An Admission Control Model Through Outband Signalling Management

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ABSTRACT

A dynamic window model is developed which provides admission control for circuit switched networks through the signalling network. This model incorporates distributed processing while achieving desired global congestion control effects. It reflects the interaction between the circuit switched path in the telephone network and the packet switched path in the signalling network. The model is solved by applying the concept of parametric analysis to study the whole circuit switching subnetwork as a composite server. The variant service rate is derived for the composite server of the circuit switch trunk in the context of a closed chain where the arrival of call services is finite. To avoid the overflow and the combinatorial complex problems, the computation is reduced into the Erlang recursive form. Mean value analysis formulae are derived for the model. Examples are given to demonstrate the validation of the analysis.

1. INTRODUCTION

The interaction between the telephone and the signalling control networks has become an important research topic in recent years. One important feature of the signalling network is that it is much faster than the telephone networks. Without further control restriction, the current signalling networks can accept more call requests than the circuit switched telephone networks can handle. This makes the admission control procedure necessary [4,9,10].

The networking environment under study is the circuit switched telephone network with separate signalling and control such as that specified by the CCITT No.7 [5, 6]. It is a known fact that only the routing control is fully implemented in practice [14]. The implementation of non-hierarchical routing enables the new routing scheme to be adjusted to dynamic traffic patterns to utilize the network resources efficiently [1,3]. However, dynamic routing brings the danger of congestion in heavy traffic as argued by Krupp [15].

The admission control is achieved in a very limited manner [14]. One example of current limited control is to recognize the incoming source address when the calling process finds no remaining link capacity available. Then an indication signal is sent to the upward node one hop ahead. Based on this indication, the previous node can block the other call requests.

This kind of simple control solution is far from being satisfactory due to the arising potential problems. First looking at one hop ahead does not provide enough information along the whole path. Thus no real end-to-end control is available. Second there is the unfairness problem, because all call requests may be rejected with the same probability even if they are from a light traffic source which consumes less resources.

Among other problems is the unmatched timing scale of the telephone networks and the control networks. Setting up a virtual circuit may take seconds of time while the processing of a call request is within milliseconds. Without proper control, the signalling network may accept more calls than the telephone network can deal with, thus congesting the circuit switched network completely.

All these problems stem from the lack of enough research on the interaction of the telephone and the control networks. We believe that the outband control network needs to monitor, transfer, and supply more complete information which is essential to the network management decisions. With this in mind we are trying to propose a traffic control model for the outband signalling environment. The main characterization of this environment includes separate signalling and control network, non-hierarchical alternative routing.

Here we propose a new admission control model which is specifically designed for the outband control facility. The main idea is to provide the signalling and control network with a feedback mechanism. A traffic control model can essentially be formulated by the following criteria and characterizations:

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i) It should provide end-to-end control;

ii) The signalling network should construct an information feedback channel;

iii) Processing and control should be distributed;

iv) It should be based on the accurate information about the current performance of the destination;

v) It should have destination rate oriented dynamic control;

vi) Analytical solutions should be available for performance evaluation of the model.

End-to-end control has been proved to be an effective flow control technique in packet switched networks [23]. Traditional telephone networks do not provide this mechanism because there is no enough control facility. Now with the separate control network, we are able to investigate the possibility of applying this technique to the telephone networks.

The CCITT Common Channel Signalling System No. 7 [5, 6] specifies the signalling network. The signalling network provides call management capability for underlying circuit-switched transport network and database transaction processing capability. We realized that its user-to-user information carriage provides a feedback path to inform the call processing source node about the status of the destination. The end-to-end feedback enables different source-destination pairs to be controlled independently; therefore, distributed processing and control can be achieved. However, this aspect needs more research in order to understand the effect of the signalling network on the distributed control of the telephone network.

The International Standard Organization has proposed performance management as one of the five functional areas in network management model. CCITT has a corresponding TMN architecture [7] for telecommunication network management. When the functional area is implemented, the management network will be able to monitor the performance of the current status of each destination node, which in turn can be transferred back to the source nodes through the signalling network. Based on the feedback performance information the source node will automatically adjust the incoming traffic of call requests in order to avoid the congestion of the destination node. A main key research problem in this study is to define this dynamic adjust mechanism which is based on the utilization, mean queue length, and/or response time of the destination, and which uses some kind of dynamic window control facility. Another key research problem is to associate the mechanism with an analytical (or numerical) model which allows prediction of system performance.

In summary, the proposed admission control model is a dynamic window control with innovative features and analytical solutions. The control points are decoupled from the area to be protected, while they are related to each other by an outband channel. It improves the traditional rate based control by using global information instead of local one. The connection failure in the telephone network is moved in some extent to the extra processing of the control network. The distributed control achieves global control effects while reducing the complexity as well as meeting the features of the signalling network. Finally, associated with the scheme there is an analytical model with closed form solution.

The paper is organized as follows. In section 2 we develop a queueing network model for the admission control scheme. In section 3 we analyze the model. In section 4 we give a numerical example. Section 5 concludes the paper.

2. MODEL DESCRIPTION

We consider the admission control strategies in a circuit switched network with a separate signalling network as shown in Figure 1.

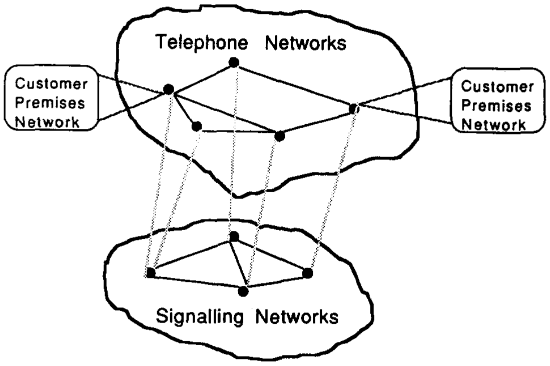

Figure 1. Interaction between Signalling and Telephone Networks.

We then derive a queueing network model in Figure 2. The queueing network model has $M+N+2$ nodes:

i) Source node S including the admission control mechanism;

ii) Destination node D monitoring the traffic in the destination area;

iii) M nodes modeling the circuit switched path with each node Ci, for $i=1,2,...,M$, corresponding to the trunk group connecting two exchanges;

iv) N nodes modeling a signalling path, each node Pi, for $i=1,2,...,N$, corresponding to a Signalling Transport Point (STP) in the signalling network working in a store-and-forward manner.

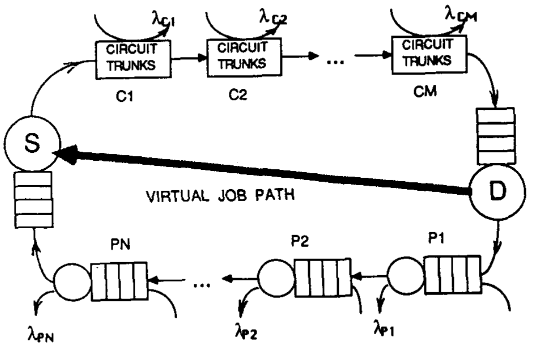

Figure 2. A Queueing Network Model for Dynamic Window Traffic Control.

Figure 2 is a mixed queueing network model. The path in the circuit switched network and that in the packet switched signalling network are connected as a cyclic closed chain. There are arbitrary but fixed number K of call requests in the closed chain. Since other paths may have intersections with this path, cross traffic is added to each node. Each cross traffic forms an open chain. Furthermore, a virtual path from node D to node S forms another open chain which represents the mechanism to control the dynamic window size. This aspect will be described in detail in what follows.

Here we can define the window size of the model as the outstanding telephone calls before disconnection. Thus the dynamic window size is the initial maximum window size minus the mean queue length of calls waiting for connection in the source node. The initial maximum window size is given by the system specification. The mean queue length of the source node can be derived by the analysis in next section.

The source node S admits incoming call requests which pass through the circuit switched path during exponentially distributed holding time period. After a call is released, feedback information is transferred through the separate signalling path. When the feedback information arrives at the source node, a new call request may be admitted to enter the network, depending on the traffic behavior as explained subsequently. The number of calls in the closed chain determines the maximum window size. To guarantee the successful operation of the described scheme, we set up the initial window size as the maximum number that will not exceed the capacity of the destination area. Then the destination is prevented from being congested by a single source node at the initial phase.

The virtual service requests along the virtual path correspond to the traffic stream going through D except those admitted from S. Regarding the virtual traffic and the call requests of the closed chain, two classes of service requests are flowing through the source node S. We assume that the virtual service requests have higher priority than the call requests in the closed chain. As long as a virtual service request is in S, the lower priority call request is blocked. Here non-preemptive service is assumed. The source node S rejects the admission of new calls as long as the destination node D is not available. By this scheme, dynamic window is realized implicitly. The more incoming call requests are blocked, the smaller will be the window size. Considering the destination node D, no priority is distinguished between the two classes of services. Only the call requests of the closed chain are relevant for the analysis. The virtual service requests are counted as cross traffic.

Each node in the circuit switched path ($C1$, $C2$, ..., CM) represents the circuit trunks. A call connection cannot be completed unless all trunks have a spare link. In the current connection procedure, the connection is established hop-by-hop. When some intermediate trunk is blocked, the previous connection is aborted, resulting in a waste of resources due to their temporary holding. Employing advanced signalling technology, it is possible to predict ahead that all links along the path are available to the incoming call. In our model a call connection is either established through the network or it is buffered at the source. No partial connection and abortion is allowed. Keeping this in mind, the path connection has the property of simultaneous resource holding. We assume the trunk holding time of a call to be exponentially distributed with mean service rate μ_C.

As we are considering the path in a circuit switched network environment, there are other cross traffic streams competing for the lines at some segment of the path. We assume the interarrival time for the incoming traffic crossing the trunk group Ci to be exponentially distributed with an arrival rate λ_{Ci}, for $i=1,2,...,M$.

Node Pi in the packet switched signalling network is a single server having exponentially distributed service with mean service rate μ_{Pi}. The cross traffic is modeled by a Poisson stream with mean arrival rates λ_{Pi}, for $i=1,2,...,N$.

The jobs at the source node S is regarded as new arrival call request traffic which are not lost. Without the path of virtual jobs, the uncontrolled model represents the fixed window mechanism. In this case, jobs entering the source node are served immediately as long as the total number does not exceed the fixed job number K. In our study, we further control the admission of calls at S with another mechanism. We assume that the virtual traffic departing from the destination node will enforce the source node to take an equivalent distributed service time. However, in order to obtain analytical solution we assume Kleinrock's independent assumption. The blocking of lower priority jobs at the source node implies that the destination area is going to be congested. Thus, the source node restricts the incoming traffic to prevent further congestion. The rejecting of new call requests corresponds to reduction of the window size. The heavier the virtual traffic becomes, the more the window size will shrink. In contrast to that, a gap in the interarrival of virtual service request allows the low priority call request to pass through. Light virtual traffic has a longer idle period and provides more chances for the low priority call requests to go through, thus increasing the window size automatically.

The global effect of this locally distributed control can be characterized by four properties of the model: *fairness, sources interaction, load level, and surveillance.* Any scheme of priority may cause discrimination. Therefore we need to investigate the fairness of the proposed scheme. Each source assumes that its traffic has lower priority. But from the global point of view, all sources generate the same priority. In other words, although the source discriminates itself, the global view treats each source equally fair. The source nodes restrain each other to limit the maximum number of call requests to be admitted. The rejection of call requests at the source node avoids temporary partial resource possession and prevents the destination from being overloaded. On the other hand, the idle period of the source nodes with respect to the the virtual jobs allows the low priority jobs to enter service as soon as possible, thus avoiding the situation of underload in the network.

Another feature of the scheme is its ability to cope with imbalance incoming calls. Each source can generate its own amount of traffic. The traffic can change from time to time. This is realistic and is superior to the model of Doshi and Heffes [8] where all incoming at each source should be the same to achieve optimal control, which is not the case in the real world. We can further extend the concept of virtual job by letting the virtual jobs keep coming to the source nodes when they accumulate at D. If the destination fails, the virtual job queue length will become so large that the sources will be blocked completely. Another way of viewing the destination node failure is to allow the virtual job to have infinite service time, thus completely blocking the sources. Therefore, this dynamic window control scheme does not allow any call to be admitted to a failed destination node.

3. MODEL ANALYSIS

First we analyze the path of a circuit switched network by extending the classical analysis of an open circuit switched network [12]. We calculate the throughput of the path by assuming open chains for cross traffic but arbitrary and fixed number of jobs in the closed chain. The circuit switched path is then reduced to an equivalent composite (flow-equivalent) station with load-dependent service rate (Figure 3). Parameters for the composite station are obtained for the analysis of the entire model. The cross traffic in the path of the packet switched signalling network is eliminated by flow balance consideration for non-bottleneck nodes as used by Mitra [17]. The resulting cyclic queueing network is solved by a set of mean value analysis formulae.

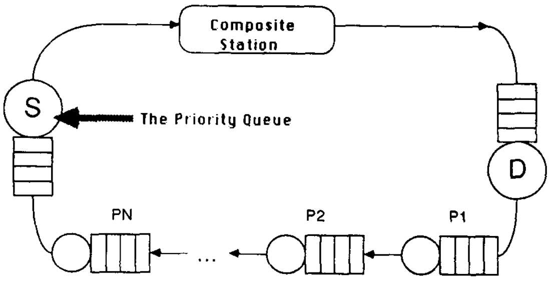

Figure 3. Reduction of the Circuit Switched Path into an Equivalent Composite Server.

3.1. Circuit Switching Path Analysis

We define some notations:

- There are M links along the circuit switched path from the source to the destination;
- Capacity of the circuit switched subnetwork is defined by $\underline{C} = (C1, C2, ..., CM)$, where Ci is the capacity of link i;
- λ_{Ci} is the arrival rate of the crossing Poisson traffic stream at link Ci;
- $1/\mu_{Ci}$ is the mean value of the exponentially distributed holding time of the lines of link i; due to the requirement of simultaneous resource holding, $1/mu\_Ci$ is the same as the call holding time $1/mu\_C$, for all $i=1,2,...,M$;
- System state is defined by $\underline{n} = (n_1, n_2, ..., n_M)$ with n_i denoting the number of calls in processing of cross traffic i;
- $\underline{e}$ is a vector of all ones describing just one call in each cross traffic.

The stationary distribution of $\underline{n}$ is given by [13].

$$\pi(\underline{n}) = G(\underline{C})\prod_{i=1}^{M}\frac{A_i^{\,n_i}}{n_i\,!} \tag{1}$$

where $G(\underline{C})=\left[\sum_{\underline{n}\geq\underline{0}\,\&\,\underline{n}\leq\underline{C}}\ \prod_{i=1}^{M}\frac{A_i^{\,n_i}}{n_i\,!}\right]^{-1}$ is the normalization constant, and $A_i=\frac{\lambda_{Ci}}{\mu_{Ci}}$.

The probability that at least h calls of the main stream can be carried along the whole circuit path is [13]

$$Prob(h) = G(\underline{C})\,G^{-1}(\underline{C}-h\,\underline{e}) \tag{2}$$

If we assume that the current dynamic window size is J for $1\leq J\leq K$, where K is the maximum window size defined before, then the throughput of the main traffic stream, which goes through all trunk circuits, is

$$X_C(J) = \left[J\cdot Prob(J)+\sum_{i=1}^{J-1} i\left[Prob(i)-Prob(i+1)\right]\right]\mu_C \tag{3}$$

where μ_C is the mean service rate of a call in the circuit switched path. Because only J calls are waiting for service, $Prob(J)$ is the probability that J calls can go through. $\left[Prob(i)-Prob(i+1)\right]$ is the probability that exactly i calls can find the idle links.

Note that in equation (3), the throughput $X_C(J)$ depends on the number of call requests J which is limited to an arbitrary but fixed number. The limitation arises from the dynamic window introduced in the model.

If we denote the whole circuit switched path by an equivalent composite station, the mean service time $1/\mu_C$ of the composite station is load-dependent

$$\mu_C(J) = X_C(J) \tag{4}$$

where $X_C(J)$ is obtained from equation (3).

In summary, equations (2), (3) and (4) provide the formulae for analyzing the circuit switched path submodel. However, the normalization constant in (2) may have two problems: combinatorial explosion of state space and underflow inaccuracy. Fortunately these problems can be resolved by the independent assumption of the cross traffic and by using the recursive relation of the Erlang blocking formula, $E(l,a)$, as we demonstrate in the following.

First from (2) we note that

$$Prob(1) = G(\underline{C})\,G^{-1}(\underline{C}-\underline{e})$$

$$Prob(h) = G(\underline{C})\,G^{-1}(\underline{C}-h\underline{e}) = Prob(h-1)\,G(\underline{C}-(h-1)\underline{e})\,G^{-1}(\underline{C}-h\underline{e})$$

$$\text{for } 1<h\leq J$$

Therefore we only need to compute

$$G(\underline{C}-(h-1)\underline{e})\,G^{-1}(\underline{C}-h\underline{e}) \qquad \text{for } 1\leq h\leq J$$

which can be reduced into

$$G(\underline{C}-(h-1)\underline{e})\,G^{-1}(\underline{C}-h\underline{e}) = \prod_{i=1}^{M}\left[1+\frac{A_i}{C_i-h+1}E(C_i-h,A_i)\right]^{-1}$$

where $E(C_i-h,A_i)$ is the recursive Erlang blocking formula [25] satisfying the recursion as follows:

$$E^{-1}(0,A_i) = 1$$

$$E^{-1}(l,A_i) = \frac{l}{A_i}E^{-1}(l-1,A_i)+1 \qquad \text{for } l\geq 1.$$

Our experiment with the above recursive computation indicates that it is more efficient than using (1) and (2) directly. The computation complexity is linear and the underflow problem is avoided.

3.2. Mean Value Analysis of the Control Model

First we define some notations:

- μ_{Pi} is the mean service rate of node Pi;
- λ_{Pi} is the mean arrival rate of the cross traffic at node Pi;
- $\bar{t}_i$ is the mean response time of node i, for $i=1,2,\ldots,N$; $\bar{t}_S$, $\bar{t}_C$, and $\bar{t}_D$ are the mean response time of nodes S, C, D;
- $\bar{k}_i$ is the mean queue length of node i, for $i=1,2,\ldots,N$; $\bar{k}_S$, $\bar{k}_C$, and $\bar{k}_D$ are the mean queue length of nodes S, C, D;
- X_i is the throughput of node i, for $i=1,2,\ldots,N$; X_S, X_C, and X_D are the throughput of nodes S, C, D;
- X_V is the arrival rate of the virtual traffic, which is defined as the traffic into node D that is not from source node S; It is also called the virtual load;
- ρ_V is the utilization of the virtual traffic.

We assume the network is balanced for the purpose of equilibrium and stability. The balanced network can be achieved by removing the bottleneck nodes. Since the circuit switched network is slow it may become a potential bottleneck. Another possible bottleneck is the source node S after introducing the virtual jobs to be served by S. From the assumption of flow balance in the packet switched path, it follows that [18]

$$\mu_{P1}-\lambda_{P1} = \mu_{P2}-\lambda_{P2} = \cdots = \mu_{PN}-\lambda_{PN} \tag{5}$$

where μ_{Pi} is the mean service rate of the packet switched node Pi, and λ_{Pi} is the arrival rate of the cross traffic at node Pi, for $i=1,2,\ldots,N$.

To obtain the performance measures of the model given in Figure 3, we extend the classical mean value analysis formulae [22]. The mean response time for the packet switched node is

$$\bar{t}_i(K) = \frac{1}{\mu_{Pi}-\lambda_{Pi}}[\,1+\bar{k}_i(K-1)\,] \qquad \text{for } i=1,2,\ldots,N. \tag{6}$$

The mean response time of the destination is

$$\bar{t}_D(K) = \frac{1}{(\mu_D - X_V)}[\,1+\bar{k}_D(K-1)\,] \tag{7}$$

where X_V is the arrival rate of the virtual jobs. μ_D is the mean service rate in the destination node D for all jobs. $(\mu_D - X_V)$ is the reduced service rate for the normal job obtained from flow balance consideration, since the virtual service requests are considered as cross traffic in the destination node D.

The mean response time of the composite station is

$$\bar{t}_C(K) = \sum_{J=1}^{K}\frac{J}{\mu_C(J)}P(J-1|K-1) \tag{8}$$

where $\mu_C(J)$ can be computed from (3) and (4) and the probability of conditional queue length distribution $P(J-1|K-1)$ is obtained from [22]

$$P(J|K) = \frac{X(K)}{\mu_C(J)}P(J-1|K-1) \tag{9}$$

and

$$P(0|K) = 1-\sum_{J=1}^{K}P(J|K) \tag{10}$$

with initial value $P(0|0)=1$.

For the source node S, we consider that the higher priority service request must be served first with $\frac{\rho_V}{(1-\rho_V)\mu_D}$ time. Then the normal call requests can be served under the reduced service rate due to the new traffic of the higher priority service request. Thus

$$\bar{t}_S(K) = \frac{\rho_V}{(1-\rho_V)\mu_D} + \frac{1/\mu_S[1+\bar{k}_S(K-1)]}{(1-\rho_V)} \tag{11}$$

which can be simplified as

$$\bar{t}_S(K) = \frac{\rho_V}{(\mu_D - X_V)} + \frac{1/\mu_S[1+\bar{k}_S(K-1)]}{(1-\rho_V)} \tag{12}$$

where μ_S is the mean service rate of S for the call request. The service rate for the virtual job is the same as its service rate at D. ρ_V is the utilization of the virtual job and is defined as $\rho_V = X_V/\mu_D$.

The network throughput for the model given in Figure 3 is

$$X(K) = \frac{K}{\sum_{i=1}^{N}\bar{t}_i(K) + \bar{t}_S(K) + \bar{t}_C(K) + \bar{t}_D(K)} \tag{13}$$

and the mean queue length at each node is derived from Little's law.

$$\bar{k}_i(K) = X(K)\bar{t}_i(K) \qquad \text{for } i=1,2,\ldots,N,S,C,D. \tag{14}$$

The above formulas, (6),(7),(8),(12),(13) and (14), yield the recursive scheme for computing the performance measures for the dynamic window model. The initial values for the recursion are

$$\bar{k}_i(0) = 0 \qquad \text{for } i=1,2,\ldots,N,S,C,D.$$

3.3. Different Processing Rates for Source and Destination

The above analysis describes the situation when the source node and the destination node have approximately equal capacity, i.e., $\mu_S \approx \mu_D$. Here we consider the case when the processing rates of the source and destination differ. The main concern is to vary the virtual job service rate at the source node. If the source node is too slow, we reduce the busy period of the virtual jobs. On the other hand if the source node is to fast, we scale the busy period.

To reflect this behavior in our analytical model, we introduce a heuristic factor α for rescaling the ρ_V of equation (12). Thus

$$\bar{t}_S(K) = \frac{\alpha\rho_V}{(\mu_D - \alpha X_V)} + \frac{1/\mu_S[1+\bar{k}_S(K-1)]}{(1-\alpha\rho_V)} \tag{15}$$

Note that if $\alpha=1$, equation (16) is equivalent to (12). Increasing α will reduce the idle period while decreasing α will speed up the admission. Thus equations (6), (7), (8), (13), (14), (15) constitute the mean value analysis for more general models.

4. NUMERICAL EXAMPLES

We assume the following parameters for the model of Figure 2 with three circuit trunks and three packet switched nodes.

Parameter	Value	
μ_S	10	
$\mu_{Pi}-\lambda_{Pi}$	20	for $i=1,2,3$;
μ_D	10	
λ_{Ci}	40	for $i=1,2,3$;
C_i	50	for $i=1,2,3$;
μ_{Ci}	1	for $i=1,2,3$;
α	1	

We set the initial maximum window size to be $K=45$. We vary the virtual load (X_V) of the destination to reflect the dynamic traffic in the destination area. The effect of changes on the dynamic window size, the throughput of the single source destination pair, and the total throughput is demonstrated in Figures 4, 5 and 6.

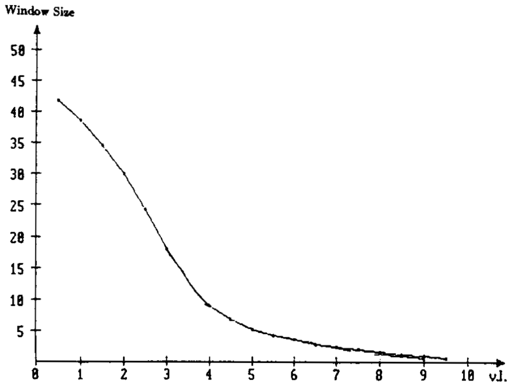

Figure 4. Virtual Load versus Dynamic Window Size.

In Figure 4 we see that the window size decreases as the destination node becomes more and more congested. When the virtual load achieves the processing capability, the destination node is completely congested and the dynamic window size is reduced to 0. This means no calls will be admitted into the failed destination. If the loads (x_V) to the destination decreases, the window size will become larger. When the window size increases, the throughput increases accordingly as shown in Figures 4 and 5.

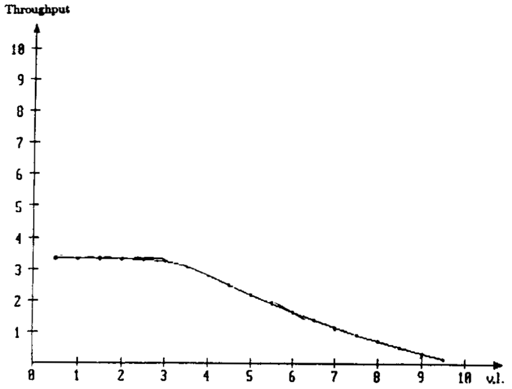

Figure 5. Virtual Load versus Throughput of the Source-Destination Pair.

Figure 5 shows that the load increase in the destination node will limit the throughput of a single source-destination pair. However, increasing the load in the single source destination pair is equivalent to the reduction of the relative virtual load, which corresponds to the left-hand side of the curve. In this case, the throughput of the single source-destination pair increases accordingly.

Figures 5 and 6 show that although the throughput of the single source-destination pair may decrease as the virtual load increases, the total throughput is still high. This demonstrates that the situation of underload does not occur as discussed before.

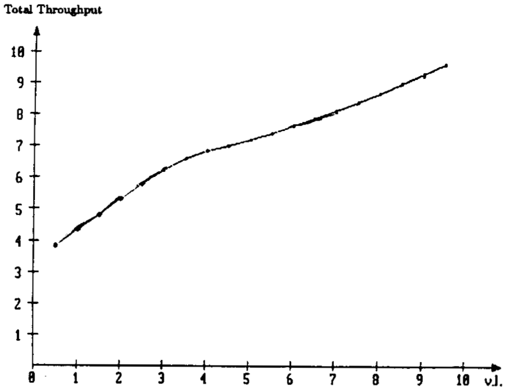

Figure 6. Virtual Load versus Total Throughput

Our analytical results have been validated by simulation. In Figure 7, there are deviations on the left-hand side of the curve. This is due to the fact that when the virtual load is not heavy, the source and the destination nodes are not bottleneck, thus the flow balance analysis technique produces certain deviation. The results become accurate on the right-hand side of the curve where the virtual traffic load has been increased. Note that we are only interested in the situation when the node *D* is congested which corresponds to the right-hand side of Figure 7. The congested node *D* generates heavy virtual traffic and the source node becomes a bottleneck. In this case we observe that the results become accurate.

In Figures 8 and 9, we observe that the results for the throughputs are accurate for both the single source-destination pair and for the total traffic, since the throughput is not sensitive to the imbalanced flow in the analytical model.

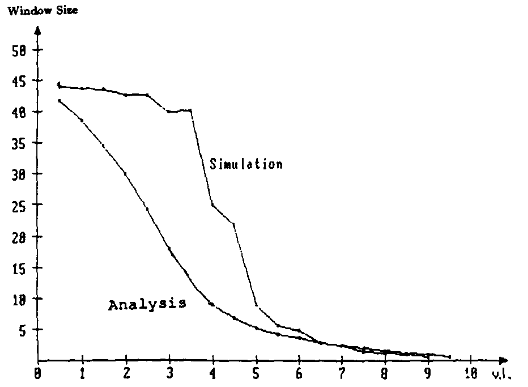

Figure 7. Virtual Load versus Dynamic Window Size.

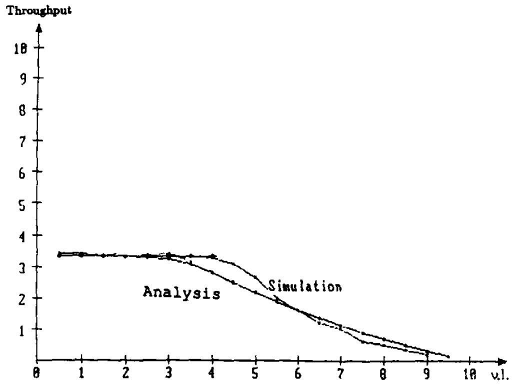

Figure 8. Virtual Load versus Throughput of the Source-Destination Pair.

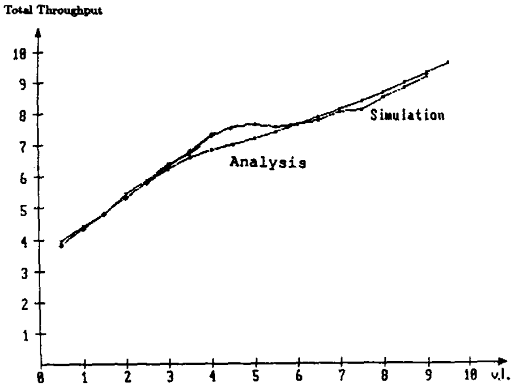

Figure 9. Virtual Load versus Total Throughput.

5. CONCLUSIONS

In this study we have proposed and analyzed a new traffic admission control model based on the new outband signalling technology. In contrast to the current opinion that rate based control is superior to the window based control, we observed that the window scheme does not cause slower acknowledgment in the closed loop feedback. With high speed outband signalling network, we can route the choke packet through the outband signalling path. This scheme of bypassing the congested area enables to adapt the window size in real time.

The contribution of our study comes from the following aspects.

- Considering the interaction of the telephone network and the outband signalling packet switched network is novel. This study can be applied to the evolution of ISDN network systems.
- Our suggestion of using Network Management System to provide feedback information on performance for congestion control is new. It may greatly simplify the design and implementation of congestion control protocol.
- The generic model and the analysis are novel. Although dynamic window control mechanism is studied by other researchers, simulation is the only approach reported up to date [19, 21].
- This model can be further used to study the interaction between different source destination pairs in the future, in contrast to other studies where the traffic from different sources is not distinguished explicitly.

In this model the destination node represents the congested area subject to be controlled. It is not restricted to a particular physical node and may dynamically be changed depending on the current traffic. As mentioned earlier the performance measures can be collected by the network management system. The feedback can be associated with the call release procedure or it can take place through a separate message transmission. Based on this information, the source controller takes action to adjust the traffic. However, the controller can be independently designed to apply any control algorithm, as long as it follows the admission constraint of this model.

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