Performability Analysis of Token Ring Networks using Hierarchical Modeling

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Abstract

It is important for communication networks to possess the capability to overcome failures and provide survivable services. We address modeling and analysis of performability affected by both performance and availability of system components for a token ring network under failure and repair conditions. Stochastic reward nets (SRN) is an extension of stochastic Petri nets and provides compact modeling facilities for system analysis. In this paper, hierarchical SRN modeling techniques are used to overcome state largeness problem. The upper level model is used to compute availability and the lower level model captures the performance. And Normalized Throughput Loss (NTL) is obtained for the composite ring network for each node failures occurrence as a performability measure.

One of the key contributions of this paper constitutes the Petri nets modeling techniques instead of complicate numerical analysis of Markov chains and easy way of performability analysis for a token ring network under SRN reward concepts.

Keywords: Performability, SRN, hierarchical modeling, token ring network.

1. INTRODUCTION

With the increase in complexity, scale, and speed of communication networks, network performance under failure has become a great issue in industry. A failure may significantly reduce the capability of the communication network to efficiently deliver service to users. The networks need to cope with failures to preserve the network service integrity under failures. For this reason, network reliability and survivability are very important metric for communication networks and performance metric have been studied in several papers [1-3].

Pure performance models assume failure free operation of the components involved. However failures of components within a system could lead to performance degradation. Thus, the effect of partial failures needs to be factored in to yield a comprehensive evaluation of the system. Pure availability models on the other hand only consider the failures of components. Thus, to get a comprehensive picture, a combination of performance and availability models is needed. This concept was first introduce by Meyer and called "performability"[4]. In this paper, we address a performability analysis of a token ring network. The token ring network consists of N nodes and N links connected. The failure of some nodes or link in a ring network may not necessarily bring the whole network down.

In this paper, we propose to carry out a composite approach to evaluate the network performability, where the transient overload analysis is incorporated into the failure frequency analysis. We use a hierarchical model which captures both the system transient behavior, availability to evaluate failure and repair impact on the system and the system steady state behavior, normalized throughput loss and mean response time.

2. STOCHASTIC REWARD NETS (SRN)

In order to make more compact models of complex systems, several extensions are made to Stochastic Petri Nets [5, 6], leading to the SRN [7]. One of the most important features of SRN is its ability to allow extensive marking dependency. In an SRN, each tangible marking can be assigned with one or more reward rate(s). Parameters such as the firing rate of the timed transitions, the multiplicities of input/output arcs and the reward rate in a marking can be specified as functions of the number of tokens in any place in the SRN. In a SRN model, assigning transition rates to state transitions and solving the continuous Time Markov Chain (CTMC), the probability mass function is then obtained.

Another important characteristic of SRN is the ability to express complex enabling/disabling conditions through guard functions. This can greatly simplify the graphical representations of complex systems. For an SRN, all the output measures are expressed in terms of the expected values of the
We take the SRN model from [11] as shown in Figure. 3 as

3.1 Upper level model: Availability model

We use availability model as upper level model. The SRN model is shown in Figure. 1. The N tokens in places pNup and pLup represent the number of nodes and links correspondingly. The firing rate $\lambda$ of transition $t_{f}$ represents the failure rate of a link. The $\lambda$ is dependent on the number of tokens in place $pLup$. When the transition $t_{f}$ fires one token moves to the place $pNudn$. Depending on reason of the failure, the network continues to operate. The amount of tokens in place $pLup$ represents the amount failed nodes. The firing of transition $t_{r_{rep}}$ represents node repairing. After repairing token moves to the place $pNudn$. The inhibitor arc the tokens would continue to move from $pLup$ to $pNudn$ after the network downed. The inhibitor arc from $pcov$ to $cov$ is used to put a constraint that there must be at least one node working for the network to be up.

The token in place $pnf$ or $plf$ means the failure of node or link correspondingly. This is done to know the reason of network failure. The firing of transition $t_{r_{rep}}$ represents the repairing of a whole network. After firing of this transition the token moves to the place $prep$. Depending on reason of the network failure immediate transition $t_{nfr}$ fires and token moves back to $pNudn$ or $pLup$. Some arcs in this model has variable arc multiplicity, which means that if transition fires the all tokens from the source place will be transferred via corresponding transition.

3.2 Lower level model: Performance model

As a lower level model, we consider a client server system based on a token ring network consisting of N workstations (nodes) and one server interconnected by a local area network. The server station receives requests from its client stations the request and returns replies to the requesting stations under failure conditions.

The client server system consists of 3 subsystems which are tagged client, server, and superclient, as shown in Figure. 2. The superclient subsystem which is lump of remaining clients enables us to closely approximate (N-1) multiples of single client subsystem. Using this approach we reduce the number of states of the Markov chain and thus can resolve state largeness problem [11].

Hierarchical SRN model is the Markov reward model where the reward rates comes from a sub-model. The upper level model is the structure state model representing the state of the system with regard to failure and repairs. The lower level model captures the performance of the system within a given structure state.

We build both the availability model as a upper level model and performance model as a lower level model.

The SRN model is automatically transformed into a Markov Reward Model (MRM) [6,7], and the upper level model describes the availability for the ring network, while the lower model characterizes the system performance under each state of the availability model [9].

Integrating system availability and performance in a single model often causes the large state space problems [8]. In order to compute performance measures for the ring network under failures and repair events, we use the hierarchical modeling approach in which the upper model describes the availability for the ring network, while the lower model characterizes the system performance under each state of the availability model [9].

Hierarchical SRN model is the Markov reward model where the reward rates are assigned to its SRN. As SRN is automatically transformed into a Markov Reward Model (MRM) [6,7], steady state and/or transient analysis of the MRM produces the required measures of the original SRN. The measures are defined in terms of reward rates associated with the markings of the SRN.

3. HIERARCHICAL PERFORMABILITY MODELING

We build both the availability model as a upper level model and performance model as a lower level model.
the client server system. But [11] did not include the effect of failures. In this paper, we employ this SRN model as a lower level model under failure conditions and construct hierarchical model.

Figure. 3 shows SRN model which consists of 3 subsystems as above mentioned. The detail meanings of places and transitions in Figure. 3 are explained on Table 1 and 2, respectively.

When the number of PN tokens in P8 reaches N-1, implying that all members of the subsystem have been polled, then with a PN token in P9, T9 fires immediately and a PN token is deposited in P4.

The zigzag sign on the input arc from Pow to s6 denotes that the multiplicity of the arc is variable. Assume that Pow contains k PN tokens where 0 < k <= N-1, and Ptw has none. Then s6 is enabled and it fires immediately by removing all k PN tokens from Pow and k PN tokens will be deposited in Poh.

Table 1. Meanings of places in Fig. 3 SRN model

| subsystem   | place | meaning                                |
|-------------|-------|----------------------------------------|
| tagged client | P0    | the client is in idle state            |
|             | P1    | client is waiting for the network token |
|             | P2    | the network token has arrived, polling token |

Table 2. Meanings of transitions in Figure. 3 SRN model

| subsystem   | transition | meaning, rate |
|-------------|------------|---------------|
| tagged client | T0         | the client has generated a request, \( \lambda \) |
|             | T1         | transmission time, \( \mu \) |
|             | T2         | the client has no request to transmit |
|             | T6         | the network token is being passed to its neighbor, (polling time), \( \delta \) |
| server      | T4, T5, T7 | same role as T1, T2, T6 respectively |
|             | Tsa        | the time required for the server to process a request, \( \tau_i \) |
|             | tss        | the time to transmit a reply, \( \beta \) |
| superclient | T4, T5, T7 | same role as T1, T2, T6 respectively |
|             | s8         | the tagged client’s request cannot be replied until request from the superclient subsystem that arrived before it have been replied. |
4. PERFORMABILITY MEASURES

In order to obtain the performability measures numerically from the SRN model, underlying CTMC is generated and solved through the use of the well known software package, SPNP (Stochastic Petri Net Package) [12] developed by researchers at Duke university. SPNP provides support for specifying the SRN using a "C" like programming language and allows the modeler to do steady-state, transient, cumulative transient and sensitivity analysis.

We assume the all transition firing rates in our SRN models are exponentially distributed.

- Unavailability

Unavailability is quantified by the transient performance of a ring networks which are exposed to link and node failures. It can be computed using the following construction in SPNP.

```c
double get_unAvail() {
    if (mark("pringfail") >= 1) return 1.0;
    return 0.0;
}
```

In our code we call this function during solving the model in transient mode at each time interval.

- Normalized Throughput Loss (NTL)

Since the effect of node failures is considered, NTL is performability measure as opposed to just performance measure. The throughput of a ring network from the lower level model depends on how many stations are working under failure conditions. NTL is the fraction of throughput with \( i \) stations, the number \( i \) is passed by upper level model when \( i \) nodes are functioning and \( N - i \) nodes are failed for each node failures occurrence. NTL is calculated using the following formula:

\[
NTL = \frac{\sum_{i} \text{Throughput}[i] \times \text{Frequency}[i]}{\sum_{i} \text{Throughput}[i] \times \text{Frequency}[i]},
\]

where \( \text{Throughput}[i] \) is the network throughput, calculated by taking the real value of \( \text{tss} \) transition’s rate with available \( i \) stations, the number \( i \) is passed by upper level mode when \( i \) nodes are functioning and \( N - i \) nodes are failed and \( \text{Frequency}[i] \) is the number of times of calling the low-level model with particular amount of available nodes \( i \), calculated by accumulating this number in local variable.

- Mean Response Time (MRT)

MRT is a time to take to service a job. To calculate MRT, we use the formula for probability that the tagged client is idle.

\[
\text{IdlePb} = \frac{1}{1 + \frac{1}{\lambda + \tau}},
\]

\[
\tau = 1 - \text{IdlePb}.
\]

Where \( \lambda \) is a client request rate, \( \tau \) is mean response time.

- throughput

The network throughput is number of reply per unit time executed by server and can be obtained as a reward rate of transition \( \text{tss} \). It is calculated by the SPNP’s build in function \( \text{rate(char* tr_name)} \).

\[
\text{Throughput} = \text{rate("tss")};
\]

5. NUMERICAL RESULTS

5.1 Input data

We now present the input data for solving our hierarchical model. For the higher level we specify failure values as once a day (\( \lambda_n = 1/24 \) in hour unit) and ones a week (\( \lambda_l = 1/168 \) in hour unit), for nodes and links correspondingly. We assign repair time as 10 minutes (\( \gamma_n = 6 \) in hour unit) and 1 hour (\( \gamma_r = 1 \) in hour unit) for nodes and the whole ring network correspondingly. And finally we put probability 0.3 that the node fails without successful bypass which means that it cause ring failure and the probability 0.7 for the successful bypass. For the lower level model, we assume that network bandwidth is 100 Mbps and network cable length is 2 Km and that request packet length is 1500 byte which corresponds to \( 1/\mu = 0.12 \) ms, \( \mu = 8.3 \), and that reply packet length is 6K bytes/packet which corresponds to \( 1/\beta = 0.48 \) ms, \( \beta = 2.08 \), and that the mean token length is 30 bytes, which corresponds to a mean polling time \( 1/\delta = 1.0/(0.01/(N+1) + 0.0024) \) ms, where \( N \) is a number of nodes. Finally we assume that the mean time taken by the server to produce a reply is 2 ms (\( \eta = 2 \)).

5.2 Numerical results

The results of unavailability analysis obtained by solving higher level SRN model are shown in Figure 4.
We tabulate the results of NTL for different number of nodes and different token requesting rates to see the changes of NTL values as shown in Table 3..

| \( N \) | Normalized Throughput Loss (NTL) |
|--------|----------------------------------|
|        | \( \lambda = 1 \) | \( \lambda = 2 \) | \( \lambda = 3 \) | \( \lambda = 4 \) |
| 3      | 0.1989915     | 0.157456     | 0.141119     | 0.132438     |
| 4      | 0.183924      | 0.143073     | 0.127887     | 0.119952     |
| 5      | 0.162672      | 0.125141     | 0.111541     | 0.104485     |
| 6      | 0.142798      | 0.109158     | 0.097127     | 0.090909     |

The results of throughput, number of reply per millisecond, are shown in Figure. 5. As \( \lambda \) and \( N \) increasing, network throughput is increasing, however if the number of nodes is greater than 7 the throughput is not increasing. It stays the same even we increase requesting rate.

Figure. 6 shows the results of mean response time of a tagged client in milliseconds. As we see the MRT depends mostly on the number of nodes.

5.3 How do we run the hierarchical model.

To build the hierarchical model we create two separate independent models written in special “C” like programming language, which is used to describe SRN models ready to analyze with SPNP package. The one file represents higher level and the other one low level model. The higher level file contains the code which calls low level model at some step of its execution. For the calling the low level model we use C-shell script, which we prepare by setting some parameters for the low level model and then call it using system function. The example of this call is shown in Listing 1. After the low level model called it is then executed and we need to get the results.
to the higher level. This is done by using pipes and language for processing text-based data, for example awk. The output of the low level model is written to standard output file with extension *.out. We use this file to read the returned values. In higher level model we open the pipe and using awk read the necessary data and then we put it to the local variable. We define guard function to call low level model for the transition \texttt{tnf} and firing of this transition causes the changes of the number of nodes which is our interest. The guard function is called when \texttt{tnf} is enabled.

```plaintext
Listing 1. Calling low level model.

```c
fshell = fopen("l_shell", "w");
fprintf(fshell, "set n = %d\n", nnodes);
fprintf(fshell, "set rfail = %d\n", ring_fail);
fprintf(fshell, "set lambda = %d\n", lambda);
fprintf(fshell, "echo $n $rfail $lambda | l6.spn\n");
close(fshell);
system("csh l_shell");
if ((pp = popen("grep TSS_THP l6.out | awk '{print $4}'", "r")) == NULL) {
perror("popen");
exit(1);
}
scanf(fpp, "%14lf", &val);
close(fpp);
printf("Value from lower level:%f\n\n", val);
if(ring_fail ==0) Thp[nnodes] = val;
```

6. CONCLUSION

We constructed hierarchical performability SRN models for a token ring network and analyzed the network performability involves both the system availability and the system performance under failure conditions. Measures of interest, such as NTL as a performability measure, unavailability from the higher level, MRT and throughput from the lower level were obtained by using reward rates in SRN models.

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