path selection. However, the algorithm cannot always find the feasible path.

Therefore, one challenge in CP is to determine the feasible path under the QoS constraints with an efficient algorithm. In order to avoid the NP-complete problem, the additive-concave-metric-based path selection (ACMP) is proposed. ACMP uses an additive metric and a concave metric in route selection. In Ref. [32], delay and bandwidth are selected as additive metric and concave metric. Bandwidth of a link is the residual bandwidth available for a flow. Delay is composed of two parts: 1) propagation delay (proportional to the distance of path), and 2) queuing delay (related to the traffic in network and the available bandwidth). In Ref. [33], Wang uses the propagation delay as the additive metric instead of total transmission delay. This is not reasonable, because the end-to-end transmission delay consists of propagation delay and queuing delay. Ignoring queuing delay in path selection is incomplete. However, queuing delay depends on bandwidth, which makes mapping the QoS requirements into routing metrics very difficult.

In this paper, we study CP problem by ACMP method [1, 33, 34]. In order to improve the QoS performance for real-time applications which require large bandwidth and low delay (i.e., videoconference), we propose to use hop count and bandwidth as the routing metrics. Two new metrics address the interdependence problem between queuing delay and bandwidth. Subject to hop and bandwidth, an algorithm with complexity $O(|N|^2)$ is proposed. The QoS performance of hop-bandwidth-based path selection (HBP), compared to the delay-bandwidth-based path selection (DBP), is evaluated through simulations using concrete statistical data accordingly. Results show that HBP not only improves end-to-end transmission performance but also reduces the cost for network. To the best knowledge of authors, there is no evaluation on actual QoS performance with concrete routing metrics. This is the first investigation on actual QoS performance from the point of HBP view.

The remainder of this paper is organized as follows. Section 2 introduces the metric selection criteria and routing policy in ACMP. Section 3 shows the network and metric model, and illustrates the performance criteria and proposed algorithm. Simulations and results are given in Section 4. Finally, the paper is concluded in Section 5.

2 Problem statement

2.1 Metric selection criteria

Routing metrics are the mathematical models for a network. They have influence not only on the complexity of path computation, but also on the type of QoS requirements supported by a network. Some factors should be considered while selecting routing metrics in a QoS network. First, the parameters must reflect the fundamental characteristics of a network. Second, an efficient algorithm for path selection subject to multiple metrics is needed, to ensure that the algorithm performs well in large network (e.g., Internet). Besides, the parameters must be orthogonal to each other to reduce redundant information. The interdependence between metrics may substantially reduce the QoS performance.

2.2 Bandwidth and hop count metric

Bandwidth metric was first proposed in ACMP in Ref. [33]. The bandwidth is defined as the residual bandwidth that is available for a new traffic, and the bandwidth of a path is the minimum residual bandwidth of all links on the path. Hop count is the link counts traversed by a route. Hop count is independent from other characteristics of the link [35]. Therefore, the bandwidth metric is orthogonal to hop count. We assume that the current state of the network is available to every node at any time instant, ignoring the dynamics of the network and the delay caused by updating the state information following a change.

In QoS routing, the requirements for applications can be characterized by four parameters, i.e., reliability, delay, bandwidth and jitter [36]. For example, E-mail and file transfer applications have stringent requirements on reliability. No bits may be delivered incorrectly. In this paper, we focus on the QoS requirements for real-time applications, such as videoconference that needs low delay and large bandwidth.

2.3 Routing policy

Definition 1. An additive metric and a concave metric based path selection (ACMP) problem: Consider a network that is represented by a directed graph $G = (N, E)$ with n nodes and m links, where N is a set of nodes and E is a set of links. Each link $(u, v) \in E$ is associated with two QoS values: one is additive metric $c_{add}(u, v)$, the other one is concave metric $c_{cav}(u, v)$. Given a constant c_1, the problem is to find the optimal path $p_{opt}(s, t)$ that has the minimal $c_{add}(s, t)$, subject to $c_{cav}(s, t) \geq c_1$.

$$p_{opt}(s, t) = \min\left(c_{add}(s, t)\right), \; c_{cav}(s, t) \geq c_1. \tag{1}$$

To illustrate the routing policy, an example is shown in Fig. 1. Fig. 1(a) is the network topology. Digit on each link represents the propagation delay (unit is seconds). There is a request R_1 for routing a packet from source node A to destination node H. We assume that R_1 requires bandwidth no less than 1Gbps (i.e., $c_1 = 1Gbps$). In order to reach the node H from node A, two routes with bandwidth larger than c_1 are given. In DBP, the route for R_1 is the path A-C-F-H, as shown in Fig. 1(b). The path in DBP traverses more hops (i.e., hop counts is 3), in order to ensure the least propagation delay (i.e., propagation delay is 3). More hop counts may cause more transmission delay and network cost [37]. In order to reduce the end-to-end transmission delay as well as network cost for R_1, we propose to use hop count metric in ACMP instead of delay. In HBP, the route for R_1 is A-D-H that is the path with 2 hops, as shown in Fig. 1(c). Obviously, the hop counts of the route in HBP are reduced. However, to the best knowledge of authors, there is no evaluation that such reduction of hop counts can improve the actual end-to-end transmission performance for real-time applications and reduce network cost.

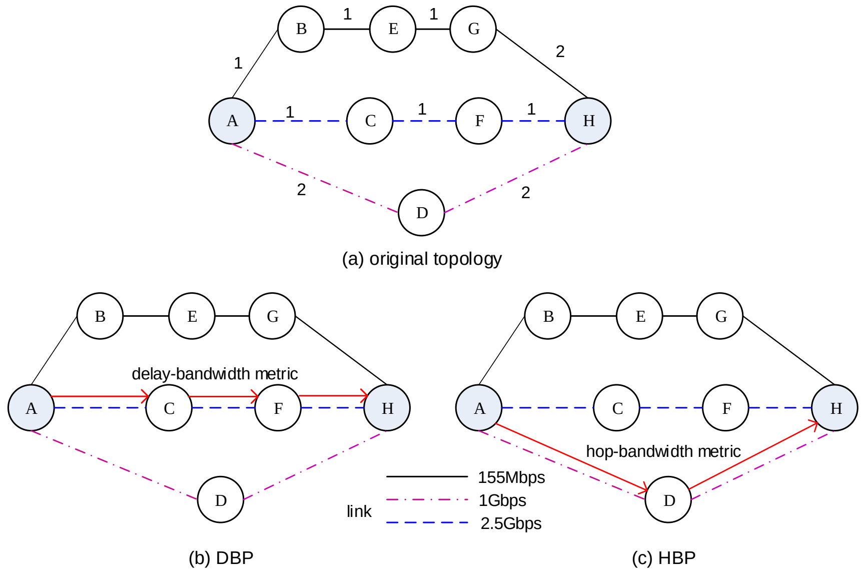


Figure 1. Routing selection with delay-bandwidth metric, hop-bandwidth metric

3 Model

3.1 Network and metric model

The given computer network is represented by a directed graph $G = (N, E)$ with n nodes and m links, where N is a set of nodes and E is a set of links. Each link between nodes P_i and P_j is represented by $e_i = (P_i, P_j)$, where $P_i, P_j \in N$ and $i, j = 1,2,3 \ldots$. The source and destination nodes are denoted by s and t, where $s, t \in N$. $p(s,t)$ denotes a path between s and t, while $p_{opt}(s,t)$ denotes the optimal path, $p_{opt}(s,t) \in p(s,t)$. R_n represents a request numbered n. Each request corresponds to route a packet in the Internet.

Metrics associated with each link are characterized by mathematical operator that is used to compute the metric value of a path. Based on the mathematical characteristic, we divide metrics into two kinds as: (a) additive metric $c_{add}(e)$. (b) concave metric $c_{cav}(e)$. Table 1 displays some typical metrics of each kind. It is assumed that both additive and concave metrics are nonnegative real numbers. The mathematical model of each kinds of metric is as follows.

(1) Additive metric

We define the value of additive metric over a path $p(s,t)$ as,

$$c_{add}(s,t) = \sum_{e_i \in p(s,t)} c_{add}(e_i). \tag{2}$$

Routing algorithms that optimize on additive metric will find a path with the minimum value of $c_{add}(e)$ among all feasible paths.

$$p_{opt}(s,t) = \min\left(c_{add}(s,t)\right). \tag{3}$$

(2) Concave metric

Concave metric sometimes names bottleneck metric. We define the value of concave metric over a path $p(s,t)$ as,

$$c_{cav}(s,t) = \min_{e_i \in p(s,t)} c_{cav}(e_i). \tag{4}$$

When optimizing on such metrics, routing algorithms determine the path with the maximum value of $c_{cav}(e)$ among all feasible paths.

$$p_{opt}(s,t) = \max\left(c_{cav}(s,t)\right). \tag{5}$$

3.2 Performance criteria

The service performance of HBP for real-time applications, compared to DBP, is evaluated with following two aspects.

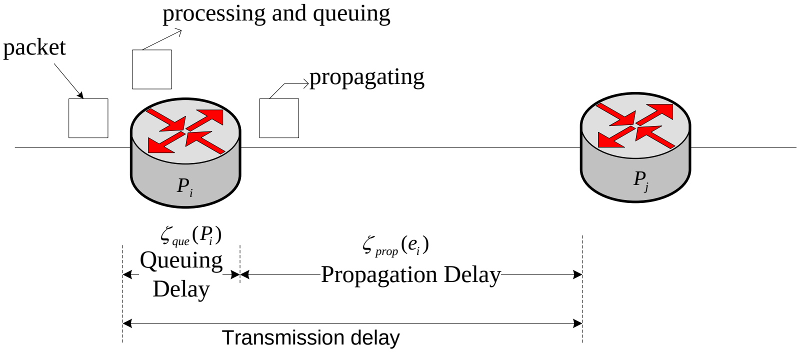


Figure 2. The composition of transmission delay

(1) Average transmission delay

Transmission delay $\zeta^{(i)}$ for each request R_i is composed of two parts. One is queuing delay $\zeta_{que}^{(i)}$, and the other one is propagation delay $\zeta_{prop}^{(i)}$, as is indicated in Fig. 2.

$$\zeta^{(i)} = \zeta_{que}^{(i)} + \zeta_{prop}^{(i)}. \tag{6}$$

Propagation delay $\zeta_{prop}^{(i)}$ for the ith request can be divided on each link covered by path $p^{(i)}(s,t)$,

$$\zeta_{prop}^{(i)} = \sum_{e_i \in p^{(i)}(s,t)} \zeta_{prop}(e_i), \tag{7}$$

in which $\zeta_{prop}(e_i) = d(e_i)/v$, $d(e_i)$ is the geographical distance of the link e_i connecting node P_i to P_j, and $v = \frac{2}{3}c$ is the transmission speed of optic fiber [38]. $p^{(i)}(s,t)$ is the path selected by R_i.

Queuing delay $\zeta_{que}^{(i)}$ for the ith request can be divided on each node P_i covered by path $p^{(i)}(s,t)$.

$$\zeta_{que}^{(i)} = \sum_{P_i \in p^{(i)}(s,t)} \zeta_{que}(P_i). \tag{8}$$

Now that both $\zeta_{prop}^{(i)}$ and $\zeta_{que}^{(i)}$ of each request have been determined, the average propagation delay $\overline{\zeta_{prop}}$ and average queuing delay $\overline{\zeta_{que}}$ of all requests can be calculated by (9) and (10) respectively.

$$\overline{\zeta_{prop}} = \frac{\sum_{i=1,2,\dots,n} \zeta_{prop}^{(i)}}{n}, \tag{9}$$

$$\overline{\zeta_{que}} = \frac{\sum_{i=1,2,\dots,n} \zeta_{que}^{(i)}}{n}, \tag{10}$$

in which n is the total number of requests in current network.

Therefore, we can calculate the average transmission delay of all requests in current network.

$$\bar{\zeta} = \frac{\sum_{i=1,\dots,n} \zeta^{(i)}}{n}, \tag{11}$$

in which n is the total number of requests in current network. $\bar{\zeta}$ is the one performance index in our experiment.

Average Cost (AC). AC is defined as the average route hops of all requests. Small AC means lower cost of algorithm.

$$\mathrm{AC} = \frac{\sum_{i=1,2,\dots,n} h^{(i)}}{n}, \tag{12}$$

in which $h^{(i)}$ denotes the hop counts of the route selected by R_i, and n is the total number of requests in current network. AC is the another one performance index in our experiment.

3.3 Algorithm description

Step 1 Wait for a new request. If the new request R_n arrives, go to step 2; otherwise, go back to step 1.

Step2 Prune all links with residual bandwidth less than constant c_1 (c_1 is defined in Definition 1), then go to step 3.

Step 3 Compute the least-hop path by the Dijkstra's algorithm. If this path has been found, accept this request and go back to step 1; otherwise, block this request and go back to step 1.

The time complexity of this algorithm is mainly related with the routing algorithm, i.e., Dijkstra's algorithm, whose time complexity is $O(|N|^2)$.

4 Simulation and analysis

Although several random algorithms to generate network topologies have been proposed, it was found that the actual topologies are highly different from ones formed by these algorithms [39]. To deal with this problem, we adopt the network topology of China Education and Research Network (CERNET) as shown in Fig. 3. The average queuing delay on each city is the collected data from the monitoring system in CERNET in one month.[2] The geographical length of each link between two cities is inferred from the railway length between two cities, since most optic fibers are constructed along the railway.[3] The bandwidth of each link is gotten from CERNET.[4] In our experiment, we choose bandwidth constraint $c_1 = 2.5Gbps$. In this paper, we simulate an incremental traffic model. In this model, the matrix of requests is not known ahead of time. Each new request enters the network one by one. Once allocated, requests in the network cannot be reconfigured.

[2] See http://www.cernet.com/flow_monitor/monitor/static_200112.htm.

[3] See http://www.shike.org.cn.

[4] See http://www.edu.cn.

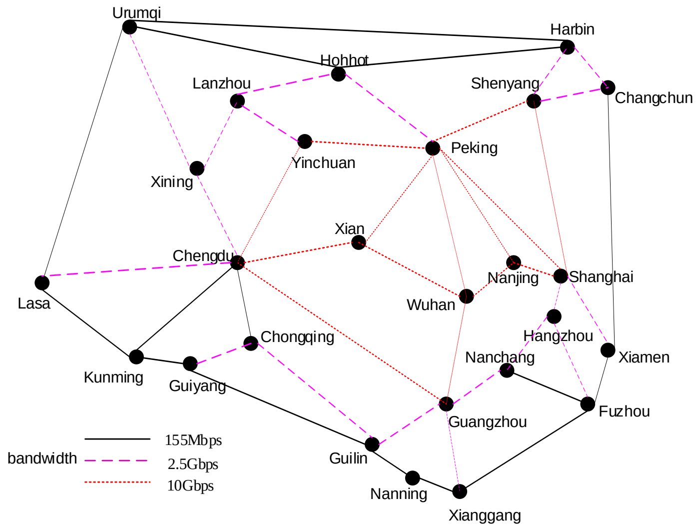
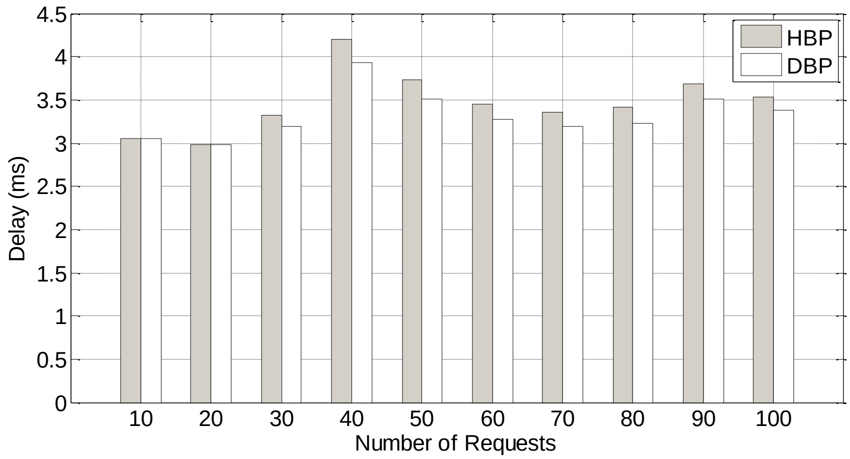
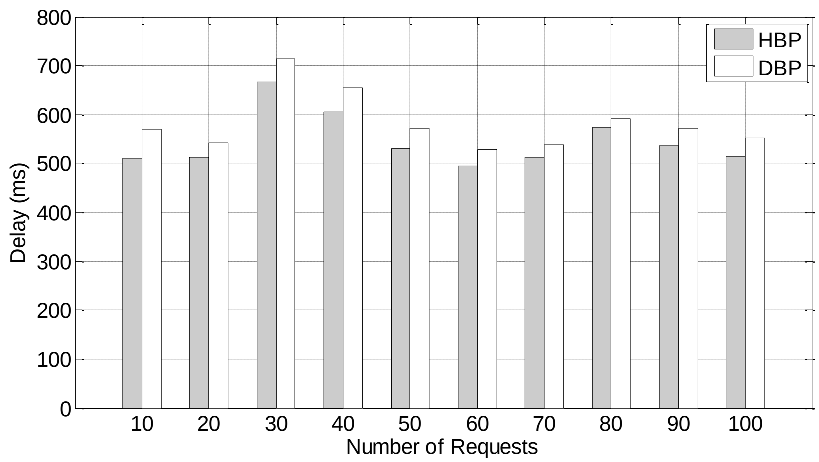


Figure 3. CERNET network



(a) average propagation delay



(b) average queuing delay

Figure 4. Simulation results with different metrics

In Fig. 4(a), we can clearly see that, the $\overline{\zeta_{prop}}$ of DBP is small, and the one of HBP is big, which means that the route in DBP has low propagation delay while the route in HBP has high propagation delay. The reason for this is that, DBP uses propagation delay as additive metric and minimizes it in route selection, while HBP may traverse a route with more propagation delay for ensuring the shortest hop, so that DBP ensures low propagation delay.

In Fig. 4(b), we can see that, the $\overline{\zeta_{que}}$ of HBP is small, and the one of DBP is big, which means that the route in HBP has low queuing delay compared with DBP. The reason for this is that the more hops may cause the more queuing delay of a route. The routes selected by HBP have the least hop while providing bandwidth guarantees, so that the routes in HBP have low queuing delay.

In Fig. 4(c), we can see that, the $\bar{\zeta}$ of HBP is small, and the one of DBP is big, which means that HBP provides low end-to-end transmission delay compared with DBP. The reason for this is that queuing delay plays the main role in end-to-end transmission delay. HBP has the low transmission delay, although small propagation delay is provided by DBP.

In Fig. 5, the result shown that, the AC of HBP is small, and the AC of DBP is big, which means that HBP has low network cost. The reason for this is that, the routes in HBP ensure the least hop while providing bandwidth guarantees, so that HBP has low cost for the network.

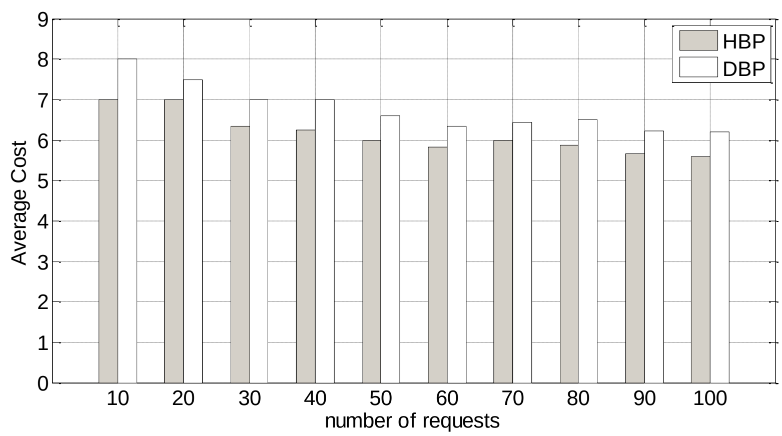


Figure 5. Average cost

5 Conclusion

One of the key issues in providing end-to-end QoS guarantees in packet networks is how to determine a feasible path that satisfies a lot of QoS constraints. In this paper, we proposed to use hop count and bandwidth as routing metric, to improve the QoS performance for real-time applications that requires high bandwidth and low delay. It addresses the interdependence problem between metrics in ACMP. Subject to two new metrics, an algorithm with complexity $O(|N|^2)$ was proposed. Simulation results show that HBP provides not only low end-to-end transmission delay but also low network cost. Our future work will focus on multiple QoS metrics (three and four) in routing decision.

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