Modified Least Loaded Routing in Virtual Path Based ATM Networks[1]

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Abstract

We consider a Virtual Path (VP) based ATM network supporting multiple traffic classes with heterogeneous traffic characteristics. Using simple FIFO scheduling policy at the ATM multiplexer, we assume that all traffic require identical end-to-end quality of service (QoS) requirement. The concept of effective bandwidth is used to determine the required bandwidth to guarantee the specified QoS requirement. We study the problem of using dynamic routing to VP-based ATM networks by transforming it into an equivalent multi-rate circuit-switched network problem. To further simplify the analysis, we restrict the choice of path to single-link and two-link routes. We propose a dynamic routing algorithm based on the Least Loaded Routing (LLR) with packing. Simulation results are used to compare the performance of this algorithm with other dynamic routing schemes.

Keywords: Dynamic Routing, Virtual Path, ATM, Least Loaded Routing

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1. Introduction

Over the past few years Broadband ISDN (B-ISDN) has received increased attention from academia and industry. B-ISDN is a communication architecture capable of supporting a wide variety of services which have diverse traffic characteristics and quality of service requirements such as voice, video, and data. Asynchronous Transfer Mode (ATM) has been recognized as a promising network technology to support B-ISDN because of its efficiency and flexibility. ATM is a fixed-length packet-oriented transfer mode which uses asynchronous time division multiplexing techniques. It allocates time slots only when needed and can achieve high bandwidth utilization by statistically multiplexing many bursty traffic sources.

Connection-oriented services are supported by establishing a *virtual circuit* (VC) between two points. To reduce network management complexity, multiple virtual circuits which share the same physical network path may be logically grouped to form a *virtual path* (VP) [19]. The routes for each VP on the physical network are pre-defined and are viewed as semi-permanent network connections. Compared with managing individual VCs in a large network, using VPs simplifies call admission control and routing, streamlines network resource management, and reduces nodal processing.

In a VP-based ATM network, a new connection is established by selecting a set of VPs which connect the source and destination. The process of selecting the set of VPs is called *routing*. The selected path must have sufficient resources to guarantee the specified QoS requirement of calls carried in that path. The QoS parameters are generally specified by cell loss probability, maximum delay and delay jitter.

Most of the previous works on routing for VP-based networks are restricted to homogeneous traffic classes. That is, only a single traffic class is supported in each VP network. In [8], Least Loaded Routing (LLR)-based algorithms for VP networks supporting homogeneous traffic classes with one quality of service (QoS) requirement are proposed. In

[10][11], the study is extended to the case in which each VP can support two QoS requirements and Markov Decision Process (MDP)-based routing algorithms are also developed. In [17], the application of LLR algorithm for multi-rate traffic class with different QoS requirements in circuit-switched networks are discussed.

In this paper, we propose a dynamic routing algorithm designed for heterogeneous traffic which is fast enough to be implemented in real-time. Section 2 models the VP-based ATM network. Section 3 presents the network routing problem. Section 4 surveys several previously proposed real-time dynamic routing schemes. It also details our dynamic routing scheme. Simulation results are presented in Section 5 which compare the performance of the different routing algorithms. Section 6 concludes the discussion of this study.

2. Network Model

Virtual Path (VP) concept is introduced to simplify traffic control and routing. We assume that the ATM network consists of several VP subnetworks, for which nodes are interconnected by VPs. Let us consider a 4-node VP subnetwork as shown in Fig. 1. To establish a VC between the switches *a* and *b*, there are four possible routes: {1}, {5, 2}, {4, 6} and {4, 3, 2}. If a route consists of one VP, it is a direct route; otherwise, it is an alternative route. Following the practices of dynamic routing in circuit-switched networks, we exclude routes that consist of more than two VPs, i.e., {4, 3, 2} in this example. Hence, the proper routes are {1}, {5, 2} and {4, 6} only. The heuristic reason is that it wastes too much network resources to route call over a path with more than two VPs. It is better off to reject the call so that the spare resources can be used to support other users. Obviously, this restriction can also reduce the number of possible paths involved in routing. The complexity of the routing algorithm will be reduced at the expense of higher call blocking probability. However, a recent paper by Krishnan [14] show that the restriction to 2-link routes imposes no penalty on network cost in broadband

ATM networks. Consequently, we shall consider only 1-link direct VP and 2-link alternative VPs in our routing decision. We shall use the words VP and link interchangeably in this paper.

Note that the admission control and routing are coupled problems since the network accepts a call only if it can find a suitable path. To route a connection through the network, we need to determine the QoS of all the existing connections in the selected logical path. A new call can be added as long as the QoS of the existing calls are maintained; otherwise the call is rejected. For large networks supporting multiple types of traffic with diverse QoS requirements, finding the optimal routing paths is infeasible because it can be very computation intensive and cannot be calculated in real-time. Feasible network routing algorithms which can be implemented in real-time use approximations to get suboptimal routing policies.

Call admission control algorithms calculate the effective bandwidth [5][12] of a call using declared traffic characteristic parameters such as average bit rate, peak bit rate, and mean burst length.

Suppose that there are K types of traffic, and n_k sources of type k are multiplexed into a single large buffer B with deterministic service rate C. Let W be the stationary buffer occupancy. For asymptotically large B, it is shown in [12] that:

$$\sum_k n_k e_k(\delta) \le C \qquad \Leftrightarrow \qquad \lim_{B \to \infty} \frac{1}{B} \log P(W \ge B) \le -\delta \qquad (1)$$

where $e_k(\delta)$ is the effective bandwidth for the type k source corresponding to δ and δ is a parameter determined by the cell loss probability requirement.

For a call accepted into the network, only the effective bandwidth is guaranteed. If we focus only on the call-level performance, such as call blocking probability, and assume that the effective bandwidth for the same type of traffic is fixed. Then routing mechanism with this predetermined bandwidth can be modelled as a multi-rate circuit-switched network.

In traditional circuit-switched networks, same amount of bandwidth (trunks) are reserved along the path regardless of the number of links involved. Thus, it is not necessary to distinguish the direct path and the alternative path. However, this is not the case in ATM networks because effective bandwidths are different in using direct and alternative paths. For instance, suppose we want to establish a VC between *a* and *b* with a maximum cell loss probability ε as is shown in Fig. 1. If the direct path {1} is used to route the call, the cell loss probability in {1} should be less than or equal to ε. However, if the alternative route {5, 2} is used, cell loss can occur at either of the two VP input buffers along the route and thus the sum of cell loss probabilities of VPs, {5} and {2}, cannot exceed ε. Hence, the individual cell loss probability in each VP must be less than ε, say ε/2. Using (1), we find that this more stringent cell loss probability implies that larger effective bandwidth is needed in each link.

In this paper, ATM networks are considered which support heterogeneous traffic with the same end-to-end QoS requirements (e.g. same cell loss probability). Calls using a direct route have less stringent QoS requirements than calls using 2-link alternative routes. In order for a node to support multiple QoS requirements, ε and ε/2, dedicated buffers are allocated (K_1 and K_2) to each class of QoS, as shown in Fig. 2. This separate buffers approach is also adopted in [7][10].

In [16], it shows that the traffic characteristics of a call are not changed as it passes through a VP along its route under certain situations. We shall make the same assumption in this paper. The effective bandwidth method [5] is used to find the bandwidth required to support the calls. For example, let us consider a voice source described by the two-states fluid flow model with three parameters: peak rate 32 kb/s, mean rate 11 kb/s and the mean burst period 0.352 seconds. Suppose the end-to-end cell loss probabilities ε is 10^{-6} and the buffers for the two queues are: K_1 = 8 kilobytes and K_2 = 4 kilobytes, respectively. The size of buffer K_2 is chosen to be smaller than K_1 so that we can balance the differences of queueing delay in using alternative and direct paths respectively. Using equation (2) in [5], the effective bandwidths for the voice call using direct path and alternative paths are 22 kb/s and 26.5 kb/s. Therefore, the alternative voice call requires 20% more bandwidth resource than the direct call. In general, the difference in bandwidth requirements between the direct call and alternative call depends on the traffic characteristics, sizes of buffer and the QoS requirement. We find that the differences in bandwidth increase with increasing burstiness of traffic and buffer sizes.

3. VP Routing Problem

Let us consider a network consisting of a set of nodes *N*, a set of links (or VPs) *L*, and a set of possible Origin-Destination (O-D) pairs *W*. We assume that there exists a unique direct link between any two O-D pairs. Associated with each O-D pair *w*, $w \in W$, is a set of possible paths. We assume that for any link l (l = 1,..., L) its capacity is a fixed value C_l. Thus, we have $L = N(N - 1)$ in a fully connected VP network.

There are *K* classes of traffic labelled k = 1,..., K entering the network. Each traffic has its own traffic characteristics but all have the same end-to-end QoS requirements. We can transform this information into effective bandwidth requirements.

A call of class *k* requires b_k^d units of bandwidth for the direct path. The same class *k* call requires b_k^a ($> b_k^d$)units of bandwidth for alternative path. Without loss of generality, we assume that $b_1^d \le b_2^d \le \ldots \le b_K^d$. The class *k* call arrives to O-D pair *w* according to a stationary Poisson process with a mean arrival rate λ_k^w. The call holding time for a class *k* call is assumed to be independent and exponentially distributed with mean $1/\mu_k$.

When a call arrives to the network, it will be either carried on a path or lost, depending on the routing policy being used. For each class *k* call carried on the network, we assume that it brings $r_k = b_k^d / \mu_k$ units of revenue to the network. In other words, we lose revenue r_k when the class k call is blocked. The objective of a routing scheme is to minimize the expected revenue loss of the network.

The network is described by a Markov chain with a finite number of states, where each state corresponds to the number of direct and alternatively routed VCs on the L VPs. The minimum revenue loss routing problem can be formulated as a Markov Decision Process (MDP). The MDP-based routing algorithms for multi-rate circuit-switched network are well-studied problems and there are many dynamic algorithms [4][9][15] in the literatures. However, those state-dependent routing policy may not be implementable due to the requirements of real-time computation and the amount of memory in the nodes.

In addition, recent papers by Hwang [10][11] show that the MDP-based routing algorithms only slightly outperform the LLR-based routing algorithms. Although [10][11] only cover the case of supporting homogeneous traffic class in VP-based ATM networks, this may give a hint on the performance of using MDP routing in multiple traffic case. Due to the simple implementation of LLR, we propose a modified LLR algorithm in the next section to handle the multi-class environment.

4. Dynamic Routing Algorithms in VP-based ATM networks

4.1. Least Loaded Routing

Least Loaded Routing (LLR) [18] is the most popular real-time adaptive routing scheme in traditional single-rate circuit-switched networks because of its simplicity. In [6] and [17], they extend the LLR algorithms to multi-rate circuit-switched network. In [8]and [11], a LLR algorithm is applied to VP-based ATM networks supporting homogeneous traffic.

In the following, we describe an extended version of the LLR algorithm to handle VP-based ATM networks with heterogeneous traffic. Suppose there are K types of traffic in a VP subnetwork and a class k call arrives at the source node. Let residual capacity $\hat{C}_l$ be the amount of unutilized capacity on link l, $l = 1,..., L$, at the instant the call arrives. When the call arrives, the residual capacity on route R is defined as $\hat{C}_R = \min\{\hat{C}_l, l \in R\}$. Let T_k be the trunk reservation threshold for class k calls, which is the amount of bandwidth reserved for 1-link direct calls. The purpose of trunk reservation is to avoid the instability problem in LLR algorithm as mentioned in [1]. In the later part of the paper, the choice of T_k will be discussed. The free bandwidth of a route is defined as $\hat{C}_R - T_k$, which is the bandwidth available for a 2-link class k alternative call. Let the candidate set for class k calls, S_k, be the set of 2-link alternative paths whose free bandwidth is larger than b_k^a, i.e., $S_k = \{R \mid \hat{C}_R - T_k \geq b_k^a\}$.

We give the LLR algorithm for VP-based ATM networks in the following.

LLR algorithm:

1. We first try to setup the connection along the direct link. If $\hat{C}_l \geq b_k^d$, accept the call in the direct link; otherwise go to step 2.
2. Select the 2-link alternative path S_k which has the largest free bandwidth.
3. If there are more than one such path, pick one randomly.
4. If the candidate set S_k is empty, block the call.

It has been shown that LLR is a very efficient algorithm for single-rate circuit-switched networks. In fact, AT&T's Real Time Network Routing [2] is an example of such an adaptive routing scheme. LLR tries to evenly distribute the loading of the network and this is highly desirable if only single-rate traffic is supported. However, this may not be the best strategy in a multi-rate environment.

For example, suppose we have two types of calls with bandwidth requirement of 1 unit (narrowband call) and 5 units (wideband call) in the network. We further assume that there are two alternative paths (path *A* and *B*) with free bandwidth of 4 and 5 units respectively. Suppose a new narrowband call arrives and we choose path *A* with LLR. Then both path *A* and *B* have free bandwidth of 4 units and any new wideband call will be rejected. On the other hand, if we pick path *B* to carry the narrowband call, path *A* and *B* will have free bandwidth of 5 and 3 units respectively. Instead of being blocked, a new wideband call can be carried on path *A*.

It is suggested in [6] that packing of narrowband calls (calls require relatively smaller bandwidth) should be employed on some links to leave room on other links for wideband calls. Siebenharr [21] proposes a dynamic algorithm known as Minimum Free Capacity Routing (MFCR) for VP-based ATM networks with several direct virtual paths connecting a node pair. The MFCR algorithm picks the direct VP with the smallest residual capacity among those VPs having enough residual capacity. Hence, MFCR tries to aggregate the unused bandwidth on one path. Although MFCR can achieve maximum packing, it leads to non-uniform distribution of traffic. It is because packing and uniform distribution of traffic are two conflicting objectives and there is a trade-off between them.

In this paper, we modify the MFCR to find 2-link alternative paths instead of 1-link direct paths as originally proposed in [21]. The modified MFCR algorithm is very similar to LLR except in step 2. Our MFCR picks the 2-link alternative route with the smallest free capacity in S_k. Gupta and Gandhi [6] proposes a modified LLR algorithm with packing to deal with this problem for circuit-switched network. In the following, we propose a real-time dynamic routing algorithm for VP-based ATM networks with heterogeneous traffic using both the packing and LLR concepts.

4.2. Proposed Routing Algorithm

Suppose there is a class k call destined for a particular O-D pair (e.g., from a to b in Fig. 1) but there is not enough capacity to carry the call in the direct link (VP 1 in Fig. 1). Let us further assume that the candidate set S_k of 2-link alternative routes is non-empty. The objective of our routing algorithm is to route the class k call over a suitable alternative path R with minimal effect on future class j ($j > k$) calls. It is because we would like to reserve space for future wideband call. For class K call, no packing is needed because it has the largest bandwidth requirement.

Let $y_R^k = \left(y_{R,K}^k, y_{R,K-1}^k, \ldots, y_{R,k+1}^k\right), k = 1, \ldots, K-1$ be a binary vector associated with route R for class k calls, where $y_{R,j}^k$ is given by

$$y_{R,j}^k = I\left(q\left(\frac{\hat{C}_R}{b_j^d}\right) - q\left(\frac{\hat{C}_R - b_k^a}{b_j^d}\right)\right), \quad j = k+1, \ldots, K, \quad R \in S_k \tag{2}$$

where

$$I(x) = \begin{cases} 1 \ , & x > 0 \\ 0 \ , & x = 0 \end{cases}$$

and $q(a/b)$ is the quotient of a divided by b.

Note that $q\left(\hat{C}_R / b_j^d\right)$ is the maximum number of class j (>k) direct calls that can be carried on route R. Hence, $y_{R,j}^k$ is an indicator value to show that whether there is a decrease in the maximum number of class j direct call that can be accepted on route R after a class k call is alternatively routed on R. The vector y_R^k shows that how the other class j direct call will be affected if a class k call is alternatively routed on R. For example, suppose we have four different classes of calls in a network and an arriving class 2 call is to be considered for alternative routing on route R_1. Further, let the vector $y_{R_1}^2$ = (1, 0), which means that there is a decrease in the maximum of number of class 4 direct calls but no decrease for class 3 direct calls, if the class 2 call is alternatively routed on R_1.

In order to compare different y_R^k associated with different alternative routes $R \in S_k$, we assign a route weight z_R^k to each y_R^k as follows:

$$z_R^k = \sum_{j = k+1}^{K} y_{R,j}^k \, r_j, \qquad k = 1, \ldots, K-1 \tag{3}$$

where $r_j = b_j^d / \mu_j$ is the reward generated by carrying a class *j* call. Note that it is the responsibility of the network operator to find the most efficient path to carry the call. Thus, we assume that the user should pay the same amount for using either direct path or alternative paths.

In essence, we would like to minimize the effect of carrying a class *k* call on future wideband calls ($j > k$) on the same path. Consequently, we assign the weighting factor for class *j* calls according to the reward generated by carrying class *j* calls to reflect this intuitive reasoning. We assume that the path *R* with the smallest z_R^k should give the best possible packing among the alternative paths in S_k.

We summarize our proposed routing policy in the following.

<u>Proposed routing algorithm:</u>

1. A class *k* call is first offered to direct route *l* if the unutilized bandwidth on the direct route $\hat{C}_l \geq b_k^d$.
2. If the direct route cannot carry the call, the call is then offered to alternative paths in S_k.

   (a) If $k = K$, select a 2-link alternative path with the largest free bandwidth in S_k. If there are more than one such paths, then pick one randomly.

   (b) If $k < K$, select a 2-link alternative route *R* with the smallest value of route weight

z_R^k in S_k. In case of ties (two or more routes having the same z_R^k), the call is offered to a candidate route that has the largest free bandwidth. If there are more than one such paths, then pick one randomly.

3. If the candidate set S_k is empty, block the call.

Example: Consider a VP subnetwork supporting three classes of calls with bandwidth requirement of $b_1^d = 1$, $b_1^a = 1.3$, $b_2^d = 5$, $b_2^a = 7$, $b_3^d = 10$, $b_3^a = 12$. Let $\mu_1 = \mu_2 = \mu_3 = 1$. Suppose that a class 1 call arrives but it cannot be carried in the direct link. Further, assume that there are four candidate routes in the set $S_k = \{R_1, R_2, R_3, R_4\}$ with free bandwidth $\hat{C}_{R_1} = 36$, $\hat{C}_{R_2} = 37$, $\hat{C}_{R_3} = 39$, $\hat{C}_{R_4} = 40$. The results of the calculations are summarized in Table 1. The alternative path is R_4 using the LLR policy, while the MFCR algorithm would pick R_1. According to our proposed algorithm, the class 1 call should be alternatively routed to R_3 because it has the smallest value of z_R^1 and the largest free bandwidth among the candidate routes in S_k.

Alternatively routed calls consume more resources on each of the two links than the resources required by a direct call. Therefore, alternative routing of narrowband calls should be preferred over that for wideband calls. To achieve this aim, we can set different values of trunk reservation threshold T_k for different classes of calls. In addition, [6] and [17] suggested that this may either improve the efficiency of the routing algorithms or the fairness of bandwidth utilization between different classes of calls. Since we would like to reduce the chance of alternative routing of wideband calls, we propose that the trunk reservation thresholds should be chosen such that $T_1 \leq T_2 \leq ... \leq T_K$. In addition, the value of T_k should be an integer multiple of b_k^d.

5. Numerical Studies

In this section, the performance of several dynamic routing algorithms are compared using simulation. Although the VP-based ATM network model evaluated supports heterogeneous traffic, we assume that the different traffic sources all have the same end-to-end QoS requirement (e.g., cell loss probability). Traffic sources are represented by their effective bandwidths as mentioned in Sections 2 & 3. So each class k call is described by its effective bandwidth requirements for direct VP, b_k^d, and for alternative route, b_k^a, respectively.

We consider a fully connected and symmetric network which has $N = 6$ nodes. Each VP has capacity $C = 100$ bandwidth units. We assume that there are two types of traffic classes: $b_1^d = 1$ unit, $b_1^a = 1.3$ units, $\mu_1 = 1$; $b_2^d = 5$ units, $b_2^a = 7$ units, $\mu_2 = 0.5$. It is found in [13] that the optimal trunk reservation problem in traditional circuit-switched networks can be formulated as a Markov decision process. However, the searching of the optimal values in multi-rate case is very difficult due to the intensive computation involved. To simplify the problem, the trunk reservation thresholds are set to the same values for all the schemes here. The trunk reservation thresholds for two classes are $T_1 = 15$ units and $T_2 = 30$ units respectively. For each set of parameters, simulation is repeated with 10 independent runs. Each run corresponds to approximately 10^5 call arrivals to the system. For each run, the initial 10% of the simulation is discarded to account for transient effects.

We consider five different routing algorithms in this numerical study, namely, direct routing, LLR, MFCR, Gupta's algorithm [6] and our proposed algorithm. Direct routing means that each call is either carried on the direct link or blocked, and no alternative routing is allowed.

Gupta's original algorithm is designed for multi-rate circuit switched network. Nevertheless, we can apply it to VP-based ATM networks with slight modifications to take into account the difference in bandwidth required by the direct and alternative routes.

In Section 4, we mentioned that the desired routing algorithm should minimize the expected revenue loss. Let β_k be the blocking probability of class *k* calls. For each class *k* call being blocked in the network, we assume that it loses $r_k = b_k^d / \mu_k$ units of revenue. Then the expected revenue *E*(loss) is given by

$$E\,(\text{loss}) = \sum_{k=1}^{K} \left(b_k^d / \mu_k \right) \lambda_k \beta_k \tag{4}$$

We compare the expected revenue loss of different algorithms in Table 2. The traffic load is varied from low (70%) to high (100%) and a 40% overload case is also tested. The performance of direct routing is used as our reference. The relative improvements of different routing schemes over direct routing are reported in Table 2. In the lightly-loaded to moderately-loaded region, there are significant reductions in the average revenue loss using alternative routing. It also shows that the idea of packing can improve the performance of LLR-based algorithms. In the highly loaded region, the probability of alternative routing is very small. Therefore, there is not much improvement using alternative paths and the performance of the four schemes are very close to each other. However, our proposed algorithm in general performs slightly better than the others in this numerical example.

In the above example, we test the algorithms with only two classes of call ($K = 2$). We now examine the performance of the algorithms with a larger set of call classes. Suppose we have four classes of calls in an ATM network and the traffic characteristics of the four classes of call are shown in Table 3. Two different traffic loading situations are tested and their performances are summarized in Tables 4. The numerical results show similar conclusions as in the two-traffic case. All the dynamic routing schemes outperform the direct routing and show approximately the same performance. This agrees with the results shown in [11] which indicates that the performance differences of various routing algorithms (LLR and MDP) are very small.

6. Conclusion

We have discussed the dynamic routing problem in VP-based ATM networks. We propose a dynamic routing algorithm based on LLR with packing and compare its performance with other routing algorithms. Our routing algorithm uses packing to find a smaller candidate set of alternative paths and then applies LLR routing to this set.

All the routing algorithms discussed, only the effective bandwidths of various calls are used but the information of arrival rates λ_k and mean call holding time $1/\mu_k$ are ignored in the routing decision. Although narrowband calls use a smaller amount of bandwidth, they may occupy the channel for a relatively long time. This may lead to high blocking probability for future calls. Hence, the arrival rates and the call holding time information should also be considered in the decision process in future studies.

Moreover, it is suggested in [20] that the choice of admission control method is more important than the choice of routing algorithm. As a result, more accurate methods to compute the effective bandwidths are required. One simple measurement-based algorithm to estimate the effective bandwidth is reported in [3].

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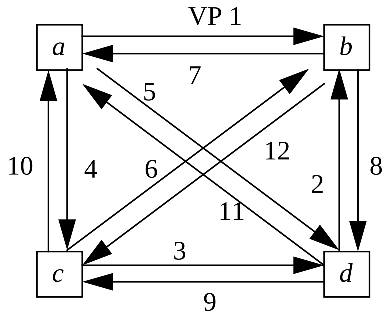

Fig. 1. A 4-node VP subnetwork

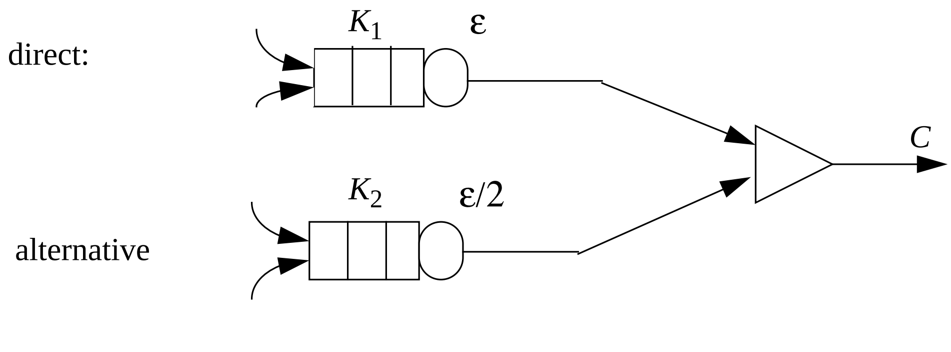

Fig. 2. Network Model

route R	free capacity $\hat{C}_R$	indicator vector $y_R^1 = \left(y_{R,3}^1, y_{R,2}^1\right)$	route weight z_R^1
R_1	36	(0, 1)	5
R_2	37	(0, 0)	0
R_3	39	(0, 0)	0
R_4	40	(1, 1)	15

Table 1: Routing computation in our proposed algorithm

Arrival Rate (λ_1, λ_2)	Percentage reduction in average revenue loss over that using direct routing			
	LLR	MFCR	Gupta	Proposed algorithm
(50, 2)	38.05%	44.03%	47.53%	48.12%
(50, 3)	15.52%	16.54%	17.48%	18.64%
(50, 4)	4.78%	4.97%	5.20%	6.13%
(50, 5)	1.35%	1.58%	1.43%	1.75%
(30, 5)	9.30%	10.06%	8.99%	10.22%
(40, 5)	5.36%	5.06%	5.06%	5.37%
(45, 5)	3.74%	3.74%	3.53%	4.17%
(70, 7)	0.06%	0.10%	0.12%	0.15%

Table 2: Relative performance of different routing algorithms

class k	b_k^d (units)	b_k^a (units)	μ_k	trunk reservation T_k (units)	λ_k	
					Data set I (81% load)	Data set II (98% load)
1	1	1.3	1	20	20	26.667
2	5	7	1	25	4	5
3	10	13	0.5	30	1	1.267
4	20	23	0.25	40	0.267	0.267

Table 3: Traffic characteristics

data set	Percentage reduction in average revenue loss over that using direct routing			
	LLR	MFCR	Gupta	Proposed algorithm
I	4.11%	3.33%	4.16%	5.01%
II	1.78%	1.29%	1.64%	2.10%

Table 4: Relative performance of different routing algorithms