Performance Benefits of Virtual Path Tunneling for Control and Management Flows in the Broadband ATM Networks

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In this paper, we analyze the performance benefits of broadband ATM networks when the call control and management flows are separated from user data flows. The virtual path tunneling concept for control and management flows are applied to the same physical ATM networks. The behaviors of channel throughput and transfer delay are analyzed. It results that the proposed virtual short-cut paths can maintain the network being stable with acceptable bandwidth. They are very useful to provide the stable control and management capabilities for Internet and mobile applications in the broadband ATM networks. In our numerical results, the effective throughputs of the proposed virtual short-cut channel are about three times than those of end-to-end user data channels with hop distances of 10, and about two times than those with hop distance of 5 when the link blocking probability increases to 0.1. It concludes that the effective channel bandwidth are greatly reduced down while physical links are not stable and user traffic flows are occasionally overflowed.

I. INTRODUCTION

The broadband ATM network was originally designed to provide the connection-oriented virtual channel with the help of signalling capability. The signalling network architecture is classified into the channel-associated or non-associated mode. In the conservative scenario of network evolution, it looks that the broadband ATM network with overlaid signalling and management architecture continues to provide the future networking services.

Currently, the major telecommunication markets steadily shift from voice telephony to Internet and mobile applications. The broadband ATM network may successfully provide the high speed Internet applications with quality-of-service (QoS) guarantee, which could be done by the connection-oriented virtual circuits with flow-based traffic control mechanism. A number of virtual circuits could be used to emulate the client/server model of legacy local area network [1]–[3]. The data-, control-, and configure-direct virtual circuits are used to emulate the connectionless LAN services. For future mobile applications, the broadband ATM network could give a good transmission infrastructure [4]–[7]. It requests the location and authentication information’s before setting up the end-to-end virtual circuits. Some virtual circuits are needed to reach to the mobile databases such as home location register and visitor location register (HLR/VLR).

To cope with these service demands, the call control and management (C&M) flows are clearly identified from the normal end-to-end user flows. The C&M traffics should not be suffered from congestion of end-to-end user traffics. To guarantee their

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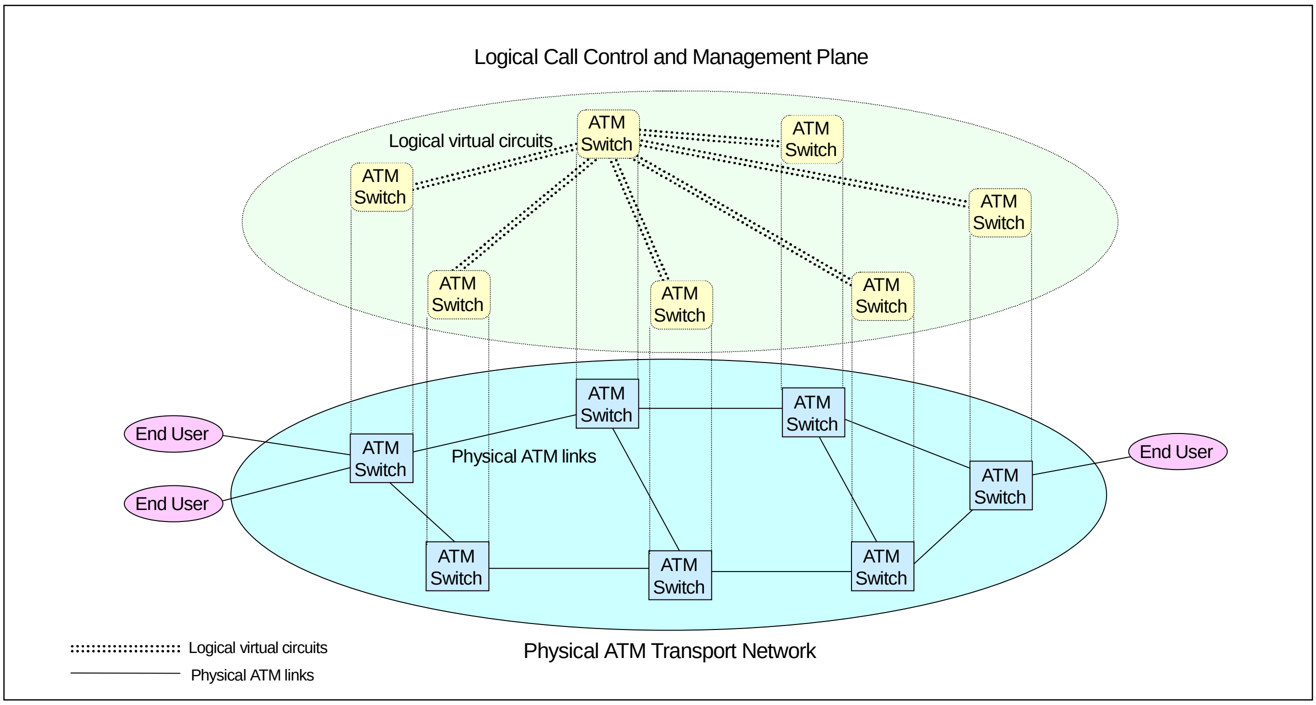

Fig. 1. An example of virtual path tunneling for call control and management in broadband ATM networks.

QoS's and bandwidths, a priority scheduling mechanism could be applied to the broadband ATM switch. It simply concludes that the C&M virtual circuits should be separated from those for user traffic. It expects that their volumes will increase for the Internet and mobile applications.

In this paper, we consider the call control and management architecture overlaying on the physical ATM network as shown in Fig. 1. The C&M planes are logically built on the same physical ATM network. Their configurations are independent of the physical ATM network. The call control and management virtual channels could be connected though a number of physical ATM switches. With virtual trunking capability between source and destination nodes, the short-cut C&M path could be built by separating from the user data path. To build control and management virtual links between the C&M nodes, the intermediate physical ATM switches provide the cut-through capability without interleaving normal user traffic flows. The star configuration for the C&M plane may be acceptable for a regional area. It looks that the short-cut C&M channel is effective to give the good throughput performance and reduce network transient situations. Their quality of service including bandwidth may be guaranteed on physical ATM links. For network reliability, the C&M virtual circuits are duplicated with different physical routes. In the proposed over lay architecture of C&M plane with virtual trunking, it notes that the user virtual circuits could be set up by the access signalling or the specific switch management protocol [8]–[10].

II. PERFORMANCE ANALYSIS OF VIRTUAL TUNNELING FOR CALL CONTROL AND MANAGEMENT

Now, we analyze the performance of logical C&M network over the same physical ATM network. It could be done by performances of throughput, transfer delay and reliability. In our analysis, the Markovian queuing network models are assumed both for end-to-end C&M flows and user data flows. The direct short-cut links for control and management traversing a number of physical ATM switches also assume with Markovian queueing network model. All the traffic flows have the behaviors with Poisson arrival and exponential distribution. It assumes that the short-cut routing paths for call control and management are fixed independent of user data flows. It also assumes that the logical C&M network has the star configuration in the same area. They are duplicated for redundancy to take the separate two physical links between source and destination similar to the existing common channel-signalling network.

First, we analyze the end-to-end virtual channel utilization according to channel blocking probability. We consider the fixed routing paths γ_C and γ_U between source and destination nodes for C&M transfer and user data transfer, respectively[1]. Now, the channel utilization's ρ_{γ_C} and ρ_{γ_U} for the routes γ_C and

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[1] The subscript C and U denote to C&M message transfer and user data transfer in the following paragraphs, respectively.

γ_U are given, respectively, by

$$\rho_{\gamma C} = \frac{\lambda^*_{\gamma C}}{\mu_C C_C} = \frac{\lambda_{\gamma C}(1-B_C)}{\mu_C C_C} \qquad (1)$$

$$\rho_{\gamma U} = \frac{\lambda^*_{\gamma U}}{\mu_U C_U} = \frac{\lambda_{\gamma U}(1-B_U)}{\mu_U C_U}, \qquad (2)$$

where $\lambda_{\gamma C}$ and $\lambda_{\gamma U}$ are the total number of packets per second which arrive at the original node on the routes γ_C and γ_U, respectively. $\lambda^*_{\gamma C}$ and $\lambda^*_{\gamma U}$ are the number of packets per second which are actually delivered to the destination nodes. B_C and B_U are the probabilities that the channels are blocked on routes γ_C and γ_U, respectively. $1/\mu_C$ and $1/\mu_U$ are the average packet lengths. C_C and C_U are the virtual channel capacities in number of bits per second.

Now, the channel blocking probability B_C and B_U are given by

$$B_C = 1-\prod_{i\in\gamma_C}\left(1-L_{C,i}{}^2\right) = 1-\prod_{i=1}^{h_C}\left(1-L_{C,i}{}^2\right) \qquad (3)$$

for the duplicate links

$$B_U = 1-\prod_{i\in\gamma_U}\left(1-L_{U,i}\right) = 1-\prod_{i=1}^{h_U}\left(1-L_{U,i}\right), \qquad (4)$$

where $L_{C,i}$ and $L_{U,i}$ are the probability that the *i*-th link is blocked on the routes γ_C and γ_U. h_C and h_U are the hop distance of routes γ_C and γ_U, respectively. In (3), we assume that all the call control and management links are duplicated for redundancy. The link blocking probability is depending on the probabilities that the link is overflowed and is in out-of-service. Here, the link blocking probabilities $L_{C,i}$ and $L_{U,i}$ are recursively calculated by

$$\begin{aligned} L_{C,i}(\beta_{C,i},\rho_{C,i},C_C) &= \beta_{C,i} + (1-\beta_{C,i})P_{over}(\rho_{C,i},C_C) \\ &\cong \beta_{C,i} + (1-\beta_{C,i})Er(\rho_{C,i},C_C) \end{aligned} \qquad (5)$$

$$\begin{aligned} L_{U,i}(\beta_{U,i},\rho_{U,i},C_U) &= \beta_{U,i} + (1-\beta_{U,i})P_{over}(\rho_{U,i},C_U) \\ &\cong \beta_{U,i} + (1-\beta_{U,i})Er(\rho_{U,i},C_U) \end{aligned} \qquad (6)$$

since the *i*-th link utilization's are given by $\rho_{C,i} = \frac{\lambda_{C,i}(1-L_{C,i})}{\mu_C C_C}$ and $\rho_{U,i} = \frac{\lambda_{U,i}(1-L_{U,i})}{\mu_U C_U}$. $\beta_{C,i}$ and $\beta_{U,i}$ are the probability that link i is out-of-service (e.g., link or channel errors, routing failure, etc.). $P_{over}(\,)$ is the probability that the given virtual circuits are overflowed. It could be approximately calculated by Erlang loss formula denoted as $Er(\,)$ [11]–[12].

Now, we consider the traffic loads of each virtual circuits. Let's define the network load ratio, $R_{C/U}$, between C&M flows and end user flows as

$$R_{C/U} = \frac{\rho_{\gamma_C}}{\rho_{\gamma_U}} = \frac{\delta(1-B_C)}{\kappa(1-B_U)}, \qquad (7)$$

where $\lambda_{\gamma C} = \delta\lambda_{\gamma U}$ and $\mu_C C_C = \kappa\mu_U C_U$ (that is, $1/\mu_U C_U$ = $\kappa/\mu_C C_C$). δ has a range of $0.01 \le \delta \le 0.05$ while we assume that the C&M traffic volumes are about 1 ~ 5 % of those of the end user traffic. κ denotes the average service time of user data messages normalized by the call control and management messages.

Now, we analyze the channel behaviors of routes γ_C and γ_U on the saturated condition. Here, we assume that all the cascading virtual channels consisting of the route γ_C or γ_U have the same bandwidth. As the channel traffic increases, the link utilization on routes γ_C and γ_U converges to overall end-to-end channel utilization. In a saturated condition, the *i*-th link utilization's $\rho_{C,i}$ and $\rho_{U,i}$ could be calculated by

$$\rho_{C,i} = \frac{\lambda_{i\in\gamma_C}\left(1-L_{C,i}{}^2\right)+\lambda_{i\notin\gamma_C}}{\mu_C C_C} \rightarrow \rho_{\gamma_C} = \left(1-L_{C,i}{}^2\right)\rho_{\gamma_C} + \rho_{i\notin\gamma_C} \quad \text{for } i=1,\ldots,h_C \qquad (8)$$

$$\rho_{U,i} = \frac{\lambda_{i\in\gamma_U}\left(1-L_{U,i}\right)+\lambda_{i\notin\gamma_U}}{\mu_U C_U} \rightarrow \rho_{\gamma_U} = \left(1-L_{U,i}\right)\rho_{\gamma_U} + \rho_{i\notin\gamma_U} \quad \text{for } i=1,\ldots,h_U \qquad (9)$$

where $\rho_{i\notin\gamma_C} = \lambda_{i\notin\gamma_C}/\mu_C C_C$ and $\rho_{i\notin\gamma_U} = \lambda_{i\notin\gamma_U}/\mu_U C_U$. $\lambda_{i\in\gamma_C}$ and $\lambda_{i\in\gamma_U}$ are the number of packets per second which arrive at the *i*-th link on the route γ_C and γ_U, respectively. $\lambda_{i\notin\gamma_C}$ and $\lambda_{i\notin\gamma_U}$ are the number of packets per second which arrives at the *i*-th link except from the given route γ_C and γ_U. From (8) and (9), it results in a saturated condition that

$$\rho_{\gamma_C} = \frac{\lambda_{i\notin\gamma_C}}{\mu_C C_C L_{C,i}{}^2} \quad \text{for } i=1,\ldots,h_C \qquad (10)$$

$$\rho_{\gamma_U} = \frac{\lambda_{i\notin\gamma_U}}{\mu_U C_U L_{U,i}} \quad \text{for } i=1,\ldots,h_U \qquad (11)$$

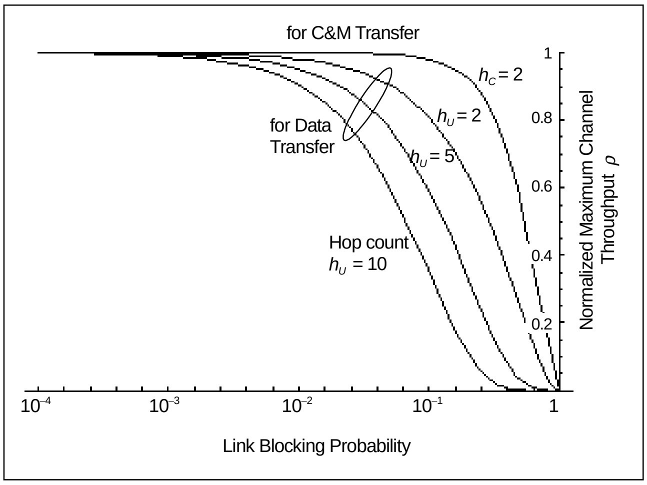

Fig. 2 Normalized maximum channel throughput versus link blocking probability.

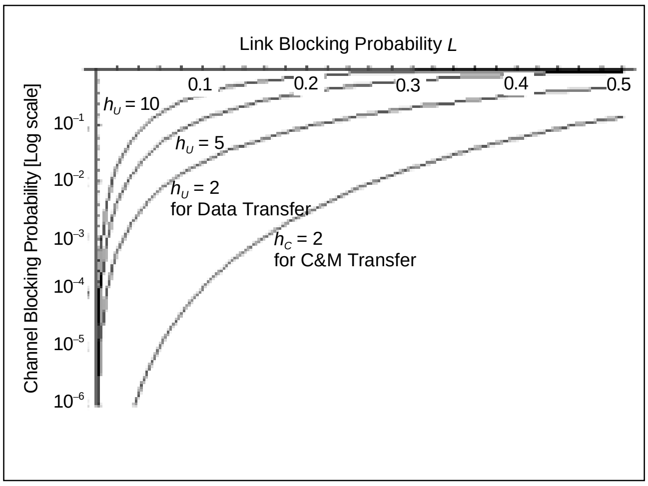

Fig. 3. Channel blocking probability versus the link blocking probability.

For the transfer delay analysis, we assume Markovian network model of cascaded M/M/1 queuing channel. The average channel delay could be simply calculated by

$$\overline{T_C} = \frac{1}{\lambda_{\gamma C}\left(1-B_C\right)} \sum_{i\in\gamma C} \lambda^*_{C,i}\overline{T_{C,i}} = \frac{1}{\lambda_{\gamma C}\left(1-B_C\right)} \sum_{i=1}^{h_C} \lambda_{C,i}\left(1-L_{C,i}{}^2\right)\overline{T_{C,i}} \tag{12}$$

$$\overline{T_U} = \frac{1}{\lambda_{\gamma_U}\left(1-B_U\right)} \sum_{i\in\gamma_U} \lambda^*_{U,i}\overline{T_{U,i}} = \frac{1}{\lambda_{\gamma u}(1-B_U)} \sum_{i=1}^{h_U} \lambda^*_{U,i}(1-L_{U,i})\overline{T_{U,i}} \tag{13}$$

where $\overline{T_{C,i}} = 1/\left(\mu_{C,i}C_{C,i} - \lambda_{C,i}(1-L_{C,i}{}^2)\right)$ and $\overline{T_{U,i}} = 1/(\ \mu_{U,i} C_{U,i} - \lambda_{U,i}(1-L_{U,i}))$.

Now, we calculate the number of lost messages on the routes γ_C and γ_U since they may be caused by link blocking or out of resources, etc. It could be measured by the average numbers of messages which are not correctly delivered to the destination, which are denoted by $\overline{N_{C,loss}}$ and $\overline{N_{U,loss}}$. They are given by

$$\overline{N_{C,loss}} = \lambda_{\gamma C}\left(\overline{T_C}B_C + 2\overline{T_C}\left(1-B_C\right)B_D\right) \tag{14}$$

$$\overline{N_{U,loss}} = \lambda_{\gamma U}\left(\overline{T_U}B_U + 2\overline{T_U}\left(1-B_U\right)B_D\right) \tag{15}$$

where B_D is the probability that a destination user is blocked since there is no available resources.

III. NUMERICAL RESULTS

As a numerical results, Fig. 2 shows the behaviors of normalized channel throughput versus the link blocking probability. The virtual channel capacities for call and management flow are acceptably maintained as the link blocking probability increases. But, the virtual channel capacity of user data flows are significantly reduced while both the hop distance and the link blocking probability increase. It means that the actual throughput may be significantly degraded by the channel and resource availability of intermediate links. Then, when the users request some bandwidths for end-to-end applications, the network should reserve their virtual channel bandwidth with considerations of end-to-end hop distance and link availability.

Figure 3 shows the behaviors of overall channel blocking probability as the link blocking probability increases. This figure shows the effects of hop distance and duplicated links according to link blocking probability. As the link blocking probabilities increase at about 10 %, the channel blocking probabilities for control and management flows keep less than 10^{-4}. But, the channel blocking probabilities for user data flows increase at about 10^{-2} for $h_U = 2$ and about 10^{-1} for $h_U = 10$. It means that the channel blocking may be serious as the hop distance increases. In combination of the saturated conditions obtained in (10) and (11), the end-to-end channel utilization are also significantly affected by the link blocking probabilities of intermediate links on the given routes.

Figure 4 shows the normalized network load ratio between C&M flows and user data flows as the link blocking probability increases. In this figure, we assume that the average message volumes and lengths of C&M flows are the same with those of user data messages, that is, δ =1 and κ =1. This figure shows that the user channel with hop distance of 5 requires about 70 % additional bandwidth than those of C&M channel when the link blocking probability is 0.1. Also, the end user applications require the channel capacity of about three times as bigger as C&M channel to deliver the same volumes of messages when the end-

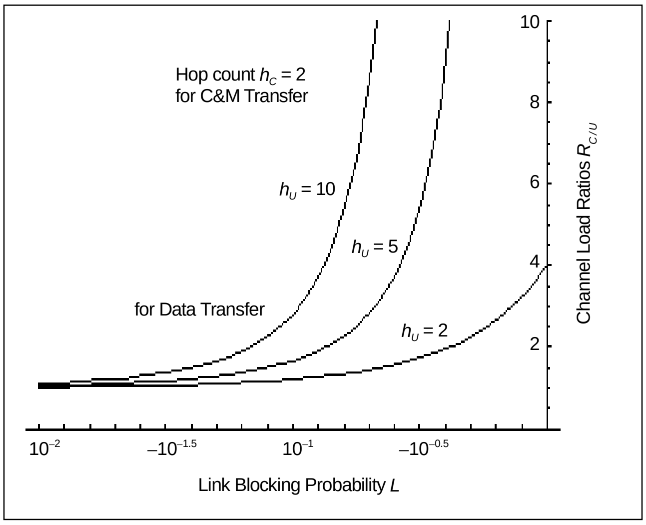

Fig. 4. Normalized network load ratio between C&M and data flows versus link blocking probability.

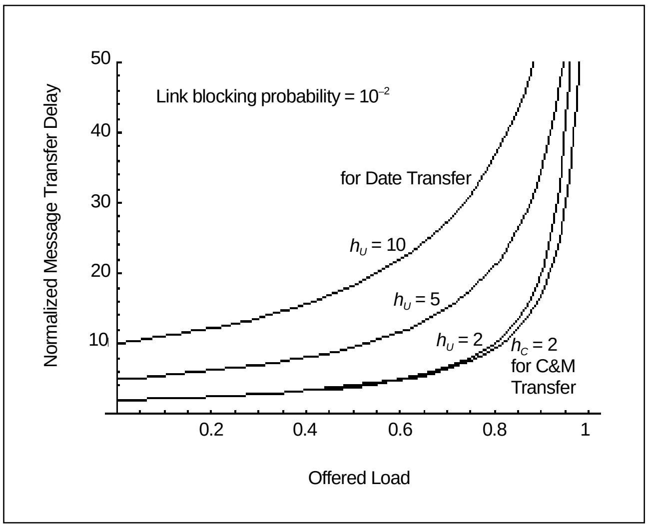

Fig. 5 Normalized mean data transfer delay for C&M and user data messages.

to-end user hop distance increases up to 10.

Figure 5 shows the behaviors of normalized mean data transfer delay for C&M channel and user data channel when the link blocking probability is 10^{-3}. This figure also shows the effect of C&M channel compared to the user data channel as the hop distance increases. The effects on channel blocking show that the mean transfer delay increases about two times than that of the normal condition at hop distance of 10 when the offered load is 0.5. But the mean transfer delay for the user data flows is nearly the same as that for the control and management flows.

IV. CONCLUSIONS

In this paper, we analyze the performance benefits of virtual path trunking when the intermediate links are unstable or blocked. We show that the user channel bandwidth should be allocated with considerations of end-to-end hop distance and link availability.

In our analysis, the end-user virtual channel with hop distances of 10 should have about 200 % additional bandwidth to get the equal capacity of proposed virtual C&M channel with the duplicated links when the link blocking probability reaches to 0.1. When the end-to-end hop distance is 5, about 70 % additional bandwidths are requested to provide the same bandwidth. It results that the effective channel bandwidth are greatly reduced down when the intermediate links are instantly blocked. The degradation effects of effective bandwidth are significant when the network scale increases and the hop distance accordingly increases.

Then, we concludes that the virtual path tunneling concept is very effective for dynamic configuration of the broadband ATM network. Also, the short delay of control and management information transfer could reduce network transient behaviors. The virtual trunking is also very useful for the Internet and mobile applications since the volumes of control and management messages will greatly increase to exchange the routing information and to deliver the location informations.

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