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On-Board Congestion Control for Satellite Packet Switching Networks

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Abstract

It is desirable to incorporate packet switching capability on-board for future communication satellites. Because of the statistical nature of packet communication, incoming traffic fluctuates and may cause congestion. Thus, it is necessary to incorporate congestion control mechanism as part of the on-board processing to smooth and regulate the bursty traffic. Although there are extensive studies on the congestion control for both baseband and broadband terrestrial networks, these schemes are not feasible for space based switching networks because of the unique characteristics of satellite link. In this article, we propose a new congestion control method for on-board satellite packet switching. This scheme takes into consideration of the long propagation delay in satellite link and takes advantage of the satellite's broadcasting capability. It divides the control between the ground terminals and satellite, but distributes the primary responsibility to ground terminals and only requires minimal hardware resource on-board satellite.

1 Introduction

Future satellites are expected to incorporate more on-board processing capability and to support more diversified communication requirements, including integrated data/voice or ISDN (Integrated Service Digital Network) compatible traffic [7, 11]. Since packet switching can obtain more flexibility and efficiency for bursty traffic, it is beneficial to incorporate packet-switching capability on-board satellite.

One characteristic of packet switching is that the required bandwidth is allocated on demand rather than on the fixed peak rate [19]. Because of the statistical fluctuation, total incoming traffic may occasionally exceed the capacity of outgoing link even the average incoming volume is within the limit. Thus, it is necessary for a packet switching network to incorporate certain *congestion control* mechanisms to smooth and regulate the bursty traffic. Although this topic is thoroughly studied for terrestrial networks [1, 6, 16], very little is known for the satellite based networks. This paper overviews the congestion control for both baseband and broadband terrestrial networks, proposes a method that is suitable for the unique operational environment of satellites and suggests promising directions for future development.

The remaining paper is organized as follows: Section 2 introduces basic concepts related to the congestion control; Section 3 overviews the congestion control schemes for baseband and broadband terrestrial networks; Section 4 describes the proposed scheme for satellite based packet switching networks; Section 5 outlines the issues for future investigation and last section summarizes the study.

2 Basic Concepts

To achieve flexibility and efficiency, packet switching systems allocate resources on demand; i.e., no bandwidth will be consumed if the connected link is idle. This feature is essential for bursty traffic, in which the packet arrival rate fluctuates significantly and the peak arrival rate is much larger than the average arrival rate. If the allocated bandwidth is fixed, as in the circuit switching, it has to be equal to the *peak rate* to accommodate the worst case. On the other

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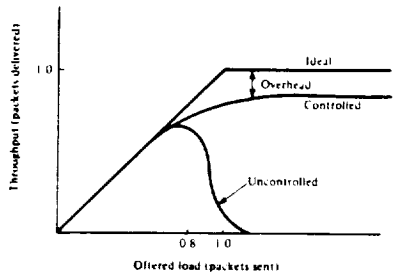
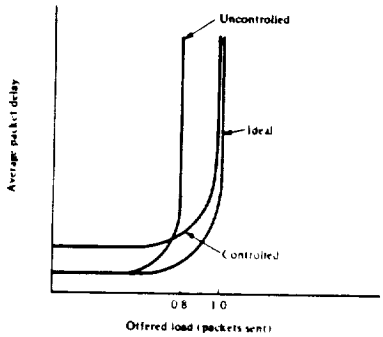


effective throughput vs. offered load



delay vs. offered load

Figure 1: The Effect of Congestion Control

hand, in the packet switching network the allocated bandwidth only needs to be roughly equal to *average rate* of the incoming traffic. Therefore, system resource can be better utilized in packet switching networks.

Due to the statistical fluctuation, packet switching network may suffer potential congestion problem. The volume of total incoming traffic may occasionally exceed the capacity of outgoing link, even the outgoing link can incorporate incoming traffic *statistically* (i.e., in average). Without proper control, the buffer may overflow and certain packets will be lost. These in turn will reduce the effective throughput and introduce long delay. The purpose of congestion control is to provide a mechanism to smooth out fluctuation by regulating the incoming traffic and to prevent severe performance degradation [6]. The typical performance of an ideal system, a controlled system and an uncontrolled system is shown in Figure 1 [19].

2.1 The delay*bandwidth parameter

Although communication networks can be characterized by a wide variety parameters, the term *delay*bandwidth* is most essential for congestion control. Delay (d) represents the required time to propagate a packet from source to destination. Bandwidth (B) represents how fast a packet can be transmitted, which normally has a unit of ***bits per second***. Delay is fixed for all technology, which is determined by the distance between source and destination and is roughly equal to $\frac{distance}{speed\ of\ light}$. Bandwidth varies with the underlying technology, ranging from 1G *bits/sec* (as in a fiber optic link) to 1K *bits/sec* (as in a phone line).

The bandwidth*delay gives a good indication of the "responsiveness" of the feedback control between source and destination. For example, if destination sends a feedback message at time t_0, the source will receive it at time $t_0 + d$; however, before the source can receive the message, there are already outstanding $d * B$ bits (in the worst case) on their way. For effective congestion control, the scheme needs to consider the current status of the buffer as well as to predict the outstanding traffic already in transmission. In general, designing congestion control schemes is harder for a network with large delay*bandwidth because of the uncertainty associated with the potentially large outstanding traffic.

Delay*bandwidth may vary drastically from one network to another Consider following examples:

- typical LAN (in which $B = 10\ Mbits/sec$, $d = \frac{1\ km}{c}$): 50 bits.
- a 200 mile T1 line (in which $B = 1.544\ Mbits/sec$, $d = \frac{320\ km}{c}$): 2500 bits.
- a 200 mile optical fiber link (in which $B = 1\ Gbits/sec$, $d = \frac{320\ km}{c}$): 1.6 Mbits.
- a low bit rate satellite beam (in which $B = 64\ Kbits/sec$, $d = 125\ msec$): 8000 bits.
- total uplink capacity of a satellite (in which $B = 512\ Mbits/sec$ [11], $d = 125\ msec$): 64 Mbits.

As we can see, the delay*bandwidth of a satellite based network is significantly larger than its terrestrial counterpart.

2.2 An Unified Permit-Bank Model

The key of congestion control is to develop a mechanism to regulate the rate of incoming traffic so that the outgoing link will not be overwhelmed. In this

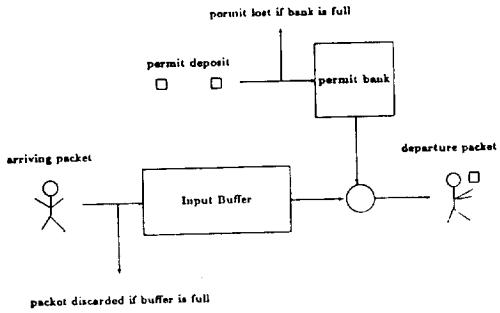


Figure 2: Diagram of Permit Bank

article, we use a simple "permit bank" model (which is also known as *leaky bucket* [4] or *token bank* [2]) to illustrated various congestion control schemes. The basic diagram of this model is shown in Figure 2. There is a buffer and a permit bank for every incoming link. The arriving packet needs to obtain a "permit" before it can be transmitted; otherwise it has to be queued in buffer or discarded. The major design issues is to develop a mechanism to "deposit" permits into the bank and to determine the size of the bank.

3 Current Approaches for Terrestrial Networks

Congestion control for terrestrial networks has been studied extensively [1, 6]. It can be basically divided into two classes: *reactive control* and *preventive control* (or *closed-loop control* and *open-loop control*). Reactive control is normally used for traditional baseband network, in which the delay*bandwidth is relative small. Preventive control is primarily aimed at the fiber-optic based BISDN (Broadband ISDN) ATM (Asynchronous Transfer Mode), in which the high data rate of optical fiber significantly increases the value of delay*bandwidth. The following two subsections outline the schemes used for the two classes. We concentrate more on the preventive control because of the resemblance of ATM networks and satellite networks (the large delay*bandwidth).

3.1 Reactive control

Reactive congestion control is invoked upon the detection of congestion. It normally depends on the feedback mechanism that sends control or status information back to the source. The source then reduces the input rate accordingly.

The most commonly used method is ***sliding window***. It can be explained by permit bank model of section 2.2. In this scheme, permit deposit is controlled by the destination. A departing packet will return the permit to destination. Depending on its buffer availability, the destination can either hold the permit or deposit the permit back (by an acknowledge packet) to the source. This holding mechanism implicitly controls the source's packet departure rate.

The size of the permit bank corresponds to the size of the window. It can be pre-determined (such as in internet) or adaptive (such as the *pacing* scheme in SNA) [17, 14]. The adaptive method relies on certain feedback information from network, such as the total round trip delay or number of hops. This information gives an indication of network's status and is carried by acknowledge packets.

The reactive control, in general, is not effective for network with large delay*bandwidth because of the relative slow feedback. By the time the feedback information reaches the source and rate control is triggered, it may be already too late to react effectively. Thus, the proposed high speed BISDN ATM network normally does not employ reactive control schemes.

3.2 Preventive control

Preventive control does not employ feedback information. Instead of reacting to the occurrence of congestion, it tries to prevent the network from reaching an unacceptable level of congestion. Various preventive control schemes are proposed for ATM networks and are an important research issue for BISDN [1].

Preventive control for ATM networks includes two major parts: *admission control* and *bandwidth enforcement*. Admission control determines whether to accept or reject a new connection at the time of call setup, and bandwidth enforcement monitors individual connections to ensure that the actual traffic flow conforms with that reported at call establishment.

admission control Admission control decides whether to accept or reject a new connection based on whether the required performance can be maintained. When a new connection is requested, the network first

examines the required service and traffic characteristics as well as the network's current load and status, and then determines whether or not to accept the new connection [8].

To effectively utilize this scheme, three major issues need to be resolved:

- the choice of traffic descriptors.
- the decision criteria.
- the effects of traffic descriptors on the network performance.

Because of the diversity of the expected ISDN traffic, it is very difficult to develop a model to predict the network's performance based on limited information obtained during call setup.

bandwidth enforcement Bandwidth enforcement mechanism is used to monitor the incoming traffic to ensure that the flow conforms with that specified at call establishment. The *leaky bucket* and its variations are the most commonly used methods [4, 2, 15, 18]. The permit bank model also can be used for leaky bucket. In this case, the permit is automatically deposited in a fixed rate, and will be discarded if the permit bank is full. The deposit rate and the size of the bank are determined at the call establishment. The rate corresponds the average rate incoming traffic and the size of the bank indicates the allowed *"burstiness factor"* of the transmission.

The input buffer can be used to queue the incoming traffic exceeding the designated burstiness factor. It provides a better control of the trade-off between packet waiting time and packet loss probability.

4 Congestion Control for On-board Satellite Switching

The packet switching satellite is like a single gigantic concentrator (or a switch) in the sky. Its characteristic is quite unique and thus needs new congestion control schemes. In following subsections, we first examine the differences between satellite networks and terrestrial networks and then describe the proposed scheme.

4.1 Comparisons between terrestrial network and satellite

From congestion control point of view, satellite based packet switching differs from terrestrial network in several aspects: propagation delay, topology complexity and operation environment. Their differences and the implication for congestion control are discussed as follows.

propagation delay Communication satellites normally station at geostationary orbit, approximately 22,300 miles from the surface of the earth. This orbit makes the propagation delay about 125 msec, which is much longer than any terrestrial link. Consequently, as we have seen in section 2.2, satellite link has the largest bandwidth*delay. Because of the sluggish feedback, reactive control similar to sliding window tends to be less effective.

topology complexity Terrestrial networks are normally composed of a number of switching nodes interconnected by various types links. On the other hand, a satellite network contains only *one* switching node, which can be accessed by all users.

The implication of a single node is twofold. First, network congestion status can be easily obtained by observing the available buffer space. Second, satellite can easily broadcast this information to all the ground terminals (this is contrary to terrestrial networks, in which , it is extremely hard to obtain its accurate"global" status and distribute to all the users). From this point of view, it is desirable to maintain certain degree of feedback control in a satellite based network.

operation environment The operation environment for satellite is rather harsh. The devices need to tolerate high temperature and radiation, and their volume, weight and power consumption are severely constrained. Also, maintenance and updating are extremely difficult.

From this point of view, the congestion scheme should distribute more functionality to the ground terminals, and make the space-based segment simple, flexible, and robust.

4.2 Proposed scheme

Because of satellite's unique characteristics, congestion control schemes for terrestrial networks are not feasible for space based packet switching. Sliding window method is not effective because of the long propagation delay. Furthermore, its fairly sophisticated protocol, such as time-out mechanism,

makes on-board implementation impractical (considering that there are about 8000 ground terminals).

Although preventive control is appealing, it is not completely satisfactory because of the potential low utilization. It comes from the fact that the switching node needs to make prediction by *a priori*, which only provides limited information. To guarantee the quality of the service (i.e., low packet loss probability), the admission tends to be conservative and cannot fully utilize the resource. This is less a problem for optical fiber based link since the bandwidth is relatively inexpensive, but is severe for satellite link in which bandwidth is still a precious resource.

The proposed congestion control method is a scheme that combines reactive control and preventive control. This scheme takes into consideration of the long propagation delay in satellite link and takes advantage of the satellite's broadcasting capability. It divides the control between the ground terminals and satellite, but distributes the primary responsibility to ground terminals and only requires minimal hardware resource on-board satellite. It takes advantage of the broadcasting capability of the satellite to overcome the long propagation delay.

This scheme include three major parts: admission control, bandwidth enforcement and a *"group feedback"* mechanism. The first two parts are similar to those in ATM congestion control. However, the two key parameters, deposit rate and bank size, can be updated dynamically according to the buffer availability of dowlinks. To achieve this, the satellite continuously broadcasts its *"congestion status"* and the ground terminals adjust their parameters accordingly. Note that, unlike sliding window method, satellite does not exchange information with ground terminals in an individual basis (so we coin the scheme as group feedback). The detailed description of the proposed scheme is described as follows:

call establishment At the call setup, the admission control will be exercised. The satellite examines the required service, traffic parameters and its own load status and decides whether to accept or reject the call. The initial value of deposit rate and bank size are determined at this time. Although these values may be updated and modified later via group feedback, they establish a "reasonable" basis for future operation and can avoid extreme, unpredicted fluctuation.

Since the deposit rate and bank size can be altered later, the admission control does not need to be very accurate and the task is considerably easier than that of ATM.

group feedback The feedback control is distributed between ground terminals and satellite. The satellite continuously broadcasts the congestion status, and ground terminals react and adjust their parameters accordingly. If the traffic is heavy and congestion is expected, the ground terminals should lower their deposit rate and bank size. In general, reducing the bank size can smooth out burstiness in a short term and reducing deposit rate will regulate and shape the traffic in a long term.

The simplest mechanism to throttle the input traffic is to lower the rate and size of all active terminals in the same proportion. A more sophisticated mechanism should examine various traffic types and their required quality of service, and then respond accordingly (e.g., reduce less for the terminal with real-time traffic). In the ideal situation, the feedback congestion control should be operated on a "continuous" basis instead of just "on or off" by some trigger. In this case, the parameters will be reduced gradually and the performance degradation will be graceful.

4.3 Potential advantages

There are several benefits to implement the proposed congestion control scheme in a space based switching network:

simple implementation The requirements for the space-based segment is relatively simple. Its major tasks are to monitor the incoming traffic and collect the statistics, and to estimate the congestion status from the data collected and broadcast it back to ground terminals.

flexibility Since the execution of group feedback is primarily done at ground segment, the design can be modified or updated without changing satellite's configuration. This feature is desirable since many factors, such as the type of services, its traffic characteristics etc., are not well understood and thus no precise design decision can be made. The proposed scheme allows the exact design to be incorporated into the ground segment when the issues are better understood, and also gives room to add new features in the future.

robustness Unlike the sliding window method, the group feedback scheme regulates incoming traffic on a statistical basis. Thus, small fluctuation can be tolerated. Occasional loss of status information will only slightly degrade the performance and will not cause drastic effects.

5 Issues for Future Study

This article only gives a preliminary investigation. To determine the feasibility and effectiveness of the proposed scheme, many issues needs to be carefully studied and many features needs to be fine tuned. The following topics are essential and need to be further studied:

traffic characteristics Because of the statistical nature of the proposed scheme, the understanding of incoming traffic characteristics plays an important role. To accurately describe ISDN traffic will be difficult due to the diversity of the services provided. Models for various types of traffics, such as voice, still video, continuous video etc., have been proposed [1]. However, model for heterogeneous traffic (traffic with mixed typed services) is hardly developed and needs further investigation.

congestion status Recall that the satellite continuously broadcasts congestion status information. This information should take into consideration of:

- current satellite load (the available buffer space the number of active connections etc.).
- the expected incoming traffic in next 125 msec (the propagation delay between ground terminals and satellite).
- the expected incoming traffic after 125 msec.

Note that the second part represents the amount of traffic arriving at satellite before ground terminals can receive the congestion information.

This congestion status can be derived either by conventional *statistic approach*, or by more radical approaches, including *neural network* and *fuzzy logic* [3, 10, 9]. Both neural network and fuzzy logic represent *model-free estimation*, which can incorporate more uncertainty and are more fault tolerant [13].

group feedback control The detailed mechanism for group feedback control for ground segment needs to be investigated. The major tasks are:

- to determine the maximal, optimal and minimal values of deposit rate, bank size and buffer size for various types of service.
- to develop a method to gracefully reduce these values if needed.

call setup Admission control should be done during the call establishment. Since its nature is similar to that of BISDN ATM networks, vast amount of research in ATM networks can be applied [1] and therefore is less crucial.

evaluation The final design should be evaluated by analytical queuing model or by simulation. Its performance and effectiveness should be determined by carefully examining following parameters:

- packet loss probability due to the satellite congestion.
- packet loss probability due to the satellite congestion *plus* ground buffer overflow.
- packet delay and jitter due to satellite link.
- packet delay and jitter due to ground buffer *plus* satellite link.
- utilization of the satellite link.

6 Summary

In this article, we overview the congestion control for terrestrial networks, compare the operation environment between terrestrial networks and satellite networks, and proposes a method that is suitable for satellite based packet switching networks. The proposed scheme employs a permit bank model, and uses a global congestion information broadcasted from satellite to adjust the deposit rate and bank size of ground terminals. This article describes the basic operation of this scheme and suggests the directions and issues for future study.

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