Multiparty videoconferencing on multi-drop VP-based SONET/ATM rings: performance analysis

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Abstract: A type of multiparty videoconferencing in VP-based SONET/ATM ring networks under the minimum hop routing rule is analysed. For this type of conference, only the video and voice of the current speaker are broadcast to other conferees. A queueing model is presented. Conference blocking probabilities and video freeze probabilities are derived and are shown to be in close agreement with the simulation results.

1 Introduction

Multiparty videoconferencing has been predicted to be one of the most important services for both business and residential users [1]. Many kinds of videoconferences with different configurations, user interactions, quality of service (QoS) requirements and network resource requirements have been proposed [2 – 4]. Among the proposed videoconferencing methods, *speaker-video conferencing* [4, 5] (only the video and voice of the current speaker are broadcast to all other conferees) demands less equipment and bandwidth resource than selectable media, common media [3] and virtual space conferences [2].

Multiparty videoconferences can be implemented in various types of networks, such as circuit-switched N-ISDN, QoS guaranteed or nonguaranteed LANs, and ATM networks [1]. In a companion paper [6], we proposed a scheme for implementing multiparty videoconferencing on SONET/ATM rings. This paper focuses on the call-level performance evaluation of speaker-video videoconferencing on virtual channel (VP)-based SONET/ATM rings.

The analysis of multiparty videoconferencing in a general network is very difficult and no effective analytical technique is available. This is because a conference typically requires the simultaneous possession of bandwidth resources from several links. Kelly [7] investigated the blocking probability in circuit-switched networks where each customer requests a fixed number of channels from a set of links. However, Kelly's model requires the enumeration of all possible paths in the networks. Therefore, for any nontrivial network, this model cannot lead to numerical solutions. Whitt [8] analysed a mathematical model of blocking system with simultaneous resource possession. In his model, there are several multiserver facilities at which several classes of customer arrive as independent Poisson processes. Each customer requests service from one server in each facility in a subset of the service facilities, with the subset depending on the customer class. Our mathematical model is a generalisation of Whitt's model in the sense that instead of leaving the system directly when a service is finished, the customer requests service from one server in each facility in another subset of the service facilities with a certain probability. The traffic model under consideration takes into account the conference dynamics of conference arrival, conference departure, and the change of speakers in a conference.

2 Network and traffic model

In general VP-based ATM networks, the bandwidth allocated to individual VPs is adjusted dynamically to improve link bandwidth utilisation and to adapt to changes of network traffic. In this paper, we argue that the re-allocation of VP capacity should be done on a much longer time scale than the speech duration of a typical conferee. In other words, we assume that the bandwidth for the conferencing service on each physical link is constant so that the VP network can be modelled as a loss network [10].

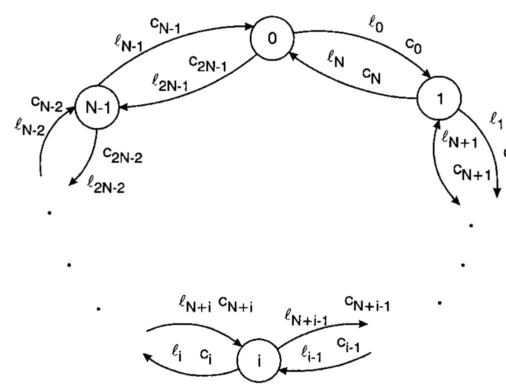

Fig. 1 *Notation for the bidirectional ring network*

2.1 Network model

On a SONET/ATM ring, the videoconferencing service is offered on switched DS1 channels [6, 11]. This allows the statistical multiplexing of different conference traffic streams onto a physical link at the call level. But bandwidth on a link may not always be available when a video source (speaker) turns active. When that

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occurs, video freeze will be experienced by certain conferees. We choose the call blocking probability and the video freeze probability as the QoS measures for speaker-only video conferences at the call level.

Consider an N-node bidirectional ring with the nodes numbered as shown in Fig. 1. Each node has two duplex links connecting to its two neighbours. Let ℓ_i denote the link from node i to node $i + 1$ on the clockwise (cw) direction and ℓ_{i+N} denote the link from node $i + 1$ to node i on the counter clockwise (ccw) direction. Let the capacity of a link be characterised by the number of channels it can support where each channel is of the DS1 type on the SONET/ATM ring and can carry audio, video and the control data of a conference source. Let c_i denote the capacity of link ℓ_i.

Nodes that have at least one conferee attached are called 'conference nodes'. Let $A = \{a_1, a_2, ...\}$ be the set of conference nodes in ascending order of node labels, i.e. $a_1 < a_2 < ...$. Among the conference nodes, we define the 'active node' as the node which has the current speaker attached. A conference spanning K conference nodes has K modes of operation where each mode corresponds to one of the conference nodes being active.

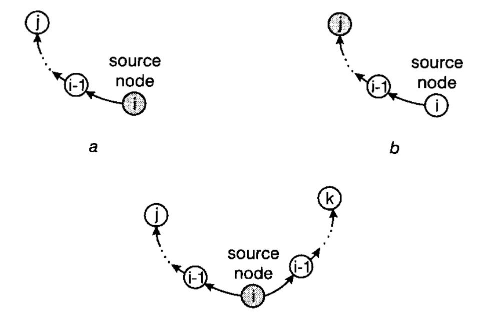

Fig.2 *Multicast connections in bidirectional ring network*

As shown in Fig. 2, three kinds of multicast connections can be defined on a ring. We use $r(i, j; cw)$ and $r(i, j; ccw)$ to denote the multicast connection from node i to j in the clockwise and the counter clockwise directions respectively and we use $r(\cdot) \cup r(\cdot)$ to denote the union of two multicast connections.

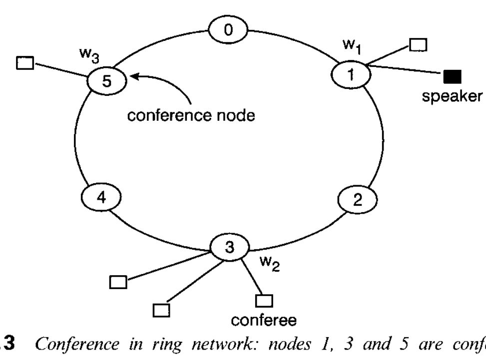

Fig.3 *Conference in ring network: nodes 1, 3 and 5 are conference nodes*

We restrict our study to the minimum hop routing rule. If there are multiple multicast connections having the same minimum hop count, one is chosen at random. To illustrate, consider the example in Fig. 3. Let $A = \{1, 3, 5\}$ be the set of conference nodes and let the current speaker be attached to node 1. Then according to the minimum hop routing rule, there are 3 minimum hop multicast connections, namely $r(1, 5; cw)$, $r(1, 3; ccw)$ and $r(1, 5; ccw) \cup r(1, 3; cw)$. When a conferee at node 3 becomes the next speaker, there are also 3 minimum hop multicast connections, say $r(3, 1; cw)$, $r(3, 5; ccw)$ and $r(3, 5; cw) \cup r(3, 1; ccw)$.

2.2 Traffic model

Let S_0 be the maximum number of conferees allowed in a conference. Then, the conference calls can be classified into $S_0 - 1$ types, where a type s ($s = 2, 3, ..., S_0$) call is a conference call with s conferees. Let b_i be the total numbers of conference subscribers at node i and let all conferees have equal community interest on all the others. Then the probability q_i that a conferee is located at node i is

$$q_i = b_i / \sum_{j=0}^{N-1} b_j$$

Let the arrivals of each type of conference calls be a Poisson process and let γ_s ($s = 2, 3, ..., S_0$) be the arrival rate of the s-party calls. Speech duration of any speaker is assumed to be exponentially distributed with mean $1/\mu$. When a conferee finishes speaking, the conference ends and leaves the network immediately with probability p_e and continues with probability $1 - p_e$. If the conference continues, the new speaker is equally likely to be any one of the other conferees. It was shown in [4] that the duration of a conference call on the network is a geometric sum of independent and identically distributed exponential random variables and is therefore exponentially distributed with mean $(\mu p_e)^{-1}$.

3 Analysis of minimum hop multicasting

We start the analysis with the derivations of the external and ongoing conference traffic rates on the network. Then we calculate the link level congestion probability, the conference level call blocking probability and the video freeze probability.

3.1 External traffic

The offered traffic to each link is assumed to be Poisson, with rate reduced suitably to account for blocking. This is called reduced-load approximation [8, 10] and it leads to a set of fixed-point equations that can be solved recursively.

A conference requires a channel on each of the active links simultaneously. Therefore, the bandwidth request of a conference can be decomposed into a set of channel requests on the set of active links. The offered load on a specific link is the superposition of channel requests from all kinds of conferences on the ring.

Consider an s-party conference. Let $\mathbf{K}_s \equiv (K_0, K_1, ..., K_{N-1})$ be the conferee distribution with K_i being the number of conferees located at node i and $K_0 + K_1 + ... + K_{N-1} = s$. Let $\mathbf{k} = (k_0, k_1, ..., k_{N-1})$ where the k_i are nonnegative integers. Under the assumption that all conferees have equal community interest to all the others, we have

$$\text{Prob}[\mathbf{K}_s = \mathbf{k}] = \begin{cases} \binom{s}{k_0, k_1, \ldots, k_{N-1}} \prod_{i=0}^{N-1} q_i^{k_i} & \text{for all } \mathbf{k} \text{ with } \sum_{j=0}^{N-1} k_j = s \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Consider a specific conference with conferee distribution $\mathbf{K}_s = \mathbf{k}$. Let R be the total number of conference nodes and let $A(\mathbf{k}) = \{a_1, a_2, ..., a_R\}$ be the set of conference node numbers. Under the minimum hop routing rule, the segment not used by this conference, called the idle segment, has hop count equal to $\max[(a_1 - a_R) \bmod N, (a_{i+1} - a_i), i = 1, 2, ..., R - 1]$. Let a^* be the active node and a_{j+1} and a_j the two end nodes of the unused segment. Then $(a^*, a_R; cw) \cup (a^*, a_1; ccw)$ is the multicast connection with minimum hop count. Under operation mode m, let there be y ($y \geq 1$) minimum hop multicast connections. In addition, let $L_i(\mathbf{k}, m)$ be the set of all links in the ith minimum hop connection and let $X(\mathbf{k}, m) \equiv \{L_1(\mathbf{k}, m), L_2(\mathbf{k}, m),..., L_y(\mathbf{k}, m)$ be the set of minimum hop connections.

For the example in Fig. 3, we have $R = 3$ and $y = 3$. The minimum hop multicast connections and the corresponding links are listed in Table 1.

Table 1: Multicast connections and links under minimum hop routing

Feasible connections	$L_1(\mathbf{k}, 1)$	$L_2(\mathbf{k}, 1)$	$L_3(\mathbf{k}, 1)$
Links	ℓ_1, ℓ_2	ℓ_6, ℓ_{11}	ℓ_1, ℓ_2
used	ℓ_3, ℓ_4	ℓ_{10}, ℓ_9	ℓ_6, ℓ_{11}

Let $\beta_s(\ell_r)$ be the probability that an s-party call is admissible and requires a channel on link ℓ_r and let $B(\ell_r)$ be the congestion probability on link ℓ_r. Given conferee distribution $\mathbf{K}_s = \mathbf{k}$ and mode m, let I_r be the set of the indices of the minimum hop multicast connections that are using link ℓ_r, i.e. $I_r \equiv \{i | \ell_r \in L_i(\mathbf{k}, m), \forall i\}$. We further assume that blockings at different links are independent. This assumption leads to an approximate solution commonly called the 'reduced load approximation' and has been shown in [7] to be reasonably accurate for multisever systems. Condition on $\mathbf{k}$ and m for $r = 0, 1, ..., 2N - 1$; then we have

$$\begin{aligned}
&\beta_s(\ell_r|\mathbf{k}, m) \\
&= \text{Prob}[\textit{the route randomly chosen from all the feasible routes contains link } \ell_r] \\
&\times \sum_{i \in I_r} \left(\begin{array}{l} \text{Prob}[\textit{route } L_i \textit{ is chosen from all feasible routes using link } \ell_r] \\ \text{Prob}[\textit{all links in } L_i(\mathbf{k}, m) \textit{ except } \ell_r \textit{ are nonblocking}] \end{array} \right) \\
&= \begin{cases} \frac{|X_r(\mathbf{k},m)|}{y} \left[\sum_{i \in I_r} \frac{1}{|X_r|} \left(\prod_{\ell \in L_i(\mathbf{k},m) \setminus \ell_r} (1 - B(\ell)) \right) \right] & |X_r(\mathbf{k}, m)| \neq 0 \\ 0 & \text{otherwise} \end{cases}
\end{aligned} \quad (2)$$

where the term $[\cdot]$ indicates the 'load reduction' factor.

By removing the conditioning on $\mathbf{k}$ and m, we obtain

$$\beta_s(\ell_r) = \sum_{\mathbf{k} \in \Omega_s} \left[\sum_{m \in A(\mathbf{k})} \frac{k_m}{s} \beta_s(\ell_r | \mathbf{k}, m) \right] \text{Prob}[\mathbf{K}_s = \mathbf{k}] \quad r = 0, 1, \ldots, 2N - 1 \quad (3)$$

where

$$\Omega_s = \left\{ \mathbf{k} | \sum_{i=0}^{N-1} k_i = s \right\} \quad (4)$$

and k_m/s is the probability that node m is active.

For s-party conferences, the reduced external load on link ℓ_r, denoted by $\lambda_s(\ell_r)$, is

$$\lambda_s(\ell_r) = \gamma_s \beta_s(\ell_r) \quad (5)$$

3.2 Ongoing conference traffic

Since the next speaker is equally likely to be any one of the other conferees, when the current speaker of a conference located at node i finishes speaking, the next speaker will be another conferee at the same node with probability $((K_i - 1)/(s - 1))$ and will be someone at the other nodes with the remaining probability. The channel holding time Y of a link, say link ℓ_{ij} is thus a geometric sum of exponential random variables and can be shown to be exponentially distributed with mean $(s - 1)/(s - K_i)\mu$ [4].

Let h_{ij} be the probability that a conferee at node i finishes speaking and the next speaker is located at node j. When $i \neq j$, we have

$$\begin{aligned}
h_{ij}(\mathbf{k}) &= \text{Prob}[\textit{conference continues}] \\
&\quad \times \text{Prob}[\textit{the next speaker is located at node } j] \\
&= \begin{cases} (1 - p_e) \frac{k_j}{s-1} & i \neq j; k_i \geq 1; k_j \geq 1 \\ 0 & k_i = 0 \text{ or } k_j = 0 \end{cases}
\end{aligned} \quad (6)$$

On the other hand, when the next speaker is located at the same node, we have

$$\begin{aligned}
h_{ii}(\mathbf{k}) &= \text{Prob}[\textit{conference continues}] \\
&\quad \times \text{Prob}[\textit{the next speaker is located at node } i] \\
&= \begin{cases} (1 - p_e) \frac{k_i - 1}{s-1} & k_i \geq 2 \\ 0 & \text{otherwise} \end{cases}
\end{aligned} \quad (7)$$

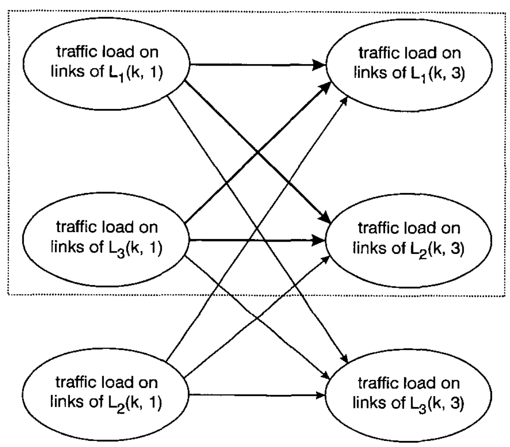

Fig. 4 *Possible transitions of traffic load along with mode changes from 1 to 3*

When there is a mode change from m to n, the traffic load on a set of links is transferred to another set of links. For the example in Fig. 3, consider the change of mode from 1 to 3. In mode 1, there are two minimum hop multicast connections, $L_1(\mathbf{k}, 1)$ and $L_3(\mathbf{k}, 1)$, using link ℓ_1 (see Table 1). In mode 3, there are also two minimum hop multicast connections using link ℓ_4, namely $L_1(\mathbf{k}, 3) = \{\ell_3, \ell_4, \ell_6, \ell_0\}$ and $L_2(\mathbf{k}, 3) = \{\ell_3, \ell_4,$

ℓ_8, ℓ_7}. Because the minimum hop multicast connection $L_2(\mathbf{k}, 1)$ does not use link ℓ_1 and multicast connection $L_3(\mathbf{k}, 3) = \{\ell_8, \ell_7, \ell_6, \ell_{11}\}$ does not use link ℓ_4, they will not be involved in the transfer of traffic load from link ℓ_1 to link ℓ_4. Fig. 4 shows the possible transitions of traffic load when the mode changes from 1 to 3. But for the transfer of traffic load from link ℓ_1 to link ℓ_4 only the link sets in the dashed box need be considered.

Now let us consider the general case of the transfer of traffic load from link ℓ_i to link ℓ_j. Let Prob$[m|\ell_i, \mathbf{k}]$ be the probability that the conference is in mode m, given conferee distribution $\mathbf{k}$ and link ℓ_i is used. Using Bayes' formula, we have

$$\mathrm{Prob}[m|\ell_i,\mathbf{k}] = \frac{\mathrm{Prob}[\ell_i|m,\mathbf{k}] \times \mathrm{Prob}[m|\mathbf{k}]}{\mathrm{Prob}[\ell_i|\mathbf{k}]} \tag{8}$$

To evaluate eqn. 8, we note that

$$\begin{aligned}\mathrm{Prob}[\ell_i|m,\mathbf{k}] &= \mathrm{Prob}[\textit{a randomly chosen feasible route contains link } \ell_i] \\ &= \frac{\textit{number of elements in } X_i(m,\mathbf{k})}{\textit{number of elements in } X(m,\mathbf{k})} \\ &= \frac{|X_i(m,\mathbf{k})|}{|X(m,\mathbf{k})|}\end{aligned} \tag{9}$$

and

$$\mathrm{Prob}[m|\mathbf{k}] = \frac{k_m}{s} \tag{10}$$

Therefore,

$$\mathrm{Prob}[\ell_i|\mathbf{k}] = \sum_{m \in A(\mathbf{k})} \mathrm{Prob}[\ell_i|m,\mathbf{k}]\frac{k_m}{s} \tag{11}$$

Next, let $T_s(\ell_j|\mathbf{k}, \ell_i)$ be the event that under conferee distribution $\mathbf{k}$ an s-party conference using link ℓ_i (among others) uses link ℓ_j (also among others) after a mode change. Prob$[T_s(\ell_j|\ell_i, \mathbf{k})]$ can be expressed as

$$\begin{aligned}&\mathrm{Prob}[T_s(\ell_j|\ell_i,\mathbf{k})] \\ &= \sum_{m,n \in U(\mathbf{k})} \begin{pmatrix} \mathrm{Prob}[\textit{conference in mode } m \textit{ in which link } \ell_i \textit{ is used}] \cdot \\ \mathrm{Prob}[\textit{mode changes from } m \textit{ to } n] \cdot \\ \mathrm{Prob}[\textit{after a mode change to } n, \textit{ a route using } \ell_j \textit{ is chosen}] \end{pmatrix} \\ &= \sum_{m,n \in A(\mathbf{k})} \left([\mathrm{Prob}[m|\ell_i,\mathbf{k}] \times h_{mn}(\mathbf{k})] \times \frac{|X_j(n,\mathbf{k})|}{|X(n,\mathbf{k})|} \right)\end{aligned} \tag{12}$$

Removing the conditioning on $\mathbf{k}$, we have

$$\begin{aligned}&\mathrm{Prob}\,[T_s(\ell_j|\ell_i)] \\ &= \sum_{\mathbf{k} \in \Omega_s} \mathrm{Prob}\,[T_s(\ell_j|\ell_i,\mathbf{k})]\,\mathrm{Prob}\,[\mathbf{K}_s = \mathbf{k}|\ell_i]\end{aligned} \tag{13}$$

where

$$\begin{aligned}&\mathrm{Prob}\,[\mathbf{K}_s = \mathbf{k}|\ell_i] \\ &= \mathrm{Prob}\,[\mathbf{K}_s = \mathbf{k}|\ell_i \textit{ is used before mode change}] \\ &= \frac{\mathrm{Prob}\,[\ell_i|\mathbf{K}_s = \mathbf{k}] \times \mathrm{Prob}\,[\mathbf{K}_s = \mathbf{k}]}{\sum_{\mathbf{k} \in \Omega_s} \mathrm{Prob}\,[\ell_i|\mathbf{K}_s = \mathbf{k}] \times \mathrm{Prob}\,[\mathbf{K}_s = \mathbf{k}]}\end{aligned} \tag{14}$$

by Bayes' formula and eqn. 11.

As ℓ_j can receive contributions from links other than ℓ_i, the relative portion that comes from ℓ_i, which we denote as the traffic transition probability $f_s(\ell_j|\ell_i$, *conference continues*) is simply

$$f_s\,(\ell_j|\ell_i, \textit{conference continues}) = \frac{\mathrm{Prob}\,[T_s(\ell_j|\ell_i)]}{\sum_{r=0}^{2N-1} \mathrm{Prob}\,[T_s(\ell_r|\ell_i)]} \tag{15}$$

But the conference can end with probability p_e. If so, $f_s(\ell_j|\ell_i$, *conference ends*) = 0. Therefore,

$$f_s(\ell_j|\ell_i) = (1 - p_e)\frac{\mathrm{Prob}\,[T_s(\ell_j|\ell_i)]}{\sum_{r=0}^{2N-1} \mathrm{Prob}\,[T_s(\ell_r|\ell_i)]} \tag{16}$$

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$$\sum_{j=0}^{2N-1} f_s(\ell_j|\ell_i) + p_e = 1$$

as it should.

Let $\Lambda_s(\ell_i)$ denote the total traffic rate (including new and ongoing conferences) from all type s conferences on link ℓ_i. Then the transferred traffic load from ℓ_i to ℓ_j has rate $\Lambda_s(\ell_i)f_s(\ell_j|\ell_i)$.

By adding the external and internal traffic contributions to the specific link ℓ_i, we have

$$\Lambda_s(\ell_i) = \lambda_s(\ell_i) + \sum_{j=0}^{2N-1} \Lambda_s(\ell_j) f_s(\ell_i|\ell_j) \qquad i = 0, 1, \ldots, 2N-1 \tag{17}$$

where $\lambda_s(\ell_i)$ is given by eqn. 5. This set of equations can be solved by Gaussian elimination or Gauss–Sidel iteration. The combined 'new call arrival plus mode change' process on link ℓ_i has rate $\Lambda(\ell_i)$ given by

$$\Lambda(\ell) = \sum_{s=2}^{S_0} \Lambda_s(\ell) \tag{18}$$

Let M_i be the occupancy of link i and let $p(\mathbf{n})$ = Prob$[M_0 = n_0, M_1 = n_1, \ldots, M_{2N-1} = n_{2N-1}]$. Under the link independence assumption, the set of links $\ell_0, \ell_1, \ldots \ell_{2N-1}$ can be modelled as a Jackson open queueing network. The steady-state solution from [9] is

$$p(\mathbf{n}) = \prod_{i=0}^{2N-1} \left(\frac{\Lambda(\ell_i)}{\mu}\right)^{n_i} \frac{p(\mathbf{0})}{n_i!} \tag{19}$$

where

$$p(\mathbf{0}) = \left[\sum_{\mathbf{n} \in \Theta} \left(\prod_{i=0}^{2N-1} \frac{(\Lambda(\ell_i)/\mu)^{n_i}}{n_i!}\right)\right]^{-1} \tag{20}$$

and

$$\Theta \equiv \{\mathbf{n}|0 \le n_i \le c_i, i = 0, 1, \ldots, 2N-1\} \tag{21}$$

The link congestion probability can be obtained from eqn. 10 by appropriately summing over the set of blocking states $\Theta_i \equiv \{\mathbf{n}|n_i = c_i\}$. In other words,

$$B(i) = \sum_{\mathbf{n} \in \Theta_i} p(\mathbf{n}) \quad i = 0, 1, \ldots, 2N-1 \tag{22}$$

3.3 Fixed-point equations

Eqns. 5 and 19 are of the forms $\tilde{\Lambda} = \Psi(\tilde{B})$ and $\tilde{B} = \Phi(\tilde{\Lambda})$, respectively, where $\tilde{\Lambda} = \{\Lambda_i\}_{i=0,1,\ldots 2N-1}$ and $\tilde{B} = \{B(i)\}_{i=0,1,\ldots 2N-1}$. The method of successive approximation is effective for their solutions. This method starts with certain initial values $\tilde{\Lambda}(0)$ and iterates,

$$\tilde{B}^{(k+1)} = \Phi(\tilde{\Lambda}^{(k)})$$
$$\tilde{\Lambda}^{(k+1)} = \Psi(\tilde{B}^{(k+1)}) \quad (23)$$

until a convergence criterion is satisfied.

4 Call blocking probability and video freeze probability

In this Section, we compute the conference level call blocking probability and video freeze probability.

4.1 Call blocking probability

When any link in the multicast connection is in congestion, the conference call is blocked. Let $B(s|m, \mathbf{k})$ be the call blocking probability of an s-party conference, given that the conference has conferee distribution $\mathbf{K}_s = \mathbf{k}$ and the speaker is located at node m. Let the set of minimum hop multicast connections be $X(\mathbf{k}, m) = \{L_1, L_2, \ldots L_y\}$. Under the minimum hop routing rule, if there are multiple multicast connections, we choose any one randomly. Therefore, with the assumption that blockings at different links are independent [7], $B(s|m, \mathbf{k})$ can be computed as

$$B(s|m,\mathbf{k}) = \sum_{i=1}^{y} \frac{1}{y}\left[1 - \prod_{\ell \in L_i}(1 - B(\ell))\right] \quad (24)$$

where $B(\ell)$ is the probability that link ℓ is in congestion, which is given by eqn. 22, and $L_i = L_i(\mathbf{k}, a)$ is the ith set of links used by the conference with conferee distribution $\mathbf{k}$ in mode m.

By removing the conditioning on $\mathbf{K}_s = \mathbf{k}$ and m, the call blocking probability for an s-party conference, denoted as B_s, is simply given by

$$B_s = \sum_{\mathbf{k}\in\Omega_s}\left[\sum_{j\in A(\mathbf{k})} \frac{k_j}{s} B(s|j,\mathbf{k})\right] \mathrm{Prob}\left[\mathbf{K}(s) = \mathbf{k}\right] \quad (25)$$

where $A(\mathbf{k})$ is the set of conference nodes, $\mathrm{Prob}[\mathbf{K}(s) = \mathbf{k}]$ is given by eqn. 1 and Ω_s is given by eqn. 3.

4.2 Video freeze probability

For an ongoing conference, when there is a change of operation mode, a new multicast connection should be established. When a link in the multicast connection is in congestion, the conferee(s) attached to the affected node will experience a period of video freeze. Let $F(s)$ denote the video freeze probability when there is a change of speaker.

Let the s-party conference have conferee distribution $\mathbf{k}$ at mode m. If the next speaker is located at the same node as the current speaker, the conference will not experience video freeze. But if the next speaker is located elsewhere, we have

$$F(s|m,\mathbf{k}) = \mathrm{Prob}\{next\ speaker\ at\ node\ i\}\ \mathrm{Prob}\{blocking|i,\mathbf{k}\}$$
$$= \sum_{i\in A(\mathbf{k})\backslash m} \frac{k_i}{s-1} B(s|i,\mathbf{k}) \quad (26)$$

For a particular conference with conferee distribution $\mathbf{K}_s = \mathbf{k}$, the probability that the current speaker is located at node m is k_m/s. Therefore, the video freeze probability of an s-party conference when there is a change of speaker, denoted as F_s, can be obtained as

$$F_s = \sum_{\mathbf{k}\in\Omega_s}\left[\sum_{j\in A(\mathbf{k})} \frac{k_j}{s} F(s|j,\mathbf{k})\right] \mathrm{Prob}\left[\mathbf{K}(s) = \mathbf{k}\right] \quad (27)$$

5 Numerical results

5.1 Example 1: symmetric model

Consider an OC-12 ring with six nodes. The OC-12 optical signal is first changed into electronic signal of 622.08 Mbps by O/E converter at each SONET/ATM ADM. A demultiplexer is used to demultiplex the signal into four STS-3c signals. An ATM STS-3c ADM is used for each STS-3c signal. Such a network can support both nonswitched and switched DS1 and DS3 services. We assume that the Multidrop VPs set up are dedicated for videoconferencing service only and a total of 30 DS1 channels are allocated at each link between two adjacent nodes for the videoconferencing service. In other words, $c_i = 30$. We further let $q_1 = 1/N$, $\forall i$, $p_e = 0.5$ and, without loss of generality, $1/\mu = 1$.

We first consider the case that there are only 2-party calls, that is, there are only point-to-point calls. Let the arrival rate be $\gamma = 40$. Using eqns. 1–3, we obtain the probability that a call requests a channel on each link as 0.125 and the traffic load from external calls on each link as $\lambda = 5$. Using eqns. 6–22, we obtain the total traffic load (including internal traffic load) $\Lambda = 10$ as it should because for the symmetric network under uniform traffic loading $\Lambda = \lambda(1 + p_e + p_e^2 + \ldots) = 2\lambda$. For 3-party, 4-party, or 5-party call cases with the same arrival rate, the probabilities that a call requests a channel on each link is 0.192, 0.237 and 0.268, respectively, and the total traffic rate is 15.37, 18.98 and 21.48, respectively. We can see that when the conference size increases, the traffic load on the ring network increases only slowly.

5.2 Example 2: nonsymmetric model

To investigate the accuracy of the analysis for nonsymmetric models, we study the network in example 1 with different numbers of DS1 channels being used for different links and different number of conferees being assigned to different nodes. Specifically, we let $(c_0, c_1, \ldots, c_{11}) = (30, 28, 28, 30, 35, 35, 28, 28, 28, 35, 35, 30)$ and $(q_1, q_2, \ldots, q_6) = (0.2, 0.133, 0.133, 0.2, 0.167, 0.167)$.

There are four types of conference call, corresponding to 2, 3, 4 and 5-party conferences. We assume a base traffic intensity of (4.5, 7.5, 7.5, 4.5) for these four types of call, $p_e = 0.4$ and $1/\mu = 1$. Fig. 5 shows that the computed blocking probability as a function of load increase over the base load. Fig. 6 shows the video freeze probability plotted against load increase.

To check the accuracy of the analysis, we also show the blocking probability obtained with computer simulation of type 2 and type 4 calls in Fig. 5. The results for type 3 and type 5 calls are similar and are therefore not shown. The results show that (1) under all traffic conditions, the blocking probability obtained by simulation is upper bounded by the analytical results and

(2) there is no significant difference between the results at $B \leq 0.02$.

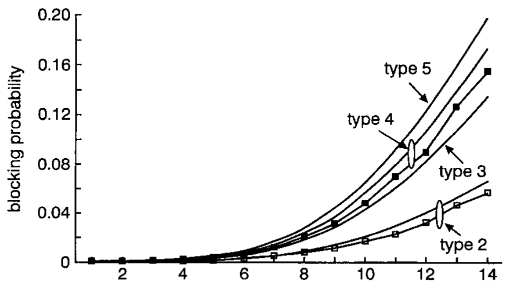

Fig. 5 *Call blocking probability against load increase*
simulation results:
—□— type 2
—■— type 4

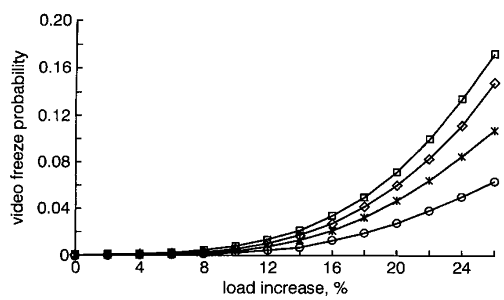

Fig. 6 *Video freeze probability against load increase (analytical results)*
—○— type 2
—×— type 3
—◇— type 4
—□— type 5

6 Summary

In this paper, we have analysed the performance of speaker-video videoconferencing on bidirectional SONET/ATM rings. Our approach is to make use of the reduced-load approximation and open Jackson network model to derive the traffic loads from new conferences as well as from speaker changes in ongoing conferences. Based on that, a set of fixed-point equations is derived the solution of which allows the call blocking probability and video freeze probability to be computed. Computer simulation confirms the accuracy of the analysis.

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