PAPER

Datagram Delivery in an ATM-Internet

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SUMMARY This paper proposes a datagram delivery (class D service) architecture in an ATM-Internet, which is the network interconnecting ATM-LANs through the IWUs, Inter-Working Unit. We can provide a fast datagram delivery system through the following techniques.

The datagram delivery to the destination terminal is performed by the datagram server, so called CLS, which is located in the ATM-LAN where the destination terminal belongs to. Each CLS only manages the addresses for the terminals belonging to the corresponding ATM-LAN. The cells belonging to a certain datagram are transferred through a single (seamless) ATM connection from the source terminal to the CLS in the ATM-LAN where the destination terminal belongs to. The source terminal only resolves the access point address corresponding to the ATM-LAN where the destination terminal belongs to, when it submits the cells to the network to transfer the datagram to the corresponding destination terminal.

The proposed datagram delivery architecture can be applied to the ATM-LAN system based on VPI routing architecture, easily. The number of the required ATM connections so as to provide datagram delivery through the proposed architecture is less than 1.0% of the ATM connections that the ATM-Internet can provide. Also, the required address space at UNI to provide datagram delivery are less than 1.0% of the UNI address space which is available to be used as an ATM connection identifier.

key words: ATM, ATM-Internet, connection-less, CLS, VPI routing, ATM-LAN, address resolution

1. Introduction

An ATM, Asynchronous Transfer Mode, will be one method for providing a highly flexible and cost-effective network for handling a wide variety of communications. The user information is handled by the small and fixed sized packet, called cell. Since the data format to be dealt with by the ATM network is independent of the user application type, it is said that an ATM network could provide flexible communication pipe to the user application effectively. The cells are transferred through the connection oriented channel, which is called virtual channel connection (VCC), in order to reduce the protocol overhead. Therefore, it is said that an ATM network could provide a high speed data communication channel for the end users.

BISDN is the high speed communication platform for public network and for CPN (Customer Premises Network). The standardization and the development of the BISDN system has been progressed by ITU-T (formarly called as CCITT) and by the various organizations [2].

As well as for the BISDN, ATM can be the good candidate for a high speed LAN [1]. With LAN or DAN (Desk Area Network), communication medium is becoming faster and faster, e.g., FDDI/FFOL, can provide more than 100Mbps communication channel to the users as the front end communication medium. Computers are getting much faster and powerful data processing capability. And, they are going to process their data through the distributed way – distributed data processing. The distributed data processing requires a lot of data communications among the computers with a small latency. As a result, the distributed computer system requires high speed data communication platform. ATM is assumed as the communication platform to be able to provide such a high speed communication channel, which is said more than hundreds of Mbps, to the computers in LAN/DAN. Also, it is assumed that ATM can deliver data to a destination point (e.g., I/O port of computer) with small latency. Below, the LAN based on ATM is denoted as an ATM-LAN.

An ATM-LAN should be the network that can be defined and be managed by users themselves [8]. The following is the features and the requirements for the ATM-LAN.

- Low Cost Communication Platform

  ATM-LAN should be provided by low cost. The operational reliability of the ATM-LAN could be less than that of the backbone network which is controlled and managed by the system operators. It would be better approach for the ATM-LAN to provide the operational reliability of the network through the end-user's applications, rather than through the network's applications as the capability of communication platform.

- Network Defined by User

  The control and management of ATM-LAN is performed by the users, rather than by the system operator. Through defining the network functionalities by the users, the network can apply for the users

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service request easily and flexibly.

- Small Number of Terminals

  Conventional CPN, such as PBX, can accommodate large number of terminals, as around a thousand of terminals. On the other hand, ATM-LAN accommodates small number of terminals, say less than few hundreds of terminals. This means that the ATM-LAN is operated as a front access network, such as a DAN or a floor network.

- Independency of the Network

  The management and the control of the ATM-LAN is performed independently within each network. ATM-LAN must have the interworking capability with other networks – let say an ATM internet. Though the networks are inter-connected as an ATM internet, the control and management of the network is performed independently. ATM internet is defined as the network that ATM-LANs are interconnected through IWUs (Inter Working Unit).

This paper proposes the high speed datagram delivery architecture that can provide a high speed connection-less service, in an ATM internet. In Sect.2, the conventional datagram delivery architectures in BISDN and data networks are discussed and the issues to be solved or to be improved are clarified. In Sect.3, the datagram delivery architecture is proposed and the modified architecture when VPI routing mechanism is applied to each ATM-LAN is discussed and evaluated.

2. Conventional Datagram Delivery

2.1 Datagram Delivery in BISDN

In BISDN, four communication service classes, A, B, C, and D, are defined [2],[3]. Class A is for CBR (Constant Bit Rate), class B is for VBR (Variable Bit Rate), class C is for connection oriented (CO) data transmission service, and class D is for connection-less (CL) data transmission service. This paper discusses about the network architecture to provide class D service, connection-less data transmission service. The UNI and NNI protocol specification above AAL layer for class D service in BISDN is discussed in I.364 [3]. In class D service, the user can submit the datagram, that is composed by a single or multiple cells, without a connection set-up procedure. On the other hand, other service classes (class A, B, C) need to perform a connection set-up procedure to establish an ATM connection to transfer the datagram to the destination point. In I.364, it is defined that the AAL protocol to provide class D service is AAL 3/4, currently. However, the proposed network architecture for class D service (datagram delivery service) is independent of AAL type. This means that, in the proposed architecture, AAL 5 that requires less protocol overhead than AAL 3/4 can be applied to class D service. In Direct method defined in I.364, CLNAP (ConnectionLess Network Access Protocol) and CLNIP (ConnectionLess Network Interface Protocol) are used as the OSI's layer 3 protocol to provide class D service. However, in the proposed architecture, there is no restriction for layer 3 protocol for class D service, basically. In this paper, Direct method is represented below as "CLS method". This is because that Direct method used CLS (ConnectionLess Server) to provide class D service.

Two mechanisms are feasible to provide class D service. One is the method that uses CLS for datagram delivery - CLS method. The other is denoted as "Meshed VCC method", in this paper, that does not use CLS for datagram delivery but does use full meshed VCCs for datagram delivery. Generally, it can be said that Meshed VCC method is appropriate for the network that has not many terminals within the network. On the contrary, it can be said that CLS method is appropriate for the network that has many terminals within the network.

In Figs.1 and 2, the network reference model and the protocol architecture for datagram delivery by class D service in CLS method are shown. Between the terminal and CLS, the bi-directional PVCC (Permanent VCC) is established. For the datagram delivery, an ATM connection is always terminated at CLS to perform CLNAP/CLNIP. After the processing of CLNAP/CLNIP, the datagram is delivered from CLS to the destination terminal or the next CLS through the PVCC.

The CLS method has the following issues.

- Since, the ATM connection must be always terminated at CLS, the latency of the datagram delivery would be large. CLS method needs, at least more than one CLNAP processing. When the datagram is relayed over the multiple CLS to reach at the destination terminal, the datagram would experience multiple CLNIP processings. In order to reduce the latency for the datagram delivery, pipe-line cell transmission technique at CLS is proposed [7]. However, whenever the datagram passes the CLS, the CLNIP/CLNAP processing, which is address resolution of the network address for the datagram and routing control for the datagram, must be fulfilled for the begin cell belonging to the datagram unit (class D protocol data unit).

- When the datagram units from the different CLSs are merged at a certain CLS and are multiplexed into the same VCC, the cells belonging to the different datagram units are interleaved at the merging point of cell flows for the datagrams. In order to

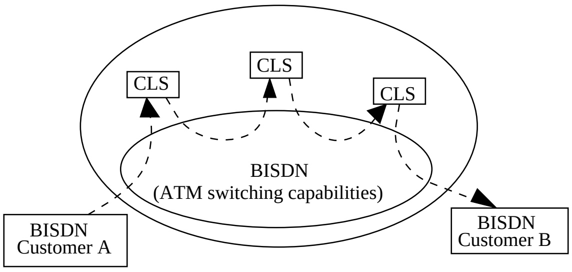

Fig.1 Reference Configuration for CLS Method

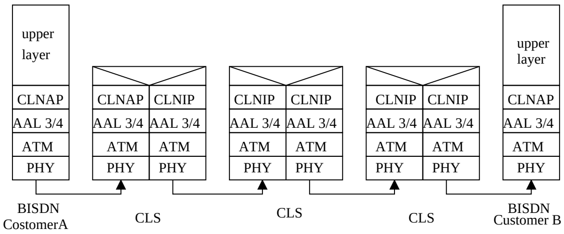

Fig.2 Protocol Stack for CLS Method

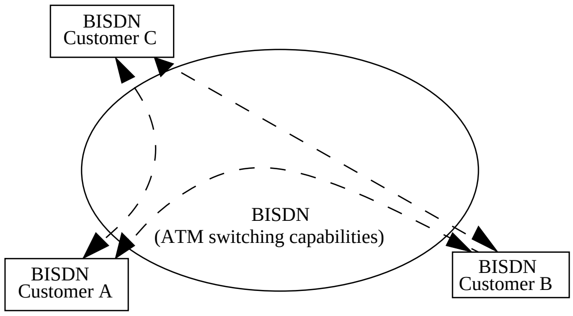

Fig.3 Reference Configuration for Full-Mesh VCC Method

Fig.4 Protocol Stack for Full-Mesh VCC Method

deal with the cell interleaving, MID field value in SAR header field will be used to identify which datagram the received cell belongs to. There are two ways to allocate MID value. One is that the MID value is allocated at the CLS where the datagram units are merged. Then, the CLS must have the functionality to change the MID value for the received cells. The other way is that, in order to transfer the MID value of the received cell transparently at CLS, the MID allocation algorithm is operated among CLSs and terminals. MID value to be used for the transmission of the datagram is allocated (or negotiated) in advance so as to allow cell interleaving.

This means that, when the cells belonging to the different datagram units are interleaved into an ATM connection to transfer the cells, certain MID value allocation algorithm must be operated.

In Figs.3 and 4, the network reference model and the protocol architecture for datagram delivery by class D service in Meshed VCC method are shown. The bi-directional PVCCs has been established between all of terminal pairs within the network. This means that full-mesh PVCCs for all terminals within the network for class D service have been provided. The datagram is delivered from the source terminal to the destination terminal without any ATM layer termination point. Since there is no termination point of ATM connection between the source terminal and the destination terminal, the Meshed VCC method can provide high speed class D service for the users.

The drawback of Meshed VCC method is the inflation of the required address space and the number of the required ATM connections to provide class D service. Since PVCC must be provided between any terminal pair within the network, the number of required ATM connections for class D service increases in proportion to the square number of the accommodated terminals in the network. Therefore, when the network accommodates many terminals, the number of required PVCCs for class D service will be so many. The required address space for class D service at UNI is two times of the number of accommodated terminals within the network. When the number of accommodated terminals is large, the required address space for class D service is also large.

Address management is discussed. With CLS method, each terminal never fulfill the address resolution procedure, when it submits the cells of class D service. Here, the address resolution means that the ATM layer address of the destination terminal is identified and analyzed through the corresponding network address of the destination terminal. Address resolution of the destination terminal is always fulfilled at CLS in CLS method. It is equivalent for the source terminal to perform the so-called default routing to the corresponding CLS. On the contrary, with Meshed VCC method, each terminal must fulfill the address resolution procedure for class D service. The source terminal resolves the ATM layer address of the destination terminal through the network address of the destination terminal.

- CLS method

  All of access points for the terminals is the same point. Here, the ATM layer access address values may not be identical. There is only one ATM layer access point to get class D service.

- Meshed VCC method

  The access point for the each terminal is individual. For a terminal, each destination terminal has the individual address that is the ATM layer access point address for the terminal for class D service.

2.2 Datagram Delivery in Data-Networks

In data networks based on IP defined by IETF (Internet Engineering Task Force), all of data transmission can be realized as a connection-less datagram delivery that corresponds to class D service in BISDN. From the view point of OSI's protocol reference model, the connection-less datagram delivery is performed as the function of OSI's layer 3 (network layer) [5],[6]. IP in Internet Protocol suite corresponds to OSI layer 3 protocol. Since Internet protocol suite uses IP as the network layer protocol, the datagram delivery is performed by connection-les manner, in the Internet. End-to-end connection is defined in TCP in Internet protocol suite. Therefore, TCP corresponds to OSI's layer 4 (transport layer) protocol. Below, datagram delivery in data networks by TCP/IP protocol suite is discussed.

In Figs.5 and 6, the network reference model and the protocol architecture are shown. LANs are interconnected by GateWays (GWs). The datagram delivery within the LAN is performed through MAC layer address to the appropriate destination terminal. On the contrary, the datagram delivery toward the terminal which is located at the other LAN is performed through the network layer address, IP address, fundamentally. The datagram toward the other LAN must be transferred to the GW first. Every GW determines which GW or the terminal the received datagram should be routed to. At the case shown in Fig.6, the datagram to be delivered from host A to host B experiences three times of network layer protocol (IP) processings at the corresponding GWs. Host A uses the MAC address of the GW1 of the LAN (LAN1), that host A belongs to, so as to transfer the datagram toward host B which is located at the other LAN (LAN3). When host A does not have the MAC address to transfer the datagram toward host B's network layer address, the host A gets the MAC address of GW1 through ARP (Address Resolution Protocol). Here, the MAC address to transfer the datagram toward the network address of host B corresponds to the MAC address of GW1 whose network layer address is not the same as the network address of host B. At GW1, the destination address of the received datagram, which is host B's network address, is analyzed, and the MAC address of GW2 is used so as to transfer the datagram toward the GW2. GW2 analyzes the received datagram's destination address and transfers the datagram to host B using the MAC address of host B. As above, each GW has the MAC address information to transfer the datagram toward the appropriate GW or the destination terminal. When a terminal or a GW does not know the MAC address corresponding to a certain network address in order to transfer the datagram toward the destination terminal, the appropriate MAC address could be resolved through an ARP procedure.

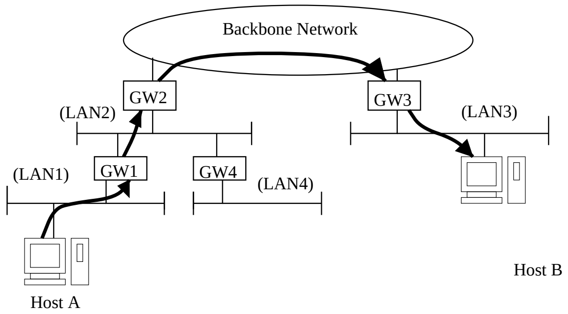

Fig.5 Reference Configuration for IP Network

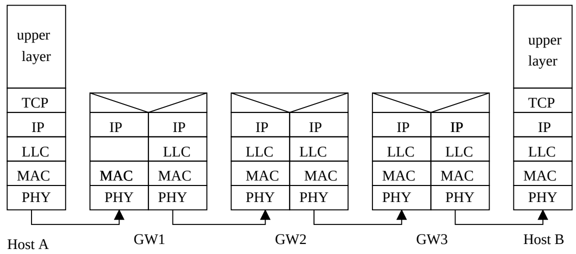

Fig.6 Protocol Stack for TCP/IP based network

In conventional data networks, the datagram toward the other LAN is always transferred to the GW to be dealt with the network layer protocol. Since the network layer protocol (IP in Internet) is processed after getting whole of datagram, whose maximum size in Ethernet is 1.5Kbytes for example, the datagram transmission can not be fulfilled in pipe-line fashion. This leads that the transmission latency of the datagram can be large because of head-line blocking by transmission of other datagrams.

3. Datagram Delivery Architecture

3.1 Network Architecture

Figure 7 shows the proposed reference network model of an ATM internet. ATM-LANs are interconnected through IWUs, and they are interconnected by UNI,

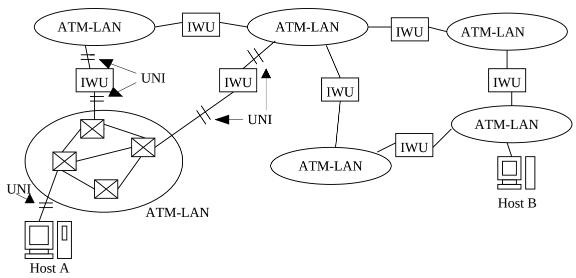

Fig.7 ATM-Internet Reference Model

rather than by NNI [8]. Therefore, the management of VCI/VPI values is independently performed within each ATM-LAN. IWU changes VCI/VPI value to relay the cells as an ATM layer function. Since the IWU changes VCI/VPI value, every ATM-LAN can assign a VCI/VPI value of an ATM connection that is across the ATM-LANs, independently. IWU has the mapping information of VCI/VPI values for the corresponding ATM connection. Then, cells can be relayed by ATM layer at IWUs. This means that ATM connection is not necessary to be terminated at an IWU – just changing VCI/VPI value.

ATM internet provides users two types of ATM connections. One is the connection allocated peak bandwidth – Peak allocated connection. The other is the connection without bandwidth allocation – Null QOS connection. The terminal which uses connection-less mode does not require the peak allocated connection, generally. This is because that they could provide secured data transmission between end-to-end terminals through layer 4 protocol which is performed by themselves. They do not always require the performance objective of the QOS for the datagram transmission. Therefore, we propose that the class D service, which is connection-less data transmission service, will be provided through null QOS connection. Here, as with class C service, which is connection oriented datagram transmission, the datagram can be delivered either over peak allocated connection or over null QOS connection. The application would select which connection type should be used for class C service.

3.2 Datagram Delivery Mechanism

The features of the proposed datagram delivery mechanism are as follows.

- Intra-LAN datagram delivery is performed by Meshed VCC method. Here, CLS method can be also applicable for intra-LAN datagram delivery.
- Inter-LAN datagram delivery is performed by the method which is described below. Each terminal can resolve the address of the network, not the address of the destination terminal, where the destination terminal belongs to.
- Address management for an end terminal is performed by a CLS in the corresponding ATM-LAN. Any terminal nor CLS in other ATM-LANs does not have the end terminal's address information.
- End terminal resolves the ATM layer address to transfer a cell toward the appropriate access point which is the end terminal or the corresponding CLS.
- Even, the datagram delivery across many ATM-LAN experiences small number of ATM layer's terminations.
- Pipe-line transmission of cells belonging to a datagram can be performed.
- Datagram delivery can be provided either by AAL type 5 or by AAL type 3/4. This is because that the proposed mechanism does not require MID allocation algorithm.

When we provide class D service (datagram delivery) through AAL 5, we could reduce the cost of the interface equipment/board between the network and the terminal. In I.364, it is discussed that class D service is provided through AAL 3/4, rather than through AAL type 5. On the contrary, class C service (connection oriented data service) will mainly provided through AAL type 5, rather than through AAL type 3/4. This is because that the protocol overhead of AAL type 5 is lighter than that of AAL type 3/4. AAL type 5 will be also used as the signaling AAL (SAAL). This means that, through the ITU-T recommendations, AAL type 3/4 could be only used for class D service and AAL type 5 could be used only for class C service. Therefore, the terminal must have both AAL type 3/4 and AAL type 5, in order to use both class C service and class D service. When we can provide class D service through AAL type 5, we can integrate the AAL types for class C service and class D service into the only one AAL type; all of data service (CO/CL) can be provided through AAL type 5. Then, it is basically unnecessary to implement AAL type 3/4 at the interface equipment/board between the network and the terminal.

One difference regarding connectionless datagram unit (CPCS-SDU) delivery between AAL type 3/4 and AAL type 5 is error detection capability for the AAL-SDU. AAL type 3/4 has an error detection code, which is CRC-10, in every SAR-PDU (cell). Here, the CRC-10 code does not have error correction capability. On the contrary, AAL type 5 does not have the error detection code in SAR-PDU, but does have CRC-32 code in

CPCS-PDU, which can be composed by multiple SAR-PDUs (multiple cells). Generally, the network address information of the destination terminal is coded in the first cell belonging to the corresponding CPCS-PDU. Therefore, using AAL type 3/4 for class D service, the wrong CPCS-PDU will not be delivered to any terminal, when the error in the begin cell (BOM cell) is detected. On the contrary, in AAL type 5, the whole of CPCS-PDU will be delivered to the wrong destination terminal, when the bit(s) of the destination's network address field within the first cell's payload (SAR-PDU) has error(s). The received CPCS-PDU will be discarded by error detection in CPCS sub-layer, after receiving the whole of wrong CPCS-PDU. This might be serious if the service is for a public network, from the view point of security concerning. The wrong CPCS-PDU delivery to a certain terminal would not, however, serious for a private network. When the multiple cell streams belonging to the different datagram units could be interleaved due to the VC multiplexing capability, the wrong CPCS-PDU delivery because of bit error(s) of address information field will not cause the collapse of the CPCS-PDU(s) that is(are) received simultaneously with the receiving of the wrong CPCS-PDU. However, the buffer overflow of the receiving terminal would happen, in this case. When the cell streams belonging to the different CPCS-PDUs can not interleaved, the delivery of the wrong CPCS-PDU will cause the delay of the delivery for the following CPCS-PDUs and would cause loss of the following CPCS-PDU(s), because of buffer overflow at CLS. Here, CLNAP/CLNIP does not have error detection nor correction capability for the header field that includes source and destination address information of CLNAP/CLNIP protocol data unit. Therefore, even when the address information of the destination terminal has bit error(s), the address information can not be corrected at CLNAP/CLNIP layer.

Regarding the retransmission of the discarded datagram unit delivered to the wrong terminal, the upper layer's protocol over CLNAP takes care of both for using AAL type 3/4 and for using AAL type 5. This is because that, for both cases, the destination terminal can not receive any SAR-PDU belonging to the errored CPCS-PDU.

The job of ARS is to resolve the VCI/VPI value to access the destination terminal, according to the network address of the destination terminal, when the source terminal does not have the mapping information between the destination network address and the VCI/VPI value to access ot – cache-missed. Here, in order to reduce the average latency to analyze the VCI/VPI value (ATM layer access address) from the destination terminal's network layer address, the mapping information can be cached at the terminal. The job of CLS is to deliver the received datagram unit, that comes from the out-side ATM-LAN, to the destination terminal that is always within the ATM-LAN where the CLS belongs to. Therefore, the address information that the CLS must manage is only for the terminals within the ATM-LAN where the CLS belongs to.

Each terminal gets an ATM layer address by the ARS (Address Resolution Server) to submit cells to the network – address resolution procedure. Here, in this paper, the ATM layer address is defined as the VCI/VPI value to transfer the cell to the appropriate access point. This procedure could be equivalent to ARP procedure in IP network. In IP network topping on Ethernet, the terminal will get the appropriate MAC layer address that corresponds to the given IP address (network address), so as to transfer the Ethernet segment (datagram) to the appropriate access point. In ATM network, MAC address in IP network could corresponds to VCI/VPI value that is the ATM layer address. Each terminal in the proposed ATM internet resolves the corresponding VCI/VPI value to submit the datagram to the network. CLS method is equivalent to the default routing . This is because that a terminal can always use the same VCI/VPI value for the transmission of the datagram. Therefore, in CLS method, address resolution procedure can not be required, basically. On the contrary, in Meshed VCC method, each terminal resolves the appropriate VCI/VPI value of the destination terminal. When the terminal does not have the VCI/VPI information of the destination terminal, the terminal gets the VCI/VPI value to transfer the cells to the destination terminal through address resolution procedure.

In Meshed VCC method, the cells of the datagram are transferred from the source terminal to the destination terminal without any ATM layer's termination. In CLS method, ATM connection is always terminated at least once to analyze the network layer address containing in the submitted datagram.

Below, the proposed datagram delivery mechanism is discussed from the view points of address management and of cell routing.

3.2.1 Address Management View

Figure 8 shows the address view for the ATM-LAN where host A belongs to, in the ATM internet shown in Fig.7. For the terminals located at the ATM-LAN where host A belongs to, host A can identify them by the corresponding individual address point. Host A access them by the individual address, directly. For the terminals that are not located at the ATM-LAN where host A belongs to, host A identifies them by the address space where the corresponding terminal belongs to, rather than by the individual access point for them.

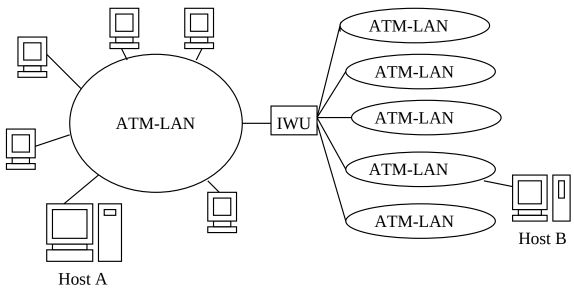

Fig.8 Address View for Host/Terminal

Host A accesses the destination terminal through the address point of the address space of the sub-net where the corresponding terminal belongs to. There is direct ATM connection without ATM layer termination point from host A to the access point of the sub-net. As shown in Sect.3.2.3, the ATM connection from the source terminal to the sub-net where the destination terminal belongs to has no ATM layer termination point.

Each CLS manages the address information of the end-terminals with the ATM-LAN where the CLS belongs to. The managed address information of the terminals is both ATM layer address (VCI/VPI) and network layer address (e.g., IP). The CLS does not need to have the address information of the end terminals that are outside of the ATM-LAN. The CLS can analyze the ATM layer address of the destination terminal within the ATM-LAN through the network layer address of the destination terminal contained in the datagram.

In order to analyze the ATM layer address from the network layer address, the ARS (Address Resolution Server) should have the following two informations.

- Address POINT information for the end terminal within the ATM-LAN where CLS belongs to.
- Address SPACE information, such as sub-net mask's of the subnet's, and access point address of the sub-net outside the ATM-LAN.

By the above management approach of the address information, the managed address information, that is ATM layer address and network layer address, will not ne large, even when the ATM internet will be scaling up. The required address information entry to be managed by ARS (Address Resolution Server) and CLS can be small, even for large ATM internet.

3.2.2 Intra-LAN Cell Routing

Datagram delivery, class D service, is performed using Meshed VCC method. When the source terminal submits cells to a certain destination terminal within the ATM-LAN, the source terminal analyzes the ATM layer access address (VCI/VPI) of the destination terminal. As well as the conventional data network, the ATM layer access address information could be cached. Then, the average latency to analyze the ATM layer access address from the destination terminal's network layer address can be reduced.

Here, the datagram delivery for the intra-LAN can be provided through CLS method, also. In this case, the source terminal does not need to analyze the ATM layer access address of the destination terminal – default routing.

3.2.3 Inter-LAN Cell Routing

When the source terminal sends a datagram to a terminal in the ATM-LAN where the source terminal does not belong to, the source terminal sends the cells to the CLS in the ATM-LAN where the destination terminal belongs to, through the direct ATM connection that has no ATM layer termination point. Here, every ATM-LAN has a CLS that deals with the datagram from the outside ATM-LANs. In order to provide class D service, an ATM connection from any terminal to the CLS in any outside ATM-LAN has been provided. The source terminal resolves the ATM access address of the CLS where the destination terminal belongs to, when it submits the cells to the network. The cells are transferred from the source terminal to the CLS where the destination terminal belongs to through the single ATM connection that has no ATM layer termination point. The CLS analyzes the network address, which the received datagram contains, to relay the datagram toward the destination terminal. The CLS resolves the destination terminal's ATM layer access address (VCI/VPI) from the network address of the destination terminal. Since there is only one ATM termination point between the source terminal and the destination terminal, the datagram delivery with small latency can be provided. Also, the datagram delivery as class D service does not require connection set-up procedure.

Figures 9 and 10 shows the datagram delivery from host A to host B. Host A resolves the ATM layer access address to send the datagram to the destination terminal (host B), when it submits the cells into the network. Through the address resolution procedure, host A gets the ATM layer access address of the CLS where host B belongs to, as the ATM layer access address of host B. Host A submits the cells attaching the resolved ATM layer access address (VCI/VPI) for host B. The CLS, where host B belongs to, resolves the ATM layer access address of host B by the network layer address of host B containing in the received datagram, so as to relay the cells to host B.

The required number of ATM connections (VCCs)

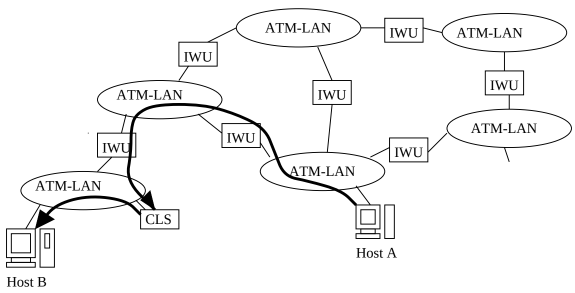

Fig.9 Datagram Delivery from Host A to Host B

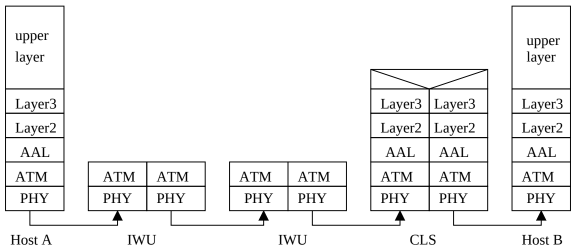

Fig.10 Protocol Stack for Datagram Delivery from Host A to Host B

for class D service is only about $(mN^2 + (m^2/2)N)$. And, the required number of VCCs per one ATM-LAN to provide class D service is about $(m^2/2 + mN)$. Here, the number of ATM-LANs is N, and the number of accommodated terminals within the ATM-LAN is m. $m^2/2$ corresponds to the required number of VCCs for intra-LAN class D service (full-meshed VCCs), and mN corresponds to the required VCCs from each terminal within a ATM-LAN to the CLSs which are located at outside ATM-LAN – for Intra-LAN class D service.

Regarding a source UNI address space (address space as a sender), the number of required ATM layer address points for class D service is only about $(N+m)$. The number of required ATM layer address points, regarding a destination UNI address space (address space as a receiving side), is only about m.

Since m and N is not so large, the required number of VCCs and the required ATM access address points for class D service are never inflated, even for the large ATM internet. This means that there are enough VCCs and ATM access address points left for connection oriented VCCs.

3.3 Datagram Delivery based on VPI Routing Architecture

3.3.1 VPI Routing

In VPI routing described in Ref.[8], neither VCI nor VPI is not changed for Intra-LAN cell routing. And, at

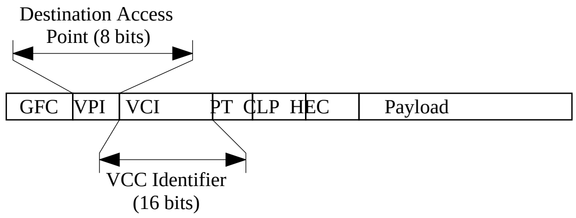

Fig.11 UNI Cell Format

the IWU that is located at the boundary of the ATM-LAN segments, VCI and VPI value will be changed. Figure 11 shows the UNI cell format when VPI routing is used. VPI field specifies the ATM layer address of the destination terminal. Both VCI and VPI values are transferred at switching node transparently. This means that neither VCI nor VPI value is changed at switching node. Cell is relayed at switching node only by VPI value, and the VPI value is never changed at switching node. VCI value is coded as the VCC identifier. The destination terminal distinguishes which VCC the received cell belongs to by the VCI value, that is assigned during the VCC set-up procedure. The source terminal resolves the VPI value, that the destination terminal is assigned, through the network layer address of the destination terminal, such as IP or NSAP (GOSIP) address. During the VCC set-up procedure, the destination terminal can identify the source terminal either through the network layer address of the source terminal or through the VPI value that is assigned to the source terminal.

Basically, the switching node only have the mapping information between VPI value and the routing tag within the switching system. This means that the entry number of the mapping table of VPI and routing tag is only upto 256 (2^8) and the entry address is only eight bits. Moreover, the switching node does not need to have the functionality to change the VPI/VCI value. As a result, VPI value could be equivalent to the MAC address in Ethernet. This is because that, in Ethernet, the source terminal can send the datagram to the destination terminal through the MAC address of the destination terminal that is unique value within the defined network. As well as Ethernet case, in VPI routing, the source terminal can send cells to the destination terminal through the VPI value of the destination terminal through the VPI value of the destination terminal that is a unique value within the ATM-LAN. The procedure to resolve the VPI value of the destination terminal from its network address can be equivalent to the ARP procedure in the conventional data networks.

Each terminal obtains the VPI value from the network, through the boot procedure. The network sets up the routing table of every switching node, so as that any cell from any input port within the network, which has the VPI allocated to the boot terminal, is relayed to the port where the boot terminal is attached to. This means that the multipoint-to-point cell relaying route from any input port (terminal) except the port, where the boot terminal is attached to, is provided. Therefore, regarding the cell relaying from the booted terminal (i.e., the input port where the booted terminal is attached to) to the other terminals (i.e., ports) should be already provided, before the terminal does boot.

During a shutdown (halt) procedure of the terminal, the assigned VPI value to the very terminal is released to be available for the terminal that will boot. When the network server, that takes care of VPI assignment and of routing table management for the switching nodes, receives a shutdown request message from the terminal, the network server lets the correspond VPI value to be available for the boot terminal and resets the routing table associated with the released VPI value.

Here, both the boot request message and the shutdown message can be sent either through a predetermined VCC, such as signaling channel, or through a broadcast channel. When the message is not terminated at the UNI point, e.g., using a broadcast channel, the message must have some information that indicates which UNI point the message comes from. Once, the UNI point where the terminal attached to is identified, the successive message(s) can be sent to each other through a certain VCC. Here, VCI value for this kind of signaling will be pre-determined within the system.

If necessary, the network will make sure where the terminal is in active, through such as loop back functionality of ATM layer [4]. Some applications above AAL layer, also, keep track of terminal activity [5],[6].

3.3.2 Intra-LAN Cell Routing

When a source terminal sends to a datagram to a destination terminal within the ATM-LAN, the source terminal resolves the VPI value of the destination terminal. The source terminal submits a cell having the VPI value of the destination terminal. When VCI value is coded so as to distinguish the source terminal, the source terminals can transfer the cells belonging a datagram, asynchronously. For example, when the eight bits of VCI field is coded as the source terminal's VPI value and the one symbol represented by the other eight bits VCI field indicates that the received cell is for class D service, the source terminal can send the cells of class D service asynchronously.

3.3.3 Inter-LAN Cell Routing

Figure 12 shows the network reference model when a datagram is transferred from host A to host B. When

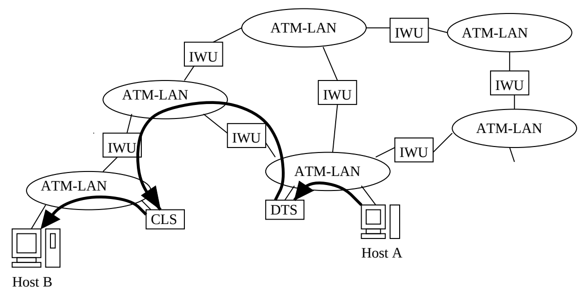

Fig.12 Datagram Delivery from Host A to Host B

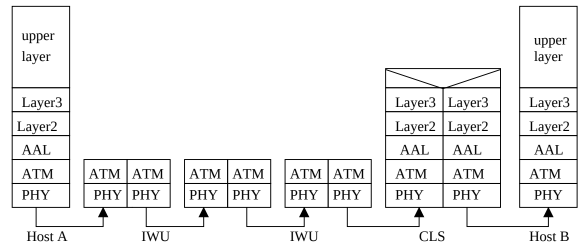

Fig.13 Protocol Stack for Datagram Delivery from Host A to Host B

the VPI routing is applied, the DTS (Datagram Transmission Scheduler) is additionally required, compared to the general case discussed in Sect.3.2. The job of the DTS is cell transmission scheduling so as to avoid invalid cell interleaving at the destination CLS. The cell transmission is scheduled so as that more than two datagrams from a given ATM-LAN are never transferred to the same ATM-LAN simultaneously, because of insufficient fields at the destination CLS. The address field to distinguish the source terminal is only eight bits, as shown below. When the destination CLS of the transferred datagram from the given DTS is different from the destination CLSs of other transmitted datagram, the datagram could be transferred asynchronously. Otherwise, the transmission of the datagram is blocked until the datagram transmission to the corresponding CLS is done.

When AAL type 5 is used for class D service, ATM connection will not be terminated at DTS. This is because that it is not necessary to reassemble the AAL-SDU at DTS. In AAL type 5, the end of the AAL-SDU is indicated by the UUI (User to User Indicator) value that is an indicator in the ATM layer. Therefore, the only one ATM layer termination point for the class D service is necessary.

The cell format from the source terminal (host A in Fig.12) to the DTS is shown in Fig.14. The source terminal resolves the identifier of the sub-net where the destination terminal belongs to, before it sends cell(s) to the DTS. The resolved destination sub-net identifier

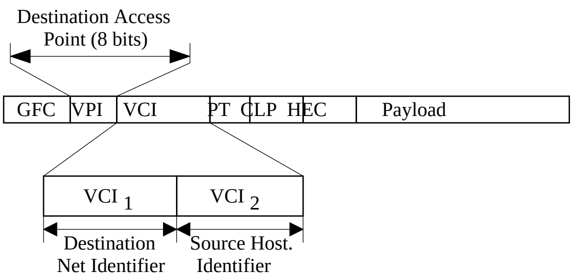

Fig.14 Cell Format from Source Terminal to DTS

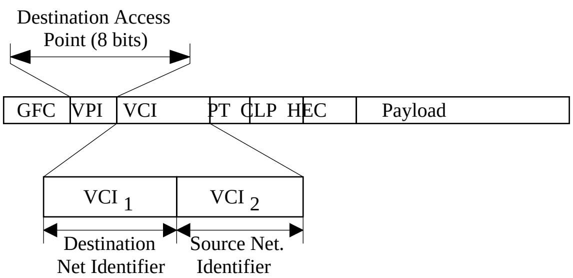

Fig.15 Cell Format Leaving from DTS

is coded in VCI_1 which is eight bits, and the VPI value of the source terminal is coded in VCI_2 which is also eight bits. Here, the VPI value from the source terminal to the DTS is the VPI value of DTS. Since DTS can distinguish which datagram the cell belongs to through VCI_2 field, the source terminal can transfer the cell to the DTS asynchronously.

The cell format leaving from DTS is shown in Fig.15. Here, the cell format that the IWU receives is the same format as shown in Fig.15. This is because that the ATM-LANs are interconnected through UNI. VCI_2 field is coded as the source sub-net identifier. VCI_1 is relayed transparently, and VPI is changed to the VPI value of IWU. The destination CLS can distinguish the cell which datagram it belongs to, through VCI_2. However, when more than two cell flows of the corresponding datagrams are interleaved, the destination CLS can not distinguish the cell which datagram it belongs to. When the destination CLSs are different, the datagram can be transferred from DTS in pipe-line fashion (asynchronously). Therefore, the job of the DTS is quiet simple – just schedule the datagram transmission as so that more than two cell flows of the corresponding datagrams which have the same destination CLS are never interleaved.

Among IWUs, the routing protocol to provide class D service is performed. By the routing protocol, IWU analyzes where the received cell should be routed. IWU analyzes where the received cell should be routed. IWU determines the VPI value of the leaving cell, through VCI_1 value that indicates the destination sub-net identifier. When VCI_1 value represents the sub-net where the IWU belongs to, the VPI value is coded as the VPI value of CLS within the sub-net. On the contrary, when VCI_1 value does not represent the sub-net where the IWU belongs to, the appropriate VPI value is attached to transfer the cell toward the next appropriate IWU. The job of IWU is changing VPI value so as that the received cell is relayed toward the appropriate IWU/CLS. VPI is looked up by VCI_1, and both VCI_1 and VCI_2 are relayed transparently at IWU. The table entry of routing table in IWU is VCI_1 of eight bits, and is the output of routing table is VPI of eight bits. This is because that the interface between IWU and the corresponding ATM-LANs (switching node's) is UNI whose VPI field is eight bits.

The destination CLS analyzes the network address of the datagram to get the ATM layer address of the destination terminal. The CLS can distinguish the source sub-net of the received cell by VCI_2 value. Therefore, the cells from the different sub-net's can be interleaved. Here, it could be possible to transfer the cells asynchronously from CLS to the destination terminal.

As discussed above, by using cell formats defined in Figs.14 and 15, the datagram delivery across the ATM-LANs experiences only one ATM layer termination point. Moreover, the terminal can submit the datagram to the network, asynchronously.

3.3.4 Scaling Up of the Network

The maximum allowable number of the sub-net's by the proposed architecture discussed in Sect.3.3.3 is upto 256 (2^8). This is because that the sub-net identifier is eight bits. When more than 256 sub-net's are interconnected, the ATM internet defined in Sect.3.3.3 is again interconnected. Figures 16 and 17 shows the case where the source terminal is host A and the destination terminal is host B. The ATM connection for class D service is terminated at the GW-CLS that works as the gateway CLS. At the GW-CLS, the network layer address information of datagram is analyzes to transfer the datagram to the destination (or appropriate) CLS). Once again, the pipe-line transmission of datagram at the GW-CLS is feasible, when there is only one datagram to the certain sub-net at the CLS.

Address view from host A can be similar to the Fig.8. The ATM internet can be managed as a subnet that has a large address space. As a result, the managed address information in each ATM-LAN can be small, even when the ATM internet is scaling up.

With routing protocol performed among IWUs and switching nodes, the routing protocol can be performed hierarchically. This means that the routing pro-

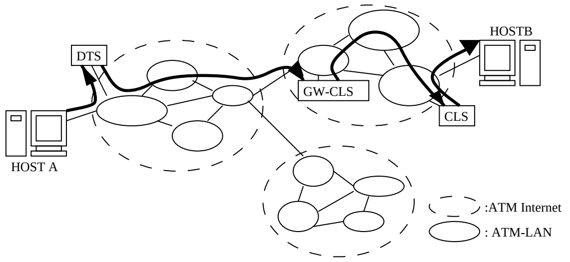

Fig.16 Datagram Delivery over ATM-Internet

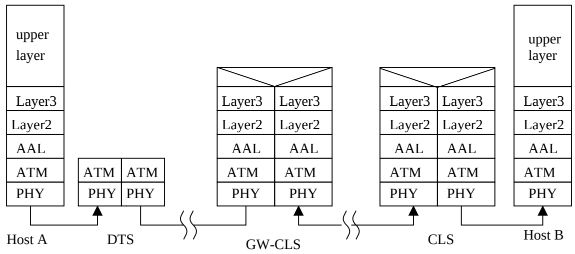

Fig.17 Protocol Stack for Datagram Transfer

tocol within the ATM internet and the routing protocol among the represented IWUs for the corresponding ATM internet can be operated independently.

3.3.5 Discussion

The following two items would be concerned with the proposed datagram delivery architecture.

- Required VCCs for class D service
- Required address space at UNI for class D service

When the number of accommodated terminals in the ATM internet increases, the VCCs and the address space at UNI might be wasted too much to provide class D service. However, as shown below, the percentage of the required VCCs and address space at UNI for class D service compared with the available VCCs and address space for all service classes in the ATM internet is enoughly small.

Figure 18 shows the required number of VCCs to provide class D service versus the number of the accommodated terminals within the ATM internet. With Meshed VCC method, the required VCCs is in proportion to the square value of the number of accommodated terminals. For example, when the number of accommodated terminals is 2^{24} ($\simeq 10^7$), about 2^{48} ($\simeq 10^{14}$) of VCCs must be provided for class D service. With CLS method, the number of required VCCs for class D service increases linerly in accordance with the number of accommodated terminals. For example, when the number of accommodated terminals is 2^{24} ($\simeq 10^7$),

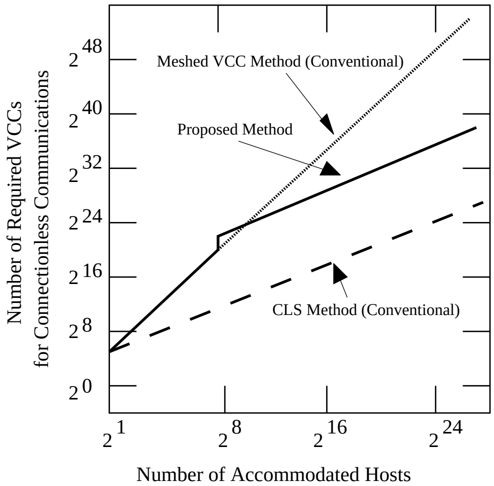

Fig.18 Required VCCs fir Class D Service

about 2^{24} ($\simeq 10^7$) of VCCs must be provided for class D service.

The required number of VCCs for class D service, when the proposed datagram delivery mechanism is used, is discussed. When the number of accommodated terminals is less than 256 (2^8), the required number of VCCs is the same as the number of VCCs for Meshed VCC method. However, when the number of accommodate terminals is more than 256 (2^8), the required number of VCCs increases roughly in accordance with the increase of the accommodated terminal. For example, when the number of accommodated terminals is 2^{24} ($\simeq 10^7$), the required number of VCCs for class D service is about 2^{32} ($\simeq 10^9$). The required number of VCCs for the proposed method is about $1/10^6$ VCCs that is required for Meshed VCC method. Comparing with the required number of VCCs for CLS method, the required number of VCCs for the proposed method is about 250 times as many as VCCs that is required for CLS method.

Figure 19 shows the required number of VCCs to provide class D service, the number of VCCs that the ATM internet can provide, and the percentage of the number of required VCCs for class D service are shown, parameterizing the number of the accommodated terminals within the ATM internet. As shown, the percentage of the number of required VCCs that the ATM internet can provide will not increase, even when the number of accommodated terminals increases. The percentage of the number of required VCCs for class D service is constant, when the number of accommodated terminals is larger than 256 (2^8). This is because that the inclination of the required VCCs for class D service and that of the number of VCCs to be provided by ATM internet is the same. The number of required VCCs for

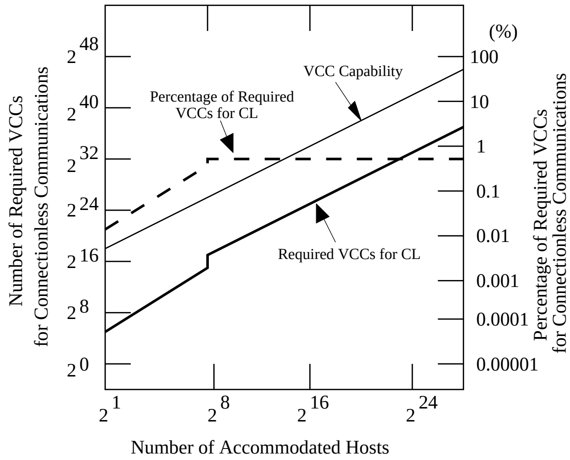

Fig.19 Required VCCs fir Class D Service

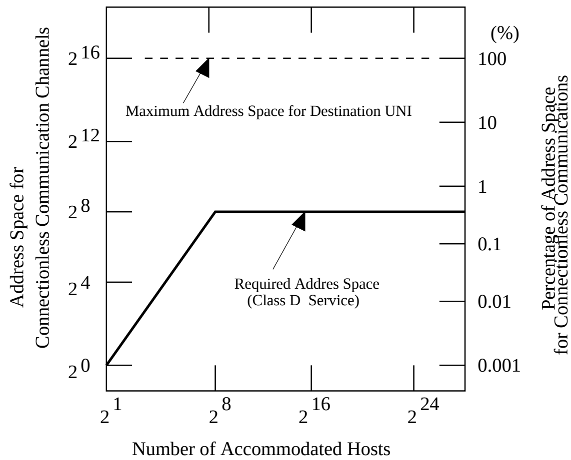

Fig.21 Required Address Space for Class D Service (CLS)

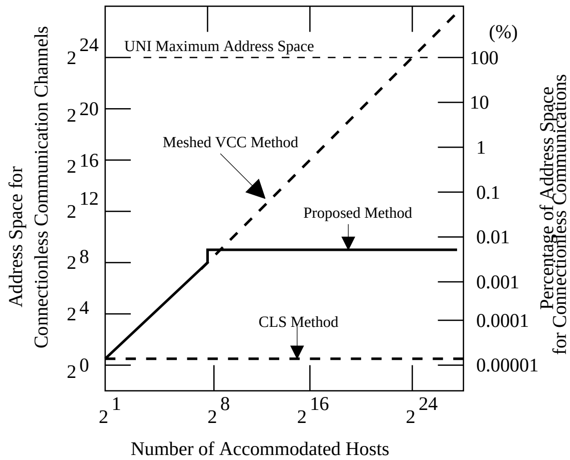

Fig.20 Required Address Space for Class D Service (UNI)

class D service will be less than 1.0% of the number of VCCs to be provided by ATM internet. This means that, at least, 99% of VCCs to be provided by ATM internet can be used for connection oriented service.

Figures 20 and 21 show the required address space for class D service at UNI versus the number of accommodated terminals in the ATM internet. Totally, 24 bits address space ($2^{24} \simeq 10^7$) would be available for UNI. Here, the address space is composed by 8 bits of VPI and by 16 bits of VCI.

Regarding the source UNI address space, 24 bits of VCI/VPI address space is shared by the terminals within a given ATM-LAN. And, the number of available address points to establish VCCs is $(2^8 - 1) \times 2^{16}$. When the number of accommodated terminals is less than 256 (2^8), the required address points for class D service is $(n-1)^2$. Here, n is the number of accommodated terminals within an ATM-LAN. When the number of accommodated terminals is larger than 256 (2^8), the required address points for class D service is less than $(2^8 - 1)^2 \times 2$. Here, $(2^8 - 1)^2$ of the address points are for Intra-LAN cell routing, and the other $(2^8-1)^2$ of the address points are for Inter-LAN cell routing. Since the required address points for Inter-LAN cell routing will never increase, even when the number of accommodated terminals increases, the total number of address points for class D service is always $(2^8 - 1)^2 \times 2$. This means that the percentage of the address points to be used for class D service will be less than $1/2^7 (\leqq 1.0\%)$ of the available address points for all VCCs.

Regarding the destination UNI address space, 16 bits of VCI address space is available. The maximum number of address points for class D service based on the proposed architecture will be less than (2^8-1), even for the large ATM internet. Therefore, the percentage of the address points to be used for class D service will be never larger than $1/2^8$, which is again less than 1.0%, of the available address points.

As a result, the required address space for class D service based on the proposed architecture will be less than 1.0% of the available address space at UNI point. In other words, more than 99% of address points will be available to be used for connection oriented VCCs.

Through the above discussions, the required VCCs and the required address space to be provided class D service will not be large. This means that there are enough VCCs and address space that are available for the connection oriented service.

4. Conclusion

Datagram delivery(class D service) architecture in ATM internet is proposed and discussed. The proposed architecture has the following features. The proposed architecture can provide high speed class D service with small latency, because of pipe-line transmission capability and of the less ATM layer termination points. Also, the proposed architecture can be applied to the ATM internet based on VPI routing architecture.

- Meshed VCC method is applied for intra-LAN datagram delivery, and the modified CLS method is applied for inter-LAN datagram delivery.
- For inter-LAN datagram delivery, the source terminal resolves the sub-net address where the destination terminal belongs to.
- Address points information of end terminals within the ATM-LAN and address space information of outside sub-net's is managed. Address management of the end terminals is performed independently within the ATM-LAN. For the terminals outside the ATM-LAN, the address information is managed by address space information, rather than address point information.
- ATM layer access address to transfer the datagram toward the destination terminal is performed by the source terminal, rather than by CLS.

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