A Study of Issues Relating to Traffic Restoration in Wide Area Communication Networks *

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Abstract

In this paper, we compare two different criteria for the traffic restoration process at a node in a wide area communication network. The issue of the timing of the reconnection is compared with the issue of ordering the virtual circuits that need reconnection. In the first scheme, an algorithm is developed to minimize the amount of time the network is congested while the latter scheme tries to minimize the probability of blocking of calls during the reconnection process. The feasibility of implementing both these schemes simultaneously in a network is studied.

1 Introduction

The growing commercial dependence on communication networks has led to an increased focus on the reliability and survivability of these networks. While there have been great strides in increasing the reliability of physical network components, some rate of failure is inevitable. Typical events that cause failures are accidental cable cuts, hardware malfunctions, software errors, natural disasters, and human error [1], [4]. Since many of the causes of the failures are outside the control of the network providers, there has been increasing interest in the design of survivable networks [1]-[4]. This work has largely focused on planning the network to reduce the impact of link or node failures when they occur. An survey of current survivability techniques is given in [4].

Recently, we have begun a research effort into developing algorithms which optimizes the use of network resources after a link/node failure rather than planning redundancy into the network. This effort has concentrated on virtual circuit based packet switched wide area networks such as IBM's proposed plaNET network architecture [5], which is a private high speed integrated network supporting a wide variety of traffic types.

Consider an arbitrary packet switched connection oriented wide area network (eg. plaNET). Such networks typically use dynamic source routing algorithms [5] wherein each network node would determine the route through the network for all virtual circuits originating at that node. After a link failure, the source nodes for the virtual circuits that were traversing the link which failed are responsible for the restoration of the affected virtual circuits. In the framework proposed in [6] for studying link failures, such source nodes are called 'primary nodes'. After a failure, a primary node will typically have many virtual circuits to reconnect. In order to provide uninterrupted service to the affected virtual circuits, the primary node must restore the virtual circuit within approximately 2 seconds for a voice connection and within 10 seconds for a data connection [1]. Several issues in the traffic restoration process at the primary node can be critical to the network performance after restoration, such as: 1) the timing of the reconnection (i.e., should calls be reconnected as fast as possible or some small spacing put in between reconnections?); 2) the main criterion for ordering the virtual circuits that need to be restored (e.g., highest bandwidth calls first); and 3) the route selection procedure.

In this paper, we report a study of the first two factors. First, how one may vary the time between successive reroutings from a node in order to reduce network congestion is analyzed. The scheme of almost simultaneously rerouting the virtual circuits is compared with a scheme wherein the rerouting of the virtual circuits is staggered thus ensuring that they do not congest the network node at the same time. We determine which approach is better by minimizing the time taken by a network node to reach steady state after the traffic restoration. To study the second issue, the effect of various call ordering policies on the network performance was analyzed in sample networks. We then consider the effects of both issues simultaneously in a network.

2 An Analysis of the Effect of Timing of Rerouting

As each virtual circuit is rerouted, it starts transmitting its entire backlog along its access link into the primary node. The link buffer at the primary node, being of a finite size, can quickly become congested. Retransmissions of dropped packets from the source add a positive feedback to the source, further worsening the congestion.

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*The research reported here was supported in part by a grant from IBM, Research Triangle Park, NC.

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Due to these factors, the packet loss rate at the network node can become very high, exceeding the grade of service (GOS) level, possibly until the backlogs of each of the restored virtual circuits is completely transmitted.

As a way of reducing the length of the congestion period, we propose here that the virtual circuits be restored at staggered time intervals, one after the other. The basic idea is that the congestion at the network node could be reduced by restoring a virtual circuit and then waiting until the network node reaches an acceptable GOS before restoring the next virtual circuit. While considering this scheme, it is obvious that the virtual circuits need to be ordered in a decreasing order of their input rates. This is due to the fact that the virtual circuit to be restored last would suffer an additional backlog, directly related to its input rate, while awaiting its turn to enter the network.

A study was carried out to determine as to when the staggered restoration scheme is superior to the simultaneous restoration scheme in terms of the time for the network link at the primary node to reach GOS states. The generic primary node queueing model developed in [6] and shown in the Figure 1 for the case of two virtual circuits was used for the study. Note that the network parameters have been normalized based on plaNET values for ease of analysis. Consider a sample backlogged packet, assuming independence of retransmissions, the probability that a packet gets blocked on its *n th* attempt is P_B^n, where P_B is the probability that the packet gets blocked on its first attempt. Using this, we could calculate the time T_i for one packet to be successfully be transmmitted to the primary node and knowing this, the time taken to transmit the entire backlog (TB_i), for the *i th* virtual circuit can be obtained. This backlog at the source has a delayed effect on the primary node and we add a settling time τ_R to TB_i to allow the network node to reach its steady state. When we are implementing the staggered scheme, the next virtual circuit would be transmitted from the source queue at this time and a similar analysis would be carried out for it.

When all the virtual circuits are being transmitted simultaneously, the virtual circuit with the lowest bandwidth would be the first to complete transmitting its backlog and at this time, changes are made to the input rate and a new P_B is recalculated. This new P_B is then used for further analysis. Details of the entire analysis have been omitted for the sake of brevity and can be found in [7].

The two restoration schemes were compared in a series of numerical studies conducted as follows. A specific ratio of the input rates of the two virtual circuits λ_2/λ_1 was chosen and for various values of the total load $\lambda = \lambda_1 + \lambda_2$, the time to reach steady state, TSS, was calculated and plotted for both schemes. The ratio of the input rates was then varied and a new plot was generated. It was seen from these plots that at low loads, the simultaneous rerouting scheme seems to be superior to the staggered rerouting scheme. Note that there exists a cross-over point in each curve after which, for further values of λ, the staggered rerouting scheme takes less time than the simultaneous scheme to reach steady state. Similar experiments were conducted for different ratios of the input rates and are given in [7].

Figure 2 is a graph plotting the input rate of the first virtual circuit λ_1, against the ratios of the two input rates. The cross-over points for each ratio are displayed as points and connected into a curve. Notice that the cross-over curve divides the entire plane into two regions, the region where the simultaneous rerouting scheme is better than the staggered rerouting scheme and the region where the reverse is true. The region for the staggered scheme is bordered by the call admission threshold of the network. It is to be noted that for smaller values of the ratio, the input rate of the first virtual circuit needs to be very high in order for the point chosen to fall into the region for the staggered scheme. Similarly, at the other end of the spectrum, for large ratios of the input rates, it takes a comparably smaller input rate λ_1 in order for the point chosen to fall into the region for staggered scheme.

A detailed simulation was conducted to validate the model, details of which are given in [7]. Note that the simulation results presented here were collected using the ensemble averaging technique given in [9] and enough runs were made (typically 5000) to obtain 95 % confidence intervals with a relative precision of at least 0.05. The confidence intervals are very small and are not presented here to preserve the clarity of the plots. The analytical scheme mentioned above could be used to determine the best rerouting strategy for the case of K virtual circuits. The algorithm would sort the virtual circuits in decreasing order of their bandwidth and then use the analytical boundary curve to make an optimum decision on the first two virtual circuits. In the event of staggered rerouting scheme being chosen, the algorithm passes on to the next two virtual circuits in the list. If the simultaneous scheme is chosen, the algorithm replaces the two virtual circuits by a combined queueing model with a cumulative input rate and considers this in conjunction with the next virtual circuit in the list. Thus, the algorithm would proceeds down the list of virtual circuits, considering them two at a time. The use of the algorithm is illustrated in Figure 3 for the case of three virtual circuits in the network being restored. Two simulations were conducted, each with three virtual circuits, with their respective input rates given in the figure. In Figure 3a, the simultaneous and staggered scheme were compared with an intermediate restoration scheme wherein the first two virtual circuits were rerouted simultaneously while the third virtual circuit was rerouted in a staggered fashion after the network had recovered from the initial restoration. From these comparisons, it is seen that for this combination of input rates, the simultaneous restoration scheme gives the best results. This is a validation of the algorithm developed above which leads to the same conclusion. In the experiment relating to Figure 3b, by applying the algorithm, we see that an intermediate scheme consisting of simultaneously restoring the first two virtual circuits followed by staggering the third circuit until the network has reached a steady state after the initial restoration, should be the optimum scheme. It can be seen that the simultaneous and the intermediate scheme reach steady state at approximately the same time. However, as has been stated previously, the choice of the analytical model (the intermediate restoration scheme) seems to be better in terms of the better performance and lower loss of packets.

3 Study of Probability of Call Blocking

An important issue for consideration concerning the effect of the simultaneous rerouting of the virtual circuits that were using the failed link is the probability of call blocking. This metric gives a measure of the impact of the failure on the individual users of the network. In order to correctly analyze and collect data on the probability of blocking of the individual calls, a study was done on the 5-Node network of Figure 4. After the link failure, the calls to be rerouted were sorted at each source node. The effect of the ordering these calls in terms of their individual mean input rates was then studied.

The input rates for the virtual circuits in this experiment were chosen from an uniformly distributed function between 0.001 and 0.010. As each virtual circuit entered the network, their sources and destinations were picked at random. Once a path had been selected, the corresponding flows on those links were updated and the call was routed. Virtual circuits were continually added to the network until the cumulative flow in the network reached a specified value. The cumulative flow in the network was defined as the sum of the bandwidths of all the calls that had been allowed to enter the network. Once the virtual circuits were set up, the network was allowed to reach a steady state of operation. Then, a specific link was chosen and failed. In the experiment, link 2-4 connecting node 2 and node 4 as shown in Figure 4 was failed. The failure of this link affects all the virtual circuits that were routed along the link.

The main purpose of this experiment was to study the effect of the ordering of the virtual circuits before rerouting at each source node rates on the probability of call blocking. The virtual circuits were ordered based on an increasing order of bandwidth, decreasing order of bandwidth and in a random fashion. The random ordering scheme was portrayed as ordering the virtual circuits in terms of their order of arrival into the network. Details of the routing are given in [7, 8]. All the virtual circuits on the failed link were either set up along a new feasible path or blocked and denied re-entry into the network. The percentage of blocked calls that were using the failed link was then collected. The simulation run was stopped after all the virtual circuits attempted reconnection.

In order to get a true statistical average, the simulation was repeated for a large number of runs and a confidence interval was calculated on the probability of call blocking. In the study, a confidence interval of 95% with a relative precision of approximately 0.05 was maintained. For this, around 3000 runs were required. The experiment was repeated for various values of the total routed flows for each ordering scheme. The results of the experiments are given in Table 1. A similar experiment was conducted using a Petri Net simulator can be found in [8]. Figure 5 shows the comparison of the percentage of blocked calls while using the various ordering schemes. As can be seen in [8], the petri net model validates the simulation experiment. It is to be noted that ordering the calls in an increasing order of bandwidth gives the best results in terms of the percentage of calls blocked. The decreasing order of virtual circuits gives the worst case scenario for the total routed flow. In terms of design issues as well as for assuring the end user of a certain fixed maximum call blocking percentage (say 10%), it can be seen from the figures that there is a marked difference in the amount of total routed flow that can be supported in the network. The figures show that the increasing order allows for about 10% more traffic to be rerouted than the decreasing order of calls.

4 Simultaneous Implementation of Restoration Schemes in a Network

We have studied two issues relating to the rerouting process after a failure and the congestion that is caused. The first issue dealt with the adjusting the timing of the rerouting process so as to minimize the the level of congestion arising from the rerouting while the second issue was concerning the probability of call blocking during the rerouting stage.

In order to study the feasibility of combining the two control methods, the virtual circuits were sorted in an increasing order at a primary node and the timing of the rerouting analyzed. The generic two virtual circuit primary node model of Figure 1 was studied for various ratios of λ_1/λ_2 for fixed values of λ_2 and the times to reach steady state, TSS, using the simultaneous scheme and the staggered scheme were plotted. The comparison of the two schemes is shown in Figure 6 for a ratio of 0.7. Thus, the simultaneous scheme is almost always preferred. This is because, by sorting the virtual circuits in an increasing order of bandwidth, the second virtual circuit accumulates a greater backlog while awaiting its turn to get rerouted. This additional backlog takes a longer time to be worked off at the network node than if the second virtual circuit were rerouted simultaneously with the first one.

Thus it is seen that there is a trade-off between controlling the level of the congestion and controlling the probability of call blocking of the virtual circuits that were using the failed link. There exists a trade off in the requirements for the two schemes making it infeasible for both of them to be implemented simultaneously.

5 Conclusions

In this paper, an analytical model was developed to determine the optimum time to reroute virtual circuits after a link failure so as to reduce the congestion. A cross over curve depicting the optimum choice of the rerouting scheme was developed based on a queueing model with two virtual ciruicts and used to build an algorithm to make a similar decision for K virtual circuits. The results were validated via a simulation model and it was seen that the congestion could be curtailed using this algorithm. Another important issue concerning the minimization of the probability of call blocking during the rerouting process, based on the ordering of calls was considered. Finally, the feasibility of using the two schemes together in a network was studied. It was seen that an essential trade off exists in the requirements for the two schemes and hence they cannot be implemented simultaneously.

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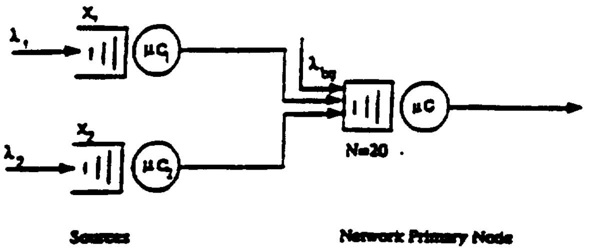


Figure 1. Generic Queueing Model with Two Virtual Circuits

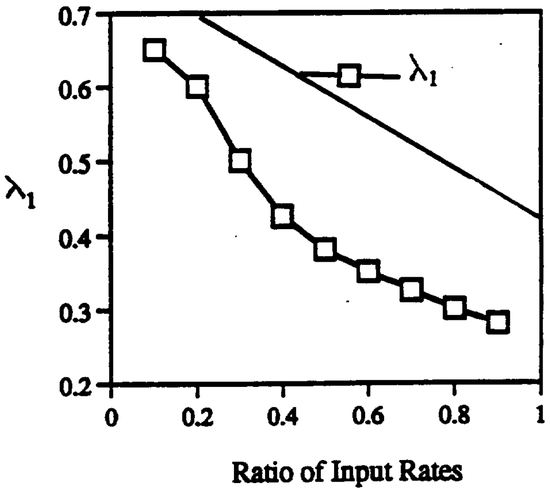
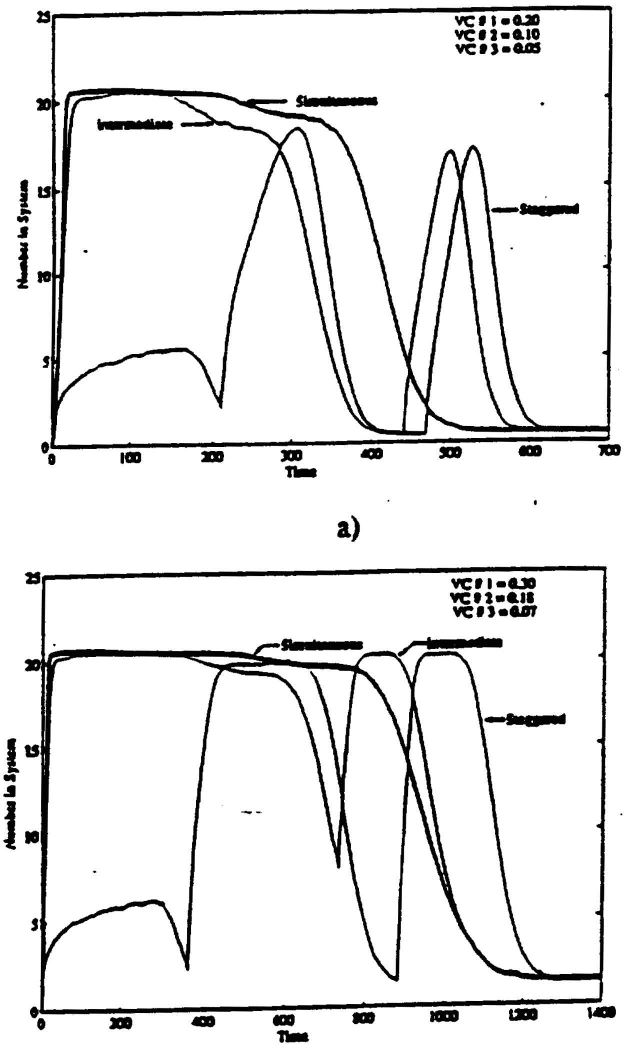


Figure 2. Analytical Boundary Curve for Selection of Time of Rerouting



a)

b)

Figure 3. Simulation Results for Rerouting 3 Virtual Circuits

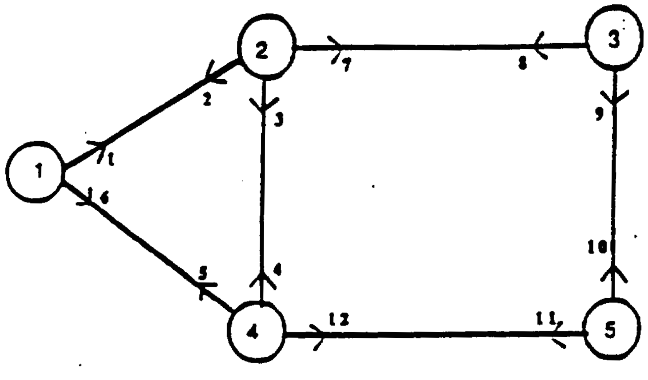


Figure 4. Sample 5 Node Network

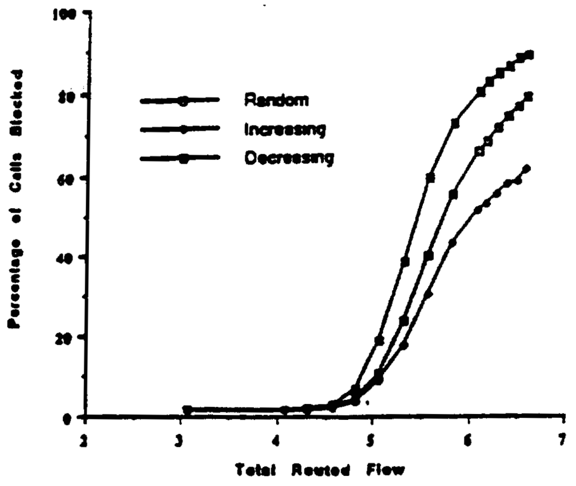


Figure 5. Comparison of Percentage of Calls Blocked in Network

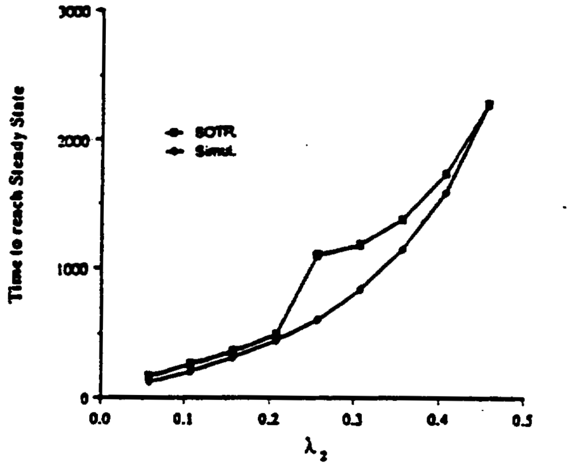


Figure 6. Comparison of Time to Attain Steady State