EVALUATING NETWORK SURVIVABILITY THROUGH EXPOSURE

McMenamin, P.G. and Fitzpatrick, G.J.
Bell-Northern Research, P.O.Box 3511, Ottawa, Canada, K1Y 4H7

Abstract
A traffic-oriented approach to network survivability is proposed for public telephone networks. The use of exposure to blocking as a tool to quantify traffic performance under network stress provides a direction for that effort.

Exposure was used to measure the effects of unplanned stress and proposed network changes on network survivability. The flexibility of exposure to consider the whole network or some smaller subset of node-pairs enhances its use as a tool for global or regional analysis of the effects of network stress. One can use the cumulative distribution of exposure over a group of node-pairs, or refer to a series of points on that distribution. This provides a meaningful comparison of various network design methods and architectures.

1. INTRODUCTION

The shared resources of a switched network have been engineered with generous safety factors and provide some survivability because of their design. As a result of resource sharing, computer modelling is required to obtain the levels of blocking that various traffic streams will encounter. By using measured traffic data, survivability can be quantified to help the network planner compare design methods and specific network proposals.

In the past, descriptions of network behavior under stress have been anecdotal (5) and usually related to disastrous incidents. A more objective method of analysis is needed as networks evolve and changes to technology are introduced.

A well designed network can provide superior traffic performance despite adversity such as equipment failure or traffic overload. The ability to plan and test designs before trouble begins is the first step to such performance protection.

Network survivability has historically focused on the ability to make at least one connection between any node-pair. Survivability in this sense has a long history in the study of military command and control networks. Public telephone networks have larger traffic volumes and fewer complete equipment failures than military networks, so can benefit from a traffic dependent measure of survivability to weight failure impact. Previous studies of survivability in public telephone networks have not established a measure for traffic performance.

At Bell-Northern Research we have modelled network traffic performance in a number of failure scenarios. We used exposure to measure survivability in a network. This paper will discuss the development, definition, and use of exposure as a tool to quantify the network traffic performance.

2. END-TO-END ASSESSMENT OF NETWORK FUNCTION

From a user's viewpoint the functioning of a telephone network is an end-to-end property. This principle is well established in transmission grade-of-service planning (2),(4),(7) and has been proposed and used in provisioning switched networks (1),(3),(6). Any telephone administration still requires operational measurements on equipment to ensure the end-to-end performance, but the functioning of the network can be described by end-to-end properties alone.

End-to-end assessment allows equivalent comparison of network configurations. Independence from network configuration is necessary in the evaluation of the performance of network function since changes in facilities and switches will occur between study cases. Given a network performance measure, survivability
can be assessed by comparing network performance under the design environment to network performance in a changed test environment. Changes to the design environment are typically equipment outages or unanticipated growth in traffic. The network performance evaluation is the subject of following sections.

3. TRAFFIC-DEPENDENT NETWORK PERFORMANCE MEASURE

In the networks we examined no incidents of complete disconnection were reported. The most likely sort of performance degradation in a telephone network is caused by a shortage of traffic capacity either from traffic overload or equipment outage.

Characterizing network performance when capacity is too low requires consideration of re-routing and congestion effects, namely a traffic approach. The extra calculation and modelling effort needed to take a traffic-dependent approach yields a close correspondence between the network performance measure and the effects as perceived by users.

Commitment to the traffic-dependent measure of performance requires a reliable method to specify traffic. Specification of traffic for characterizing end-to-end performance requires more than a single busy-hour approach. Single busy-hours are appropriate for single resources. The multiple resources of an entire network can reach capacity limits in different places and times. We chose to characterize traffic by a set of time-consistent point-to-point traffic matrices representing the daily time variations of business day traffic.

4. EXPOSURE: A TRAFFIC-BASED MEASURE OF NETWORK PERFORMANCE

Exposure quantifies the blocking performance of diverse traffic sets in a network. A traffic set includes the traffic offered to one or more node-pairs for a specified period. The basic traffic set used was one node-pair over an hour period. Exposure can be tabulated using either call attempts or offered traffic. It is the empirical cumulative distribution of blocking obtained by enumerating calculated, simulated, or measured end-to-end blocked and offered traffic over a collection of traffic sets.

Let us construct the definition of exposure. Divide a network into node-pairs. If the offered traffic between some pair is observed for a unit of time, then the traffic will be blocked at some measured level X%. If we then consider a collection of node-pairs and their blockings, we can identify all the offered traffic in the collection experiencing more than X% blocking. The proportion (Y) of that traffic to total traffic in the collection gives us an exposure level. We say that Y% of traffic is exposed to more than X% blocking. Exposure is an aggregate measure of service in the network. It is the proportion of traffic encountering blocking at any specified level. This is illustrated in the following example:

- 100 Call Units > 5% Blocking
- 250 Call Units > 3% Blocking
- 150 Call Units > 2% Blocking

Figure 1 Point-to-Point Blockings and Traffic for Computing Exposure Statistics

The network is offered a total of 500 call units and 350 call units are experiencing more than 3% blocking. If we consider only the 400 call units originating and terminating in the Southern Region then 62.5% of that traffic is exposed to more than 3% blocking. Whereas in the whole network 70% of traffic is exposed to more than 3% blocking.

The above division is spatial and a parallel example of exposure can be constructed in the time domain, as following cases will show.
5. USE OF EXPOSURE IN A SURVIVABILITY STUDY

The flexibility of exposure in considering the whole network or some smaller subset of node-pairs and time periods enhances its use as a tool for communicating the global or regional analysis of the effect of network stress. One can use the cumulative distribution of exposure over a group of node-pairs, or refer to a series of points on that distribution. For a given set of network nodes and offered traffic the use of exposure provides a robust measure of network performance under varied architectures, switch configurations and evolution plans.

An exposure distribution (as opposed to average end-to-end blocking) does not obscure the rare occurrences of high blocking where and when they occur within a network whose average performance is satisfactory.

Exposure and survivability concepts have been used in several studies at Bell-Northern Research. We have performed comparisons of various network architectures. Each has been subjected to a series of network stresses and exposure results have been obtained. Several examples are given in the following sections.

5.1 Detection of a Trend to Increasing Sensitivity

Exposure was first used graphically showing the entire empirical distribution for study cases. Figure 2 demonstrates an increasing exposure to blocking through time over a 100 to 200 node network as it grows, is reconfigured, and is subjected to a normal degree of forecast uncertainty. After becoming confident with the regularity of these empirical (as opposed to analytical) distributions, we chose three levels of blocking (1%, 5% and 20%) to encapsulate the information. Table 1 shows the forecast network of year 20 with exposure indicated by region.

Table 1 Regional Blocking Exposures

<table>
<thead>
<tr>
<th>Year</th>
<th>Time Period</th>
<th>Percent Total Network Exposure to:</th>
<th>&gt;5% Blocking</th>
<th>&gt;20% Blocking</th>
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</thead>
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<tr>
<td></td>
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<td>Total Network Exposure to:</td>
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<td>5%</td>
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<td>Average</td>
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<td>.04</td>
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<td>Peak/Average</td>
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<td></td>
<td>Peak/Average</td>
<td>1.80</td>
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(Zero Values not Shown)

Table 2 Variation of Exposure Over Time
Not only can the trend of sensitivity to stress be detected, it can be dissected to show the nature of the concentration of sensitivity in space (Table 1) and in time (Table 2).

5.2 Effect of Transmission Route Failures

Network transmission facilities were failed in a critical cross-section. If all the links were removed from such a cross-section the network would be separated into two distinct sub-networks.

The effects of a failure on internal and external traffic in distant regions are displayed in Figure 3. Effects on inter-regional traffic performance (exposure to more than 20% blocking) were found to be determined solely by the percent of cross-section loss, as shown by the accuracy of a linear fit between the two variables in Figure 4. Eliminated as significant in coping with such failures were a variety of routing options for circuits. Exposure to high (more than 20%) blocking was a useful indicator in making the comparisons between proposed remedies.

5.3 Effect of Switch Failures

Network evolution was modelled for switches in large metropolitan environments and for switches in somewhat isolated situations. Complete and partial switch failures were simulated and the exposure results reported. Figures 5 and 6 show the effect of the environment and evolution plans as measured through exposure. Figure 5 represents a switch which served an isolated, yet large community growing rapidly. Figure 6 shows the effect of a complete failure on a switch in a large metropolitan environment. Exposure decreases with time, due to evolutionary plans, but the near term effect of an equivalent failure is much more devastating in the isolated case. This reflects the ability of the multiple-switch metropolitan environment to absorb the affected traffic.

5.4 Results

The design and analysis of the networks were performed through the use of Bell Northern Research network planning tools such as GPTM (General Purpose Trunking...
6. CONCLUSIONS: EXPERIENCE WITH EXPOSURE

Exposure is a weighted, end-to-end blocking performance measure. It gives us a single comprehensive basis to reduce discussion and speculation about network performance. We were also able to avoid shifting of criteria from case study to case study. The concept was found acceptable to telephone company planners and was used in examining and supporting recommendations. The ability of different regions to examine their own subsets of the networks using exposure was particularly useful, given regional architecture differences. We feel that exposure can withstand critical regulatory and technical appraisal in quantifying network traffic performance for comparative studies of contentious issues.

The requirements for a study of this sort are:

- end-to-end traffic estimates
- network node description and routing scheme
- a sizing algorithm using the above
- an end-to-end blocking evaluator for networks and traffic
- a mapping of equipment failures to trunk failures for an end-to-end blocking evaluator.

The exposure criterion itself uses a bookkeeping operation which identifies traffics exposed to various levels of blocking.

The benefits we have experienced are:

- the ability to separate and combine at will the subnetworks of interest without confounding results
the ability to concisely summarize performance over the breadth of an entire network and over all operating times.

These properties permit exposure to be the vehicle for a presentation of results of extensive survivability analyses.

We would like to acknowledge the help of George Yee, of Bell-Northern Research, who coded and used PERSUE (Performance and Survivability Evaluator) to perform a number of the case studies illustrating exposure.

REFERENCES


Summary of Questions/Answers

Date: 13 June 1983
Session: 2.3
Paper: 6

Q.1 (J.R. De Los Mozos)
You have performed survivability studies of specific networks with one program called PURSUE. Is it a program for survivability evaluation or does it do any network synthesis based on survivability objectives? Could you please comment on this.

A.1 (P.G. McMenamin & G.J. Fitzpatrick)
PERSUE is in fact a framework for analysis with some specialized software modules. The framework holds other tools developed and used at BNR. The synthesis or design portion of PERSUE is the General Purpose Trunking Model (GPTM) and it provides a GOS on finals. When the synthesis has been performed the resulting trunk quantities are assigned to existing or planned transmission facilities. We impose some contraints on the transmission network and use a least cost routing algorithm. We then model the failure of facilities and compute the effect of the failures on various traffic sets, using a reassignment of flows to the remaining facilities. These results are then used to evaluate network survivability.