Effect of Buffer Size and Packet Delay on the Survivability of Packet Switched Networks

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***Abstract*—In this paper, the survivability of general-case packet-switched networks is studied. Most of network properties are considered as random variables and a queuing-theory based model is derived. In this model, the effect of buffer size and packets' delay on the survivability of the network is considered. Simulation results are used to validate the proposed model. The simulation results agree very well with the model.**

***Index Terms*—Survivability, Packet Switched Networks, Buffer Size, Delay**

I. Introduction

The problem of designing networks able to survive an enemy attack or natural disaster is of paramount importance. Recent work has focused on the mathematical formulation of physically meaningful survivability criteria, the development of analysis methods to rank networks in terms of these criteria, and the generation of networks which are optimal with respect to these criteria. Numerous partial results for a variety of network models are available.

The study of network survivability has been divided into two nearly disjoint areas: deterministic survivability and probabilistic survivability. In the former, an adversary is usually assumed to have complete knowledge about the system to be attacked and also uses a deterministic attack strategy. In a probabilistic model, the adversary may have only partial information about the enemy's network or may employ a randomized attack strategy.

Because of the dichotomy of network and attack models, typical survivability criteria can also be classified as either deterministic or probabilistic. A network may be considered to "survive" an attack if 1) all points (nodes) can communicate with each other; 2) there are some flow paths between specified pairs of points; 3) the number of points in the largest connected section exceeds a specified threshold; or 4) the shortest surviving path between each pair of points is no longer than a specified length.

The object of a deterministic analysis might be to determine if these criteria are met subject to a known attack while a probabilistic analysis might seek to find the probabilities that these criteria will be satisfied. Corresponding design objectives could then be constructing networks subject to fixed resources which maximize the effort the adversary must make to "destroy" the network, or the probability that the network will survive.

The purpose of this paper is to perform a probabilistic analysis of packet-switched network considering the packet loss and delay of packets as survivability measures. The effect of buffer size is also examined.

The rest of this paper is organized as follows: in Section II a literature survey is presented. In Section III the preliminaries and assumption of the problem are clarified. In Section IV a model for evaluating the survivability is derived. Section V presents the simulation results and Section VI concludes the paper.

II. Related Work

III. Preliminaries

IV. Evaluating the Survivability

With the above assumptions, we begin the modeling process.

Step 1: we calculate the packet loss of a typical path. The packet loss of a path, PL_{path}, is the sum of packet losses of all of its constituent nodes:

$$PL_{path} = \sum_{i=1}^{n} PL_i \tag{1}$$

Now, we obtain the expectation or mean value of packet loss in a path. The long term average rate of packet loss in a node is equal to packet loss probability of that node, denoted it by PL_i.

$$E\left[PL_{path}\right] = E\left[\sum_{i=1}^{n} PL_i\right] = \sum_{i=1}^{E[n]} E\left[PL_i\right] \tag{2}$$

Now, we have to calculate the mean value of packet loss in each node. The packet loss probability is the probability that the buffer is full and there is no space for new packets. From queuing theory it is equal to PL [4]:

$$PL = P_{B+1} = \frac{\left(\frac{\lambda}{\mu}\right)^{B+1}\left(1-\frac{\lambda}{\mu}\right)}{1-\left(\frac{\lambda}{\mu}\right)^{B+2}} \tag{3}$$

An important thing to consider is that our model is of open queuing network type and the assumption of independence of arrival is no longer held. That is, the arrival rate to the second node is dependent on service rate and packet loss of the first node. In the same manner, the third node is dependent on the second node and so on. Therefore the Poisson property of arrivals in no longer valid and the computation will be very complex. For this reason, we define an approximating assumption: the arrival rate of all nodes remain Poisson, but the corresponding λ changes. For example, suppose that we want to know the arrival rate of node i; we know that the arrival rate of its preceding node is λ_{i-1} and the packets are lost with the probability PL_{i-1}. Therefore, with a simple approximation, the arrival rate of the i^{th} node can be calculated:

$$\lambda_i = \lambda_{i-1} \times PL_{i-1} \tag{4}$$

And also:

$$\lambda_1 = \lambda \tag{5}$$

Step 2: we calculate the mean value of a typical path's delay. A packet traversing from source to destination, wait a time equal to W in each node, then enters a link and has a propagation delay equal to t_p. Therefore, as there are N nodes and $N-1$ links, the path's delay is:

$$Delay_{path} = \sum_{i=1}^{E[n]} W_i + (N-1)\, t_p \tag{6}$$

Where, W_i is the value of W when $\lambda = \lambda_i$, and W is the waiting time of a $m/m/1/k$ queue which in turn is [4]

$$W = \sum_{n=0}^{B} \frac{(n+1)\, P_n}{\mu\,(1-P_{B+1})} = \frac{L-(B+2)\, P_{B+1}+1}{\mu\,(1-P_{B+1})} \tag{7}$$

L is the mean number of packets in a node and is equal to [4]:

$$L = \frac{\lambda \left(1+(B+1)\left(\frac{\lambda}{\mu}\right)^{B+2} - (B+2)\left(\frac{\lambda}{\mu}\right)^{B+1}\right)}{(\mu-\lambda)\left(1-\left(\frac{\lambda}{\mu}\right)^{B+2}\right)} \tag{8}$$

Therefore, we have:

$$\begin{aligned} & E\left[Delay_{path}\right] \\ & = \sum_{i=1}^{n}\left(\frac{L_i-(B+2)\, P_{i,B+1}+1}{\mu\,(1-P_{i,B+1})}\right) + (E\,[N]-1)\, E\,[t_p] \\ & = \sum_{i=1}^{n}\left(\frac{L_i-(B+2)\, P_{i,B+1}+1}{\mu\,(1-P_{i,B+1})}\right) + \frac{E\,[Len_{link}]}{C} \end{aligned} \tag{9}$$

Len_{link} is a random variable and demonstrates the distribution of links' length. C is the light speed or more precisely, the propagation speed of waves in the links.

Now, for evaluating the survivability of a path, we employ the following reasoning: If the path doesn't fail, as long as the values of packet loss and packets' delay don't exceed a specific threshold, the survivability is equal to one. When these values exceed their thresholds, the value of survivability has inverse relation with the difference of packet loss and delay to their threshold. Now, if this path fails, with some probability, a spare path is chosen, and then the survivability of this new path determines the survivability of the previous one. Therefore the similarity of the statistical properties of the paths helps us and the following equations are obtained:

$$\begin{aligned} & Survivability \\ & = \frac{1-P_{path\_failure}}{1+\max\left(PL_{path}-T_{PL},0\right)+\max\left(Delay_{path}-T_{Delay},0\right)} \\ & + P_{path\_failure} \times P_{existence\_of\_backup\_path} \times Survivability \end{aligned} \tag{10}$$

$$((1+\max\left(PL_{path}-T_{PL},0\right)+\max\left(Delay_{path}-T_{Delay},0\right)) \times (1- \tag{11}$$

V. Simulation Results

VI. Conclusion

We have presented in this paper a queuing-theory based model for general-case packet-switched network in which the nodes are $m/m/1/k$ queues. Parameters such as buffer size and packets' delay were considered important in determining the survivability of such network. Simulation results are in accordance with the model. It was shown that increasing the buffer size has a positive impact on the survivability. Increasing the number of nodes and the link failure probability both decrease the survivability.

The future work is to impose more realistic limitations on network properties such as dependence of node failures on each other, the impact of traffic resulted from path replacement on packet loss, the impact of link failure on packets' delay, assuming different structures for network nodes, dependence of link failures on each other, the possibility of repair and recovery in the network and so on.

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