# The Generic Flow Control (GFC) Protocol: A Performance Assessment

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**Abstract**

*Two candidate protocols for the Generic Flow Control (GFC) of Broadband Integrated Services Digital Network (B-ISDN) are currently being considered by the Accredited Standards Committee T1 (ASC T1). One proposal advocates the use of a Distributed Queue Dual Bus (DQDB) like mechanism with a three level priority scheme. The other proposal is based on a slotted ring with control terminal equipment (C-TE), assigning periodic credit authorizations to the transmitting stations. This paper analyzes the performance behavior of the two protocols according to traffic scenarios and boundary conditions defined by the International Telephone and Telegraph Consultative Committee (CCITT) and T1.*

## 1. Introduction

The GFC protocol, designated by four bits in the Asynchronous Transfer Mode (ATM) header[1], regulates the media access between multiple B-ISDN Terminal Equipment (B-TEs) at the customer premises. As such, it is a key access protocol for terminals attached to the public networks that must satisfy the Quality of Service (QOS) requirements such as bandwidth allocation, response time and throughput. Many candidate access protocol proposals[2][3][4][5] have been presented to the CCITT Study Group XVIII and the U.S. National Standards Committee (ASC T1 Technical Subcommittee S1). Proposals submitted to T1S1 have been being critically discussed and evaluated. Based on the initial evaluation, two candidate alternatives have emerged as competing architectural proposals: A ring (cycle-reset) protocol (proposed by BT and NTT)[6] that is based on a slotted ring with a periodic credit authorization mechanism and a bus protocol (proposed by AT&T)[7] with priorities similar to the Distributed Queue Dual Bus (DQDB) standard of IEEE 802.6. T1S1 has developed a Working Document[8] that defines a set of terminal configurations and traffic profile scenarios as well as GFC mechanism requirements to be used for evaluations of the GFC protocol candidates. This paper presents a performance comparison of the two candidate protocols based on results of such simulations. This work is intended to expand the knowledge base required to expedite the standardization and by no means attempts to bias the reader towards any one protocol. It should be noted that other factors, in addition to performance should be considered when evaluating these proposals.

## 2. GFC protocol descriptions

When the standards bodies began work on the ATM protocol, it became apparent that a flow control mechanism across the User Network Interface (UNI) and an access control within the Customer Premises Network (CPN) were necessary. Fields were reserved in the ATM header for such purposes. The first 4-bit field, called the Generic Flow Control field, was later exclusively designated for controlling access among multiple B-TEs to the network in a CPN. Thus, GFC is a shared medium access control mechanism that operates among multiple B-TEs attached to the same UNI. It schedules, coordinates and mediates media access among multiple B-TEs to an ATM network while attempting to maximize bandwidth utilization.

The configuration of multiple B-TEs on a shared medium constitutes a local area network (LAN) architecture such as bus, ring, star or star-bus structure. Although B-TEs at the customer premises can be configured with the LAN topologies, the access control mechanism of the GFC differs from that of the LAN in several aspects:

- Fair access to the medium is defined in terms of QOS requirements of individual connections. A B-TE may have multiple connections with different QOS requirement at any given instant. Fairness implies the equal access for connections with the same QOS requirement.

- GFC applies to the traffic from B-TEs to the network. Traffic from the network shall not be subject to the GFC access control mechanism.

The remainder of this section describes two GFC proposals that have emerged within T1S1 as the prime candidates for standardization:

- GFC-dual-bus: An AT&T Proposed GFC mechanism based upon an adaptation of the distributed Queue Dual Bus architecture.
- GFC-dual-ring: A BT and NTT proposed GFC mechanism based upon an adaptation of the Orwell slotted dual ring architecture.

Note that the candidate GFC protocol should be able to operate in any of the agreed B-TE physical configurations (e.g., a bus, a bus-star, or a ring). B-TEs should operate under all configurations without modification.

## 2.1 GFC-dual-bus

This candidate architecture[7], which is a derivative of a Distributed Queue Dual Bus protocol[11], divides the GFC field of the ATM header into two sub-fields, a 1-bit priority indication (PI) and a 3-bit request priority (RP) [see Table 1].

| GFC Field Assignment | | |
|---|---|---|
| Field Name | Value | Assignment |
| PI* | 0 | All VBR, most jitter tolerant CBR, Unassigned cell |
| | 1 | Least jitter tolerant CBR |
| RP** | 001 | All VBR |
| | 010 | Most jitter tolerant CBR |
| | 100 | Least jitter tolerant CBR |

*PI Indicates the delay priority of the cell

**RP is used to get access to the bus/ring

**Table 1 GFC-dual-bus GFC Field Definition**

The priority indication sub-field carries information about the cell in which it is carried. This field is intended primarily for cells traveling in the B-TE-to-Network direction and indicates the delay-sensitive priority of cells for B-ISDN Network Termination 2 (B-NT2). The request priority sub-field is used in the opposite direction of the information cell transmission to request an empty cell from the upstream terminals for getting access to the bus with the priority indicated.

Each B-TE monitors the GFC field and maintains counters to keep track of the number of empty slot requests from its downstream terminals for each of the three priorities. A terminal can place a request only when it has no request with higher priority outstanding. A terminal is allowed to transmit a cell only if all previous requests from downstream terminals have been satisfied. Constant bit rate (CBR) services are assigned higher priority than variable bit rate (VBR) services in order to reduce the jitter for CBR cells. A traffic shaper is applied to a VBR service to control the rate at which this service connection can place requests onto the bus.

The GFC-dual-bus also introduces a balancing parameter and a burst parameter to enhance the traffic shaping and fairness. When the balancing counter of a B-TE reaches the value of its assigned balancing parameter, a B-TE stops occupying the available empty slots. This mechanism reduces the chance that a single terminal with very high traffic load can monopolize the channel. The burst parameter controls the number of additional cells a VBR connection may queue for transmission. Thus, the delay for a VBR terminal can be controlled by the burst parameter assigned to it without increasing its share of the additional bandwidth or its guaranteed bandwidth. Dual, unidirectional bus based protocols must include additional procedures to determine the direction for transmitting cells to other B-TEs on the bus. This is not a problem in a ring protocol where each direction of transmission completes a ring which passes through each B-TE.

## 2.2 GFC-dual-ring

This candidate architecture[6], which is a slotted ring[12] based GFC protocol, uses the periodic timing signal (called RESET) to control the rate at which terminals can transmit cells. The GFC field is divided into two sub-fields, a 2-bit A sub-Field and a 2-bit B Sub-Field [see Table 2].

Initially, all terminals operate without any control in an unrestricted access mode. When a congestion condition is detected or any B-TE requests the GFC operation, one of the terminals becomes a "control B-TE" and causes all other terminals to switch to restricted access mode. Each B-TE maintains a counter which is the upper bound on the number of cells a terminal can transmit between 'resets'. A B-TE is permitted to transmit a cell on an empty cell slot if the value of the counter is positive. As each cell is transmitted, the counter is decremented by one. When a B-TE receives a 'reset' cell, it restores the value of its counter to the preassigned quota (predetermined value of window size). The Control B-TE issues a 'reset' signal when it detects the medium idle, or if the time elapsed since the last 'reset' reaches a predefined cycle time. It controls the cell rate by changing the rate at which it transmits resets. The cycle time is set to guarantee a minimum access rate for each B-TE. The quota of each B-TE is negotiated with the network when a connection is established. Thus, the number of cells a given B-TE can transmit depends on the rate and the type of connection.

| A Sub-Field | | | B Sub-Field | | |
|---|---|---|---|---|---|
| First Cell | Next Cell | Assignment | First Cell | Next Cell | Assignment |
| 00 | - | NULL A (NA) | 00 | - | NULL B (NB) |
| 01 | 00 | Reset Indication (RI)* | 01 | 00 | Reset (R)* |
| 01 | 01 | Reserved A1 (RA1) | 01 | 01 | Reserved B1 |
| 01 | 10 | Reserved A2 (RA2) | 01 | 10 | Reserved B2 |
| 01 | 11 | Reserved A3 (RA3) | 01 | 11 | Reserved B3 |
| 10 | - | Trial Indication (TI) | 10 | - | Trial 1 (T1) |
| 11 | - | Garbage (G) | 11 | - | Trial 2 (T2) |

* Reset and Reset Indication are represented by two consecutive cells

**Table 2 GFC-dual-ring GFC Field Definition**

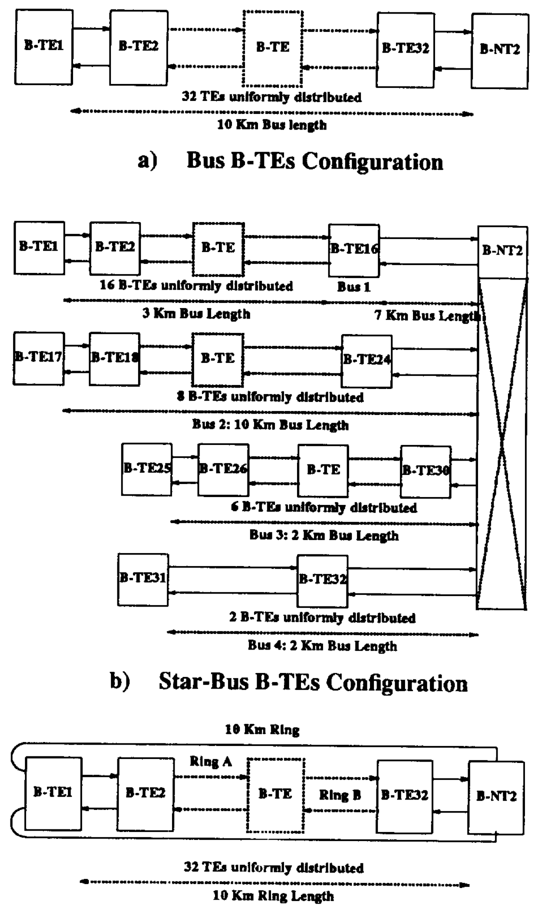
Since this GFC architecture is proposed for media access control to a network based on a physical ring topology, the cells inserted in the ring must be removed after their trips from the source to destinations have completed. In this architecture, the cells are deleted by the destination B-TE, which is referred as "destination deletion (DD)" mechanism. The DD mechanism allows a destination B-TE to delete the cell payload. The cell can be then reused by other B-TEs in the remainder of the ring between the destination and source B-TEs. The DD mechanism improves the performance by recovering the bandwidth (cell-slots) occupied by transmitted cells after they reach their destination on the ring.

## 3. GFC simulation studies

The simulations were performed according to the test scenarios and conditions agreed upon by the standards bodies[8]. The simulation test campaign consists of seven test scenarios that evaluate the proposed GFC mechanisms and B-ISDN access architectures along three dimensions that impact the performance of the customer premises network: CPN topology, traffic type, traffic load and terminal distribution.

The seven test scenarios model distinct CPN environments so as to evaluate the GFC performance in various settings. Some basic parameters such as the bit rate of the UNI interface (155.52 Mbps), propagation delay (5 microsecond/km), length of shared media (maximum 10km) and total number of terminals for test (32 B-TEs) are predefined constants. The simulation parameters that were varied in each scenarios include:

A. CPN Topology: The three topologies (bus, star-bus and ring) used in the simulations are depicted in figure 0.




**a) Bus B-TEs Configuration**



**b) Star-Bus B-TEs Configuration**



**c) Ring B-TEs Configuration**

**Figure 0 CPN Topology Configuration**

B. Traffic Types: Both constant bit rate (CBR) and variable bit rate (VBR) services are used, with bit rates ranging from 64 kbps to 45 Mbps. Five CBR and eight VBR traffic load types are used in various scenarios. The traffic types and their assigned rates are shown in Table 3.

| Type | Rate (mean) | Representing Data Type | Inter-burst Time Distribution | Burst Length Distribution | mean length* (cells) |
|---|---|---|---|---|---|
| I | CBR 34 Mbps** | | | | |
| II | CBR 2 Mbps | | | | |
| III | CBR 64 kbps | | | | |
| IV | VBR 700 kbps** | connectionless data | deterministic | fixed | 200 consecutive |
| V | VBR 25 Mbps | VBR video | exponential | exponential | 2 consecutive |
| VI | VBR 25 Mbps | connection oriented data | exponential | exponential | 20 consecutive |
| VII | VBR 1 Mbps | background data/slow video | exponential | exponential | 3 consecutive |
| VIII | VBR 20 Mbps | VBR video/data | exponential | exponential | 30 consecutive |
| IX | VBR 6 Mbps | slow video | exponential | exponential | 3 consecutive |
| X | VBR 700 kbps | connection-oriented data | exponential | exponential | 10 consecutive |
| XI | VBR 1.4 Mbps | connection-oriented data | exponential | exponential | 10 consecutive |
| XII | CBR 45 Mbps | | | | |
| XIII | CBR 1.5 Mbps | | | | |

*It is assumed that each burst length is rounded up to an integer number of cells, and each 53 octet cell is generated into the GFC input buffer at the rate of 149.76 Mbps.

**All CBR and VBR traffic are assumed to use 47 and 44 of the 48 octets of the cell information field, respectively.

**Table 3 Traffic Types and Models Used in Simulation**

C. Traffic Load and Terminal Distribution: 32 B-TEs are distributed with different traffic types and load conditions in the seven test scenarios. The assignment of test loads are shown in Table 4.

All connections were assumed to be established prior to the beginning of simulation except those on terminals 20 and 25 in TEST 2. The first cell arrival at each terminal were assumed to be at time t=0 except arrival at terminals of load type IV in Test 1, 2 and 3. In TEST 2, the connect establishment cell time on terminals 20 and 25 was assumed to be the first cell arrival time. For connectionless VBR traffic types, the first cell arrival time is given in Table 5.

| Terminal | B-TE 6 | B-TE 11 | B-TE 16 | B-TE 22 | B-TE 27 | B-TE 32 |
|---|---|---|---|---|---|---|
| Cell Time* | 0 | 1,000 | 10,000 | 12,000 | 30,000 | 35,000 |

**Table 5 First cell arrival time for CL VBR traffic**

## 4. Test scenarios

This section presents brief descriptions of seven test scenarios defined in the reference[8] in terms of the above three simulation parameters.

### 4.1 TEST 1

This test uses a bus configuration, with traffic types, test loads and terminal distribution assigned as in Table 4.

### 4.2 TEST 2

This test uses the same configuration and traffic load as TEST 1. Instead of having all terminals initiating traffic at the beginning of the simulation (time t=0), terminals 20 and 25 start at cell times of 750,000 and 600,000, respectively. This test allows observations on the impact of added traffic load on other terminals.

### 4.3 TEST 3

This test uses a star-bus configuration, with the same traffic types, test loads and terminal distributions as in TEST 1.

Traffic from all terminals are directed towards the network. There is no traffic crossed between one bus and another local bus.

### 4.4 TEST 4

This test is the same as TEST 3 except for the following differences:

- Only B-TEs with the Load Type VIII (except B-TE 4) send their traffic to the network interface, although some of the traffic may be routed back to B-TEs on another local bus.
- All other traffic is assumed to be within each local bus, and is stripped by the B-NT2.

## 4.5 TEST 5

This test uses a dual ring configuration, with traffic types, test loads and terminal distribution assigned as in column 4 of Table 4. The traffic loads differ from TEST 1 in that the very bursty VBR (0.7 Mbps with the burst length of 200 consecutive cells) traffic is replaced by the less bursty VBR (1.4 Mbps with the burst length of 10 consecutive cells) traffic. The following rules for selecting destinations and a ring path apply:

- All traffic Types, except the Type XI, are bi-directional between B-TEs and B-NT2 (e.g., Type I traffic direction is offered from B-TE 25 to B-NT2 and from B-NT2 to B-TE 25).
- Destinations of traffic Load Type XI terminals are randomly distributed among all B-TEs except for the source. The destination is changed per burst.
- The shortest path selection is applied for all of the traffic.
- Two rings (Ring A and Ring B) are used. Information on the direction from terminals to B-NT2 are transmitted on the Ring A, while information on the direction from B-NT2 to terminals are transmitted on the Ring B.

## 4.6 TEST 6

This test uses a bus configuration, with traffic types, test loads and terminal distribution assigned as in column 4 of Table 4. The traffic type differs from the TEST 1 in that the burst rate of 0.7 Mbps VBR traffic was changed from 200 cells/burst to 10 cells/burst.

Destinations of traffic Type X are randomly distributed among downstream B-TEs, including B-NT2. The destination is changed per burst.

## 4.7 TEST 7

This test uses a bus configuration, with only CBR traffic. Type III traffic (CBR 64 kbps) is applied to 24 separate connections on each terminal (B-TE 3 to B-TE 32). Type XIII traffic (CBR 1.5 Mbps) is applied to 25 separate connections on B-TE 1 (see column 5 of Table 4).

| Type | B-TE Assignment In Test 1, 2, 3 | B-TE Assignment In Test 4 | B-TE Assignment In Test 5, 6 | B-TE Assignment In Test 7 |
|---|---|---|---|---|
| I | 25 | 9,28,32 | 25 | - |
| II | 1 | 5,7,8,10,11,15 | 1 | - |
| III | 2,9,10,17,18,26 | 1,3,6,12,14,26 | 2,9,10,17,18,26 | (3 to 32)** |
| IV | (6,11,16,22,27,32)* | - | - | - |
| V | 4 | - | 4 | - |
| VI | 20 | - | 20 | - |
| VII | 3,5,7,8,12,13,14, 15,19,21,23,24, 28,29,30,31 | 17,19,20,21,23, 24,27,29, | 3,5,7,8,12,13,14, 15,19,21,23,24, 28,29,30,31 | - |
| VIII | - | 4,13,18,22,26, 30,31 | - | - |
| IX | - | 2,25 | - | - |
| X | - | - | (6,11,16,22,27,32)* | - |
| XI | - | - | (6,11,16,22,27,32)* | - |
| XII | - | - | - | 2 |
| XIII | - | - | - | 1*** |

Note: B-TEs are assigned to different Load Types in test cases (i.e., B-TE 25 is assigned to a Load Type I in Test 1,2,3,5,6 and a Load Type III in Test 7).
*Terminals 6, 11, 16, 22, 27, 32 are Type IV in Test 1, 2, 3, Type XI in Test 5, and Type X in Test 6, respectively.
**Type III is applied to 24 separate connections on each B-TE.
***Type XIII is applied to 25 separate connections on B-TE 1

**Table 4 Test Load Type and Terminal Assignments**

## 4.8 Simulation conditions and assumptions

The simulation program is written in 'C' language. The simulation uses the discrete event, asynchronous discrete time technique. The system ticks are in units of cell transmission time. Note that a cell transmission time is $424 / 149.76 \times 10^6$ seconds (approximately 2.831 microseconds; e.g., delay time of 10.4 means the delay is 10.4 cells transmission time). As the clock advances, events such as traffic generation and cell transmission are processed and the statistics are collected accordingly. This simulation was implemented with the following considerations:

A. The results include the following numerical measurements at each terminal:
   - Total number of cells transmitted
   - Mean access delay (in units of a cell transmission time)

- Standard deviation of access delay
- Maximum jitter for CBR services (in number of cells)
- Mean queue size (length in number of cells)
- Maximum queue size (length in number of cells)

B. The simulation was run for $1.5 \times 10^6$ cell transmission times collecting all statistics from cell time t=0 until the end.

C. All CBR sources transmitt the traffic at time t=0. VBR sources start an inter-burst interval at time t=0.

D. The unit of traffic load at each terminal, originally stated as bits per second, was converted to cells per cell transmission time.

E. Access delays were measured from the time a cell arrives at the terminal to the time the first bit of the cell was transmitted on the bus/ring.

In addition, the following assumptions were made in simulating the GFC-dual-ring protocol:

A. Traffic destinations: The test scenarios in the reference[8] do not specify the destinations of traffic loads. In this simulation, all CBR traffic were assumed to be destined to the network (to B-NT2) for all tests except TEST 5. The destination of VBR traffic varied with every burst and was randomly selected.

B. Destination deletion: It was assumed that the destination terminal, upon receiving a cell, was able to remove the cell immediately and could reuse it if cells were waiting and qualified for transmission.

C. Cell stripping: When the destination deletion mechanism was not used, cells were removed by B-NT2.

D. Bus/Ring size: Two different ring sizes were used; a 10 km "Long Bus/Ring" and a 2 km "Short Bus/Ring".

## 5. Simulations summary

This section briefly describes the results of the simulations in terms of access delay and mean queue sizes. The simulation of the two GFC proposals were based on our best knowledge and understanding of candidate protocols as described in the documents currently available[7][8]. The results of the simulations are summarized below.

### 5.1 TEST 1 results

A. Figure 1 compares the average access delay (in terms of cell transmission time) per terminal for GFC-dual-bus protocol and GFC-dual-ring protocol. The channel utilization in this test is about 85%, a high traffic load.

It is apparent that the GFC-dual-ring protocol causes higher delays than the GFC-dual-bus protocol does. The GFC-dual-bus protocol allows terminals to access the bus as long as free capacity is available, while the GFC-dual-ring protocol limits the access to its preallocated window size. Terminals in the GFC-dual-ring architecture must wait for periodic reset, which causes the medium to become idle more frequently. This leads to a waste of the bandwidth utilization. The GFC-dual-bus protocol allows full medium access but does not guarantee the bandwidth.

Since this GFC-dual-ring protocol specifies a window size for each B-TE as a function of the information rate, the B-TEs that have large burst durations experience higher access delays. Type IV B-TEs (6, 11, 16, 22, 27 and 32) which have burst durations of 200 consecutive cells, experience a large delay of approximately 8,500 cell times. B-TE 20, which has a burst duration of 20 consecutive cells (but has a large window size of 18), experiences access delay of 4,500 cell times while all other terminals experience much smaller access delays. When the GFC-dual-ring protocol uses destination deletion mechanism, there is a small reduction in the access delays, however, such delays are still very high for large burst duration B-TEs. The results indicate that for GFC-dual-ring protocol, it would be important to specify the window size not only as a function of information rate, but also as a function of burst duration.

B. Figure 1Q shows the mean queue size at each terminal. The queue size is a function of burst rate, therefore, type IV B-TEs and B-TE 20 have a relatively large mean queue size. Terminal 20 has a relatively small access delay but has a large queue size due to combined effect of large window size and large burst.

Note that the destination deletion mechanism greatly reduces the average buffer occupancy and the average access delay on very bursty VBR connections. The average queue size and access delay are reduced by about 1/6 when using the destination deletion mechanism in the case of terminal 20. The destination deletion does not have much effect on terminals of Load Type IV due to the nature of their traffic load.

C. Figure 1.1 and Figure 1.1Q compare the average access delay and the average buffer occupancy of the GFC-dual-ring protocol. Both scenarios use the same traffic load distribution and protocol. These figures show that the length of the buses has an observable influence on the access delay and queue size at each terminal. The long bus length introduces more propagation delay of reset signals, thus idling the medium more often.

## 5.2 TEST 2 results

Figures 2, 2Q, 2.1 and 2.1Q show the results of TEST 2. The only difference between TEST 1 and TEST 2 is that the traffic of terminals 20 and 25 are joined at a later time than the rest of the terminals. The effect of time variant traffic load varies depending on the traffic type of terminals. For the GFC-dual-ring protocol, the access delay of CBR traffic is reduced approximately by 8%. In the case of the short burst VBR and the long burst VBR, the access delays are reduced by 5% and by 15%, respectively. For the GFC-dual-bus protocol, there is no change in the CBR traffic. While the access delay of short burst VBR terminals is reduced approximately by 20%, the long burst VBR terminals are increased significantly more than two times. This increase is due to the available bandwidth being monopolized by terminals with a high traffic rate; this is the nature of the protocol.

## 5.3 TEST 3 results

Figures 3 and 3Q depict the result of TEST 3 which has a configuration of star-bus topology, where terminals 1 to 16, 17 to 25, 26 to 30, and 31, 32 are distributed on four separate buses respectively. Each bus has the same bandwidth capacity of 155 Mbps. The access delays of terminals 22, 27, 32 decreased significantly compared to the results of TEST 1 because they were located on a separate bus which has lighter utilization.

## 5.4 TEST 4 results

TEST 4 has a star-bus topology but with a different traffic load distribution from TEST 3. The results are shown in Figures 4 and 4Q. Terminals 4, 13, 18, 22, 30 and 31 have high access delay and large queue size because the load on these terminals have the distribution of 20 Mbps average rate with the average burst length of 30 cells. Terminal 13, which is located the farthest upstream on bus 1, has higher access dealy due to higher traffic load on that bus.

## 5.5 TEST 5 results

TEST 5 uses a dual ring topology, which employs a similar protocol to that used in the bus topology; i.e., it has two symmetrical rings, Ring A and Ring B. Information is transmitted from the terminal to B-NT2 direction on ring A, while information is transmitted from the B-NT2 to terminal direction on ring B. Most of the user traffic load to the network is carried on ring A.

Figures 5 and 5Q show the results of TEST 5 on Ring A. Note that terminals with VBR services experience comparatively larger delay than those with CBR services due to the bursty nature of VBR services. It is also obvious that in a short ring in the GFC-dual-ring protocol, terminals have much less access delay and mean queue length.

## 5.6 TEST 6 results

TEST 6 assigns the destination terminal for some of the connections. The results are shown in Figures 6 and 6Q. In the GFC-dual-ring protocol, the effect of destination deletion improves the access delay performance about 20%; which is similar to TEST 1.

## 5.7 TEST 7 results

TEST 7 contains all CBR services, where B-TE 1 has 25 connections of 1.5 Mbps each (aggregate rate of 37.5 Mbps); B-TE 2 has one connection of 45 Mbps; and B-TE 3 to B-TE 32 have 24 connections of 64 Kbps each (aggregate rate of 1.536 Mbps each). All the connections are assumed to generate cells at the beginning of the test.

Figures 7 and 7Q show the average access delays and buffer occupancy at each terminal. B-TE 1 in the GFC-dual-bus protocol experiences much more delay than the one in the GFC-dual-ring protocol. This is because cells from 25 connections arriving at the same time at B-TE 1 have to contend with the rest of the B-TEs downstream in the GFC-dual-ring protocol, while cells are guaranteed to be delivered at the beginning of each cycle in the GFC-dual-ring protocol by assigning window size. Terminals 3 to 32, having twenty-four 64 Kbps connections, are assigned the window size of two. The GFC-dual-bus protocol performs slightly better on terminals 2 to 32, but not on B-TE 1. These figures show the unfairness of both protocols towards the downstream terminals. In the GFC-dual-bus protocol, this is caused by the propagation delay of the requests sent to the upstream terminals. In the GFC-dual-ring protocol, it is due to the privilege of occupying empty slots by upstream terminals between two consecutive reset intervals. The standard deviation of long bus shows the proportional increase towards the downstream terminals, while the standard deviation of short bus remains constant generally.

## 6. Overall characteristics comparison

This section describes comparison of overall characteristics of performance, complexity and reliability based upon simulation results of two candidate protocols.

### 6.1 Performance of the GFC-dual-bus proposal

A. This architecture is basically a slot reservation and contention system. The protocol attempts to minimize the access delay for CBR services by assigning high priority to them. However, large jitter may exist due to the heavy CBR traffic on the buses. If a cell's delay jitter exceeds its cell generation time, the cell may be considered to be lost for a CBR connection. Although the cell loss could be very small, this event may be possible.

B. Traffic shaping, by limiting the rate at which a service can put a request to the up-stream terminals, smoothes the flow of bursts from a VBR service. At the same time, a VBR service is still able to access the spare bandwidth due to the proper burst control by the burst parameter.

C. The VBR services are assigned the lowest priority since they can tolerate large delays. The average rate is guaranteed for the VBR services, and they access the spare bandwidth by using a burst parameter and a balancing parameter.

D. The access unfairness for the downstream terminals due to propagation delay still exists. However, the effect of the unfairness is comparatively small when the minimum required length of the shared medium is considered to be 20 km, as specified in the GFC working document[2].

### 6.2 Performance of the GFC-dual-ring proposal

A. The GFC-dual-ring protocol guarantees the bandwidth assigned to each terminal through a window size allocation procedure. The access of a number of cells (window size) is guaranteed during a cycle time. There will be no possible cell loss. The access to the spare bandwidth of a VBR service is not directly guaranteed since the window size allocated to a VBR service is based on its average rate. As with the slotted ring protocols, the GFC-dual-ring protocol inherits the principal disadvantage of being wasteful of bandwidth.

   Although the allocation of window size guarantees the access to the buses within a cycle duration, it does not mean that small access delay for VBR services is guaranteed at all times. Due to the bursty nature of VBR services, the arrival instant and burst length varies significantly. If the window size for a given VBR service is assigned according to its average rate, the maximum access delay for a VBR service can be very large even if the average access delay is small.

B. During a cycle time, the upstream terminals always have the chance to transmit earlier than the downstream terminals. This will not affect the performance much since the cycle time is short (250 microseconds).

   Because ring based protocols restrict the number of cells a B-TE may transmit between two consecutive reset intervals but do not schedule the cells for transmission, a B-TE receiving a reset signal could conceivably cluster all its cells in consecutive slots on the ring. Such cell clustering is a consequence of the reset/transmission window approach and can introduce significant cell jitter.

C. It is obvious from the simulation results that, in general, the destination deletion technique significantly improves the performance of the GFC-dual-ring protocol.

D. It is observed that the performance of short bus is better than that of long bus due to the propagation delay of the reset signals. However, there is no distinct criterion to classify between the short bus and the long bus.

E. VBR terminals generating long or short bursts of traffic experience lots of access delay because the window size allocated to this terminal is determined by the average rate of the VBR source.

### 6.3 Complexity and reliability of both proposals

A. The GFC-dual-bus protocol uses a burst parameter and a balancing parameter to improve the performance for VBR services. However, the negotiation of the value of burst and balancing parameters during the connection setup could be complicated. The exact procedure of determining these two parameters has not been defined. The negotiation of the burst parameters, however is provided as an option.

B. As specified in the GFC-dual-ring protocol, four configurations (long/short bus/ring) are defined as options to accommodate the size of the bus, or the ring. This may complicate the implementations. The control terminals need to determine whether the system should run in either short or long configuration. The protocol should not vary greatly for different configurations.

C. The GFC-dual-ring protocol uses window size to control the access. The allocation and reallocation of window size to each service at each terminal at the connection setup time could be complicated. Introducing a fraction of window size or dynamic window size control needs to be explored in more detail. The GFC-dual-ring protocol inherits the principal advantage of reliability from the slotted ring protocols.

## 7. Conclusion

In this paper, the performance of two GFC proposals has been studied extensively.

A. Both protocols provide guaranteed access for transmission for CBR services. The GFC-dual-bus protocol offers two levels of high priority for CBR services over the network. The GFC-dual-ring protocol guarantees the throughput of negotiated bandwidth by allocating proper window size. However, the GFC-dual-ring protocol may provide better CBR services if the window size is properly set.

B. The GFC-dual-bus protocol allows the VBR services to share the spare bandwidth. The GFC-dual-ring protocol guarantees the access of VBR services according to their average rate. However, the access delay may become enormous if the traffic has a very bursty nature.

C. Due to the possible idling of the channel imposed by the GFC-dual-ring protocol, the medium utilization is reduced; this increases the access delays of all the services if the overall traffic load is heavy.

D. Both protocols introduce unfairness towards the downstream terminals. In the GFC-dual-bus protocol, a very high load upstream terminal has a tendency to monopolize the channel from the downstream terminals due to propagation delay, even though the effect is reduced by the traffic shaper and usage of the burst parameter. Within the range of 20 km, which is the typical distance of the interface network applying GFC, the unfairness introduced by the propagation delay is slight. The GFC-dual-ring protocol overall provides the pre-negotiated bandwidth access to the medium during a cycle. However, upstream terminals are allowed to exhaust their window allocation earlier than those of the downstream terminals between reset intervals.

E. The complexity of implementing the burst parameter and the balancing parameter of the GFC-dual-bus protocol is still under study. The GFC-dual-ring protocol also has to consider the complexity of implementing the allocation and maintenance of windows.

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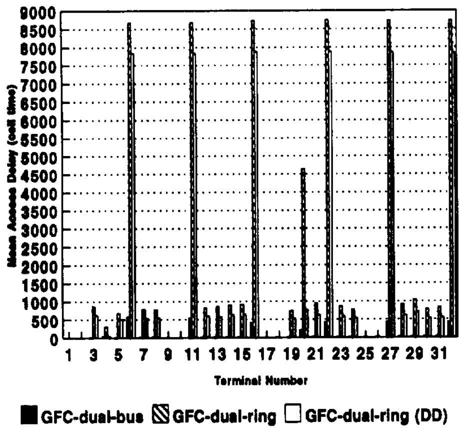
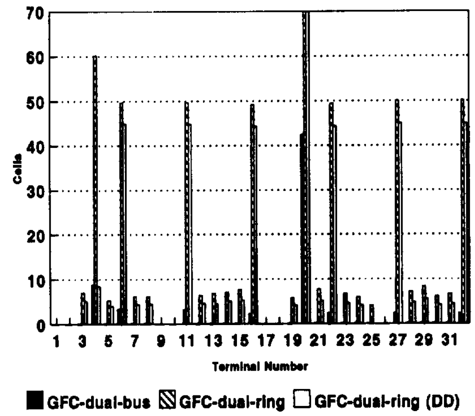



Fig 1. TEST 1 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols




B-TE 20 values: GFC-dual-bus=42 GFC-dual-ring=935 GFC-dual-ring (DD)=154

Figure 1Q. TEST 1 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols

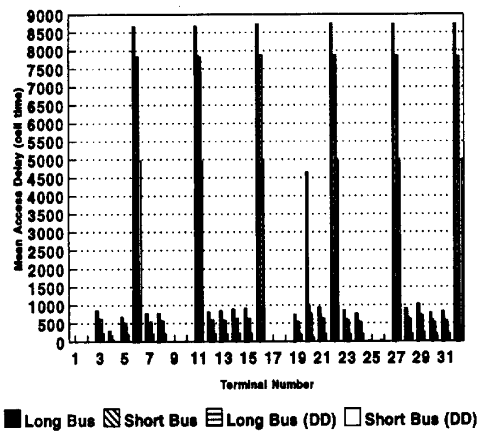



Figure 1.1. TEST 1 Mean Access Delay of GFC-dual-ring Protocol

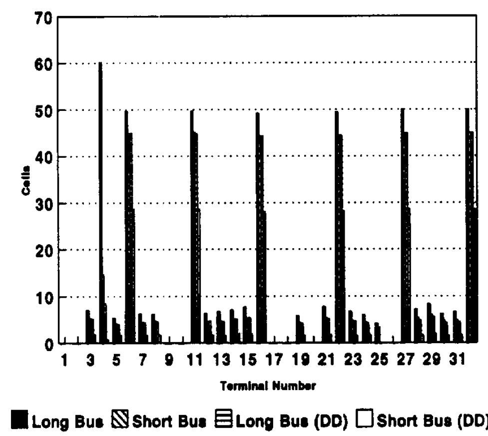



Figure 1.1Q. TEST 1 Mean Queue Length of GFC-dual-ring Protocol

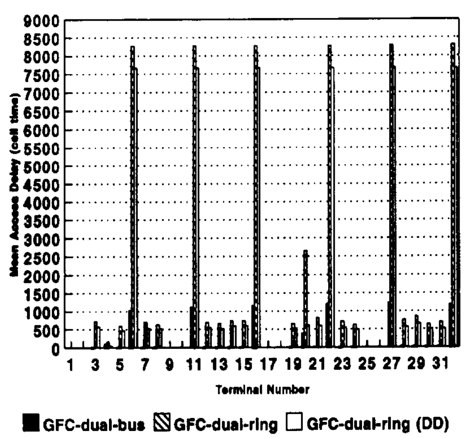
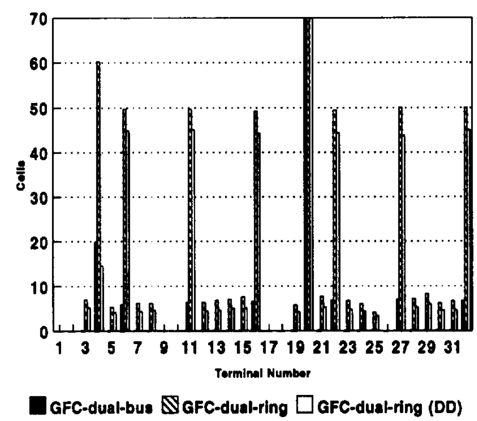



Figure 2. TEST 2 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols




B-TE 20 values: GFC-dual-bus=79 GFC-dual-ring=532 GFC-dual-ring (DD)=121

Figure 2Q. TEST 2 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols

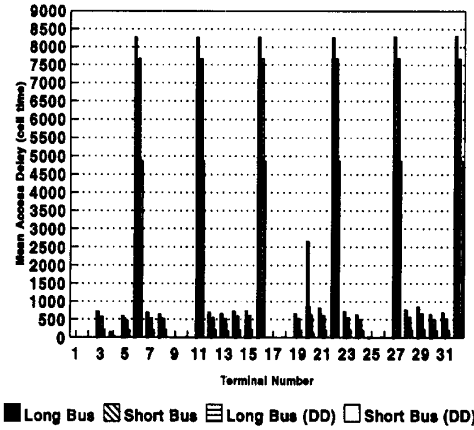


Figure 2.1. TEST 2 Mean Access Delay of GFC-dual-ring Protocol

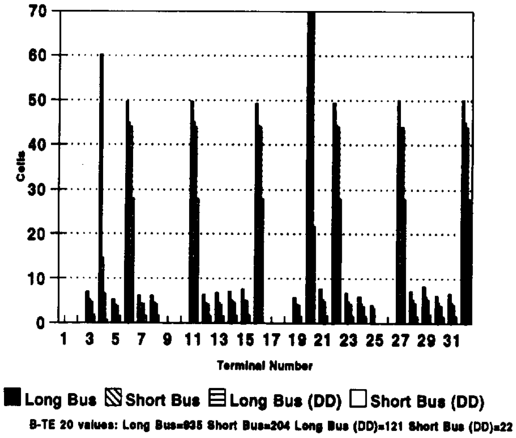


Figure 2.1Q. TEST 2 Mean Queue Length of GFC-dual-ring Protocol

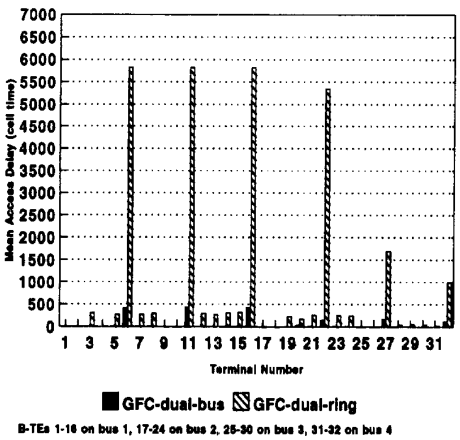


Figure 3. TEST 3 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols

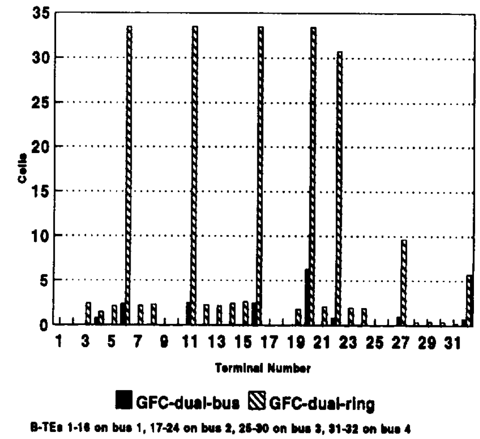


Figure 3Q. TEST 3 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols

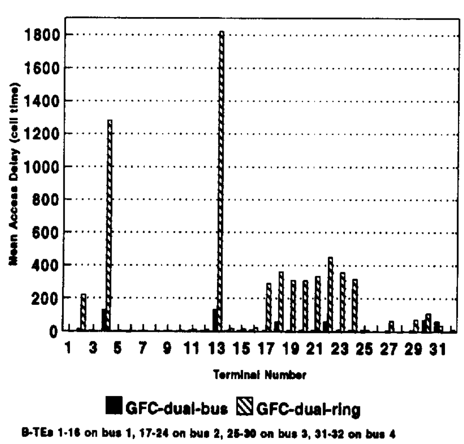


Figure 4. TEST 4 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols

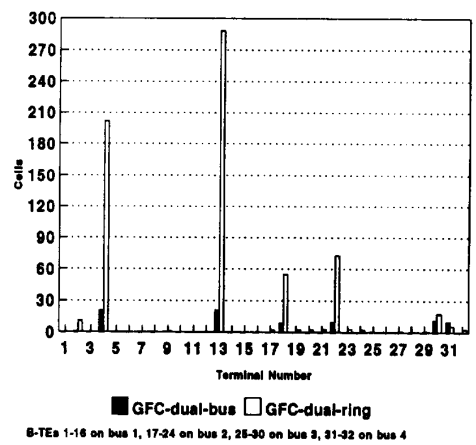
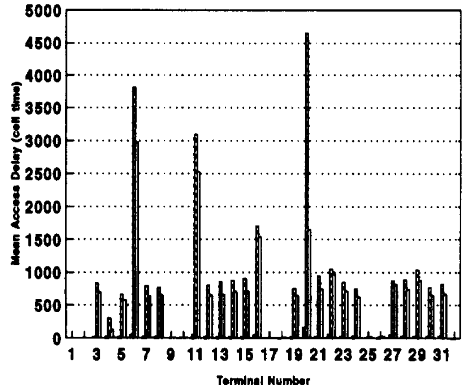
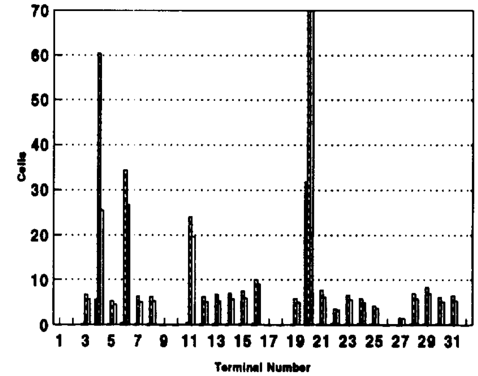


Figure 4Q. TEST 4 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols




■ GFC-dual-bus ▨ GFC-dual-ring (L Ring) □ GFC-dual-ring (S Ring)

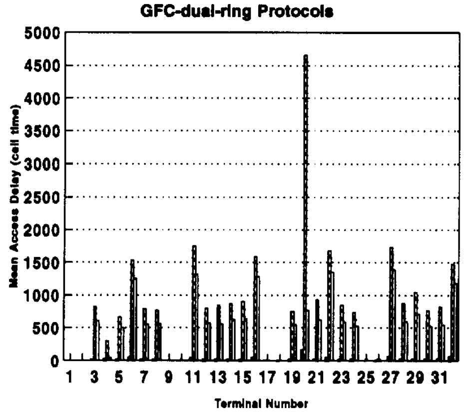
**Figure 5. TEST 5 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols**




■ GFC-dual-bus ▨ GFC-dual-ring (L Ring) □ GFC-dual-ring (S Ring)

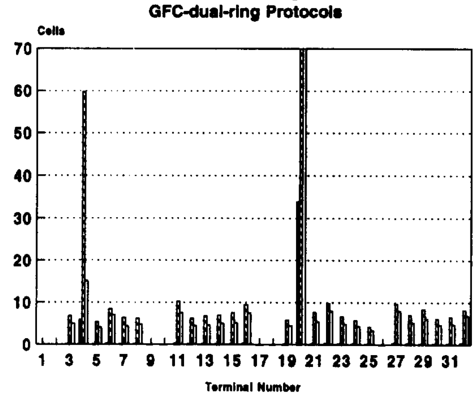
B-TE 20 values: GFC-dual-bus=32 GFC-dual-ring (L Ring)=935 GFC-dual-ring (S Ring)=332

**Figure 5Q. TEST 5 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols**




■ GFC-dual-bus ▨ GFC-dual-ring □ GFC-dual-ring (DD)

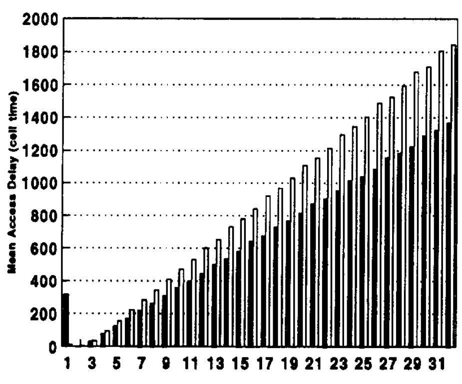
**Figure 6. TEST 6 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols**




■ GFC-dual-bus ▨ GFC-dual-ring □ GFC-dual-ring (DD)

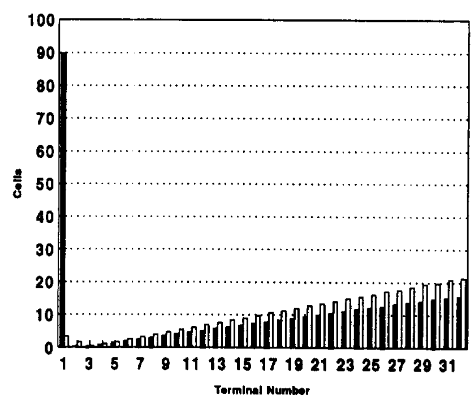
B-TE 20 values: GFC-dual-bus=34 GFC-dual-ring=937 GFC-dual-ring (DD)=210

**Figure 6Q. TEST 6 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols**




■ GFC-dual-bus □ GFC-dual-ring

**Figure 7. TEST 7 Mean Access Delay of GFC-dual-bus and GFC-dual-ring Protocols**




■ GFC-dual-bus □ GFC-dual-ring

**Figure 7Q. TEST 7 Mean Queue Length of GFC-dual-bus and GFC-dual-ring Protocols**