The Concept of Fairness and a GFC Protocol

Xinli Hou, Ignas G. Niemegeers
Tele-Informatics and Open Systems Group
University of Twente
P.O.Box 217, 7500 AE, Enschede, The Netherlands

Abstract

The success of B-ISDN will depend on the way in which B-ISDN services are offered to users. Multiple access to a single UNI is a cost effective solution for the provision of B-ISDN services in customer premises. In a multiple access configuration, a fairly shared access must ensure that each terminal will get a guaranteed bandwidth to provide an acceptable Quality of Service (QoS) and the allocation of the remaining bandwidth will result in the same improvement of QoS for all the terminals. An approach to allocate the remaining bandwidth is proposed which is based on both the guaranteed bandwidth required by the terminal and the probability that the terminal's bit rate exceeds its guaranteed bandwidth. The basic GFC protocol mechanism and the GFC field settings for a dual bus CPN are described as well.

1. Introduction

Standards are being developed for the broadband integrated services digital network (B-ISDN). The success of B-ISDN will, to a large extent, depend on the way in which B-ISDN services are offered to users. A Customer Premises Network (CPN) provides multiple terminals with the possibility to access B-ISDN via a single User-Network Interface (UNI). This will lead to a cost effective solution for the provision of B-ISDN services in customer premises, since resources such as the Line Terminator (LT) are shared by several terminals. Internal traffic, originating and terminating in the same premises, can be switched by the CPN. Therefore users will not be charged for unnecessary access to the public network. Sharing a resource such as the bandwidth at a UNI among several terminals raises an issue of how the resource is to be allocated when congestion occurs. The Generic Flow Control (GFC) mechanism at the UNI is used to control the information transfer in order to alleviate short-term overload conditions which may arise. The functional description of the GFC mechanism is given in CCITT recommendation I.150 [2]. GFC

protocols are being studied by standardization bodies in order to provide a fairly shared access to the UNI in a shared medium CPN. Since these GFC protocols also control the access to the internal shared medium, they are sometimes called multi-configuration medium access protocols [7].

The GFC protocol is shaped by a number of factors, such as the logical configuration of the CPN, the call bandwidth allocation strategy and, of course, the concept of fairness. Some GFC protocols are developed for a logical ring [5], others for a dual bus [1]. In the early implementation of B-ISDN services, for each call its peak bandwidth would be allocated. The drawback of the peak bandwidth allocation is that no dynamic multiplexing gain is achieved and hence resulting in a poor utilization of the bandwidth. The target bandwidth allocation strategy is statistical capacity allocation which allows the terminals to describe their traffic behavior with more parameters than the peak bit rate only. The network may accept calls depending on the statistical behavior of all the terminals, leading to a better utilization of the network resources.

In this paper, we focus on the concept of fairness in Section 2. A GFC protocol is proposed in Section 3 to provide all the terminals with an acceptable Quality of Service (QoS) and the same additional improvement of QoS. Section 4 concludes the paper with open issues.

2. The Concept of Fairness

From the network point of view, the shared bandwidth at the UNI should be equally shared by all the terminals since the network knows nothing but the total bandwidth available. It confirms with the opinion from the user point of view in data communication networks which support only a single type of service. The famous example is Distributed Queue Dual Bus (DQDB) protocol in the IEEE 802.6 standard, which tries to even up the available bandwidth so that each station will get about the same amount of bandwidth [6]. However, a broadband CPN provides B-

ISDN services which have diverse characteristics. The opinion from the user point of view is no longer the same as that from the network point of view.

B-ISDN services can be classified into two categories by the variability of the bit rate: the Constant Bit Rate (CBR) services and the Variable Bit Rate (VBR) services. In order to provide an acceptable quality of service, a guaranteed bandwidth must be provided to all the terminals. To meet the requirement, the call admission procedure has to ensure that the total guaranteed bandwidth should be less than the capacity of the network. The policing function monitors the traffic of each call. Whenever the agreement on the traffic characteristics is violated, the policing function examines the impact of the violation on the QoS of other calls and takes further actions, e.g. dropping cells, accordingly. The remaining bandwidth should be allocated to the terminals supporting VBR service in such a way that the same improvement of the quality of service will be achieved by all the terminals, in terms of access delay, delay jitter and cell loss probability (due to the shortage of the buffer in the terminal).

Assume that terminal i requires at least a bandwidth v_{gi} to provide an acceptable QoS, v_{gi} is called the guaranteed bandwidth. A bandwidth of $v_{Ti} = v_{gi} + v_{ei}$ is allocated to the terminal. So far as the terminal produces traffic at a rate less than or equal to the allocated bandwidth v_{Ti} , the flow control mechanism ensures the agreed QoS both for the guaranteed bandwidth v_{gi} and for the extra bandwidth v_{ei} . With this assumption, **a fair sharing of the bandwidth means that all the terminals will have the same probability of exceeding the total allocated bandwidth v_{Ti}** . The question here is how to determine v_{ei} in order to provide a fair sharing?

In the first approach, the remaining bandwidth is equally divided to all the terminals. Assume that N is the number of the terminals, C is the total bandwidth at the UNI, and the remaining bandwidth $v_R = C - \sum_i v_{gi}$, we have

$$v_{ei} = v_R / N$$

This is an extension of the philosophy of the fairness in DQDB. It does not take any stochastic characteristics of the terminal into consideration.

In the second alternative approach, the remaining bandwidth is divided in such a way that each terminal will get an equal fraction of its guaranteed (or peak) bandwidth [1], i.e.

$$v_{ei} = v_{gi} \times \frac{v_R}{\sum_k v_{gk}}$$

To provide an acceptable QoS, the guaranteed bandwidth depends on the statistical characteristics of the terminal. For instance, the guaranteed bandwidth for a CBR service such as telephony is the same as the source bit rate. On the other hand, the guaranteed bandwidth for a VBR service may be a certain fraction of its peak bit rate. It is better than the first approach since it takes the statistical characteristics of the terminal into consideration through the guaranteed (or peak) bandwidth.

The approach proposed in this paper allocates the remaining bandwidth according to the behavior of each terminal more precisely. Assume that S_i is the probability of the terminal i generating traffic at a rate greater than the guaranteed bandwidth v_{gi} , we propose

$$v_{ei} = v_{gi} S_i \times \frac{v_R}{\sum_k v_{gk} S_k} \quad (\text{EQ.1})$$

The idea is based on the following derivation. Assume that the bit rate v_i at which terminal i generates traffic is a random variable with a probability density function (pdf) $p_i(v)$, and a peak bit rate v_{pi} , see Figure 1.

Figure 1. Probability density function of terminal i 's bit rate

Let

$$S_i = \text{probability} \{v_i > v_{gi}\} = \int_{v_{gi}}^{v_{pi}} p_i(v) dv$$

$$S_{i1} = \text{probability} \{v_{gi} < v_i \leq v_{Ti}\} = \int_{v_{gi}}^{v_{Ti}} p_i(v) dv$$

and

$$S_{i2} = \text{probability} \{v_i > v_{Ti}\} = \int_{v_{Ti}}^{v_{pi}} p_i(v) dv$$

It is obvious that $S_i = S_{i1} + S_{i2}$.

A fair sharing can be ensured, as defined previously, if

$$S_{2i} = S_{2j} \quad \text{for all } i \neq j$$

or in another form if:

$$S_i - S_{i1} = S_j - S_{j1} \quad \text{for all } i \neq j$$

To reach this target, the greater S_i is, the greater S_{i1} should be. To increase S_{i1} the only parameter that can be changed is v_{Ti} , or more precisely, v_{ei} because

$$S_{i1} = \int_{v_{ei}}^{(v_{ei} + v_{ai})} p_i(v) dv$$

The pdf $p_i(v)$ characterizes the bit rate at which terminal i produces traffic, v_{ei} is required by the terminal to provide an acceptable quality of service, neither of them should be changed by the GFC protocol in the congestion conditions.

In summary, in order to provide a fairly shared access, the greater the probability that the bit rate of terminal i exceeds v_{ei} is, the more extra bandwidth should be allocated to the terminal. In addition, the amount of extra bandwidth should also be proportional to the guaranteed bandwidth v_{gi} . This leads to the bandwidth allocation formula (EQ.1).

S_i can be estimated as follows: assume that in any given duration T the bit rate of terminal i exceeds the guaranteed bandwidth for a time duration T_{oi} . Then terminal i uses T_{oi}/T as the estimate of S_i . It is obvious that the longer the duration T is, the more accurate the estimate of S_i is. The estimation can be done incorporated with the traffic policing function.

One of the advantages of our approach is that there is no need to distinguish the CBR service from the VBR service. The remaining bandwidth does not need to be allocated to the CBR service. In the first two approaches, VBR terminals must be recognized so that the remaining bandwidth will be assigned to them only. In our approach, $S_i = 0$ for CBR terminals and therefore no extra bandwidth will be reserved for CBR terminals.

The second advantage of our approach is that it attempts to take into consideration the probability density function of the terminal bit rate, resulting in a more fairly shared access to the UNI capacity and the internal shared medium.

3. The GFC Protocol

In this section a GFC protocol is described for a dual bus CPN as shown in Figure 2. The latter has been shown in [3] as an example of a physical configuration for shared medium applications. The protocol architecture of the CPN is shown in Figure 3. The physical layer conforms to

the B-ISDN UNI physical layer specification in [4]. The GFC protocol, as one of the ATM layer protocol procedures, controls the access to the unassigned ATM cells. The other functions of the ATM layer, e.g. header generation, and the AAL layer will not be addressed in this paper.

Figure 2. Physical configuration of a dual bus CPN

Figure 3. Protocol architecture

3.1. The GFC field settings

The GFC protocol should be implemented based on the four-bit GFC field in the ATM cell header at the UNI. There are four basic GFC signals: restricted, unrestricted, reset and request for the transmission of a minipacket¹ in the opposite bus. The signals are written into the GFC field of an assigned or unassigned ATM cell on the opposite bus. However, the first three signals, restricted, unrestricted and reset, are reflected by the head-end of the bus to which these signals are applied and the request signal is terminated at the head-ends. The GFC field settings are shown in Figure 4.

3.2. Basic access mechanism

The estimate of S_i is broadcast to all the terminals. Whenever a call is accepted, an ATM cell conveying the guaranteed bandwidth required by the call is broadcast to enable each terminal to update the total guaranteed bandwidth required. The capacity at the UNI, which is the same as that of the dual bus, is known in advance. Therefore, each terminal is able to compute dynamically the available

1. A minipacket is, in the context of this paper, an ATM Service Data Unit.

Figure 4. The GFC field settings

extra bandwidth v_{ei} , and hence its total allocated bandwidth v_{Ti} . Since a terminal may access to one of the two buses for different calls, these parameters S_i , v_{gi} , v_{ei} and v_{Ti} must be calculated respectively for each bus. In the following sections, we describe the GFC protocol for the access to any one of the buses. The access to the other bus will follow the same procedure but with different parameter values. To simplify the description, the unit of bandwidth will be cells per second.

Once a minipacket arrives at the ATM layer for transmission on a particular bus, say, bus A, a *request* will be sent on the opposite bus, bus B, to all the upstream terminals.

Each terminal has a counter REQ for each bus which measures the total load of all the downstream terminals like in DQDB. A terminal receiving a request for the transmission of a minipacket on a particular bus by a downstream terminal, increases its request counter REQ for that bus by one. Every time an unassigned ATM cell is passed to the downstream terminals, REQ is decreased by one.

Figure 5. Access state diagram of a bus

3.2.1 Unrestricted access

Each bus has two access states: unrestricted access and restricted access (Figure 5). When a bus is in the unrestricted access state, each terminal can claim any unassigned ATM cell passing by on that bus, regardless of the counter REQ. In each terminal, when a minipacket arrives at an empty queue for transmission on a particular bus, a

timer T and a counter R start from zero. R counts the number of ATM cells on the bus claimed by the terminal. Let T_{Mi} be a threshold which determines the maximum guaranteed access delay² for terminal i . If timer T is close to T_{Mi} and R is much less than $v_{Ti} \times T_{Mi}$, indicating that terminal i can not get its allocated bandwidth v_{Ti} with the agreed QoS, the terminal sends a *restricted signal* on the opposite bus. This terminal, say, terminal i becomes the master of the bus and the bus enters the restricted access state.

After sending the restricted signal, the terminal continues claiming any unassigned ATM cells until either R reaches $v_{Ti} \times T_{Mi}$ or its transmission queue becomes empty. If R reaches $v_{Ti} \times T_{Mi}$, it will send a *reset signal* on the opposite bus to enable other terminals to transmit data. If the transmission queue becomes empty first, an *unrestricted signal* is sent to change the bus back to the unrestricted access state.

3.2.2 Restricted access

Each terminal reads the GFC field of all the unassigned and assigned ATM cells. If a terminal reads a restricted signal applying to the current bus, indicating that the bus enters the restricted access state, it ceases claiming any unassigned ATM cells on this bus until the receipt of a reset signal (reset cycles like Orwell). After receiving a reset signal, each terminal k , $k = 1 \dots N$, resets its SEND counter for this particular bus, and SEND is incremented once the terminal has claimed an unassigned ATM cell.

Let $T_{min} = \text{minimum} \{T_{Mk}, k = 1 \dots N\}$. Whenever SEND reaches $d_k = v_{Tk} \times T_{min}$, the terminal k ceases claiming any unassigned ATM cells until either

- 1.) a time-out occurs indicating that time T_{min} has elapsed since the last reset signal. The terminal enters the auto-resetting state, the counter SEND is reset. The terminal is therefore allowed to claim at most d_k unassigned ATM cells again, or
- 2.) a reset signal arrives. If the terminal is not in the auto-resetting state, it resets its SEND counter and is able to claim unassigned ATM cells again. If the terminal is in the auto-resetting state, the auto-resetting state is canceled. However, SEND is not reset. The terminal is allowed to transmit minipackets until SEND reaches d_k .

The possibility of the auto-resetting ensures that if a reset signal is corrupted each terminal is still able to trans-

2. The access delay is defined as the time duration between the instant when a minipacket enters the transmission queue and the instant when the first bit of the minipacket is being transmitted.

mit at least at the allocated bandwidth.

The reset signal is sent by the master terminal on the opposite bus to the head-end terminal, the head-end terminal sends this reset signal on the controlled bus. The master will issue a reset signal when either of the following conditions occurs

- 1.) $\left(\sum_{k=i+1}^N d_k \right)$ unassigned ATM cells have been passed by the master to the downstream terminals from terminal $i+1$ to terminal N , since the last reset signal (having passed through the head-end) arrived at the master, or
- 2.) after the last reset signal has issued for a duration greater than the round trip time of the bus, an unassigned ATM cell is to be passed to the downstream terminals and the counter REQ of the master is zero.

The first condition indicates that the downstream terminals as a whole have got their allocated bandwidth. A reset signal should be sent to allow the upstream terminals to transmit minipackets. The second condition will be fulfilled in case that the downstream terminals do not need all the bandwidth allocated to them, a reset signal is sent to allow the heavily loaded upstream terminals to make use of this part of the bandwidth.

In the restricted access state, the master terminal, terminal i , continues monitoring the traffic on the controlled bus. When it observes that the upstream terminals (from terminal 1 to terminal $i-1$) utilize only a part of their allocated bandwidth, the master will change the access state of the bus to the unrestricted access. It is done as follows. Once a reset signal is sent off, the master starts counting by counter F the number of assigned cells passing by on the controlled bus. When the condition of sending another reset signal occurs, counter F is checked. If F is close to $\left(\sum_{k=1}^{i-1} d_k \right)$, indicating that the upstream terminals have utilized all the allocated bandwidth, a reset signal is sent. If F is much less than, e.g. less than 80% of, the threshold, an unrestricted signal instead of a reset signal is sent on the opposite bus and is reflected by the head-end. Reading a unrestricted signal applying to the current bus in the GFC field of an ATM cell, each terminal knows that the bus enters unrestricted access state.

3.2.3 Remarks

It is noted that the counter REQ has not been used to build up a distributed FIFO queue to even up the mean access delay among terminals. Instead, only a maximum guaranteed access delay is ensured for each terminal. The two reasons to do so are as follows. At the first place, dif-

ferent terminals may have a different requirement for the maximum guaranteed access delay T_{Mi} . So far as the access delay is less than T_{Mi} , the agreed QoS will be provided to users. And secondly, only the mean access delay does not determine the delay parameter of QoS of B-ISDN services from the user point of view. Session synchronization and assembly of minipackets in the AAL layer and the layers above may introduce extra delay to eliminate the delay jitter of minipackets. Therefore, for any given mean access delay, the less the delay jitter is, the better the QoS will be offered to users. In contrast, the maximum guaranteed access delay is more directly related to the delay parameter of the QoS.

4. Conclusions and Open Issues

When a GFC protocol is applied to a CPN which provides multiple access to a single UNI, a fairly shared access has to be ensured in the sense that each terminal will get a guaranteed bandwidth to provide an acceptable quality of service. The remaining bandwidth should be shared by terminals supporting the VBR service, leading to the same improvement of QoS for all the terminals.

A number of GFC protocols are being studied by standardization bodies. However, we believe that the best one should take the statistical parameters of the terminals into account. An approach is proposed to share the remaining bandwidth which depends not only on the guaranteed bandwidth of each terminal but also on the probability that the terminal's bit rate exceeds its guaranteed bandwidth. Finally a GFC protocol is described to implement the bandwidth allocation strategy.

Modelling and simulation of the proposed GFC protocol is planned to investigate its performance. Further study is needed to see how this protocol can support other configurations and multiple access priorities to distribute the delay jitter to connections which can better tolerate it.

Reference

- [1] Adams J.L., "A Multiservice GFC Protocol", International Journal of Digital and Analogue Communication Systems, Vol.4, No.2 1991 pp.123-130
- [2] CCITT Recommendation I.150, "B-ISDN ATM Aspects", Geneva, Jan.1990
- [3] CCITT Recommendation I.413, "ISDN User-Network Interface with Broadband Capabilities", Geneva, Jan.1990
- [4] CCITT Recommendation I.432, "B-ISDN User-Network Interface Physical Layer Specification", Geneva, Jan. 1990
- [5] Kasahara H. et al, "Distributed ATM ring-based switching Architecture for MAN and B-ISDN Access Networks", Proceeding Workshop on Broadband Communications, Estoril, Portugal, Jan.1992 pp.82-92

THIS PAGE WAS
BLANK IN THE ORIGINAL