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André B. Bondi

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André B. Bondi

Department of Computer Sciences
Purdue University
West Lafayette, IN 47906

CSD-TR 483

ABSTRACT

Many computer systems have components with FCFS queueing and service time distributions that may not be exponential. Exact models of such systems are usually intractable. When the component is a local area network gateway, the analysis is complicated by the possibility that a job's queueing delay may depend not only on the network's service parameters, but also on the load offered by all hosts attached to it. Modeling the delay at LAN gateways as self-contained units may be possible, but this does not tell us about their impact on the performance of the system as a whole. A method of predicting this impact based on Marie's algorithm for the solution of closed queueing networks with Coxian servers has been proposed. An open-queue model of a local area network is driven by the throughputs of each of its gateways; the gateway at each host is treated as a Coxian server whose queue length will match that predicted by the open model. These Coxian servers are then used in Marie's algorithm to predict the performance of each host in turn. The procedure is iterative; it is terminated when the convergence criteria for Marie's algorithm are met by the models of all hosts. The method has been applied to a modified version of the Berry-Chandy model of a token ring with nonexhaustive service. The results are close to those predicted by simulations of a ring with two hosts for various traffic loads.

The choice of Marie's algorithm as the solution framework is motivated by its ability to capture the variable nature of the inter-arrival processes in networks with servers having high service time coefficient of variation. Simulation data suggest that the arrival variability may be a contributing factor to a curious phenomenon: if a closed network contains a sufficiently large number of jobs, the queue length of the bottleneck server may decrease as its service time coefficient of variation is increased. This phenomenon is predicted both by Marie's algorithm and exact solutions of small systems.

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1. Introduction

The service characteristics of local area networks deviate greatly from the product form assumptions [Bas75a] of closed queueing network models of computer systems solvable by efficient algorithms. This is because they (or the ports through which they are reached) often have non-exponential service time distributions with FCFS service at each host, or because they may delay or block waiting and newly arrived jobs even when they are idle [Bux81a,Tro81a].

Some types of local area networks have been accurately modeled in isolation as open queues with infinite Poisson arrival streams, while host computers have usually been treated as closed queueing networks with finite populations [Buz73a]. Rather than modeling hosts and local area networks in isolation, we would like to predict the performance of the local area network and the system collectively. The assumption Poisson arrivals is invalid in closed systems with finite populations. This limits the ability of the isolated models to predict the performance of the local area network in the system as a whole. Because an exact model of a system containing a local area network port can usually be solved only by the often computationally intractable procedure of enumerating and solving the system's steady state equations, approximate methods must be used to predict the system's performance instead. In this paper, we shall present a framework for modeling the influence of local area network contention on hosts' performance. We shall call the framework a model integration scheme, because it combines closed queueing network models of hosts and with existing models local area networks to produce an integrated model that makes predictions about the performance of the entire system. We shall demonstrate the applicability of the framework by using a modified form of the Berry-Chandy token ring model [Ber83a] to predict the effect of a token ring with non-exhaustive service (e.g. the Zurich ring [Bux81b] or PRONET [Sal82a]) on the performance of connected hosts. We shall compare the results with simulations for a variety of host workloads and ring utilizations.

The remainder of this paper is organised as follows. In Section 2, we shall describe some properties of closed networks with non-exponential FCFS servers, and use these properties to motivate the choice of Marie's method for solving models of closed queueing networks with non-exponential servers [Mar78a] as the basis of our model integration scheme. The remainder of the paper describes the model integration scheme and compares its predictions with simulation results. The work described here is taken from [Bon84a]. The notation used in this paper is described in Table 1.

Table 1: Notation

C_i	Service time coefficient of variation of server i
K	Number of servers in a network
MPL	Number of jobs in a closed network
N	Same as MPL
P	Routing probability matrix
R_0	System response time
R_i	Response time of server i
S_i	Mean service time of server i
U_i	Utilization of server i
V_i	Visit ratio of server i, solution of $\mathbf{V}=\mathbf{VP}$
X_0	System throughput
X_i	Throughput of server i

2. Development of the Method

Our modeling framework uses open queueing models of general servers in conjunction with a closed queueing network algorithm to make predictions about the performance of closed systems. When applied to local area networks, the framework should attempt to account for the interaction between two mutually dependent performance measures that are predictions of closed queueing network models:

(a) Each host's throughput, and hence the traffic it offers to the local area network, is influenced by the delays at all its servers.

(b) Conversely, the network access delay at each host is affected by the combined traffic offered to the network by all hosts, because the job at the head of one host's network access queue may be blocked until the network is freed by a job at another host. Thus, the queueing delay at a port is partially determined by factors *external* to the local host.

We propose to approximate blocking by treating the blocking servers as non-exponential servers, and then solving the resulting closed queueing network using an accurate and efficient algorithm for non-product form networks. In the case of LAN ports, the service time coefficients of variation (CV's) will depend on the total LAN loading and on the LAN's performance characteristics.

Before describing how the non-exponential servers are fitted, we shall briefly discuss the role of service and interarrival time variance and blocking in queueing delays. The intuition that is gained from this discussion will be used to motivate a heuristic for modeling the effect of contention for local area networks on the performance of the attached hosts.

2.1. The Effect of Service Time Variability

Queueing delays are caused by a number of contributing factors. Among these are mean service time, mean arrival rate, service time CV, and interarrival time CV. In systems in which a waiting job is served immediately by an idle server, the last two factors are the ones that contribute to a job's waiting time. To see this, consider a D/D/1 queue (regular arrivals, fixed service time). If the server is initially idle and the interarrival time exceeds the service time, no queueing will occur. In this instance, the mean response time is equal to the service time; in systems with either service time or interarrival time variance, queueing is bound to occur, as a job may arrive while the server is busy.

Our choice of a framework for incorporating an open queueing model of a server into closed queuing network algorithm is motivated by its ability to capture the effects of service time variability on the performance measures of closed networks. The data in [Bal79a] showed that increased service time variability usually degrades the system throughput. In his Ph.D. thesis, Bondi [Bon84a] showed that increasing the service time variance of the most heavily utilized (or bottleneck) server in a closed network may decrease its mean queue length. This behaviour, which Bondi called the *bottleneck anomaly*, is contrary to what is usually assumed about queue lengths in open networks [Whi83a]. The anomaly occurs because increased service time variance at the bottleneck server leads to markedly increased interarrival time variability at adjacent servers. The resulting increase in the other servers' queue lengths draws jobs away from the bottleneck server, and its queue length is thereby reduced. This phenomenon is predicted both by Marie's approximate algorithm for closed queueing networks with non-exponential servers [Mar78a] and by global balance solutions contained in [Bal79a, Rug81a] and [Bon84a]. An outline of Marie's algorithm appears in Figure 1. Briefly, Marie's algorithm treats each queue as a Coxian server with state dependent arrival rates ($\lambda(n)/C_k/1$); a server's arrival rate is assumed to be instantaneously zero when all jobs in the system are queued there. Thus,

$$\lambda_i(N)=0 \tag{1}$$

The arrival rates are obtained by solving the complementary closed queueing network, i.e. the network containing all servers but that of interest. The normalising constant vector of server i's complementary network is denoted G_i in Figure 1. Before the next iteration, each server is fitted with a set of load-dependent service rates that are used to compute the next estimate of the throughputs of the complementary networks. The service rates of each server are corrected after each iteration to ensure that the queue lengths of all servers add up to the network population and that the flow balance constraints $X_i = V_i X_0$ are approximately satisfied.

The corrections are described in [Mar78a] and [Bon84a] and will not be repeated here.

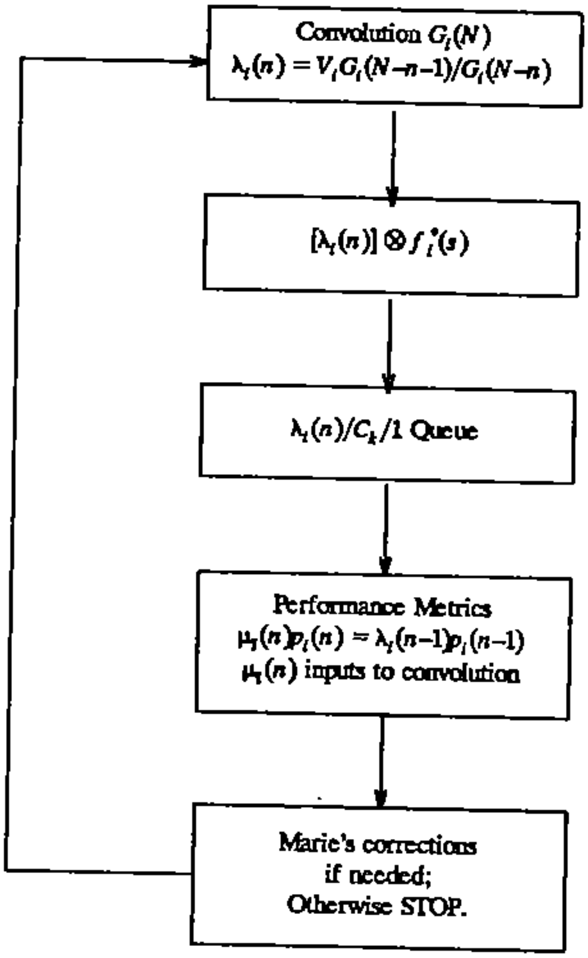

Figure 1: Scheme for Marie's algorithm

We believe that Marie's algorithm is accurate because it implicitly accounts for the variable nature of arrival processes in non-product form networks by treating the arrival processes as as state-dependent. We have chosen the algorithm as the basis of our model integration scheme because of its ability to capture this effect of and because of its accuracy and speed.

2.2. The Effect of Blocking

Queueing is also bound to occur if a server is blocked immediately after rendering service, unless the interarrival time, service time, and blocking time are all constant and the total of blocking and service times is less than the interarrival time. Servers with blocking are not uncommon. In a token ring, a packet must await transmission until the token arrives at its port [Bux81b]. Data transfer at a disk or sectored drum cannot occur until the correct sector is under the read/write heads [Cof69a,Cof73a]. In each of these cases, an idle server is blocked before service is rendered. This blocking causes the server's queue length to increase. If the distribution of the blocking time is known and is independent of the service time, the effect on queueing throughout the network may be captured by replacing the service time distribution with the convolution of the blocking and service time distributions.

A different approach is required when the distribution of the blocking time is not explicitly available. We propose a scheme that attempts to account for variable blocking delays by modifying the LAN port's coefficient of variation of service time, while leaving the mean service time, and hence the server's utilization, fixed. As argued in [Bon84a], the advantage of this scheme is that it approximately accounts for the effect of blocking on the variability of the interdeparture times at the ports and hence the effect of the corresponding interarrival time variability on other stations in the network.

3. An Integration Scheme: The Method of Apparent Coefficients of Variation

Suppose that a system component i may be modeled as an open queue fed by one or more Poisson streams, but that the (effective) service time distribution f_i either is not Coxian or else cannot be determined explicitly because of blocking even though average waiting times are available.

If the service time distribution can be explicitly determined and has finite moments, an accurate approximation f_i^a with the same moments may be constructed which is a mixture of exponentials and therefore has a rational Laplace transform. The rational Laplace transform corresponds to a Coxian distribution. The system may then be solved using Marie's algorithm [Mar78a] without further modification.

Now consider the case in which the distribution of the combined service and blocking times cannot be explicitly determined, although the mean service time S_i and the mean waiting time $W(X_i, S_i)$ are available for a given throughput X_i. The variability of the arrival process at i in the closed network will be approximated by the state-dependent arrival rates $\{\lambda_i(n)\}$ produced by Marie's algorithm. We suggest that the original server be replaced in Marie's algorithm by a Coxian server having the same traffic intensity and the same waiting time as the original when driven by a Poisson arrival process with the same rate X_i. The average throughput X_i is given by

$$X_i = \sum_{n=0}^{N-1} p_i(n)\lambda_i(n) \tag{2}$$

where $\{p_i(n)\}$ is the marginal queue length distribution of server i obtained from Marie's algorithm for $\lambda_{(n)}/C_k/1$ queues [Mar80a] and the $\lambda_i(n)$'s are state dependent arrival rates obtained as described in Figure 1.

$$\begin{aligned} &\lambda_i(N) = 0 \\ &\lambda_i(n) = V_i \frac{G_i(N-n-1)}{G_i(N-n)}\ , \qquad 0 \le n < N \end{aligned} \tag{3}$$

Formally, the mean waiting time of the replacement server in an M/G/1 queue is fully determined by its utilization $\rho_i = X_i S_i$ and its *apparent* CV C_i, using the Pollacek-Khinchine formula. The apparent CV may be found by solving

$$\frac{\rho_i^2(1+C_i^2)}{2X_i(1-\rho_i)} = W(X_i, S_i) \tag{4}$$

for C_i. A fitted Coxian service time distribution with mean $1/\mu_i$ and CV C_i may then be used to approximate the server of interest in Marie's algorithm. Thus, the impact of the system component on the performance of the entire closed network may be approximately determined. Servers with CV's that are larger than one may be fitted with two-stage (H_2)

hyperexponential distributions; those with CV's between one and 0.5 may be fitted with Erlang-k (gamma) distributions; those with positive CV's between zero and 0.5 may be fitted with generalized Erlang distributions [Mar80a]. The algorithm is summarized in Figure 2.

```
General Server Model Integration Algorithm:
     repeat
       for each server $i$ do begin
         Obtain the load-dependent arrival rates $\lambda_i(n)$ from
           equation (3);
         If the service time distribution $f_i$ is available then
           fit Coxian distribution $f_i^a$
         else begin
           $X_i := \sum_{n=0}^{N-1} \lambda_i(n) p_i(n)$;
           Solve equation (4) for "apparent CV" $C_i$;
           Fit Coxian distribution $f_i^a$ ($H_2$, $E_k$, Gen. Erlang) to moments;
           end (* else *)
       end; (* for each server *)
       Run one Marie iteration;
       If constraints not satisfied, apply Marie's corrections;
     until constraints satisfied.
```

Figure 2: Marie-based integration scheme for general servers

4. Modeling LAN Contention's Impact on Hosts' Performance

A local area network (LAN) may be regarded as a device that is accessed via ports attached to each mainframe or host computer. Many networks can only transmit one packet of data at a time. Examples of these are Ethernet [Met80a] and the Zurich token ring [Str83a]. Other networks, such as the slotted Cambridge ring [Lun81a], may carry more than one packet at a time. In the absence of buffering, a job will move to its machine's port every time it generates a packet, and then return to the CPU once transmission of the packet is complete. In this respect, a port is no different from a secondary storage device as treated in the central server model [Buz73a]. However, the waiting time of a job at the port is influenced by factors external to the host, such as the traffic offered by other hosts. Attempting to capture these external factors in the apparent service time CV allows us to approximate the effect of the variance of the jobs' interdeparture times on queue lengths at the remaining servers in the host. Notice that this approach differs from those previously used in simultaneous resource possession problems: these approaches attempt to capture delays due to factors other than service by modifying the *apparent* service time means [Jac82a, Sau81a, Agr83a].

The principle of the LAN model integration algorithm is that apparent CV's of ports at each host may be estimated once trial values for the packet arrival rates at all hosts are available. Let i_k denote the server index of the LAN port at host k. Let X_{i_k}, $k=1,...,n$ denote the packet arrival rate at the LAN port of the kth host. Let $W_{L(k)}(X_{i_1}, X_{i_2}, \ldots, X_{i_n}, S_{i_k})$ denote the waiting time of a packet there, as predicted by an open queue model. Then, by analogy with Section 4.3, the apparent CV of the kth LAN port server, C_{i_k} may be obtained by solving

$$\frac{\rho_{i_k}{}^2(1+C_{i_k}{}^2)}{2X_{i_k}(1-\rho_{i_k})} = W_{L(k)}(X_{i_1}, X_{i_2}, \ldots, X_{i_n}, S_{i_k}) \qquad (5)$$

where ρ_{i_k} denotes the utilization of the LAN by the kth host. Once the C_{i_k}'s have been obtained, an iteration of Marie's algorithm may be performed for each host independently to obtain better estimates of its performance measures, including the throughputs used as parameters for the open LAN models.

The proposed algorithm is self-correcting: in the event that the hosts generate packets at a rate that saturates the LAN, the apparent CV's of the port servers will be large enough to reduce the predicted throughputs, and hence the apparent service time CV's, at the end of the next iteration. Notice that the algorithm is not precisely the same as Marie's, since the apparent service time CV's of the ports must be modified at the end of each iteration, while the original algorithm keeps CV's fixed. However, this effect will diminish as the outputs converge.

```
LAN Model Integration Algorithm:
      Estimate throughput at each gateway (decomposition at each host);
      repeat
         Determine resultant waiting time at all gateways
            using open model, current estimate of throughputs;
         Fit "apparent CV's" from (5), Coxian distributions to gateways;
         Run one Marie iteration for each host as in Figure 2, yielding
            new estimate of throughputs and queue lengths;
         Apply Marie's corrections to each host if needed;
      until Marie's convergence criterion satisfied at each host.
```

Figure 3: Proposed algorithm for integrating gateway model into host models

5. An Example: Token Ring with Non-Exhaustive Service

In this section, we present the results of using the algorithm depicted in Figure 3 to incorporate a modified form of the Berry-Chandy [Ber83a] token ring model into closed queueing network models of the hosts. The data are given in the Appendix. The modifcation of the Berry-Chandy model is described in [Bon84a]. It is worth noting that Kuehn's model [Kue79a] yields very similar results to those of the modified Berry-Chandy model when packet lengths are assumed fixed.

Following the notation of [Bux81a], the (fixed) packet transmission time was taken to be

$$T_p = \frac{(l_h + l_d)}{\nu} + k\,(d_a \tau + \frac{1}{\nu})$$

where l_h is the header length in bits, l_d is the data length, ν is the line speed in bits per second, k is the number of stations, and d_a is the distance between neighbouring stations (assumed constant). The token passing time between neighbouring stations was taken to be

$$T_t = \frac{l_t}{\nu} + \frac{1}{\nu} + d_a \tau$$

where l_t is the token length. These formulae assume a 1 bit delay at each station. We have used the following parameter values for the ring model:

$l_h = 112 \ bits$

$l_d = 1000 \ bits$

$l_t = 24 \ bits$

$\nu = 1 \ Mbits/sec$

$d_a = 40 \ metres$

$\tau = 5\times10^{-9} \ sec/metre$

For our analysis, the mean service time $E[S]$ was equated with T_p and the token passing overhead d was equated with T_r.

In our integrated model, it is assumed that a job that transmits a packet will be delayed until the transmission is complete. The integrated model's predictions have been compared with SLAM network-oriented simulations [Pri79a] of a ring with two connected hosts for a variety of parameter values. The network is illustrated in Figure 4. Simulations of networks with identical and non-identical hosts were run to check the heuristic's ability to capture the effect of asymmetric network loadings. The simulations of the identical hosts were run with all local servers exponential and with the CPUs' service time CV's ranging between 1 and 5. Runs of networks with non-identical hosts were performed for hosts with exponential servers only. Confidence bounds on the performance measures were obtained by replicated simulations on differenst sets of random number generation seeds.

We present the for two models of systems with non-identical hosts and exponential local servers and models of a rings under light, moderate, and moderately heavy loadings with identical hosts having (a) exponential local servers and (b) non-exponential CPU's with all other local servers exponential. The results show that the approximation scheme estimates the server throughputs to within 5% of their simulated values and the utilizations to within 7%. When the ring loading is less than about 50%, the relative error in the queue length estimates is never more than 10%, while that of the response time estimates never exceeds 13%. When the ring loading exceeds 50%, the response times and queue lengths of the port servers are

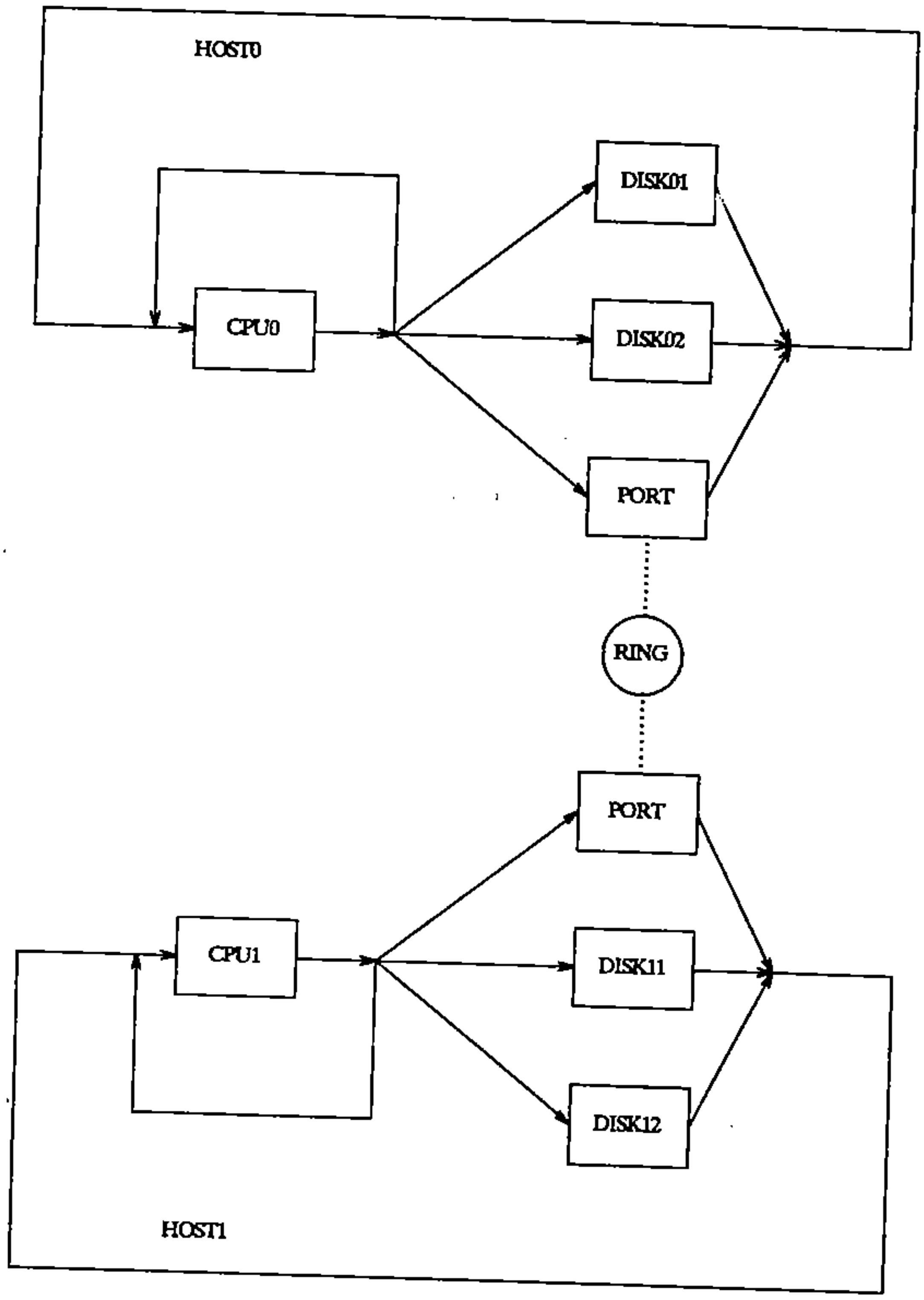

Figure 4: Two hosts connected to a token ring

underestimated by at most 25%; the relative errors increase with the service time CV of the CPU. The corresponding measures of the other servers are always estimated to well within 15% of the simulated values.

The occurrence of queue length discrepancies in models with ring loadings of more than 50% indicates that the effect of non-exhaustive service on network access delay and on the interdeparture time CV of the port server may not have been fully accounted for. This may be explained as follows: our integration scheme attempts to capture the blocking effect by modifying the apparent service time coefficient of variation, while keeping the mean service time fixed. In token rings with non-exhaustive service, the cycle time variance, and hence that of the blocking time, is greatest at low utilizations, while the cycle time mean increases at higher utilizations. Consequently, as the ring utilization increases, the approximation method overestimates the effect of cycle time variability on the ports' interdeparture processes and underestimates the effect of the cycle time mean on the ports' queue lengths. Notice that this problem is not as significant in the two-host asymmetric model shown in Table A2. Host 1 only offers enough traffic to keep the ring busy about 6% of the time, which is small compared with the load offered by Host 0. It follows that the cycle time variance of the ring in this model is larger than that of a ring with the same total utilization as that in Table A2 and equal arrival rates at all hosts. Nevertheless, our integrated model is most accurate at light and moderate load levels. These load levels are currently common for local area networks in practice. For example, Schoch and Hupp [Sch80a] have reported that Ethernet loadings very seldom exceed 10%.

6. Conclusion

The aim of this paper was to describe a method for integrating models of local area networks into an algorithm for solving closed queueing network models. We argued that the accuracy of Marie's method [Mar78a] enables us to use it to solve models of systems with non-exponential servers. We suggested that servers with variable blocking times, such as local area network gateways, also be treated as non-exponential servers. The reasoning behind this proposal was that the service time's apparent coefficient of variation could capture not only the effect of blocking on queueing delays, but also its effect on the server's departure process, whose impact on performance was described in Section 2. Also, reducing the problem of modeling closed networks with blocking servers to that of modeling networks with non-exponential servers enables us to use Marie's method to predict the performance of the entire system.

The usefulness of our approach has been demonstrated by applying it to the previously unsolved problem of modeling the effect of local area network access delays on hosts' performance. The method of apparent coefficients of variation was used to construct non-exponential replacements for the gateway servers whose waiting times matched those predicted by an accurate open-queue model of a token ring. The resulting integrated model was solved by Marie's method to yield accurate predictions about the performance of each attached host. The numerical data show that our approach accurately predicts the demands made on the ring by each host. Our approach also predicts the impact of the ring traffic generated by one host on the ring access delays of the other hosts, as well as the effect of these delays on the hosts' system throughputs. Thus, we have shown that it is possible to combine an open-queue model of a non-product form subsystem with a fast closed queuing network solution algorithm to produce an integrated model of the system as a whole.

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Appendix: Test of the Model Integration Scheme

This appendix contains tables comparing the performance measures predicted by the integrated model of a token ring and hosts described in Section 5 with simulations of systems having the same service and routing parameters. Confidence limits are presented for server queue lengths, utilizations, response times, and throughputs. Notice that the ring utilization given in the tables is the utilization due to each host. For models of asymmetric rings, the total ring utilization is the sum of the ring utilizations due to each host; for symmetric rings, the total ring utilization is double the figure shown in the tables.

Table A1: Asymmetric Network Model 1.

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits for Host 0

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	114.00	0.0030	1.0
disk1	10.00	0.0150	1.0
disk2	3.00	0.0150	1.0
gate	100.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.9476	0.9580	0.011	0.0121	0.9358	0.9802
disk1	0.4156	0.3986	0.043	0.0099	0.3804	0.4168
disk2	0.1247	0.1227	0.016	0.0115	0.1015	0.1439
gate	0.3204	0.3142	0.020	0.0094	0.2970	0.3315

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	2.7753	2.8047	0.011	0.0624	2.6901	2.9194
disk1	0.6448	0.6128	0.052	0.0673	0.4892	0.7364
disk2	0.1408	0.1341	0.050	0.0108	0.1143	0.1539
gate	0.4390	0.4489	0.022	0.0048	0.4401	0.4577

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	315.9523	318.4250	0.008	5.0528	309.1424	327.7077
disk1	27.7151	27.1850	0.019	1.4631	24.4972	29.8728
disk2	8.3145	8.1663	0.018	0.5977	7.0681	9.2644
gate	277.1531	279.9250	0.010	3.6834	273.1581	286.6918

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0088	0.0088	0.002	0.0002	0.0085	0.0091
disk1	0.0233	0.0226	0.031	0.0036	0.0159	0.0293
disk2	0.0169	0.0164	0.029	0.0011	0.0143	0.0185
gate	0.0016	0.0016	0.002	0.0000	0.0016	0.0016

Table A1, continued.

Asymmetric Network Model 1
Comparison of Predicted Values,Simulation Means
and
95% Confidence Limits for Host 1

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	131.00	0.0030	1.0
disk1	10.00	0.0150	1.0
disk2	20.00	0.0450	1.0
gate	100.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.4204	0.4423	0.049	0.0118	0.4206	0.4640
disk1	0.1605	0.1698	0.055	0.0134	0.1451	0.1945
disk2	0.9628	0.9587	0.004	0.0269	0.9092	1.0081
gate	0.1241	0.1236	0.004	0.0035	0.1172	0.1300

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.6644	0.7021	0.054	0.0815	0.5523	0.8518
disk1	0.1887	0.1908	0.011	0.0169	0.1597	0.2219
disk2	2.9895	2.9102	0.027	0.0762	2.7703	3.0502
gate	0.1574	0.1741	0.096	0.0060	0.1632	0.1851

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	140.1480	144.8500	0.032	4.3933	136.7789	152.9211
disk1	10.6983	11.0700	0.034	1.0619	9.1192	13.0208
disk2	21.3966	21.6500	0.012	0.8377	20.1110	23.1890
gate	106.9832	110.9000	0.035	3.0792	105.2432	116.5568

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0047	0.0048	0.030	0.0006	0.0038	0.0059
disk1	0.0176	0.0173	0.018	0.0021	0.0134	0.0212
disk2	0.1397	0.1355	0.031	0.0093	0.1184	0.1526
gate	0.0015	0.0016	0.045	0.0000	0.0015	0.0016

Table A2: Asymmetric Network Model 2.

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits for Host 0

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu1	114.00	0.0030	1.0
disk1	10.00	0.0150	1.0
disk2	3.00	0.0150	1.0
gate	100.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	0.9528	0.9581	0.006	0.0063	0.9465	0.9698
disk1	0.4179	0.4126	0.013	0.0263	0.3644	0.4608
disk2	0.1254	0.1279	0.020	0.0166	0.0974	0.1584
gate	0.3199	0.3116	0.027	0.0063	0.3000	0.3232

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	2.8010	2.8063	0.002	0.0694	2.6787	2.9338
disk1	0.6499	0.6366	0.021	0.0560	0.5337	0.7396
disk2	0.1417	0.1433	0.011	0.0190	0.1083	0.1782
gate	0.4071	0.4138	0.016	0.0017	0.4107	0.4168

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	317.6102	317.8250	0.001	5.0265	308.5908	327.0592
disk1	27.8605	27.1000	0.028	0.2287	26.6799	27.5201
disk2	8.3582	8.0765	0.035	0.4261	7.2937	8.8593
gate	278.6113	279.5750	0.003	5.6486	269.1978	289.9522

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	0.0088	0.0088	0.004	0.0003	0.0083	0.0094
disk1	0.0233	0.0235	0.008	0.0021	0.0196	0.0274
disk2	0.0170	0.0178	0.042	0.0024	0.0133	0.0222
gate	0.0015	0.0015	0.014	0.0000	0.0014	0.0015

Table A2, continued.

Asymmetric Network Model 2
Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits for Host 1

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu1	121.00	0.0030	1.0
disk1	50.00	0.0150	1.0
disk2	20.00	0.0150	1.0
gate	50.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	0.3334	0.3474	0.040	0.0306	0.2911	0.4036
disk1	0.6888	0.7019	0.019	0.0800	0.5549	0.8490
disk2	0.8265	0.8303	0.005	0.0510	0.7366	0.9240
gate	0.0533	0.0533	0.000	0.0057	0.0429	0.0638

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	0.4662	0.4892	0.047	0.0488	0.3994	0.5789
disk1	1.4407	1.4595	0.013	0.2680	0.9671	1.9519
disk2	2.0299	1.9835	0.023	0.2938	1.4438	2.5232
gate	0.0632	0.0678	0.068	0.0075	0.0540	0.0816

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	111.1246	114.6750	0.031	9.8633	96.5548	132.7952
disk1	45.9193	47.0625	0.024	3.4813	40.6670	53.4580
disk2	18.3677	18.8100	0.024	1.6898	15.7056	21.9144
gate	45.9193	47.8350	0.040	5.1001	38.4655	57.2045

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu1	0.0042	0.0043	0.015	0.0001	0.0040	0.0045
disk1	0.0314	0.0310	0.013	0.0043	0.0231	0.0389
disk2	0.1105	0.1058	0.045	0.0200	0.0690	0.1426
gate	0.0014	0.0014	0.012	0.0000	0.0014	0.0014

Table A3: Symmetric Network Model 1: Lightly Loaded Ring.

(a) All local servers exponential

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	121.00	0.0050	1.0
disk1	50.00	0.0150	1.0
disk2	20.00	0.0450	1.0
gate	50.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.5239	0.5302	0.012	0.0409	0.4550	0.6054
disk1	0.6494	0.6355	0.022	0.0387	0.5643	0.7066
disk2	0.7793	0.7838	0.006	0.0500	0.6918	0.8757
gate	0.0504	0.0485	0.039	0.0032	0.0426	0.0544

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.8951	0.9135	0.020	0.0883	0.7513	1.0757
disk1	1.2771	1.2160	0.050	0.1185	0.9983	1.4336
disk2	1.7750	1.8275	0.029	0.2113	1.4393	2.2158
gate	0.0529	0.0526	0.006	0.0046	0.0441	0.0610

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	104.7755	105.5600	0.007	5.4763	95.4994	115.6206
disk1	43.2956	43.5800	0.007	2.1660	39.6008	47.5592
disk2	17.3183	17.5850	0.015	1.1660	15.4429	19.7271
gate	43.2947	43.5200	0.005	2.8928	38.2055	48.8345

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0085	0.0086	0.016	0.0004	0.0078	0.0094
disk1	0.0295	0.0278	0.059	0.0014	0.0253	0.0304
disk2	0.1025	0.1044	0.018	0.0188	0.0698	0.1389
gate	0.0012	0.0012	0.000	0.0000	0.0012	0.0012

Table A3, continued.

Symmetric Network Model 1

(b) Service time CV=2 at the CPU
Visit ratios and mean service times as in Model 1a

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	121.00	0.0050	2.0
disk1	50.00	0.0150	1.0
disk2	20.00	0.0450	1.0
gate	50.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.4940	0.5009	0.014	0.0234	0.4580	0.5438
disk1	0.6124	0.6095	0.005	0.0239	0.5657	0.6534
disk2	0.7349	0.7634	0.037	0.0860	0.6054	0.9215
gate	0.0475	0.0462	0.028	0.0015	0.0435	0.0489

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	1.0164	0.9694	0.048	0.0827	0.8174	1.1214
disk1	1.2242	1.2240	0.000	0.1814	0.8908	1.5572
disk2	1.7097	1.7560	0.026	0.2369	1.3209	2.1912
gate	0.0499	0.0504	0.010	0.0017	0.0473	0.0535

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	98.8065	99.6963	0.009	2.6141	94.8939	104.4986
disk1	40.8291	40.8813	0.001	1.5624	38.0109	43.7516
disk2	16.3316	16.4438	0.007	1.1233	14.3800	18.5075
gate	40.8284	41.4775	0.016	1.3266	39.0404	43.9146

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0103	0.0097	0.059	0.0008	0.0083	0.0112
disk1	0.0300	0.0299	0.003	0.0049	0.0209	0.0389
disk2	0.1047	0.1068	0.020	0.0175	0.0748	0.1389
gate	0.0012	0.0012	0.006	0.0000	0.0012	0.0012

Table A3, continued.

Symmetric Network Model 1

(c) Service time CV=5 at the CPU
Visit ratios and mean service times as in Model 1a

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	121.00	0.0050	5.0
disk1	50.00	0.0150	1.0
disk2	20.00	0.0450	1.0
gate	50.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.4544	0.4503	0.009	0.0241	0.4061	0.4945
disk1	0.5634	0.5668	0.006	0.0183	0.5331	0.6005
disk2	0.6760	0.6948	0.027	0.0577	0.5888	0.8009
gate	0.0437	0.0428	0.020	0.0012	0.0406	0.0451

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	1.1306	1.0520	0.075	0.1746	0.7313	1.3727
disk1	1.1723	1.2199	0.039	0.0988	1.0383	1.4014
disk2	1.6511	1.6810	0.018	0.1148	1.4702	1.8918
gate	0.0461	0.0467	0.014	0.0007	0.0454	0.0480

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	90.8876	92.2200	0.014	6.7831	79.7586	104.6814
disk1	37.5569	37.6900	0.004	3.8651	30.5894	44.7907
disk2	15.0227	15.3100	0.019	2.0138	11.6103	19.0097
gate	37.5561	38.4400	0.023	1.0956	36.4272	40.4528

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0124	0.0115	0.075	0.0026	0.0068	0.0163
disk1	0.0312	0.0325	0.039	0.0037	0.0256	0.0393
disk2	0.1099	0.1101	0.002	0.0110	0.0898	0.1304
gate	0.0012	0.0012	0.013	0.0000	0.0012	0.0013

Table A4: Symmetric Network Model 2: Ring Loading ca. 25%.

(a) All local servers exponential
Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits for Station 0

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	124.00	0.0030	1.0
disk1	45.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	75.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.5162	0.5223	0.012	0.0064	0.5105	0.5342
disk1	0.9367	0.9009	0.040	0.1277	0.6664	1.1354
disk2	0.1873	0.1961	0.045	0.0142	0.1701	0.2221
gate	0.1211	0.1165	0.040	0.0006	0.1154	0.1175

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.9038	0.9056	0.002	0.0300	0.8506	0.9607
disk1	2.7317	2.7170	0.005	0.0380	2.6472	2.7868
disk2	0.2259	0.2338	0.034	0.0322	0.1747	0.2929
gate	0.1386	0.1401	0.010	0.0013	0.1377	0.1424

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	172.0780	172.7375	0.004	0.8610	171.1558	174.3192
disk1	62.4477	62.6500	0.003	0.4519	61.8198	63.4802
disk2	4.1632	4.1735	0.002	0.0592	4.0648	4.2822
gate	104.0793	104.5450	0.004	0.4999	103.6267	105.4633

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0053	0.0052	0.012	0.0002	0.0049	0.0056
disk1	0.0437	0.0386	0.133	0.0168	0.0076	0.0695
disk2	0.0543	0.0573	0.052	0.0045	0.0489	0.0656
gate	0.0013	0.0013	0.030	0.0000	0.0013	0.0014

Table A4, continued.

Symmetric Network Model 2

(b) Service time CV=2 at the CPU
Visit ratios and mean service times as in Model 2a

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits for Station 0

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	124.00	0.0030	2.0
disk1	45.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	75.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.4844	0.4974	0.026	0.0068	0.4848	0.5100
disk1	0.8790	0.9083	0.032	0.0120	0.8862	0.9303
disk2	0.1758	0.1872	0.061	0.0078	0.1730	0.2015
gate	0.1136	0.1139	0.003	0.0013	0.1115	0.1163

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	1.0153	0.9600	0.058	0.0188	0.9254	0.9946
disk1	2.6419	2.6761	0.013	0.0263	2.6278	2.7245
disk2	0.2126	0.2208	0.037	0.0068	0.2084	0.2332
gate	0.1303	0.1429	0.088	0.0031	0.1372	0.1486

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	161.4756	169.0875	0.045	2.0312	165.3559	172.8191
disk1	58.6000	61.4188	0.046	0.8143	59.9228	62.9147
disk2	3.9067	4.1031	0.048	0.0515	4.0086	4.1977
gate	97.6667	102.2050	0.044	1.1798	100.0377	104.3724

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0063	0.0057	0.108	0.0001	0.0054	0.0059
disk1	0.0451	0.0436	0.035	0.0008	0.0422	0.0450
disk2	0.0544	0.0540	0.007	0.0008	0.0526	0.0554
gate	0.0013	0.0014	0.071	0.0000	0.0014	0.0014

Table A4, continued.

Symmetric Network Model 2

(c) Service time CV=5 at the CPU
Visit ratios and mean service times as in Model 2a

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits for Station 0

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	124.00	0.0030	5.0
disk1	45.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	75.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.4430	0.4523	0.020	0.0014	0.4342	0.4703
disk1	0.8038	0.8349	0.037	0.0010	0.8220	0.8477
disk2	0.1608	0.1544	0.041	0.0066	0.0704	0.2384
gate	0.1039	0.1040	0.000	0.0000	0.1036	0.1043

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	1.1103	1.0608	0.047	0.0117	0.9125	1.2090
disk1	2.5733	2.6280	0.021	0.0254	2.3049	2.9511
disk2	0.1964	0.1815	0.082	0.0124	0.0238	0.3391
gate	0.1200	0.1301	0.077	0.0016	0.1094	0.1507

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	147.6646	153.9500	0.041	0.0021	153.9237	153.9763
disk1	53.5880	55.7400	0.039	0.0000	55.7400	55.7400
disk2	3.5725	3.7275	0.042	0.0283	3.3680	4.0870
gate	89.3135	93.2650	0.042	0.0219	92.9864	93.5436

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0075	0.0069	0.088	0.0001	0.0059	0.0078
disk1	0.0480	0.0471	0.018	0.0005	0.0412	0.0531
disk2	0.0550	0.0488	0.128	0.0025	0.0166	0.0810
gate	0.0013	0.0014	0.068	0.0000	0.0012	0.0016

Table A5: Symmetric Network Model 3: Moderately Loaded Ring.

Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	124.00	0.0030	1.0
disk1	25.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	95.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.7500	0.7619	0.016	0.0139	0.7363	0.7875
disk1	0.7560	0.7592	0.004	0.0183	0.7256	0.7928
disk2	0.2722	0.2937	0.073	0.0162	0.2639	0.3235
gate	0.2223	0.2168	0.025	0.0030	0.2114	0.2223

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	1.6628	1.6615	0.001	0.0384	1.5909	1.7321
disk1	1.6878	1.6445	0.026	0.0256	1.5975	1.6915
disk2	0.3553	0.3848	0.077	0.0438	0.3043	0.4653
gate	0.2942	0.3097	0.050	0.0052	0.3002	0.3193

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	249.9574	253.5500	0.014	3.4874	247.1431	259.9569
disk1	50.3946	50.3350	0.001	0.7336	48.9872	51.6828
disk2	6.0474	6.3428	0.047	0.1760	6.0195	6.6660
gate	191.4973	194.5625	0.016	2.6853	189.6293	199.4957

Response Times						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0067	0.0065	0.024	0.0001	0.0064	0.0067
disk1	0.0335	0.0327	0.026	0.0007	0.0313	0.0340
disk2	0.0588	0.0607	0.031	0.0085	0.0452	0.0762
gate	0.0015	0.0016	0.060	0.0000	0.0016	0.0016

Table A6: Symmetric Network Model 4: Ring Loading ca. 60%.

(a) All local servers exponential
Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	114.00	0.0030	1.0
disk1	10.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	100.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.8993	0.9077	0.009	0.0175	0.8754	0.9399
disk1	0.3944	0.3893	0.013	0.0129	0.3655	0.4131
disk2	0.3550	0.3823	0.071	0.0243	0.3376	0.4269
gate	0.3050	0.2947	0.035	0.0069	0.2820	0.3073

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	2.4252	2.3439	0.035	0.0676	2.2197	2.4681
disk1	0.5922	0.5679	0.043	0.0365	0.5008	0.6351
disk2	0.5102	0.5638	0.095	0.0576	0.4580	0.6695
gate	0.4722	0.5160	0.085	0.0227	0.4743	0.5577

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	299.7600	302.3500	0.009	5.9099	291.4928	313.2072
disk1	26.3000	26.1550	0.006	0.4113	25.3995	26.9105
disk2	7.8900	8.1713	0.034	0.1867	7.8283	8.5142
gate	262.9500	265.1250	0.008	5.2528	255.4750	274.7750

Response						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0081	0.0077	0.049	0.0001	0.0076	0.0078
disk1	0.0225	0.0195	0.156	0.0080	0.0048	0.0341
disk2	0.0647	0.0691	0.063	0.0086	0.0533	0.0848
gate	0.0018	0.0019	0.065	0.0001	0.0018	0.0021

Table A6, continued.

Symmetric Network Model 4

(b) Service time CV=2 at the CPU
Visit ratios and servce time means as in Model 4a
Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	114.00	0.0030	2.0
disk1	10.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	100.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.8505	0.8839	0.038	0.0142	0.8578	0.9101
disk1	0.3730	0.3658	0.020	0.0098	0.3478	0.3839
disk2	0.3357	0.3433	0.022	0.0046	0.3348	0.3517
gate	0.2890	0.2888	0.001	0.0070	0.2760	0.3017

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	2.4003	2.3401	0.026	0.0367	2.2726	2.4076
disk1	0.6084	0.5626	0.081	0.0405	0.4882	0.6370
disk2	0.5193	0.4774	0.088	0.0514	0.3829	0.5719
gate	0.4719	0.6197	0.239	0.0303	0.5641	0.6753

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	283.5067	294.3500	0.037	5.2624	284.6824	304.0177
disk1	24.8690	25.4713	0.024	0.9032	23.8120	27.1305
disk2	7.4607	7.7608	0.039	0.1769	7.4358	8.0857
gate	248.7194	258.4000	0.037	4.8853	249.4252	267.3749

Response						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0085	0.0079	0.070	0.0002	0.0075	0.0084
disk1	0.0245	0.0221	0.109	0.0009	0.0204	0.0237
disk2	0.0696	0.0614	0.134	0.0058	0.0507	0.0720
gate	0.0019	0.0024	0.205	0.0001	0.0023	0.0025

Table A6, continued.

Symmetric Network Model 4

(c) Service time CV=5 at the CPU
Visit ratios and servce time means as in Model 4a
Comparison of Predicted Values, Simulation Means
and
95% Confidence Limits

Parameters			
Server Name	Visit Ratio	Service Time	Service Time CV
cpu	114.00	0.0030	5.0
disk1	10.00	0.0150	1.0
disk2	3.00	0.0450	1.0
gate	100.00	0.0012	0.0

Utilizations						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.8084	0.8465	0.045	0.0045	0.8383	0.8547
disk1	0.3545	0.3314	0.070	0.0131	0.3072	0.3555
disk2	0.3190	0.3115	0.024	0.0307	0.2550	0.3679
gate	0.2751	0.2624	0.049	0.0030	0.2569	0.2678

Queue Lengths						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	2.3795	2.3889	0.004	0.0525	2.2924	2.4853
disk1	0.6228	0.5363	0.161	0.0482	0.4477	0.6248
disk2	0.5276	0.4539	0.162	0.0896	0.2892	0.6185
gate	0.4701	0.6210	0.243	0.0040	0.6137	0.6283

Throughputs						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	269.5342	267.7750	0.007	3.0753	262.1252	273.4248
disk1	23.6433	22.8512	0.035	0.3304	22.2442	23.4583
disk2	7.0930	6.8589	0.034	0.0438	6.7784	6.9394
gate	236.4059	235.4250	0.004	2.6616	230.5352	240.3148

Response						
Server	Pred. Val.	Sim. Mean	Rel.Err.	St.Dev.	Lower CL	Upper CL
cpu	0.0088	0.0089	0.014	0.0002	0.0085	0.0093
disk1	0.0263	0.0235	0.121	0.0018	0.0202	0.0268
disk2	0.0744	0.0661	0.126	0.0128	0.0425	0.0896
gate	0.0020	0.0026	0.242	0.0000	0.0026	0.0027