Two-Layer Modeling for Local Area Networks

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1. Introduction

During the recent years, the Open-Systems Interconnect (OSI) Reference Model is becoming a standard which structures the protocols into seven layers and specifies the interfaces of computer communication networks. In the framework of the layered model, various performance studies have been made for the individual layer, in which the layers above and below the one of concern have been represented simply by source, workload and transmission models for analytical tractability. However, only a few works have been published for a performance study where two or more layers are combined together. Such a performance model is significant for network users to predict performance of network functions imbedded in their application programs.

In this paper, we apply the OSI layers model to LAN (Local Area Networks) and concentrate on the modeling of the MAC layer and the Transport layer in a layered protocol architecture. In our model, the LLC layer is treated as a simple 'time-delay' source, i.e., we consider a connectionless service for the LLC layer.

2. Modeling of a MAC Layer (Polling Systems)

For the MAC layer, we consider a nonexhaustive cyclic polling system, which includes the following features: 1) The number of stations in the LAN is N. 2) Messages arrive at the MAC-queue of station i according to the Poisson process at rate λ_i ($i = 1, 2, \ldots, N$). 3) The mean and variance of the message transmission times at station i are b_i and $b_i^{(2)}$, respectively. 4) The mean and variance of the switch-over time are r and δ^2, respectively. The switch-over time represents the propagation delay between two adjacent stations plus the bit latency at each station (these are assumed to be symmetric throughout the paper). 5) The server utilization due to station i is given by

$$\rho_i = \lambda_i b_i \qquad i = 1, \ldots, N \tag{1}$$

The total utilization of the server, ρ, is defined as

$$\rho = \sum_{i=1}^{N} \rho_i . \tag{2}$$

We utilize the following analytical results for the nonexhaustive cyclic polling system:

Nonexhaustive service with symmetric load: An exact analysis has been obtained for the symmetric case in which arrival rates and service time distribution functions are identical for all stations. The average message waiting time w_i for station i is found in [1] as:

$$w_i = \frac{\delta^2}{2r} + \frac{N[\lambda b^{(2)} + r(1 + \lambda b) + \lambda \delta^2]}{2[1 - N\lambda(r + b)]} \qquad i = 1, \ldots, N \tag{3}$$

where $\lambda = \lambda_1 = \lambda_2 = \cdots = \lambda_N$, $b = b_1 = b_2 = \cdots = b_N$ and $b^{(2)} = b_1^{(2)} = b_2^{(2)} = \cdots = b_N^{(2)}$.

Nonexhaustive service with asymmetric load: We employ an approximation method in [2] where the mean message waiting times given by

$$w_i = \frac{1 - \rho - \rho_i}{1 - \rho - \lambda_i r} \frac{1 - \rho}{(1 - \rho)\rho + \sum_{j=1}^{N} \rho_j^2} \left[\frac{\rho}{2(1 - \rho)} \sum_{j=1}^{N} \lambda_j b_j^{(2)} + \frac{\rho}{2r} \sum_{j=1}^{N} \delta_j^2 + \frac{r}{2(1 - \rho)} \sum_{j=1}^{N} \rho_j (1 + \rho_j) \right] \qquad i = 1, \ldots, N \tag{4}$$

are shown to be in good agreement with simulation results.

The corresponding MAC-transit delays (elapsed time for messages in the MAC layer submodel) are then obtained by

$$f_i = w_i + b_i + \frac{Nr}{2} \qquad i = 1, \ldots, N \tag{5}$$

The last term on the right-hand side of the above equation represents the mean propagation delay between sender i and a receiver station.

3. Modeling of a Transport Layer (Single-chain, Closed-queueing Network)

Let us follow Reiser [3] to obtain a queueing model for the Transport layer. Namely, there are uni-directional virtual channels (called *chain* below) between designated pairs of stations. Each chain has a source and a sink, and messages on the chain are individually acknowledged. These assumptions lead to a model of closed queueing networks each of which connects two stations. In the current paper, each station in the LAN is assumed to establish only a single chain with another station.

Chains interact with each other in the MAC layer submodel (i.e., contention in the channel access) as we model it with a multiple-queue single-server queueing system. To incorporate the effects of MAC layer into the queueing chain, we equate the service time of MAC-queue to f_i for station i, given by (5), and assume that the service discipline is IS (Infinite Service). We also assume that the LLC layer is modelled by the IS queue because we consider connectionless-type service for the LLC layer here.

Service times of a source queue correspond to the interarrival times of messages which an application program at the source station generates. On the other hand, a sink queue is considered in the following ways:

- When data messages piggyback acks in the closed chain, the service times at the sink queue correspond to the interarrival times of the messages generated by the application program (abbreviated as AP in Figs.1, 2) at the destination station (Fig.1).
- When acks are returned by themselves, service times at the sink queue correspond to the time to generate the ack at the Transport queue in the destination (Fig.2). Messages will be passed to the application program separately with acks.

Our solution algorithm for the Transport layer submodel follows the MVA (Mean Value Analysis) method in [3]. Let us define the equilibrium quantities for queue j in a single-chain, closed network c:

$W^{(c)}$: Window size of closed network c
$\tau_j^{(c)}$: Mean service time of queue j in c
$n_j^{(c)}(W^{(c)})$: Mean queue length of queue j in c
$t_j^{(c)}(W^{(c)})$: Mean queueing time at queue j in c
$\lambda^{(c)}(W^{(c)})$: Throughput of closed network c

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Now we can compute the throughput of the closed network c recursively, starting with $n_j^{(c)}(W^{(c)}) = 0$, using the following relationships [3]:

$$t_j^{(c)}(W^{(c)}) = \begin{cases} \tau_j^{(c)} = f_i, & \text{if } j = \text{MAC-queue at station } i \\ \tau_j^{(c)}, & \text{if } j = \text{LLC-queue} \\ \tau_j^{(c)}\left[1 + n_j^{(c)}(W^{(c)} - 1)\right], & \text{otherwise} \end{cases} \qquad (6)$$

$$\lambda^{(c)}(W^{(c)}) = W^{(c)} / \sum_{k \in Q^{(c)}} t_k^{(c)}(W^{(c)}) \qquad (7)$$

$$n_j(W^{(c)}) = \lambda^{(c)}(W^{(c)})\, t_j^{(c)}(W^{(c)}) \qquad (8)$$

where $Q^{(c)}$ is a set of queues in closed network c. In (6), f_i is obtained from (5) for the MAC layer submodel. In turn we can use $\lambda^{(c)}(W^{(c)})$ as input values for the MAC layer submodel. This observation leads to an iterative solution algorithm for the combined two-layer modeling.

4. Solution Algorithm for Two-layer Modeling

The outline of our numerical iterative algorithm is:

(*a*) set arrival rates to the MAC layer submodel to some initial values (e.g., set $\lambda_i = 0$ for all i)

(*b*) calculate mean message waiting times using (3) or (4). If the solution is infeasible, then modify arrival rates small enough to satisfy the stability condition for the polling systems [2].

(*c*) calculate the throughput for each chain in the Transport layer submodel using the MVA solution algorithm (6)-(8); these values will be used in the next iteration cycle as arrival rates to the MAC layer submodel.

The convergence criterion for the n th iteration is defined by

$$\Delta_n = \sum_{i=1}^{N} [\lambda_i^{(n)} - \lambda_i^{(n-1)}] < \varepsilon \quad (\text{e.g. } \varepsilon = 10^{-6}) \qquad (9)$$

5. Numerical Results

In this section, numerical results are presented and compared to the simulation results in order to assess the accuracy of our algorithm. The simulation results are depicted with 90% confidence intervals. We consider two models with the following parameters:

$N = 6$
Data-message transmission time: 1 msec.
Switchover times: $r = 0.005$ msec., $\delta^2 = r^2$
Processing time at the Transport-queue: 4 msec.
Processing times at the LLC-queue and AP-queue: zero

First, we consider a symmetric case with ack piggybacking for closed chains (Fig.1). There are three closed queueing networks each of which contains a single chain. We use (1) for the analysis of the MAC layer submodel. Fig.3 presents delays dependent on the window size of chains.

Next, we consider the asymmetric case where explicit acks are returned to the source station from the destination (Fig.2). We use the approximation method (2) because two different types of messages coexist in the MAC layer. In Fig.4, values of mean message delays are plotted against the window size of chains. We assume that window sizes of all chains are identical and ack transmission times are fixed at 0.1 msec.

6. Concluding Remarks

In this paper, we have built a two-layer performance model of LAN, which consists of a MAC layer submodel and Transport layer submodels. We are investigating the case of a multi-chain closed-queueing network which appears when each station on LAN establishes multiple sessions with other stations.

References

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[2] O.J.Boxma and B.Meister, "Waiting Time Approximations for Cyclic-Service Systems with Switch-over Times," *Performance Evaluation Review*, Vol.14, No.1, pp.254-262, May 1986.

[3] M.Reiser, "A Queueing Network Analysis of Computer Communication Networks with Window Flow Control," *IEEE Transactions on Communications*, Vol.COM-27, No.8, pp.1199-1209, August 1979.

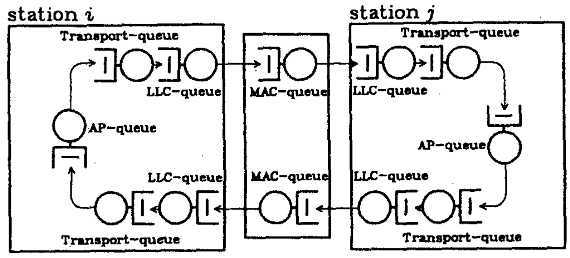

Fig.1. Transport Layer Submodel with Piggybacked Ack

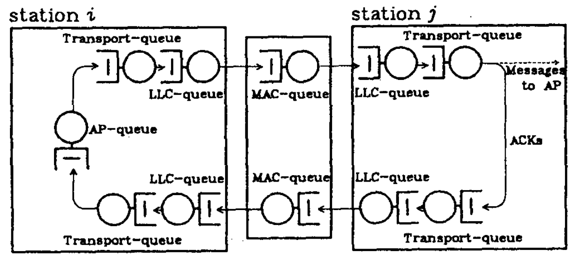

Fig.2. Transport Layer Submodel with Explicit Ack

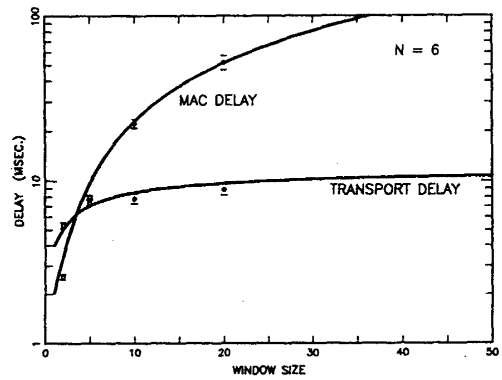

Fig.3. Delays in a Symmetric-load and Piggybacked Ack Model

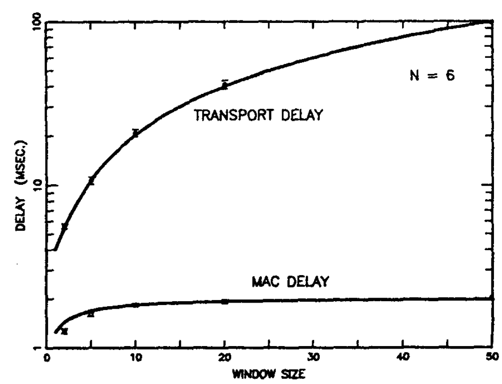

Fig.4. Delays in an Asymmetric-load and Explicit Ack Model