Dynamic Congestion Control in Interconnected Computer Networks

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Abstract

In interconnected networks, the performance of a network is affected heavily by the traffic transmitted from other networks. A network may become subject to congestion when the internetwork traffic increases rapidly. It is well known that congestion gives rise to a degradation in network performance. In this paper, we evaluate window-based congestion control mechanism in an internetwork environment. We also propose and study two dynamic window congestion control algorithms. These algorithms provide further control to window mechanism by adjusting the window size in accordance with the availability of the network resources at the destination. Dynamic algorithms are evaluated as compared with fixed window control by means of computer simulation.

1.Introduction

The objective of congestion control in a computer network is to prevent or minimize the degradation in the system performance caused by the overload of messages. Various congestion control strategies have been proposed and implemented [5],[7]. Window mechanism is one of the effective congestion control schemes.The window mechanism limits the number of packets injected into the network by a source. The maximum number of packets allowed to be in transit gives the 'window size' between a source and destination. The packets in transit are the ones that have been transmitted, but not yet acknowledged by the destination [7].

In this paper, a window based congestion control mechanism is evaluated in an interconnected network ('internetwork' for short) environment. With the window mechanism, each network is allowed to send up to a certain number of messages to another network without getting acknowledgement. The control is intended for the purpose of preventing congestion in gateways and attached networks caused by the overload of internetwork messages. First, an evaluation of fixed window control mechanism is provided. Then two dynamic window congestion control algorithms are proposed and studied. The algorithms provide further control to window mechanism by adjusting the window size in accordance with the availability of network resources at the destination. A comparison of dynamic algorithms with fixed window control is provided in terms of throughput and delay performance. It is shown that dynamic algorithms have considerable performance advantages over the fixed window control.

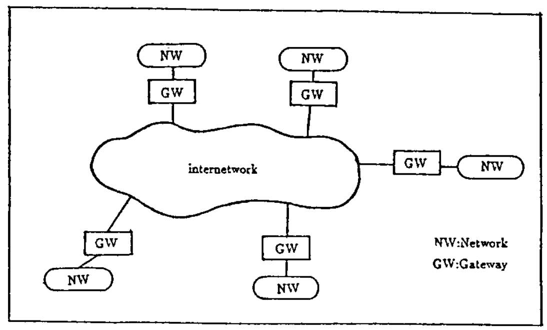

Figure 1: Internetwork structure

2.Simulation Model

Fig.1 presents the internetwork structure we study on where the individual local networks are connected to the system via their gateways.

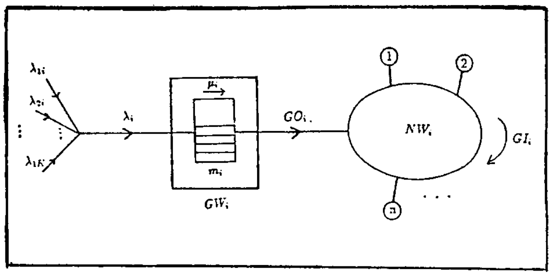

Figure 2: Model for a destination gateway and its connected network

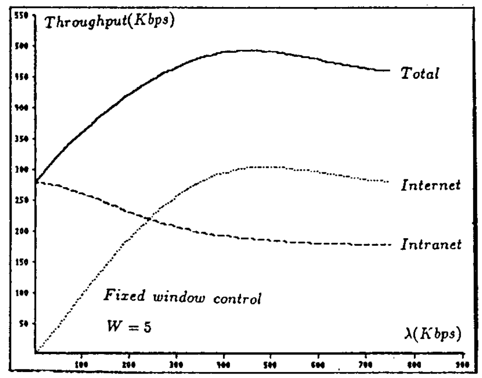

Figure 3: Throughput of a network versus internetwork load

Our study is concerned primarily with investigating the effect of internetwork traffic on the performance of connected networks and providing gateway-to-gateway level congestion control to prevent internetwork message overload at the gateways and networks. In Fig.2 a model is provided for a gateway and its adjacent network within the internetwork.

The parameters appearing in the model can be described as follows:

$\lambda_{ji}(packets/second)$: Arrival rate of internet messages transmitted from network j to network i where λ_{jj}=0 and j=1..K (assuming that K individual networks are interconnected).

$\lambda_i(packets/second)$: Total arrival rate of internet messages to network i ($\lambda_i = \sum_{j=1}^{K} \lambda_{ji}$).

$m_i(packets)$: Buffer capacity of gateway i.

$\mu_i(packets/second)$: Message processing rate at gateway i.

$GO_i(packets/second)$: Rate of internet packets processed at gateway i to its destination network.

n_i : number of nodes within network i.

$GI_i(packets/second)$: Total intranet traffic rate within network i. It is the sum of the rates of internal messages generated by each node.

The assumptions for the internetwork simulation model are:

- The arrival process of internet and intranet messages follows a Poisson process.
- No multipacket message exists in the system, that is all messages consist of one packet only.
- Message lengths are exponentially distributed with the average length of l for both internet and intranet messages.
- The gateway has a finite number of buffers and each buffer can store only one packet. Service time distribution for the internet messages at the gateway is exponential.
- The transmission error rate is negligible.

The resource limitations for internetwork messages arriving at the destination are buffer size and message service rate of the gateway connected to the destination network and the link capacity of the network. Some of the internetwork messages can be discarded at the destination gateway because of unavailable buffer space. A copy of each packet is kept at its source until the acknowledgement of that packet returns from the destination. If the acknowledgement doesn't come within a prespecified period of time (i.e. timeout period), the packet will be retransmitted.

3.Fixed Window Control

We first evaluate the throughput and delay performance of a network in an internetwork environment where the

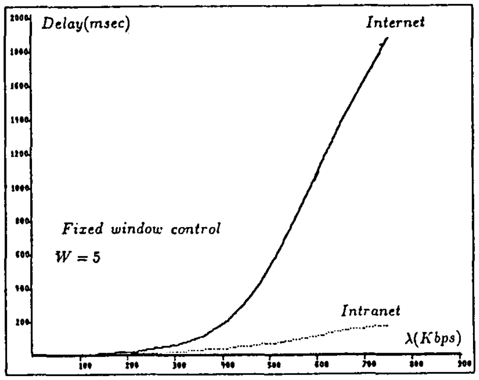

Figure 4: Average message delay versus internetwork load

Table 1: System parameters in simulation model

$K = 6$	$n_i = 10$
$\tau = 0.1 sec$	$GI_i = 300 pac/sec$
$\mu_i = 750 pac/sec$	$C_i = 10^6 bit/sec$
$m_i = 10$	$l = 1000 bit/pac$

maximum number of messages in transit between a network pair (i.e. internetwork window size) is restricted to a fixed value. An extensive study on fixed window congestion control is presented in [9].

Figs. 3,4 provide the performance characteristics of both internetwork and intranetwork messages for the network model where the internetwork traffic changes from light to heavy load. The system parameters used for this evaluation are given in Table 1, where τ denotes the timeout period for internetwork messages and C_i is used to denote the speed of the network i. The fixed internetwork window size is W=5. Carrier Sense Multiple Access (CSMA) method is used for the transmission of messages within the network.

It can be observed from the figures that for large values of offered internetwork load, a degradation in the throughput and delay performance of the messages is observed due to the increasing number of rejections at the destination gateway. If there exists a further control to reduce the window size in the case of a congestion at the destination, then fewer number of rejections occur resulting in a drop in the average delay of internetwork messages. This is the idea behind the proposed dynamic congestion control algorithms.

4.Proposed Congestion Control Algorithms

We propose two control algorithms, namely Algorithm_1 and Algorithm_2 that can adjust internetwork window size dynamically according to the availability of network resources. The main difference between the algorithms is the location of the control of internetwork traffic. In the first algorithm, internetwork traffic is regulated at its destination while in the second one source networks control the traffic flow.

The first algorithm adjusts the window size based on the utilization rates of the resources at the destination gateway. Let r_i denote the rejection rate of messages and u_i the utilization rate of buffers at the gateway adjacent to network i. The algorithm enforces the system to operate without exceeding some threshold values of these system parameters to prevent the overloading of the system due to internetwork messages.

Initially the internetwork operates with an initial window size of W_{init} between network pairs. The choice of initial window size value has not much effect on the performance over a long period since by executing dynamic window algorithms, the window size will soon have a proper value due to the congestion state at the destination. We can start at the maximum window size value (W_{max}) allowed by the destination network. The lower limit on window size is one (W_{min}=1). The following algorithm is executed periodically at gateway i for the messages destined to network i.

Algorithm_1

If ($r_i \geq R$) or ($u_i \geq U$) then

If ($W_{ji} > W_{min}$) then

Send a control message to source gateways to decrease the window size by 1
(For each source network j
$W_{ji} = W_{ji} - 1$)

Otherwise

If ($W_{ji} < W_{max}$) then

Send a control message to source gateways to increment the window size by 1
(For each source network j
$W_{ji} = W_{ji} + 1$)

W_{ji} denotes the current value of window size between the source network j and destination network i. It can take the values between W_{min} and W_{max}. The maximum window size (W_{max}) between network pairs is decided at the start by the destination network depending on the availability of its resources. R and U are the threshold values for the rejection rate of internet messages and utilization rate of buffers at the destination gateway.

Algorithm_2 is a different version of Algorithm_1 in the sense that in this case the control is provided by the gateway next to the source network. When a source gateway senses the congestion at a destination, it limits the number of packets destined to that network by dynamically adjusting its window size. The control is provided for each source-destination gateway pair independently. The control parameters used in the algorithm are the retransmission rate and response time of messages transmitted by the source network.

For the source network j and the destination network i assume that n_{ji} and t_{ji} denote the retransmission rate of messages and average response time of messages respectively.

The following algorithm is executed periodically by the gateway adjacent to network j.

Algorithm_2

For each destination gateway i do

If $(n_{ji} \geq N)$ or $(t_{ji} \geq T)$ then

If $(W_{ji} > W_{min})$ then

Decrease the window size by 1
$(W_{ji} = W_{ji} - 1)$

Otherwise

If $(W_{ji} < W_{max})$ then

Increase the window size by 1
$(W_{ji} = W_{ji} + 1)$

N and T denote the threshold values for the control parameters. W_{ji} is the current window size value between the networks j and i.

5.Performance Measures

In this section comparative performance results are presented for fixed and dynamic window control. The principal performance criteria employed are total throughput

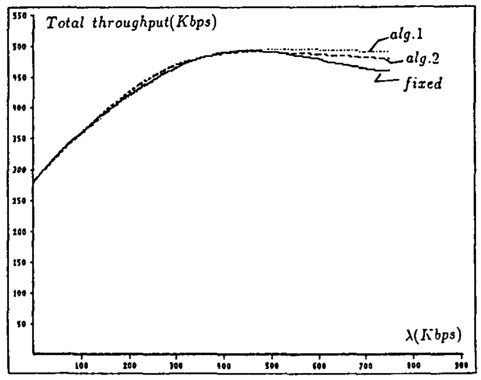

Figure 5: Total throughput versus internetwork load

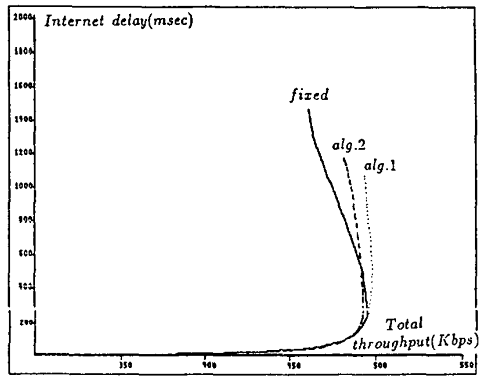

Figure 6: Average internet delay versus total throughput

and average internetwork message delay as a function of the offered internetwork load.

Fig.5 presents a comparison of the fixed and dynamic window control on the basis of total message throughput versus offered internetwork load. At light loads there is no difference in the throughput values since no congestion is observed and the dynamic control algorithms do not intend to reduce the load. At moderate and high load, message throttling effect of the control algorithms prevents the congestion, and thus, the decrease in the throughput value while the internet load is increasing. Although there does not exist much difference in the throughput values, the dynamic algorithms are effective in preventing the decrease in throughput for large internetwork loads.

Fig.6 exhibits the behaviour of average internetwork

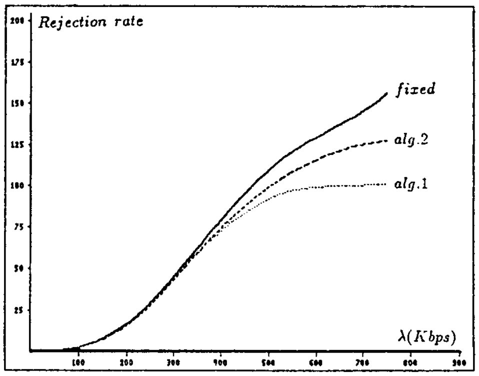

Figure 7: Rejection rate at destination gateway

message delay with respect to total network throughput. Delay increases with increasing throughput because of the contention at gateway and network resources. When the throughput reaches the maximum value attainable, the increase of delay becomes very steep. After that point, further increase in the offered internet load may lead to both a decrease in throughput and an increase in delay. Dynamic algorithms are effective in preventing the sudden rise of delay.

Fig.7 gives the rejection rate of internet messages at the destination gateway for the fixed and dynamic window control. For the large values of offered internetwork load, dynamic control algorithms try to reduce the increase in the number of rejections by adjusting the window size value to the current system load.

The next point to evaluate is the fairness of our dynamic control algorithms under different networking conditions. We simulated the control algorithms with many different possible configurations[10]. Here we present only average internetwork delay versus total throughput curves for some of these configurations.

In the previous example we evaluated the system performance for 6 networks connected to the internetwork. Fig.8 provides internetwork delay characteristics for relatively small and large number of networks. It can be observed from the figures that regardless of the size of interconnected network, dynamic window algorithms are effective in preventing the adverse effects of message overload on the system performance.

In Figs. 9,10 similar graphs are presented for different gateway buffer sizes and gateway message service rates. We can conclude from the figures that for many possible configurations equally good performance results are achieved by the dynamic control algorithms.

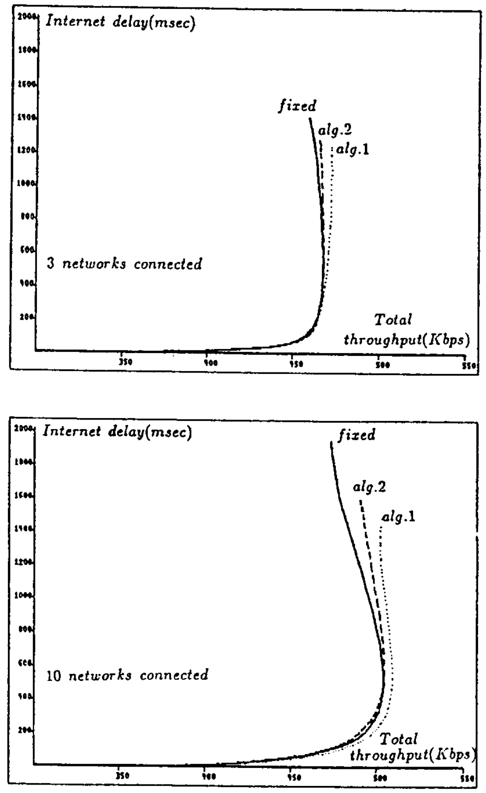

Figure 8: Average internet delay versus total throughput for different number of networks connected to internetwork

6.Conclusions

From the above discussion, the following points can be concluded for the efficiency of the dynamic control algorithms:

- The performance of a network comprising an internet is affected heavily by the internetwork messages. For the large values of offered internetwork load a degradation in the performance is observed due to the increasing number of rejections at the destination. The dynamic algorithms provide a solution to the overload case by adjusting the internetwork traffic rate to the current system load.

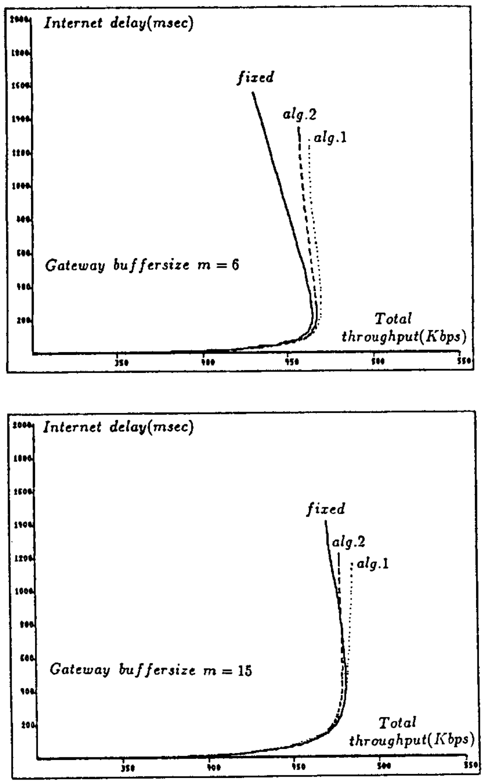

Figure 9: Average internet delay versus total throughput for different buffersizes of destination gateway

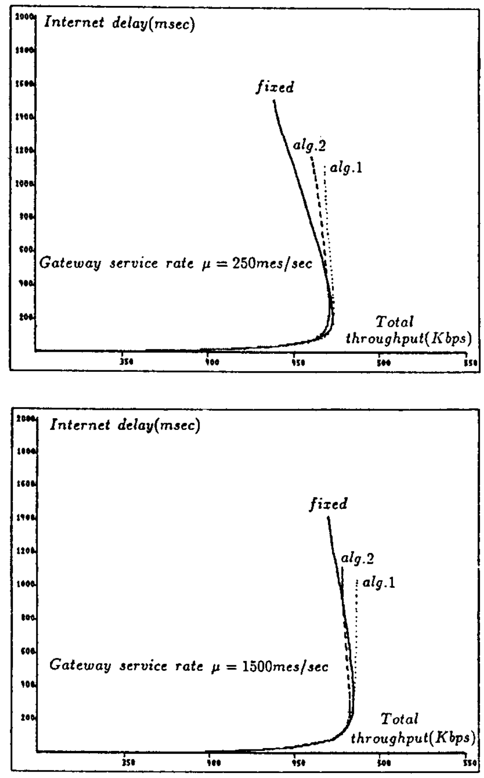

Figure 10: Average internet delay versus total throughput for different gateway service rates

- The dynamic algorithms are effective for moderate and large internetwork load values. For the light values of offered load, since no congestion is observed the message transmission operates under normal conditions. It is guaranteed by the algorithms that when the system is lightly loaded, networks operate at maximum window size allowed which is a desired property to make full use of the available resources.
- The dynamic control algorithms provide a stable throughput behaviour, in the sense that for the large values of internetwork load throughput does not decrease with increasing load value.
- In fixed window control the number of rejections at the destination and thus the number of retransmissions of the internet messages increase without bound with the increasing load due to limited network resources. This will cause a steep increase in the delay of messages when the system is overloaded. The dynamic control algorithms reduce the number of rejections by limiting the number of messages in transmission under overload conditions. As a result, large message delays are prevented. Dynamic control algorithms are superior to fixed window control in end-to-end delay of internet messages.
- Dynamic control algorithms yield satisfactory network performance under different load conditions, and different network patterns. Various system parameters (i.e. number of networks within internet, gateway buffersize, gateway service rate) have been used in the evaluation of fairness of the algorithms. It has been observed that network performance is not sensitive to the values of different system parameters when the dynamic control algorithms are applied.

- The comparison of two dynamic control algorithms shows that, under heavy load conditions better performance characteristics can be obtained with the control at destination gateway (Algorithm_1). This results from the fact that, the destination gateway is capable of providing a lack of traffic effectively for the large values of internet load since it can throttle all source networks in case of a possible congestion. In the 2nd algorithm source networks try to prevent congestion at the destinations of their messages by estimating the current load at the destinations.

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