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Bifurcated-*M* routing for multi-point videoconferencing

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Abstract

Dynamic routing, if properly designed, can increase the throughput of a network. In this paper, we formulate a traffic model for multi-point videoconferencing in a VP-based ATM network and derive the link level and the conference level blocking probabilities for Fixed Routing, "Maximum Free Circuit" Routing (or M Routing) and the "Bifurcated-M Routing". The traffic bifurcation principle can also be applied to MTB, M^2, or other routing schemes to provide additional improvements.

Keywords: Teleconferencing network; Dynamic routing; Traffic model

1. Introduction

Among the many potential broadband video services for business applications, videoconferencing has been regarded as one of the most welcomed service. In videoconferencing system, good quality compressed video requires much larger bandwidth than the audio and thus careful allocation of bandwidth resources to the video traffic in the network is essential.

There are various ways to show the video images of the conferees at different sites and that leads to many videoconferencing system designs. The single camera system [1] is for connecting two conference studios. Split screen systems, voice switched systems and continuous presence systems are the other possible types. Virtual space teleconference [2] is designed to connect multiple conference sites to provide continuous visual presence of all sites and conveys the spatial relationship between participants. Ferguson and Mason [3] studied a videoconference network design problem for a multipoint conference. The traffic engineering aspects of videoconferencing were reported in Ref. [4], assuming all conferences involve only two studios. In addition, there are many other related works focusing on the Variable Bit Rate (VBR) video source traffic model and statistic multiplexing [7].

Videoconferencing solutions and standards have existed for some time in N-ISDN environment [10]. New solutions are emerging for packet-switched networks, such as Asynchronous Transfer Mode (ATM) and Internet networks and a series of standards are being developed [19]. In this paper, we assume that the videoconferencing service is offered on a Virtual-Path (VP)-based ATM network. We study the dynamic routing at the connection, or call level and model the ATM network as a multirate loss network. This modeling is supported by the concept of "effective bandwidth" which encapsulates all cell-level behavior of multiplexing, buffering and related quality of service (QoS) issues. This separation of the call level from the cell level is essential for the tractability of high-level design problem [20].

With the advent of stored program control switching network and the installation of out-of-band signaling, it is possible to implement sophisticated dynamic routing schemes through the exchange of link status information during call set-up. With proper design, dynamic routing can reduce the blocking of calls. Previous dynamic routing studies were focused on the traditional telephone networks and many adaptive routing schemes [16] such as AT&Ts *Real-Time Network Routing* (RTNR) [13], Krupp's *Random Alternate Routing* [14], M and M^2 scheme [11] and *MTB* scheme [12] were proposed. Recently, point-to-point adaptive routing algorithms have also been proposed for homogeneous VP-based ATM networks [21,22]. However, to the best of our knowledge, there is no reported research on dynamic routing for multipoint videoconferencing in ATM network on the call level.

This paper focuses on the analysis of three routing schemes for multipoint videoconferencing in VP-based ATM networks. Section 2 presents the videoconferencing traffic characteristics and formulates the traffic model. We

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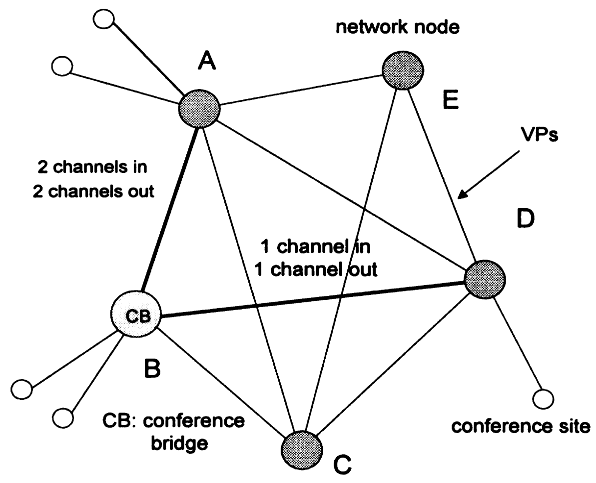

Fig. 1. Conference under selectable media conferencing mode.

use the traffic decomposition principle to derive the relation between the link level and the conference level blocking probabilities. In Section 3, we analyze the performance of the videoconferencing network under fixed routing. In Section 4, we study the *M* routing scheme in videoconferencing network. In Section 5, *Bifurcated-M* routing is proposed. The conference call blocking probability for fully connected networks is derived. Section 6 discusses the analytical results and we conclude this paper in Section 7.

2. Conference traffic model

Consider a Virtual Path (VP)-based ATM network for the provisioning of videoconferencing service. A VP is a logical connection between a node pair and each VP contains a bundle of Virtual Circuits (VCs). The use of VP can reduce call-setup delays, simplify routing and node processing. Usually, each VP carries one type of traffic with a specific QoS requirement.

For the purpose of analysis, let us assume that the topology of VP sub-network carrying the videoconferences is an *N*-node fully connected network, as commonly assumed in homogeneous VP-based ATM networks [21–22]. This is a reasonable assumption because the connectivity of the backbone ATM network is usually very high. The routing rules studied in this paper, however, remains general and can be used in any mesh topology. In addition, we assume that the bandwidth allocated for each VP remain fixed for purposes of routing VCs, as the time scale of interest is significantly smaller than those involved with the dynamics of VP subnetwork [20–22]. From now on, we shall refer the VP subnetwork as a *conference network* and a VP as a *link*. The network under consideration can then be viewed as a multirate loss network.

Two types of videoconferencing are considered in this paper [5,8]. For a *common media conference*, each conference requires a *conference bridge* for performing the functions of collecting the video and audio signals from the conference sites, mixing the audio signals, composing the common-media video signal and distributing the resulting video and audio signals to all conference sites. For a *selectable media conference*, each conference site can choose a different composite video. Both types of videoconferences require all sites to send their video streams to the conference bridge.

The main functions of the conference bridge are admission control, session control and stream manipulation. Admission control involves collecting information such as bandwidth resources required by the conferees at different sites, checking the current bandwidth resources in the network and deciding whether to admit the call or not. Session control includes call set-up (such as participant identification, authentication and capability exchange, etc.), adding and dropping participants, call monitoring for floor control and selecting video and audio for individual sites. Stream manipulation includes audio mixing, video composition, transcoding and distribution. To minimize the bandwidth demand of a conference, we select the node with the maximum number of conference sites attached to be the conference bridge node. We assume, for simplicity, that all videos are transmitted in the same format. That is, each video stream requires about the same bandwidth and occupies one channel on a link. Hence for the subsequent discussion, channel will be used as a unit of bandwidth.

As an example, Fig. 1 shows the channel requirements of five sites conferencing call. There are two sites at nodes *A* and *B* and one site at node *D*. If we put the conference bridge at node *B*, thus two channels and one channel are needed on links $A \rightarrow B$ and $D \rightarrow B$, respectively, for inbound traffic. For outbound traffic, two channels and one channel are needed on links $B \rightarrow A$ and $B \rightarrow D$, respectively, for selectable media conference, and one channel on both links for common media conference. Variations such as the outbound traffic can go through different paths depending on the network states are possible. However, we will restrict our study to the selectable media conference and not consider these variations. The numbers of inbound and outbound channels are equal and only duplex channels need to be considered. For simplicity, a channel in the following means a duplex channel.

Let *M* be the maximum number of sites allowed in a conference. Then, the conference calls can be classified into $M - 1$ types, where type $s(s = 2, 3, \ldots, M)$ is the *s*-site call. Let the arrivals of these conference types be independent Poisson processes with rate $\gamma_2, \gamma_3, \ldots, \gamma_M$. The conference duration is assumed to be exponential distributed with mean $1/\mu$. Let each unidirectional link has a capacity equal to that of *F* video channels. In addition, we assume that the overflowed traffic streams are independent Poisson processes in alternate path routing as in Refs. [11–14].

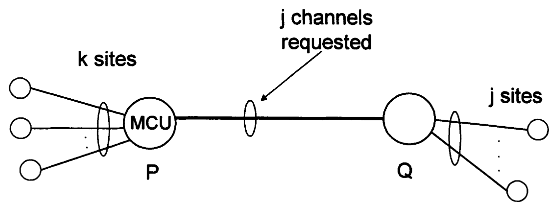

Fig. 2. Channel request on link PQ.

2.1. Traffic decomposition

A properly designed videoconferencing service should have a low blocking probability (for example $<10^{-3}$). At low blocking conditions, the link occupancies can be assumed to be independent [9]. As different numbers of channels are required on different links for a conference, we can decompose a type s call into a number of channel requests on different links.

Without loss of generality, consider the channel occupancy on a particular link PQ as shown in Fig. 2.

Let $\tilde{K}_1, \tilde{K}_2, \ldots, \tilde{K}_N$ be the number of sites located at nodes 1,2,…,N. For an s-site conference, let $\tilde{\mathbf{K}}(s) \equiv (\tilde{K}_1, \tilde{K}_2, \ldots, \tilde{K}_N)$ with $\tilde{K}_1 + \tilde{K}_{2,} + \ldots + \tilde{K}_N = s$. Let $\mathbf{k} = (k_1, k_2, \ldots, k_N)$ where the k_is are non-negative integers. Under the assumption that all sites have equal community interest on all the others, we have

$$P[\tilde{\mathbf{K}}(s) = \mathbf{k}] = \begin{cases} \binom{s}{k_1, k_2, \ldots, k_N} \left(\frac{1}{N}\right)^s & \text{for all } \mathbf{k} \text{ with } \sum_{j=1}^{N} k_j = s \\ 0 & \text{otherwise} \end{cases}. \tag{1}$$

Let $k_{\max} \equiv \max(k_1, k_2, \ldots, k_N)$ and let $\psi_{PQ}(s, j, k_{\max}, \alpha)$ be a composite event defined as *{In a s-site conference, node P and α other nodes all have $k_{\max}$ sites attached; node Q has j-sites attached}*. Therefore

$$P[\psi_{PQ}(s, j, k_{\max}, \alpha)] = \sum_{k \in \Phi_1} P[\tilde{\mathbf{K}}(s) = \mathbf{k}]$$

where

$$\Phi_1 = \{\mathbf{k} | \sum_{i=1}^{N} k_i = s,\ k_q = j,\ k_P$$
$$= k_{\max} \text{ and } \alpha \text{ other } k_i s \text{ all equal to } k_{\max}\}$$

Let $\psi_{PQ}(s, j)$ be the event that *node P is chosen as the conference bridge node for an s-site conference and node Q has j-sites attached*. Then

$$P[\psi_{PQ}(s, j)] = \sum_{k=j}^{s-j} \sum_{\alpha=0}^{\lfloor s/k \rfloor - 1} \frac{1}{\alpha + 1} P[\psi_{PQ}(s, j, k, \alpha)]$$

$$j = 1, 2, \ldots, \left\lfloor \frac{s}{2} \right\rfloor$$

where the factor $1/(\alpha + 1)$ is the probability that node P is chosen as the conference bridge node from those $\alpha + 1$ nodes all having the same maximum number of sites attached.

Then the probability of the event $\psi(s, j)$ that an s-site conference call requires j channels on link PQ is given by

$$P[\psi(s, j)] = P[\psi_{PQ}(s, j)] + P[\psi_{QP}(s, j)] = 2P[\psi_{PQ}(s, j)]$$

Let λ_j ($j = 1, 2, \ldots, E$) be the arrival rate of requests that requires j channels on a link. By adding the contributions from all conference types, we have

$$\lambda_j = \sum_{s=2j}^{M} (\gamma_s P[\psi(s, j)]) \qquad j = 1, 2, \ldots, \left\lfloor \frac{M}{2} \right\rfloor \tag{2}$$

Borrowing from the multirate loss network terminology [6], hereafter we denote a conference call using a specific link L as a class-k call on link L when that conference requires exactly k channels on link L. In other words, a class-k call is just a k-channel request.

2.2. Conference level blocking probability

A conference call is blocked if one of the involved links does not have the requested number of channels. Therefore, the call blocking probability for an s-site conference can be obtained by the facility-independence approximation [9] as

$$B_C(s) = 1 - \sum_{\Phi_2} \left[\prod_{\substack{j=1 \\ j \neq P}}^{N} (1 - B_L(k_j)) P[\tilde{\mathbf{K}}(s) = \mathbf{k}] \right] \tag{3}$$

where $B_L(k_j)$ is the link level blocking probability for class-k_j calls and is given by Eqs. (9), (14) or (16) depending on the routing rules used, $\Phi_2 = \{\mathbf{k} | \sum_{l=1}^{N} k_j = s\}$, $P[\tilde{\mathbf{K}}(s) = \mathbf{k}]$ is given by Eq. (1) and $B_L(0) = 0$ for obvious reason.

3. Fixed routing

With fixed routing, all video streams are sent through the direct links. If any direct link does not have the requested number of video channels, the conference is blocked.

By decomposing the videoconferencing traffic onto individual links, we can describe the link loading by a state vector $\mathbf{n} = (n_1, n_2, \ldots, n_E)$ where n_i is the number of conferences on the link that are occupying i channels each and E is the maximum number of channels requested on a link. Since the total number of occupied channels on a link cannot exceed the link capacity F, the set of admissible states on the link, Ω, is given by

$$\Omega = \{\mathbf{n} | \sum_{j=1}^{E} j n_j \leq F\} \tag{4}$$

The equilibrium distribution of the state probability $P[\mathbf{n}]$ is given by a product form solution [17]:

$$P[\mathbf{n}] = \begin{cases} \dfrac{1}{G}\dfrac{\rho_1^{n_1}}{n_1!}\dfrac{\rho_2^{n_2}}{n_2!}\cdots\dfrac{\rho_E^{n_E}}{n_E!} & \mathbf{n} \in \Omega \\ 0 & \text{otherwise} \end{cases}. \quad (5)$$

where

$$\rho_i = \lambda_i/\mu$$

$$G = \sum_{n\in\Omega}\prod_{i=1}^{E}\frac{\rho_i^{n_i}}{n_i!}$$

With that, the link channel occupancy Y has distribution

$$P[Y = i] = \sum_{n\in\Omega(i)} P[\mathbf{n}] \quad (6)$$

where

$$\Omega(i) = \{\mathbf{n}|\sum_{j=1}^{E} jn_j = i\} \qquad 0 \le i \le F \quad (7)$$

Let

$$G(i) = \sum_{n\in\Omega(i)}\prod_{j=1}^{E}\frac{\rho_j^{n_j}}{n_j!} \quad (8)$$

Substituting Eqs. (5) and (8) into Eq. (6), we have

$$P[Y = i] = \frac{G(i)}{\sum_{j=0}^{F} G(j)}$$

Therefore, under fixed routing, the link level blocking probability $B_L^{(F)}(k)$ for class-k calls is given by

$$B_L^{(F)}(k) = P[Y > F - k] = \sum_{i=F-k+1}^{F} P[Y = i] \quad (9)$$

Substituting Eq. (9) into (3), the conference level blocking probability for fixed routing can be obtained.

4. *M* Routing

In this section, we derive the link level blocking probability when the *maximum residual bandwidth* (M) [12] routing is used and the complete sharing of bandwidth resources among the E classes of traffic is assumed. M routing is a state dependent alternate path routing which can increase the network throughput by directing an overflowed call to an alternate path that has the maximum residual bandwidth. A path q in the network is specified by a link set L_q. Each node pair has a direct path and we consider only two-hop alternate path, i.e. $|L_q| = 2$. The total number of such two-link alternate paths, denoted as m, is equal to *N-2* for an N-node fully connected network.

The residual bandwidth $R(q)$ of path q is defined by

$$R(q) = \min_{j\in l_q}\left(F - \sum_{i=1}^{E}\mathrm{in}_i^{(j)}\right)$$

where the minimization is performed for all j in the set L_q. Therefore, the occupancy of path q, denoted as x, is simply

$$x = F - R(q)$$

In case two or more paths have the same R-value, the overflowed call is routed to one of the candidate paths at random. The set of *class-k* direct and alternate call blocking states, $\Omega_k^{(B)}$, is given by

$$\Omega_k^{(B)} = \{\mathbf{n}|\mathbf{n} \in \Omega, \mathbf{n} + \mathbf{e}_k \notin \Omega\}$$

where set Ω is defined by Eq. (4) and $\mathbf{e}_k$ is a vector of size E with a '1' at the kth position and zero elsewhere. The probability that a link has occupancy i, denoted as $\pi(i)$, is

$$\pi(i) = \sum_{n\in\Omega(i)} P[\mathbf{n}]$$

where $P[\mathbf{n}]$ is the link state probability and $\Omega(i)$ is defined in Ref. [7].

Let X be a random variable denoting the occupancy of an alternate path, then

$$U_k(x) \equiv P[X = x|\text{class} - k\text{admissible}]$$

$$= \begin{cases} [\pi(0)]^2 & x = 0 \\ 2\pi(x)(\sum_{i=0}^{x-1}\pi(i)) + [\pi(x)]^2 & 0 \quad lt; x \le F - k \end{cases}.$$

Also, let $V(x) \equiv P[X > x]$. Then

$$V(x) = 1 - (\sum_{i=0}^{x}\sum_{n\in\Omega(i)} P_L(\mathbf{n}))^2$$

Consider a particular direct link AC. If the residual bandwidth of AC is less than k, then a *class-k* call will be blocked on the link AC and gets routed randomly to one of the paths with the largest residual bandwidth, say to path ABC. Let there be a total of α such paths. Given that path ABC has occupancy x and is class-k admissible, the probability that $\alpha - 1$ other alternate paths all have the same occupancy and are class-k admissible, and each of the remaining $m - \alpha$ alternate paths has occupancy larger than x, denoted as $f_k(\alpha|x)$, is given by

$$f_k(\alpha|x) = \binom{m-1}{\alpha-1} U_k(x)^{\alpha-1} V(x)^{m-\alpha}$$

using the link independence assumption.

Given that the class-k admissible alternate path ABC has occupancy x, the overflowed *class-k* traffic rate from *AC to*

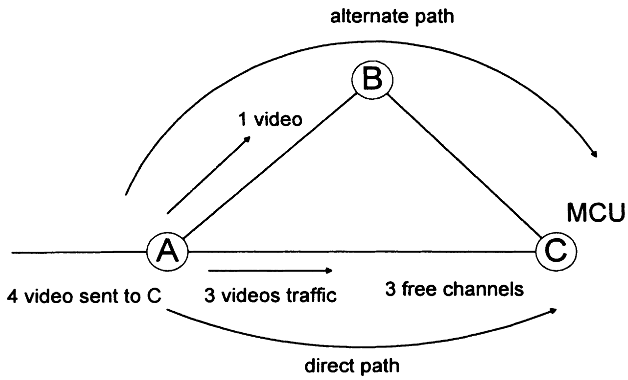

Fig. 3. An example to illustrate the Bifurcated Routing scheme.

ABC, denoted by $h_k(x)$, is given by

$$h_k(x) = \sum_{\alpha=1}^{m} \frac{\lambda_k B_L(k)}{\alpha} f_k(\alpha/x)$$

$$= \lambda_k B_L(k) \frac{[U_k(x) + V(x)]^m - V(x)^m}{m b_k(x)}$$

where

$$B_L(k) = \sum_{n \in \Omega_k^{(B)}} P[\mathbf{n}] \tag{10}$$

Therefore, given that link *AB* is in state $\mathbf{n} \in \Omega/\Omega_k^{(B)}$, the total overflowed class-*k* traffic, $A_k(\boldsymbol{n})$, obtained by removing the conditioning on the second link, is given by

$$A_k(\mathbf{n}) = 2m \sum_{j=0}^{F-1-k} h_k(\max[g(\mathbf{n}), j]) \cdot \pi(j) \tag{11}$$

where $g(\boldsymbol{n})$ is the occupancy at state $\boldsymbol{n}$, i.e.

$$g(\mathbf{n}) = \sum_{j=1}^{E} j n_j$$

At state $\mathbf{n}$, the *class-k* call arrival rate including direct and overflowed traffic is

$$\Lambda_k(\mathbf{n}) = \begin{cases} \lambda_k + A_k(\mathbf{n}) & n \in \Omega/\Omega_k^{(B)} \\ 0 & \mathbf{n} \in \Omega_k^{(B)} \end{cases}. \tag{12}$$

Therefore, for state $\mathbf{n} \in \Omega$, the global balance equation is given by

$$\sum_{k=1}^{E} ((n_k + 1)\mu P[\mathbf{n} + \mathbf{e}_k] + \Lambda_k(\mathbf{n} - \mathbf{e}_k) P[\mathbf{n} - \mathbf{e}_k])$$

$$= \sum_{k=1}^{E} ([\Lambda_k(\mathbf{n}) + n_k \mu]) P[\mathbf{n}] \tag{13}$$

Let $\tilde{\Lambda}$ denotes the set of $\Lambda_k(\mathbf{n})$ and $\tilde{P}$ denotes the set of $P(\boldsymbol{n})$. Then Eqs. (12) and (13) can be expressed in the fixed point model form Ref. [11]: $\tilde{P} = f_1(\tilde{\Lambda})$ *and* $\tilde{\Lambda} = f_2(\tilde{P})$. The $P[\mathbf{n}]$s can be computed by the successive over-relaxation method [15] with the set of alternate traffic rates obtained from Eq. (11) in each iteration. Then, the link level blocking probability for *M* routing can be computed as

$$B_L^{(M)}(k) = B_L(k)[1 - (1 - B_L(k))^2]^m \tag{14}$$

Finally, substitute Eq. (14) into (3), the conference level blocking probability for *M* routing can be obtained.

5. Bifurcated-*M* routing

In the last section, we used the term "class-*k*" call to denote the request of *k* channels for *k* video streams on a link. Obviously, some of the *k* video streams can be sent to the conference bridge via an alternate path. This motivates us to the design of a modified *M* routing scheme called Bifurcated-*M* Routing. The bifurcation principle can also be applied to other routings to give Bifurcated M^2 routing, Bifurcated *MTB* routing, etc. for multi-rate traffic. We will focus, however, only on the study of Bifurcated-*M* routing in this paper.

In Bifurcated-*M* routing scheme, the class-*k* overflowed traffic is divided into two parts: the class-*u* traffic and the class-*v* traffic, where, $u + v = k$. Refer to Fig. 3, let there be a class-*k* call to link *AC*. Let link *AC* has *u* free channels where $u < v$. Then Bifurcated-*M* routing stipulates that link AC will carry the class-*u* traffic and an alternate path, say path ABC, will carry the remaining part, i.e. the class-*v* traffic.

Bifurcated-*M* routing offers two advantages over *M* routing. First, the Bifurcated-*M* routing can make full use of the direct link under all conditions. Second, a *v*-channel alternate path is always easier to be found than a *k*-channel one for $v < k$. Hence the blocking probability is expected to be lower and this will be verified in Section 6.

The analysis of Bifurcated-*M* routing for multipoint conferences is similar to that of *M* routing. Let the class-*v* admissible alternate path ABC has occupancy *x*. Then the class-*v* traffic that overflows from link AC to path ABC has rate $\varphi_v(x)$ given by

$$\varphi_v(x) = \sum_{\alpha=1}^{m} \frac{T_A(v)}{\alpha} f_v(\alpha|x)$$

where $f_v(\alpha|x)$ is given by the same representation in last section and $T_A(v)$ is the total alternate class-*v* traffic, which is given by

$$T_A(v) = \begin{cases} \lambda_v B_L(v) & v = E \\ \lambda_v B_L(v) + \sum_{i=v+1}^{E} \lambda_i B_L(i) \Big(\sum_{n \in \Omega(F-i+v)} P[\mathbf{n}] \Big) & 1 \le v \le E-1 \end{cases}. \tag{15}$$

where $B_L(v)$ is the direct and alternate path blocking probability derived in Eq. (10), λ_v is the rate of class-*v* traffic derived in Eq. (2), and $P[\mathbf{n}]$ is the link state probability to be derived.

In Eq. (15), we have assumed that all the overflowed bifurcated traffic streams from all the conference sites are independent Poisson processes, so that their sum is also a Poisson process. This is the same assumption used in all fixed points models and has been verified to be very accurate on many occasions [6,12].

Following the derivation of the last section, we have the rate $\varphi_v(x)$ of class-v traffic that overflows from link AC to path ABC given by

$$\varphi_v(x) = T_A(v)\frac{[U_v(x) + V(x)]^m - V(x)^m}{mU_v(x)}$$

Given that link AB is in state $n \in \Omega/\Omega_k^{(B)}$, the total overflowed class-k traffic, denoted as $A_v^{(BM)}(\mathbf{n})$, is given by

$$A_v^{(BM)}(\mathbf{n}) = 2m \sum_{j=0}^{F-1-k} \varphi_v(\max[g(\mathbf{n}), j])\pi(j)$$

Therefore, at state $\mathbf{n}$, the total class-k traffic arrival rate $\Lambda_k(\mathbf{n})$, including direct and overflowed traffic, is given by

$$\Lambda_k(\mathbf{n}) = \begin{cases} \lambda_k + A_k^{(BM)}(\mathbf{n}) + \sum_{i=k+1}^{E} \lambda_i\Big(\sum_{n\in\Omega(F-i+1)} P_L[\mathbf{n}]\Big) & k = 1,2,\ldots,E-1 \text{ and } \mathbf{n} \in \Omega/\Omega_k^{(B)} \\ \lambda_E + A_E^{(BM)}(\mathbf{n}) & k = E \text{ and } \mathbf{n} \in \Omega/\Omega_k^{(B)} \\ 0 & \mathbf{n} \in \Omega_k^{(B)} \end{cases}.$$

We can obtain, for state $\mathbf{n} \in \Omega$, the global balance equation just like Eq. (13). Using the same iteration procedure, we can obtain the state probabilities $P[\mathbf{n}]$s. Substitute the $P[\mathbf{n}]$s into Eq. (10), the link blocking probability $B_L(k)$ is obtained.

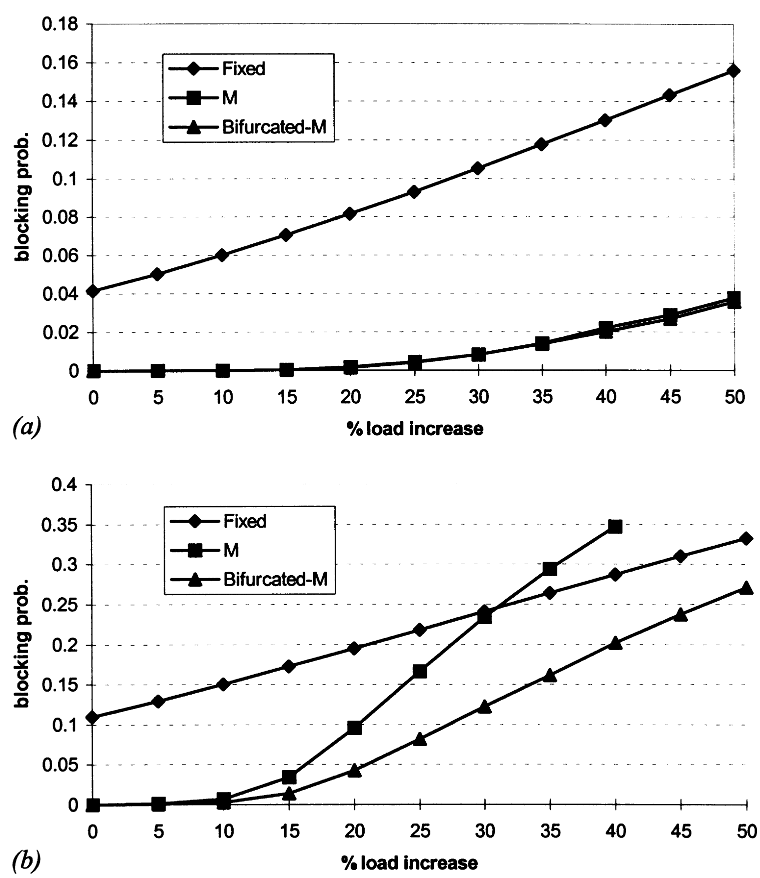

Fig. 4. Link blocking for fixed, M and Bifurcated-M routings.

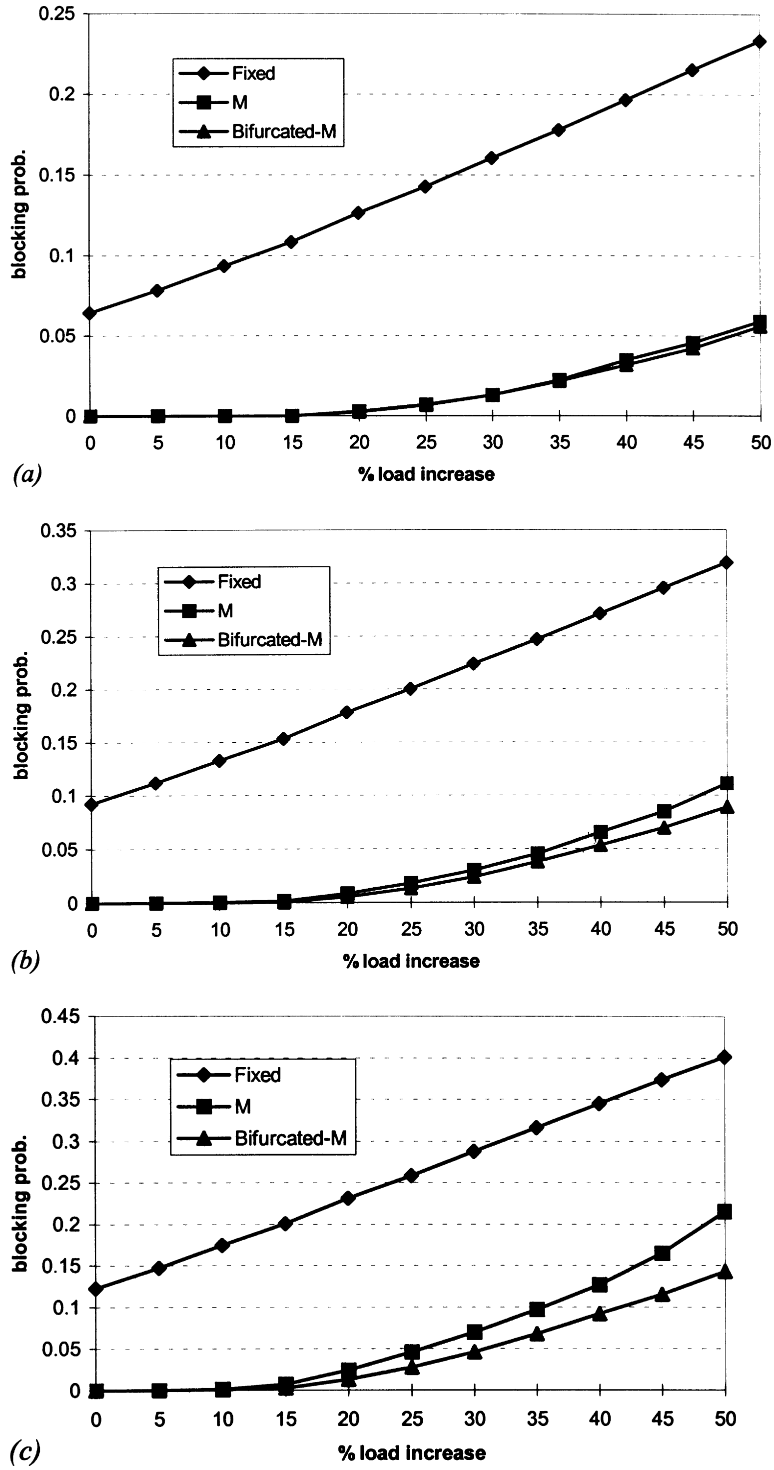

Fig. 5. Comparison of conference level call blocking probabilities.

To derive the class-k traffic blocking probability $B_L^{(BM)}(k)$ under Bifurcated-M routing rule, we define two events as

$$E_1 = \{\text{the direct link is full and the class} - k \text{ call is blocked on all the alternate paths}\}$$

$$E_2 = \{\text{the direct link is not full and all the bifurcated alternate routings fail for the class} - k\text{call}\}$$

The probabilities of these two events are

$$P[E_1] = [1 - (1 - B_L(k))^2]^m \left(\sum_{n \in \Omega(F)} P[\mathbf{n}] \right)$$

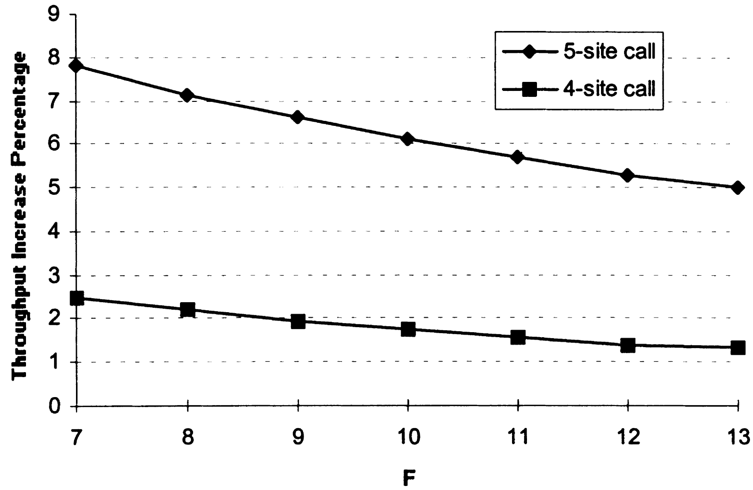

Fig. 6. Throughput improvement of Bifurcated-M routing over M routing.

$$P[E_2] = \sum_{i=F-k+1}^{F-1} \left(\begin{array}{c} P[\text{the direct link is in occupancy state } i]\cdot \\ P[\text{class} - (i - F + k) \text{ traffic stream is blocked in all alternate paths}] \end{array} \right)$$

$$= \sum_{i=F-k+1}^{F-1} \left(\left(\sum_{n \in \Omega(i)} P[\mathbf{n}] \right) \cdot [1 - (1 - B_L(i - F + k))^2]^m \right)$$

$P[E_1 \cup E_2]$ is the probability that a class-k call is blocked under Bifurcated-M routing rule since $E1$ and $E2$ are disjoint, we have

$$B_L^{(BM)}(k) = P[E_1] + P[E_2] \tag{16}$$

Finally, we can substitute Eq. (16) into Eq. (3) to obtain the conference level blocking probability under Bifurcated-M routing rule.

6. Illustrative example and performance comparisons

To evaluate the performance of various routing schemes in conferencing networks, we consider a seven nodes fully connected network with all links having the same number of $F = 10$ video channels. We consider only three types of conferences: three site, four site and five site conferences in the network. Then, there exists $E = \lfloor 5/2 \rfloor = 2$ classes of calls on the link level, i.e. those requesting for one channel each and those requesting for two channels each. Let the mean conference duration time to be normalized to one time unit, i.e. $1/\mu = 1$. Let the traffic load for the three conferee types be $(\gamma_3, \gamma_4, \gamma_5) = (1.75, 2.0, 7.5)$ and let this be the base load. By traffic decomposition, the class-1 and class-2 traffic rates on the link level is computed from Eq. (2) to be $(\lambda_1, \lambda_2) = (5.4887, 0.1992)$.

Fig. 4 shows the link level blocking probabilities under the fixed, M, and Bifurcated-M routings as a function of the percentage of load increase from the base load. For class-1 traffic, the blocking probabilities for M and Bifurcated-M routing are very close to each other and are both significantly lower that that of fixed routing. But for class-2 traffic, the blocking probability of M routing rapidly increases when the network runs into the overload zone. In particular, its blocking probability overtakes that of the fixed routing above the 29% load overload point. This is obviously due to the unstable behavior of alternate path routing as explained in Ref. [18]. For Bifurcated-M routing, the same occurs, but at a much higher overload point of 68% (not shown).

Fig. 5 shows the conference level blocking probabilities for three, four and five site conferences. The significant throughput improvement of the M and Bifurcated-M routings over that of the fixed routing is obvious. As expected, the performance of Bifurcated-M routing is always better than that of the M routing and the amount of improvements increase with the number of the conference sites. For example, at the same blocking level of 0.05, the throughput improvement of Bifurcated-M over M routing is 0.61% for the three site conferences, 2.9% for the four site conferences and 5.2% for the five site conferences.

We now consider the cases where there are only four and five site conferences in the network. The three site case is not considered because only class-1 calls are generated on the link level and therefore The blocking probability under Bifurcated-M routing is the same as that of M routing. Fig. 6 shows the percentage of throughput increase for Bifurcated-M routing over that of M routing at various values of F under the same conference level blocking probability of 0.05. It shows that the advantage of the Bifurcated-*M* routing is particularly prominent for the conferences with larger number of sites.

7. Conclusion

Three routing schemes for multipoint videoconferencing in a VP-based ATM network are analyzed. Numerical results show that dynamic routing can significantly increase the network throughput over that of the fixed routing. The traffic bifurcation principle is introduced to improve the balancing of load. Applying it to the *M* routing, we have shown that it can significantly increase the throughput.

The improvement of the Bifurcated-*M* routing comes from that it can allocate a class-*k* call between two nodes on different paths. If we try to allocate each channel requirement individually for a class-*k* path requirement respectively using *M* routing, a small performance improvement can be expected. The tradeoff, however, is that more paths need be set up and more connection nodes are involved. Actually, this “individual channel allocation” method is a generalization of the Bifurcated-*M* routing.

The performance of Bifurcated-*M* routing under asymmetric traffic condition in a general network is expected to be even better. But its analysis is beyond the capability of the fixed-point model analysis used in this paper. Note that we have only studied the selectable media conferences in this paper. The analysis of the common media conferences using dynamic routing appears to be more difficult and is beyond the scope of this paper.

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