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Titel: The routing protocol for the connectionless service on an ATM/DQDB internetwork

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In de nabije toekomst zal een nieuw netwerk ontstaan: het Broadband Integrated Services Digital Network. Dit netwerk zal zijn gebruikers voorzien van een aantal diensten, die geïntegreerd zullen worden op één eindpunt op de locatie van de gebruiker. Eén van de diensten dat het B-ISDN zal bieden is het verbindingsloze transport van gebruikersdata (connectionless service). Om deze dienst te bieden is er een protocol nodig voor het bepalen van de beste route van de bron naar de bestemming. Dit afstudeerverslag beschrijft een voorstel voor dit routeerprotocol. Tevens wordt uiteengezet hoe dit protocol invloed heeft op de InterWorking Unit tussen het B-ISDN en het DQDB MAN.

Trefwoorden: ATM, DQDB, SMDS, CBDS, BCLB, Interworking, B-ISDN, Connectionless Dienst, Routeren, IS-IS, OSPF.

CONTENTS

SAMENVATTING

In de nabije toekomst zal een nieuw netwerk ontstaan: het Broadband Integrated Services Digital Network. Dit netwerk zal zijn gebruikers voorzien van een aantal diensten, die geïntegreerd zullen worden op één eindpunt op de locatie van de gebruiker. Een aantal voorbeelden van deze diensten zijn: video, CD kwaliteit audio, video vergaderen, hoge snelheid datatransmissie en natuurlijk verbeteringen op het huidige telefoonsysteem. Om de introductie van deze diensten te versnellen zal een gedeelte ervan worden aangeboden op bestaande Metropolitan Area Networks (MAN's). Een voorbeeld van zo een MAN is de Distributed Queue Dual Bus (DQDB), dat is ontwikkeld door het Institute of Electrical and Electronics Engineers (IEEE).

Eén van de diensten dat het B-ISDN zal bieden is het verbindingsloze transport van gebruikersdata (connectionless service). Om deze dienst te bieden is er een protocol nodig voor het bepalen van de beste route van de bron naar de bestemming. Dit afstudeerverslag beschrijft een voorstel voor dit routeringsprotocol. Tevens wordt uiteengezet hoe dit protocol invloed heeft op de InterWorking Unit tussen het B-ISDN en het DQDB MAN.

In de Verenigde Staten bestaat al een connectionless dienst op DQDB MAN's: de Switched Multi-megabit Data Service (SMDS). SMDS is ontwikkeld door Bellcore[1] en gebruikt voor zijn routeringsprotocol een gedeelte van het Open Shortest Path First protocol. Dit OSPF protocol hanteert een hiërarchische structuur en ondersteunt punt-punt verbindingen (zoals B-ISDN) en multi-access netwerken (zoals DQDB). Er is echter een ander routeringsprotocol, geïntroduceerd door ISO, dat veel minder bandbreedte en middelen gebruikt dan OSPF, ten koste van een lagere routeringsprestatie. Dit Intermediate System-to-Intermediate System (IS-IS) routeringsprotocol maakt gebruik van variabele lengte velden die worden overgeslagen door routers, die deze velden niet herkennen. Op deze manier is IS-IS in staat zichzelf uit te breiden zonder veel aanpassingen aan bestaande hard- en software in de routers (Intermediate Systems).

Vanwege deze voordelen is IS-IS een beter alternatief voor het routeringsprotocol in het B-ISDN/DQDB-MAN netwerk dan OSPF. Om de routeringsprestaties te verbeteren zou één van de volgende uitbreidingen aan het protocol moeten worden toegevoegd:

- *Selectie van lager nivo router (nivo 1) door hoger nivo router (nivo 2).* Met deze uitbreiding berekenen nivo 2 routers de beste nivo 2 router voor een bron-area/bestemmings-area combinatie, gebaseerd op nivo 2 routeringsinformatie.
- *Hop-count feeding.* Met deze uitbreiding berekenen nivo 1 routers de beste nivo 2 router voor transport van data naar een bepaalde bestemmings-area, gebaseerd op hop-count informatie, afkomstig van nivo 2 routers.

[1]Bellcore is het onderzoeksinstituut van de Amerikaanse Bell Operating Companies (BOCs).

SUMMARY

In the near future a new network will be introduced: Broadband Integrated Services Digital Network (B-ISDN). This network will provide users with a multitude of services integrated on only one end point at the customer premises. These services may be: video services; CD-quality audio; video conferencing; high speed data transmission and of course improvements of the plain old telephone services (POTS). In order to facilitate the introduction of the B-ISDN architecture a subset of its services will be provided by existing Metropolitan Area Networks like the one developed by the Institute of Electrical and Electronics Engineers, the Distributed Queue Dual Bus (DQDB).

One of the services that B-ISDN will offer is the connectionless transfer of user data. For this service, there is a need for a protocol to determine the best paths from the source user to the destination user. This thesis proposes such a routing protocol for the connectionless service together with the impact it has on the InterWorking Unit between the B-ISDN network and DQDB-MANs.

In the USA, a connectionless service on DQDB MANs already exists: the Switched Multi-megabit Data Service. SMDS is developed by Bellcore[2] and uses for the routing protocol a subset of the Open Shortest Path First protocol. This OSPF protocol uses hierarchical routing and supports point-to-point links (B-ISDN) and multi-access networks (DQDB). However, there is another protocol, introduced by ISO, that uses far less bandwidth and resources than OSPF does at the cost of lower routing performance. This protocol, Intermediate System-to-Intermediate System (IS-IS) routing protocol, has the additional advantage of using variable length fields that are skipped by not compatible routers. This way, IS-IS is able to extend itself without major changes to existing hard- and software in the routers.

Because of these reasons, IS-IS is a better alternative for the routing protocol in the B-ISDN/DQDB-MAN internetwork than the one proposed for SMDS. To increase the performance, one of the following extensions to the IS-IS protocol should be introduced:

- *Lower level (level 1) router selection by higher level routers (level 2).* With this extension, level 2 routers calculate the best level 2 router for a particular source-area/destination-area combination based upon Level 2 routing information.
- *Hop-count feeding.* With this extension, level 1 routers calculate the best level 2 router for every destination area based upon hop-count information, gathered from attached level 2 routers.

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[2]Bellcore is the research institute of the American Bell Operating Companies (BOCs).

LIST OF ABBREVIATIONS AND ACRONYMS

AAL	ATM Adaptation Layer
ANSI	American National Standards Institute
ATM	Asynchronous Transfer Mode
BCLB	Broadband ConnectionLess data Bearer service
BIS	Boundary Intermediate System
BOM	Beginning Of Message
CBDS	Connectionless Broadband Data Services
CCITT	Comité Consultative Internationale de Telegraphique et Telephonique
CLMAP	ConnectionLess MAN Access Protocol
CLMNP	ConnectionLess MAN Node Protocol
CLNAP	ConnectionLess Network Access Protocol
CLNNP	ConnectionLess Network Node Protocol
CLNP	ConnectionLess Network Protocol
CLS	ConnectionLess Service
CLSF	ConnectionLess Server Function
COM	Continuation Of Message
COMBINE	COMposite Broadband INterworking and End-to-end models
CPCS	Common Part Convergence Sublayer
CPE	Customer Premises Equipment
CRC32	Cyclic Redundancy Check 32 bits
CS-PDU	Convergence Sublayer Protocol Data Unit
CUG	Closed User Group
DM-PDU	Derived MAC PDU
DQDB	Distributed Queue Dual Bus
DTPDU	Data Transport Protocol Data Unit
EOM	End Of Message
ES	End System
ETSI	European Telecommunication Standardisation Institute
HLPI	Higher Layer Protocol Indicator
ICIP	Inter-exchange Carrier Interface Protocol
IDRP	InterDomain Routing Protocol
IEEE	Institute of Electrical and Electronic Engineers
IM-PDU	Initial MAC PDU
IS-IS	Intermediate System-to-Intermediate System routeing protocol
ISDN	Integrated Services Digital Network
ISSIP	Inter Switching System Interface Protocol
IWU	InterWorking Unit
L1-IS	Level 1 Intermediate System
L2-IS	Level 2 Intermediate System
LSP	Link State Protocol data unit (packet)
LAN	Local Area Network

LIST OF FIGURES

1. INTRODUCTION

In the near future a new network will be introduced: Broadband Integrated Services Digital Network (B-ISDN). This network will provide users with a multitude of services on only one end point at the customer premises. These services may be: video services; CD-quality audio; video conferencing; high speed data transmission and of course improvements of the plain old telephone services (POTS).

In order to facilitate the introduction of the B-ISDN architecture a subset of its services will be provided by existing Metropolitan Area Networks like the one developed by the Institute of Electrical and Electronics Engineers (IEEE), the Distributed Queue Dual BUS (DQDB) or IEEE 802.6. After the first step on the B-ISDN evolution ladder where MANs introduce subsets of future B-ISDN services, the next step will be the use of ATM as a backbone for connecting several of these MANs into a larger internetwork. After the final step ATM will have replaced most of the MAN subnetworks to form the Broadband Integrated Services Digital Network where the user has a wide variety of services available.

The interconnection of B-ISDN with DQDB MANs is within the scope of the RACE project COMBINE (COMposite Broadband INterworking and End-to-end models), as this project studies the interconnection of B-ISDN with all broadband MANs. This thesis contributes to the COMBINE project.

One of the services that B-ISDN will offer is the connectionless transfer of user data. For this service, there is a need for a protocol to determine the best paths from the source user to the destination user. This thesis proposes such a routing protocol for the connectionless service together with the impact it has on the InterWorking Unit between the B-ISDN network and DQDB-MANs.

In the USA, the Switched Multi-megabit Data Service (SMDS) is offered on DQDB as its connectionless service, whereas Europe uses a variant: the Connectionless Broadband Data Service (CBDS). This thesis will reflect the results of the study on the possibility of adapting the proposed routing protocol that will be used for SMDS as well as the possibility of adapting other routing protocols for use in an ATM/DQDB internetwork and ultimately in a B-ISDN environment.

Part A serves as background information on the interworking problem and the provision of a connectionless service.

Chapters two and three give a brief description of the ATM and DQDB technology respectively. Chapter four summarises a connectionless service as defined by Bellcore: the Switched Multi-mega bit Data Service. It is Bellcore's view that SMDS will be one of the first data services B-ISDN will offer. For early availability SMDS will be offered on IEEE 802.6 based Metropolitan Area Networks. Differences with CBDS which is being developed by the European Telecommunication Standardisation Institute (ETSI) are given also.

PART A: BACKGROUND

2. ASYNCHRONOUS TRANSFER MODE

The Asynchronous Transfer Mode (ATM), which is chosen by CCITT as the solution to Broadband-ISDN, will be used because of the flexible properties of this transmission, multiplexing and switching technique. It is flexible in a way that it supports easy user-access, variable bit rates, possibility to quickly introduce new services and integration of services. At this moment (August, 92) ATM still is subject to change, but it probably will not change drastically from the description given in this document. Beside a general approach to ATM a description of only those ATM subjects in relation to the interworking with IEEE 802.6 (DQDB) and the provision of a connectionless service will be given.

The first section of this chapter describes the different connections in an ATM network. The second section gives a description of the ATM Protocol Reference Model (PRM), whereas the third section outlines the different ATM Adaptation Layer (AAL) service classes and service types. The final three sections describe the ATM cell structure, the Convergence Sublayer PDU (CS-PDU) and the Segmentation and Reassembly Protocol Data Unit (SAR-PDU) respectively for the connectionless service.

2.1. Connections in ATM

One of the basic characteristics of ATM is the limited functionality in the header which is largely supported by ATM's connection-oriented character. Fields like source and destination address and sequence number are not required in an ATM network. Every virtual connection will be identified by a number, which only has local significance per link in the virtual connection. Also there is no information field processing and flow control present in the network. Therefore, the basic remaining function of the ATM header is the identification of the virtual connection. This function is performed by two sub fields of the header: Virtual Channel Identifier (VCI) and Virtual Path Identifier (VPI). The VCI identifies dynamically allocatable connections; VPI identifies semi-statically allocatable connections.

Virtual Channels

Each Virtual Channel Link (VCL) between two ATM nodes in the ATM network is characterised by a Virtual Channel Identifier which is assigned at call set-up. A VCI has only local significance on the link between the two ATM nodes, so VCI values will be translated in every ATM node. The header and incoming link number will be used for the translation and will result in another header/outgoing link number combination. A Virtual Channel Connection (VCC) is a concatenation of VCLs thereby forming an end-to-end route through the network in order to support the transparent transfer of

The model shows a layered structure similar to the one used in OSI. New here is the vertical layered structure; a separation in so-called 'planes'. Three types are used: user plane, control plane and management plane. The user plane handles the transfer of user information including verification and re-transmissions if necessary. The control plane is responsible for call-control and connection-control, i.e. signalling for call and connection set-up, re-negotiation of call or connection characteristics, ending calls and releasing connections. The management plane takes care of co-ordination between all planes (plane management) and layers (layer management).

The concept of horizontal layers and possible sublayers has been derived from the OSI Reference Model. The main reason for the use of this concept is the grouping of related functions. However, the OSI model was designed for use in data communications whereas ATM networks support the transport of a multitude of information-flows. The horizontal layers of the ATM Protocol Reference Model are: the physical layer; the ATM layer; the ATM adaptation layer (AAL) and the higher layers. The higher layers for example can offer a connectionless service.

The physical layer is subdivided in a Physical Medium (PM)-layer and a Transmission Convergence (TC)-layer. The PM-layer is medium-dependent and responsible for correct bit-transmission and -receipt. Above the PM-layer resides the TC-layer which is responsible for transmissionframe generation and -correction, cell-delineation and the generation of Header Error Control sequences (see par. 2.4)

The ATM-layer performs: multiplexing/de-multiplexing of cells from different sources; Virtual Channel Identifier (VCI) and/or Virtual Path Identifier (VPI) translation in ATM nodes; ATM header removal before delivery of the cell to the AAL and header generation after receipt of a cell from the AAL. A more accurate description of the ATM header-fields can be found in section 2.4.

The ATM Adaptation Layer adapts the higher layers to the ATM layer. It is made possible by the division of AAL in two sublayers: a Segmentation-and-Reassembly (SAR)-layer and a Convergence-Sublayer (CS). These two layers are described in section 2.6 and 2.5 respectively.

2.3. AAL service classes and service types

As was stated before ATM is very flexible. It can handle virtually any bit rate and burstiness and therefore virtually any imaginable application can be supported. In order to prevent an uncontrolled growth of service offering and to minimise the number of protocols used in B-ISDN a limited number of service classes in the AAL are defined. Today, four service classes are distinguished:

- **Class A:** e.g. circuit emulation, constant bit rate video
- **Class B:** e.g. variable bit rate video and audio
- **Class C:** e.g. connection oriented data transfer
- **Class D:** e.g. connectionless data transfer

To provide these service classes certain functions of the Segmentation and Reassembly layer and the Convergence-Sublayer must be combined for each service payload. Momentarily seven types are preset, one is still reserved for future functions.

- **CLP: Cell Loss Priority**. When this bit is set the cell is more susceptible to loss in case of network congestion than when this bit is not set.
- **HEC: Header Error Control**. This field implements a simple header error-correcting code. Single bit errors can be corrected and multiple bit errors can be detected.

2.5. The Convergence Sublayer PDU of AAL type 4

The Convergence Sublayer (CS) is the top layer of the ATM Adaptation layer situated directly above the Segmentation and Reassembly (SAR)-Layer. Here, packets from higher layers are provided with a CS-PDU header and -trailer to facilitate transmission on ATM links. The CS layer consists of a Common-Part Convergence Sublayer (CPCS) and an optional Service Specific-Part Convergence Sublayer (SSCS). For providing connectionless services there is no need for a SSCS sublayer. The structure of the CPCS-PDU is given in Figure 2.4.

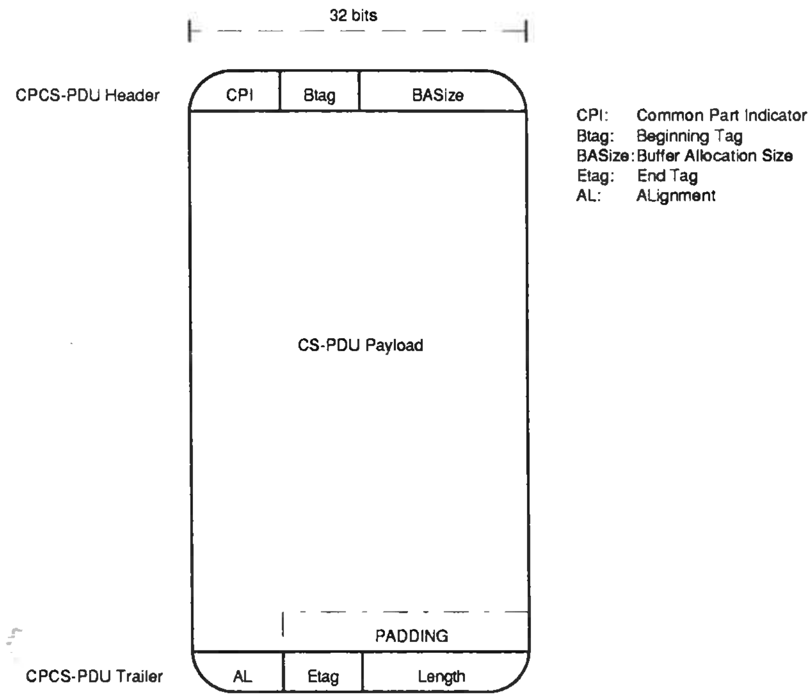

Figure 2.4: *Common-Part CS-PDU structure (AAL type 3 and 4)*

The *Common Part Indicator* (CPI)-field indicates how subsequent fields in the CPCS-PDU header and trailer should be interpreted. At this point only one coding has been agreed upon: CPI = all ones means that the *Length* (Length) and the *Buffer Allocation Size* (BASize)-fields give the length of the CS-PDU payload in octets. Other values are reserved and for future standardization.

The *Beginning Tag* (Btag) and *End Tag* (Etag)-fields of one CS-PDU should have the same value. Cells have been lost when the Btag field from a BOM and an Etag field from a EOM for one CS-PDU have different values.

PDU therefore contains a BOM bit-configuration in its ST-field, the last SAR-PDU an EOM and all intermediate SAR-PDUs a COM bit-configuration. In the case of a CS-PDU being smaller than a SAR-PDU payload (44 octets) a SSM bit-configuration will be inserted in the ST-field.

A *Sequence-Number* (SN)-field makes it possible for a SAR-PDU belonging to a single CS-PDU to have a modulo-16 numbering. This way SAR-PDU sequence faults can be detected.

The *Multiplexing IDentification* (MID)-field connects a SAR-PDU to one CS-PDU. Every SAR-PDU corresponding to one CS-PDU therefore contains the same value. With this field it is possible to multiplex different CS-PDUs onto one ATM-link.

The *Length-Indication* (LI)-field indicates how many octets in the SAR-PDU payload really contain user-information. The value of this field for a BOM or COM is fixed at 44 and for a SSM it can be any value from 8 to 44 octets. For an EOM it may be in the range from 4 to 44 octets or it may have the value of 63, which is used in the Abort-SAR-PDU.

Finally, the *Cyclic Redundancy Check* (CRC)-field is used for SAR-PDU error-detection. It covers the SAR-PDU header, the SAR-PDU payload and the LI-field.

3. DISTRIBUTED QUEUE DUAL BUS

The name Distributed Queue Dual Bus originates from its medium access principle: a physical dual bus with a distributed queuing mechanism. It was mainly developed by the Institute of Electronics and Electrical Engineers (IEEE) to meet the need of Metropolitan Area Networks (MANs). It resulted in the IEEE 802.6 DQDB standard, which was then adopted by the European Telecommunication Standardisation Institute (ETSI). ETSI now focuses on the definition of a DQDB network structure and the provisioning of public data services. This standard is defined as much as possible in line with the ATM standard. In this thesis, DQDB will be described in relation to the interworking with ATM and the supply of connectionless services.

The first section of this chapter briefly outlines the topology of DQDBs dual bus architecture. The second section gives a description of the DQDB Protocol Reference Model, whereas the third section describes the DQDB slot-structure. The final two sections show the structure of the Initial Medium-Access-Control PDU and the Derived Medium-Access-Control PDU respectively.

3.1. DQDB topology

In the next few years MANs will offer a subset of the B-ISDN services to facilitate migration to this new technique. The DQDB Medium Access Control protocol has been designed by the IEEE 802.6 committee with this fact in mind. The DQDB protocol is based on a physical dual bus topology with buses running on 2, 34, 140, 155 or 622 Mbit/s. These buses are unidirectional and contra-flowing, which means that signals are transmitted in one direction on either bus and in opposite directions to each other. Figure 3.1 shows the dual bus configuration.

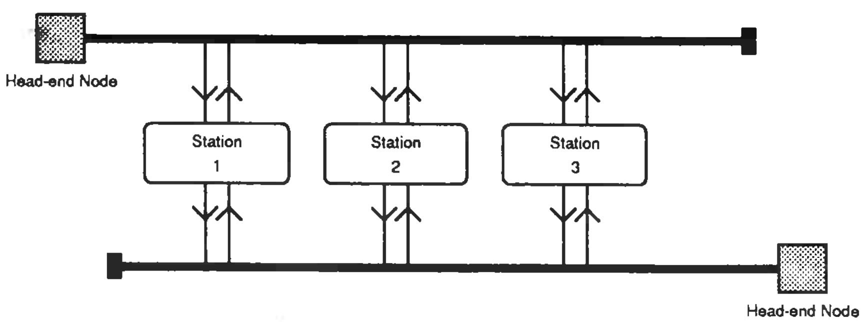

Figure 3.1: *The DQDB dual bus structure*

The DQDB buses are slotted buses, i.e. data is transmitted in slots (frames) of fixed size (53 octets with a 48 octet payload as in ATM). The slots are generated by head-end nodes. Whenever a station wants to transmit data a request bit on one bus is set to sublayers are equal or nearly equal to the functions of the SAR and CS sublayer. The bottom sublayer of the SerVice layer is the Derived Medium-Access-Control sublayer (DM), which is mainly responsible for the segmentation and reassembly of an Initial Medium-Access-Control PDU (IM-PDU) to fixed-size segmentation units of 44 octets (the DM-PDU payload). The IM sublayer is the top layer of the SV layer. At the sender a MAC Convergence Protocol (MCP) header and a common header and trailer are added to a MAC service data unit before the resulting IM-PDU is passed on to the DM sublayer for segmentation. On the receiving side the headers and trailer are removed from the IM-PDU to leave the original MAC service data unit.

3.3. DQDB slot structure

The structure of a DQDB slot is given in Figure 3.3. It consists of a one octet Access Control Field (ACF) and a 52 octet DQDB segment. Together the DQDB slot has a total length of 53 octets to make interworking with ATM less complicated. The ACF field handles the access of different users to the same medium and is therefore divided in 5 sub fields:

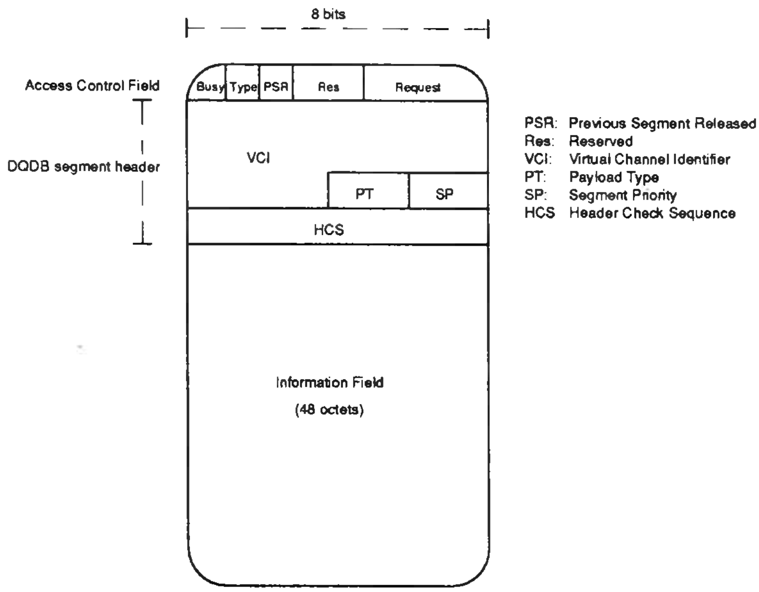

Figure 3.3: *Structure of a DQDB slot*

- **Busy:** The busy bit indicates whether the cell containing the bit already has user information in the DQDB segment. When this bit is set the slot is in use and cannot be filled by other users.
- **Type:** This bit defines the type of the DQDB slot. Two types are available: Pre Arbitrated slots and Queued Arbitrated slots. Pre Arbitrated slots are used for isochronous services like speech and video, whereas Queued Arbitrated slots are used for non-isochronous (e.g. connectionless) services like data transmission.
- **PSR:** The Previous Segment Released bit is set whenever a slot has been read. This way special stations can remove the slot from the bus to make more efficient use of the available bandwidth.
- **Res:** The two Reserved bits are for further study.

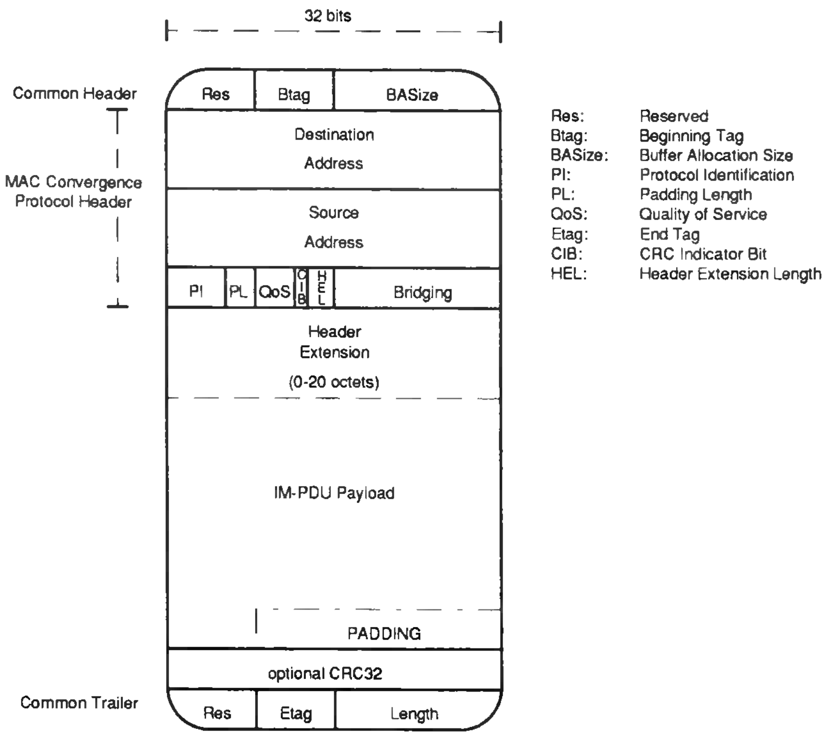

Figure 3.4: *Initial MAC Protocol Data Unit (IM-PDU)*

- **DA,SA:** Destination Address, Source Address. These fields with a total length of 64 bits each are used to indicate the sending and receiving party. The first four bits show which numbering plan is used, whereas the remaining 60 bits can be used for the coding of individual or group addresses (e.g. according to the E.164 numbering plan of CCITT). For the source address only individual addresses can be used.
- **PI/PL:** Six bits of this octet are used for Protocol Identification and the remaining 2 bits for Padding Length indication. The padding length part shows the length of the padding field which can be any number from 0 to 3 octets. Protocol identification is used to identify the MAC service user to which the IM-PDU payload is to be sent at the node(s) identified by the Destination Address field.
- **QoS:** This combined field has a two specific functions:

1. QoS delay: Three bits are used for indication of the requested quality of service with respect to delay in accessing the network.
2. QoS loss: One bit is used for indication of the requested quality of service with respect to loss in the network. Currently this field is reserved and set to 0

- **CIB:** The CRC Indicator Bit indicates whether the optional CRC field is present in the IM-PDU (1=present, 0=absent).
- **HEL:** This three bit Header Extension Length equals the length of the header extension field in octets divided by four. The numerical value of this field can be 0 to 5 inclusive. A value of 0 means that no header extension is present in the IM-PDU. The values 6 and 7 are invalid.
- **BR:** The Bridging field may be standardised for use in carrying the maximum number of bridges that the IM-PDU is allowed to pass through. This would enable the IM-PDU to be discarded when the number reaches a pre-set value. This field is reserved for future use. All bits are set to 0.

4. SMDS AND CBDS

The Switched Multi-megabit Data Service (SMDS) is intended to be a high-performance, high-speed public network packet-switched data service. It is developed by Bellcore, the research institute of the Bell Operating Companies in the United States to extend Local Area Network (LAN)-like performance beyond the subscriber's premises, across a metropolitan or wide area. Several of its important aspects are: independency of technological evolution; economic use of network-means and privacy protection. For early availability SMDS is offered on IEEE 802.6 based Metropolitan Area Networks.

The first section shows the SMDS topology, the second outlines some of the SMDS features. Paragraphs three and four describe two of the SMDS interface protocols: the DQDB based SMDS Interface Protocol and the DQDB based Inter Switching System Interface Protocol. The final section outlines the differences between SMDS and the European (ETSI's) version: Connectionless Broadband Data Services (CBDS).

4.1. Generic network topology for providing SMDS

Figure 4.1 illustrates an example of a generic network providing SMDS. Bellcore uses the term Local Access Transport Area (LATA) for this geographic area within which a Bell Operating Company provides telecommunication services. As illustrated in the example, the Customer Premises Equipment (CPE) is provided access to the network supporting SMDS at a point referred to as Subscriber to Network Interface (SNI). A suite of protocols that operates across an SNI that provides access to SMDS is referred to as an SMDS Interface Protocol (SIP). Parts of the SIP are terminated in the network at an SMDS Switching System (SSS). At this point the SSS provides functions which include the relaying of connectionless messages, Access Class enforcement and enforcement of the maximum number of data units that can be sent concurrently across an SNI.

In the future when more SSSs per LATA are available extra functions will be introduced, e.g. routing of connectionless messages, route management and congestion management. The point at which these SSSs are interconnected is referred to as an Inter Switching System Interface (ISSI) and the suite of protocols that operates across such an interface is referred to as an Inter Switching System Interface Protocol (ISSIP).

Ultimately, networks providing SMDS require the ability to interconnect SSSs to Inter-exchange Carriers (ICs). The point at which this connection is made is referred to as an Inter Carrier Interface (ICI) and the protocols as Inter Carrier Interface Protocol (ICIP). An SSS that terminates an ICIP will have the additional function of Inter Carrier selection.

Local Traffic Discard

This function identified and discards any SIP-CLS-PDU received across a given SNI that has an individual destination address corresponding to the SNI from which it was received.

Encapsulation

This function encapsulates the SIP-CLS-PDU received across an SNI with an encapsulation header and trailer. The encapsulation function header and trailer contain the same fields as the header and trailer of the AAL CS-PDU.

Relaying

This function, performed by the Relaying Entity, receives SIP-CLS-PDUs from the SIP-CLS entity that are destined for the local SSS and sends it back to the SIP-CLS entity for transmission. It also receives ISSIP-CLS-PDUs and checks the 'Hop Count Indicator'. Depending on its value the Relaying Entity drops the PDU or decrements the counter and sends it back to the ISSIP-CLS entity for transmission.

Routing

This function determines the route a received packet must take on the way to its destination.

End-User Blocking

This function allows an Inter-exchange Carrier to request that a LATA discard interexchange data units originating from a particular Subscriber to Network Interface and destined for the IC requesting this feature. Only ICs may request End-User Blocking.

At the CLS layer within a CPE additional functions are:

Addressing

This function provides the ability to a CLS User Layer entity to select, on a per SIP-CLS-SDU basis, to which destination CLS User Layer entity or entities the SIP-CLS-SDU is to be delivered.

Carrier Selection

This function provides the ability to a CLS User Layer entity to explicitly select, on a per SIP-CLS-SDU basis, the end-user's preferred carrier.

4.3. The SMDS Interface Protocol (SIP)

In order to indicate protocols, systems, carriers and CPEs to be IEEE 802.6 based a subscript $_I$ will be added. E.g. the IEEE 802.6 based Inter Switching System Interface will be indicated by $ISSI_I$ and the protocol by $ISSIP_I$.

The SMDS Interface Protocol (SIP_I) is based on the connectionless part of the DQDB MAN MAC protocol as defined in the IEEE 802.6 standard [2]. This section will show the relationship of the SIP_I and the IEEE 802.6 proposed standard. Figure 4.2 depicts the correlation between the SIP_I and IEEE 802.6 protocol layers.

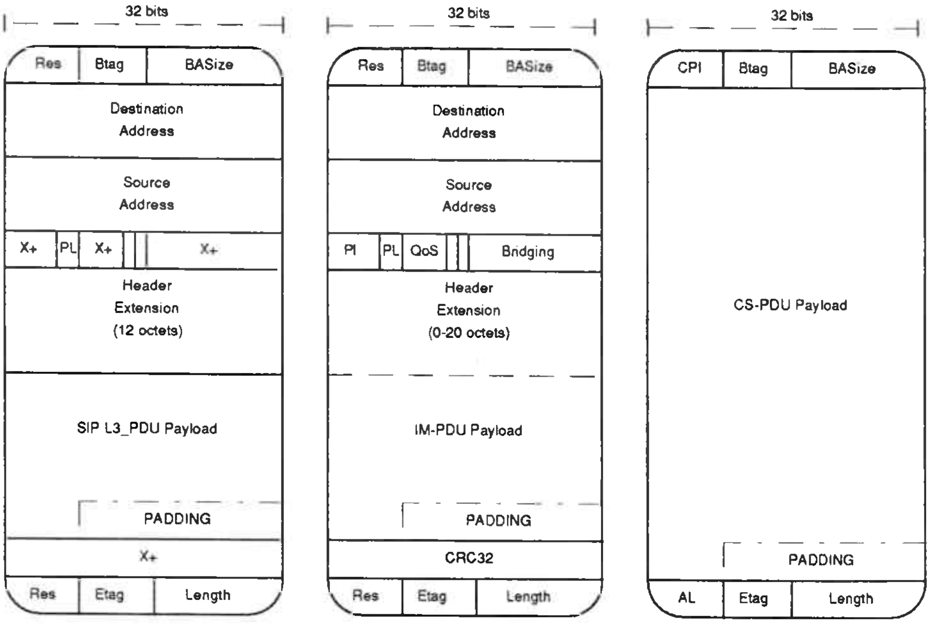

Figure 4.4: *Format of L3_PDU, IM-PDU and CS-PDU*

At present, the HE is used to provide Carrier Selection and SIP version identification. Other elements are for further study. Each element contains the following fields: Element Length (EL); Element Type (ET) and Element Value (EV). The Header Extension Padding (HE-PAD) field is used to align the HE field at 12 octets and has a variable length of 0-9 octets.

The differences of the IM-PDU and ATM's CS-PDU are:

- **Addressing:** In DQDB the addressing is performed in the SerVice sublayer, whereas in ATM this function is considered to reside above the ATM Adaptation Layer (CLNAP, see chapter 6).
- **PI/PL, QoS, Br, HE:** In DQDB these fields are present, in ATM absent.
- **CRC check:** In DQDB there is an optional 4 octet CRC field present, whereas in ATM this field is absent.
- **Length values:** The Length field in DQDB equals the total length in octets of every field between the common header and common trailer. In ATM this field equals the length of the CS-PDU payload (excluding the PADDING field).
- **Payload length:** In DQDB the length of the IM-PDU can not exceed a value of 9188 octets, whereas in ATM there is no maximum payload length defined.

SIP_I L2_PDU

The format of a SIP_I L2_PDU, a DQDB DM-PDU (plus DQDB segment header and ACF) and an ATM SAR-PDU (plus ATM header) is shown in Figure 4.5. L2_PDUs contain a 7 octet header, a 2 octet trailer and a 44 octet payload.

The Type, PSR, Reserved and Priority fields in the ACF of the L2_PDU are all set to zero in the SSS_I to CPE_I direction (this indicates the highest priority). The network control information is set to all zeros for empty L2_PDUs and to a fixed value of "11111111 11111111 11110000 00100010" for busy L2_PDUs.

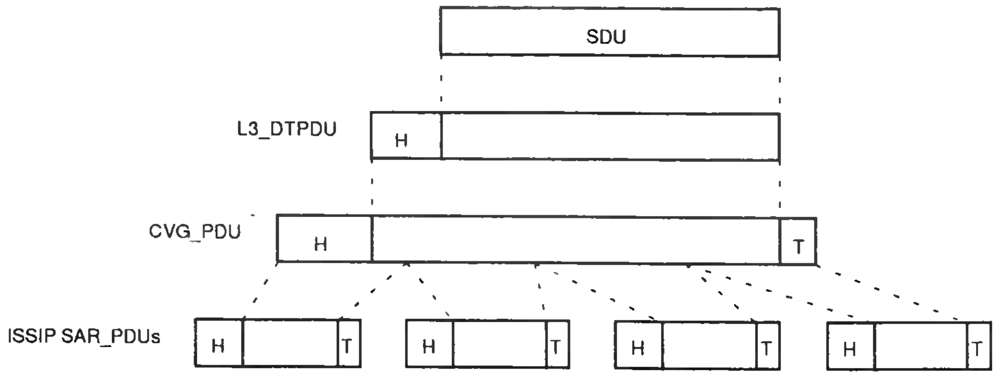

Figure 4.6: *ISSIP L3_PDU, ISSIP L2_PDU and their encapsulation process*

The functions performed by the $ISSIP_I$ Level 3 are the responsibility of three protocol entities: the $ISSIP_I$ Data Transport Protocol (L3_DTP); the Routing Management Protocol (RMP) and the Layer Management Protocol (L3_LMP).

The RMP calculates the shortest paths from its host to the other SSS_Is in the network based upon a derivation of the Open Shortest Path First (OSPF) specification as described in [5]. It provides for the generation and update of the routing tables, that are used by the L3_DTP. The L3_LMP performs congestion management functions and other layer management functions. Some of these congestion management aspects are described in [4], others are for further study.

$ISSIP_I$ L2_PDU

The $ISSIP_I$ Level 2 performs four major functions, which can be divided into three functional groups as is depicted in Figure 4.7. The first functional group provides multiplexing and $ISSIP_I$ cell header validation ($ISSIP_I$ cell), the second functional group provides segmentation, reassembly and error detection ($ISSIP_I$ SAR PDU) and the third functional group verifies the integrity of the assembled SDUs (CVG_PDU).
The $ISSIP_I$ cell and $ISSIP_I$ SAR PDU correspond with IEEE's 802.6 DQDB slot and DM-PDU respectively. It must be noted here that a Single Segment Message can only have one of two values in the Payload Length field: 40 or 44 octets, since the minimum length of a CVG_PDU is 40 and since it is 4 octet aligned. The $ISSIP_I$ cell, $ISSIP_I$ SAR PDU, CVG_PDU and L3_DTPDU are illustrated below.

- **Access classes:** For SMDS only access classes for DS3 access rates are defined (4,10,16,25 and 34 Mb/s). CBDS provides access classes on all interfaces and access rates (1.5,4,10,16,25,104,124 and 155 Mb/s). Note that the access classes provided by the service on an interface can only be smaller than or equal to the access rate on that particular interface.
- **Closed User Groups:** The possibility of forming Closed User Groups (CUGs) is not mentioned in the SMDS standard as opposed to CBDS but can be built up using SMDS' address screening feature. This feature is also present in CBDS but only as a supplementary service.

PART B: OPEN ISSUES & PROPOSALS

5. VIEW OF THE ATM/DQDB INTERNETWORK

This chapter describes a view of the combined ATM and DQDB internetwork and the related interworking fields for the provision of a connectionless service.

The first section shows how a possible ATM/DQDB internetwork could look like, the second gives an evolution scenario for the provision of connectionless services and the final section clarifies the scope of this document on the interworking related problems (i.e. routing).

5.1. Internetwork topology overview

Figure 5.1 depicts a possible internetwork topology at the point in time at which some DQDB and B-ISDN installed bases coexist in the network. It is a phase in between the first phase where only DQDB installed bases exist and the final phase where mainly B-ISDN installed bases exist. The possible migration from the first until the final phase is summarised in the next section. For provision of the connectionless service on this internetwork, SMDS terminology is used.

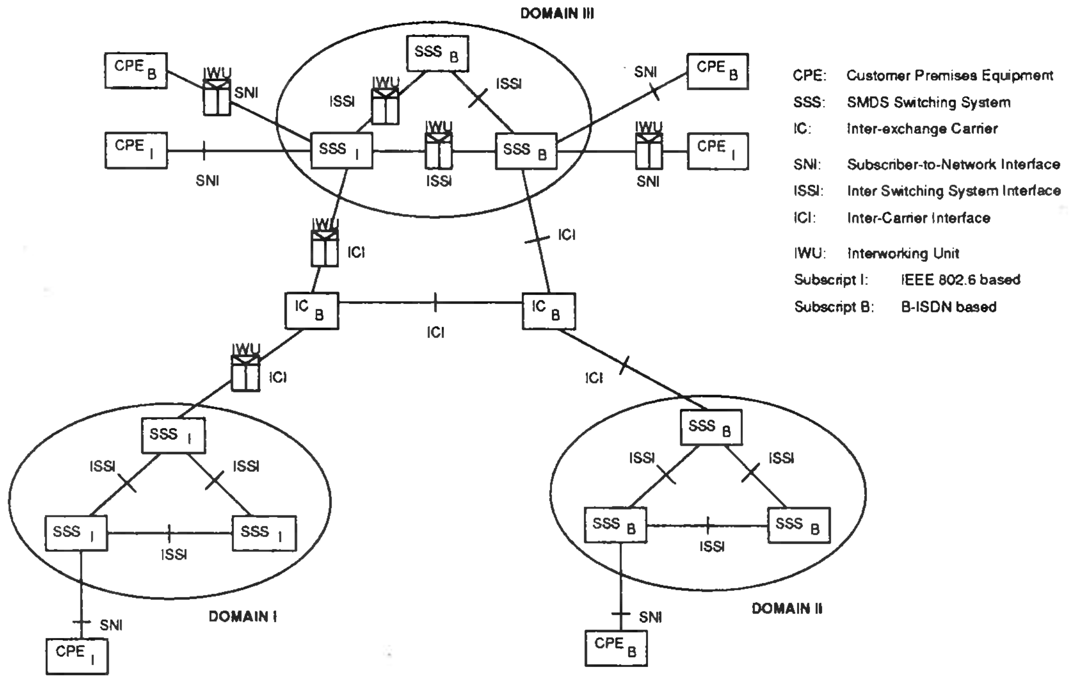

Figure 5.1: *Possible ATM/DQDB internetwork topology*

As can be seen from the figure only a subset of the entire internetwork is depicted. The figure shows several autonomous systems interconnected by a number of Interconnected to the same SMDS Switching System. Bellcore has proposed a subset of the Open Shortest Path First routing protocol [5] for routing inside Local Access Transport Areas: the Routing Management Protocol (RMP [4, pp. 5-25/5-55]).

Phase 2 also provides the interconnection of Boundary SSSs to Inter-Exchange Carriers (ICs) as a means to provide communication between several domains. A service user in one domain now can communicate with a user inside another domain. These ICs can be DQDB based (IC_I) but will most probably be B-ISDN based because of the date when these ICs are expected to be introduced. In this part of phase 2 there is also a need for a routing protocol to determine the best paths between routing domains (LATAs). Since it is likely that different service providers use different intra-domain routing protocols, this inter-domain protocol should be able to recognise and handle different routing information formats. Bellcore has not yet defined such a protocol.

In Phase 3 SMDS will be offered using the B-ISDN technology as part of the B-ISDN multi-service interface. The ICs will now all be B-ISDN based and the DQDB based SMDS Switching Systems will be replaced with B-ISDN based SSSs (indicated by SSS_B). However, the access path from the service user to the network in this phase will still be DQDB based[6]. Phase 4 finally introduces a B-ISDN based access path to the user.

5.3. Scope of this document on Connectionless Service

This section will present the scope of this document on the connectionless service as will be provided in an internetwork where B-ISDN and DQDB installed bases will coexist. This document will mainly study the interworking problems related to the routing and relaying of connectionless messages in the ATM/DQDB environment. Routing occurs when a user wants to communicate with a user attached to another SS in the same domain (intra-domain routing) or with a user in another domain (inter-domain routing). Relaying is the actual transfer of data after the routing function has calculated the best path to the destination.

The routing protocol as used in the Switched Multi-mega bit Data Service may not function in a large internetwork as the ATM/DQDB environment ultimately will be. Therefore, this document will study the possibility of adapting the proposed Routing Management Protocol so that it can be used in B-ISDN and in the evolution stages towards this final state. Further, this thesis will study the possibility of introducing the intra-domain routing protocol used by the ISO ConnectionLess Networklayer Protocol (CLNP): i.e. the Intermediate System-to-Intermediate System routing protocol (IS-IS protocol: ISO 10589 [6]).

[6]It is assumed that 802.6 based Customer Premises Equipment will be introduced in the market before B-ISDN CPE. Therefore, it is expected to be common to find 802.6 based CPE served from B-ISDN SSSs. The interworking functionality may be present inside the B-ISDN based SSS or it may reside in special interworking units outside the SS.

6. ROUTING ISSUES AND TERMINOLOGY

This chapter will try to open up the discussion concerning routing issues and the related terminology for the routing protocol as will be used in the ATM/DQDB internetwork and ultimately in the B-ISDN environment. Today (August, 92), no routing protocol has been defined, so this chapter will give an initial view of the demands this routing protocol should satisfy. Furthermore, a description of some already defined areas in the draft recommendation for connectionless services I.364 [7] will be supplied together with a recommendation on issues that are not (yet) addressed. The terminology introduced in this chapter will be indicated by ***bold, italic*** characters.

The description of the defined and un-addressed issues will apply to the type (ii) configuration as described in Recommendation I.211 [8], i.e. a ConnectionLess Server Function (CLSF) residing inside the B-ISDN (direct provision of the connectionless service) as opposed to the type (i) configuration which resides outside the B-ISDN (indirect provision).

The first section describes the current status of the Draft Recommendation I.364 as is being standardised by CCITT for the provision of a connectionless service on an ATM network. The second section notices some not (yet) addressed issues concerning the provision of such a service on an ATM/DQDB internetwork, e.g. the functionalities that must (may) be present in an ConnectionLess Server Function (CLSF). The final section outlines some routing protocol and topology requirements as an input to the next chapters.

The sections two and three serve as an input to the RACE project COMBINE (COMposite Broadband INterworking and End-to-end models) to form the Deliverable 5 [9], a report from RACE to the European Community.

6.1. Status of Draft Recommendation I.364

Draft Recommendation I.364 provides with a protocol for supporting a Broadband ConnectionLess data Bearer service (BCLB) across the B-ISDN UNI; the ConnectionLess Network Access Protocol (CLNAP). This protocol uses the AAL type 4 unassured service (lost or corrupted data units are not retransmitted) for transmission of variable size Connectionless Network Access Protocol PDUs (CLNAP-PDUs) and includes the necessary functionality to provide the connectionless layer service. The protocol stack for the support of connectionless services is depicted below in Figure 6.1. The CLNAP user in this figure e.g. may be a high-speed terminal directly connected to a connectionless server, a LAN-bridge, an InterWorking Unit (IWU) or an entity in a connectionless server.

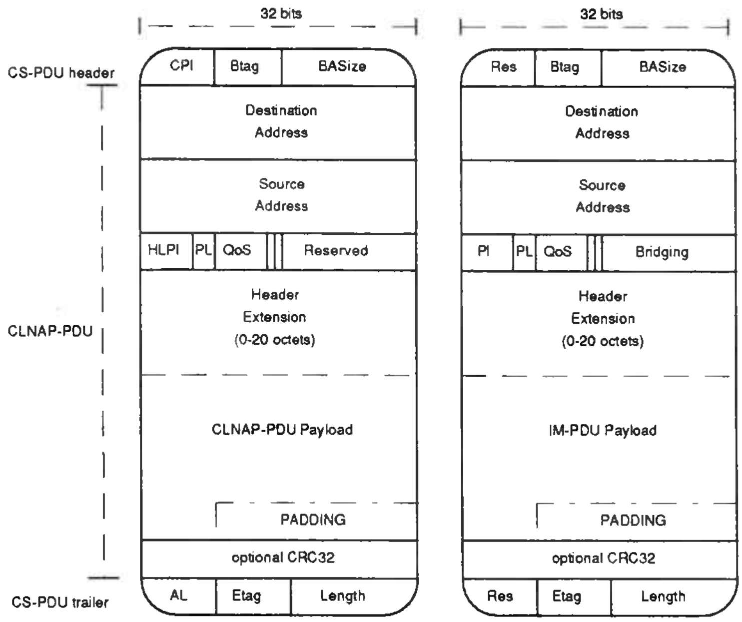

Figure 6.2: *CLNAP-PDU and IM-PDU structure*

- **QoS:** This four bit field is used to indicate the requested service characteristics for the transfer of the SDU, it is for further study.
- **CIB:** The CRC Indicator Bit is set whenever there is a CRC field present in a CLNAP-PDU.
- **HEL:** The three bit Header Extension Length field marks the length of the Header Extension field. It may contain any number between 0 and 5, indicating the number of 32 bit words in the header extension field (maximum of 20 octets). The values 6 and 7 are not valid for the HEL.
- **Reserved:** The reserved field is introduced for alignment with DQDB's IM-PDU. Its purpose is for further study.
- **Header Extension:** The header extension field is for further study.
- **CLNAP-PDU Payload:** (part of) the CLNAP-SDU to be transported.
- **Padding:** Used for alignment of the CLNAP-PDU on a 32-bit boundary. Note that the padding field of the CS-PDU is set to zero as a result of the CLNAP padding.
- **Optional CRC:** This optional 32 bit field may be present or absent as indicated by the CIB field. The field contains the result of a standard CRC32 calculation performed over the CLNAP-PDU with the "Reserved" field always treated as if it were coded as all zeros. The support of this field by the network is for further study.

6.2. Open issues for the provision of connectionless services in an ATM/DQDB environment

In order to visualise the undefined areas for the provision of connectionless services in an ATM/DQDB environment, Figure 6.3 can be used for reference-purposes. As this document solely deals with interworking between ATM and DQDB at a connectionless level only DQDB MANs supporting connectionless traffic (i.e. QA-slots, see chapter 3) are depicted.

Timer-based allocated access links will be set-up to the CLSF on transmission of the first data-unit and will stay allocated for a specified timer-interval. Whenever there is data to be transmitted during this interval no call-set-up will be necessary, which results in faster access to the server. After expiration of the timer the connection will be released. The problem depicted for call-by-call allocated access links is applicable here also.

On the DQDB MAN side the access link to the CLSF is called ***DQDB access link***. Since the DQDB technology is inherently connectionless for connectionless asynchronous services there is no need for call-set-up and release when establishing connections to the (in this case DQDB based) CLSF. The interface between the connectionless service user and the Connectionless Server Function on the DQDB side is called User-to-MAN Interface (UMI) on top of which a ***ConnectionLess MAN Access Protocol (CLMAP)*** is used for information exchange between user and server.

The ***italic, bold*** terminology introduced in this chapter is a proposal for harmonisation of the terminology to be used in an environment consisting of ATM and DQDB based networks. As such, the term ***CLMAP*** is introduced for the protocol accessing the connectionless service on DQDB based networks. The reason for this is that the connectionless subset of the complete MAN protocol IEEE 802.6 using the Initial-MAC PDU (IM-PDU) for information exchange still has no name attached to it.

6.2.2. Allocation of network links

Since there will be a larger amount of traffic present on the network links (links between the connectionless server functions) these links should be allocated semi-permanently on the B-ISDN side. Semi-permanently allocated network links will be set-up and released irregularly and dependent on offered traffic.

Exchange of information between CLSFs on the B-ISDN side is possible through the use of a ***ConnectionLess Network Node Protocol (CLNNP)*** across the interface between these servers, the Network Node Interface (NNI). On the DQDB side a ***ConnectionLess MAN Node Protocol (CLMNP)*** across a ***MAN Node Interface (MNI)*** will be used. For interworking purposes these node protocols should have as high a degree of commonality as possible so translation of these protocols inside an interworking unit situated between a B-ISDN based CLSF and a DQDB based CLSF can be fast and efficient.

6.2.3. Connectionless server functionalities

In order to provide with a connectionless service some functionalities must be present in the ConnectionLess Server Functions. In addition, several other functions may be implemented based upon the needs of the users of this service. The list given below illustrates some general server functions that could be implemented in the CLSF on the B-ISDN side. Some or all of these functions may also be introduced on the DQDB side. It must be noted that the Connectionless server functions may reside in a larger ***Broadband Switching System (BSS)*** in which connection-oriented traffic (B-ISDN: service classes A through C and DQDB: Pre-Arbitrated slots) is handled also. In the following summation CLNAP also means ***CLMAP*** and UNI also means UMI.

Address Mobility

This function provides with the possibility for the users to be portable or completely mobile. Portable users change location on an infrequent basis, whereas mobile users change location constantly. Therefore a plug-and-play scenario should be included in the CLSF.

Cell Discarding

This function is necessary for error cells or for cells violating policing parameters like exceeding the Access Class. It may also be used during periods of congestion.

Charging

The CLSF will be responsible for the calculation, formatting and short-term storage of charging data.

6.3. Routing protocol and -topology requirements

As was seen before one of the functions of the ConnectionLess Server Function is the E.164 based routing of connectionless packets (CL-PDUs) from the source to one or more destinations. The E.164 address-space will be used in the ATM/DQDB internetwork supporting the connectionless service since these address-spaces already exist in the separate networks. In order for the routing protocol to function properly some requirements can be summarised.

High Speed Stability

The routing protocol must be stable in the high speed ATM/DQDB environment. Routing tables inside the CLSFs must be updated regularly and fast so that the situation where a CL-PDU is routed based upon obsolete routing tables can be avoided. To meet this requirement the exchange of routing information should be done with the lowest delay possible (high peak rate of the links between the CLSFs). This needs further study.

Medium Independency

The routing protocol should be able to function independent of the underlying technology (ATM or DQDB) i.e. no interworking on routing protocol information should be needed.

E.164 Based Routing

The routing protocol should primarily base its routing decisions upon universally administered E.164 addresses. Routing inside a DQDB based network based upon other addressing schemes (48 bit locally administered addresses, 16 bit addresses and 60 bit MSAP addresses) needs further study.

Network Growth Independency

The impact of the growth of the ATM/DQDB internetwork on the routing protocol should be as minimal as can be. Software and/or hardware updates in inside an area, between areas and between routing domains. In the ATM/DQDB internetwork a DQDB based network may be such a routing domain.

7. ROUTING PROPOSAL

This chapter ultimately will make a proposal for a routing protocol that can be used inside an ATM/DQDB environment for the support of the connectionless service. First, existing routing algorithms like distance vector and link state algorithms are compared together with a comparison of dynamic vs. static routing and distributed vs. centralised routing. The result of this comparison will be a proposal for the routing algorithm which will be the basis for the ultimate routing protocol. Then, in the second section, some existing routing protocols which use the algorithm resulting from the first section are described and compared in general. Next, a proposal for the routing protocol to be used in the heterogeneous internetwork, based upon the protocols outlined in the second section will be given. The final section outlines some possible additions and modifications to the proposed routing protocol.

7.1. Routing algorithms

This section will compare the generalised routing algorithms on which existing routing protocols like e.g. the Open Shortest Path First (OSPF; used in the Internet [5]), the Routing Information Protocol (RIP; used by Novell [10]) and the OSI Intermediate System-to-Intermediate System (IS-IS [6]) protocol are based.

Routing algorithms can be categorised as follows:

- **STATIC:**
- **DYNAMIC:**
    1. *Centralised*
    2. *Distributed*
        - a. Distance vector
        - b. Link State

STATIC ROUTING

Static routing algorithms, also known as non-adaptive or deterministic routing algorithms, calculate routes based upon some rule in advance and downloads these routes to the specific routers (connectionless servers). Since the calculation of these routes is performed on an off-line fashion this form of routing can *not* respond to changing traffic conditions or topology. An advantage of this method is the ability to use sophisticated off-line optimisation algorithms. Furthermore, due to the centralised off-line computation there is no need for extra hardware inside the routers which results in lower costs. Resulting from its properties, static routing is most suited for small and stable environments.

Distributed routing
With distributed routing, network entities (routers) report routing information about their local environment to other network entities as opposed to centralised routing where all information is being sent to the RCC. This exchange of routing information occurs periodically and on certain events according to an optimisation protocol like e.g. Best Information as used in the Routing Information Protocol (RIP, [10]).

Adaptive, distributed routing algorithms have the major advantage of automatic and fast adaptation to changes in traffic, topology and configuration (adding or removing of complete subsystems). Some disadvantages are: the complexity of design (increases with the number of routers) and the impossibility of implementing a complex computation algorithm because of the real-time nature of distributed routing.

Distributed routing algorithms in their turn fall into two categories, i.e.: Distance Vector and Link State routing algorithms. These algorithms will be described in the next two sub-sections.

7.1.1. The Distance Vector routing algorithm

In distance vector routing, also known as Bellmann-Ford routing, routers periodically exchange their full routing tables with their direct neighbours. These tables describe the entire topology of the routing domain. On receipt of such a table the router calculates the new shortest paths (in terms of some sort of metric like delay, hops or dollar value) to every other node in the network and forms a new table. After a certain event or period this table is exchanged again.

Originally, the IP-Internet used a distance vector routing algorithm for its Interior Gateway Protocol: the Routing Information Protocol (RIP). It was one of the first adaptive, distributed routing algorithms to be used in a large network. RIP had a number of desired properties like e.g.: calculation of routes in every node and the ability to adapt to changes in delay conditions in the network, but as it turned out it was not suitable for use in the constantly growing, unstable network like the IP-Internet.

A distance vector algorithm has a number of disadvantages for use in a large network:

- The distance vector algorithm is a global algorithm in a sense that the inputs to the computation at one node are the outputs of the computation at the neighbouring nodes. For calculation of the best routes a node is dependent of the output from its neighbour(s). After calculation of these best routes the node forwards the resulting routing table to its neighbours after which these neighbours can start their calculation. Not only does this introduce a delay in the exchange of recent routing information at every node, but also the undesired possibility of fault propagation. Since a node bases his calculation upon information received from neighbours, a fault in a routing table can spread throughout the entire network, resulting in severe performance deterioration.
- The routing tables that are exchanged periodically and on certain events grow in size corresponding to the network growth. Not only does this consume more and more precious bandwidth leaving less for data exchange, but it also increases the processing time used for building new routing tables. This in turn also adds to the delay in the exchange of recent routing information resulting in an even slower response to changes in topology and metrics.

nodes this will result in a consistent and efficient algorithm meeting the demand of fast adaptation to changes in topology and metrics.

Also, this algorithm is less prone to fault propagation because of the fact that the routers, for the calculation of the best routes to all of the destinations, use routing information gathered from the entire network and not just from their neighbours.

However, as the link state algorithm uses flooding to distribute routing information concerning direct neighbours of the sending router, this may cause a high overhead on the available bandwidth when the network grows. Furthermore, packets may loop in the network when there exist multiple paths between several nodes. In order to control the bandwidth use because of the exchange of routing information it is necessary to introduce a hierarchical routing structure.

With hierarchical routing the network is divided into smaller subnetworks in which an instance of the routing protocol handles the routing of connectionless packets from the source to the destination (intra-subnetwork routing). This way, flooding is restricted to the subnetwork in stead of the entire network. When the destination is not on the subnetwork the routers sends the packet to a boundary router which belongs to a higher routing level. For the routing of connectionless packets between these subnetworks (inter-subnetwork routing) another routing protocol may be used.

Besides minimising the overhead caused by flooding a means of prohibiting looping packets must be implemented in the algorithm. This too needs further study. Some other solutions and improvements are given in the next sections.

7.1.3. Conclusion

From this summation of existing generic routing algorithms it may be concluded that static routing is not suitable because of its inability of adapting to changes in topology and traffic, which will be very much needed considering the expected size of the future ATM/DQDB internetwork. This large size together with the inconsistency problem and the routing table calculation also rules out the first form of dynamic routing, i.e. centralised routing. Regarding the scaling problems of distance vector distributed routing in the early IP-Internet and the possibility of fault propagation, link state distributed routing should be used.

The next section briefly summarises some existing routing protocols that use the distributed link state algorithm for the routing of connectionless packets from the source to the destination or to a boundary router.

7.2. Summary of existing routing protocols

The existing distributed, link state routing protocols to be summarised in this section are: the Open Shortest Path First (OSPF) protocol [5] as used in the IP-Internet; the Intermediate System-to-Intermediate System (IS-IS) protocol [6],[12, App. A] as used by ISO CLNP and the ISSI Routing Management Protocol (RMP) [4, pp. 5-25/5-55] as used by SMDS.

Since the IS-IS and OSPF protocols are more alike than they are different, only the essential differences that exist are described here. Furthermore, a brief description of

Since RMP is a subset of the OSPF specification[8], only the ISO IS-IS specification and the OSPF specification will be described in more detail.

The differences outlined in this section are in the area of: *routing information contents*; *routing information exchange* and *field coding*. No conclusions as to which protocol performs better in certain conditions will be drawn yet. It just serves as a basis for the ultimate proposal for the routing protocol to be used in the ATM/DQDB environment.

Routing information contents:
Like any other link state protocol, OSPF and IS-IS routers flood information about their direct neighbours throughout the routeing domain.

In IS-IS, two link-state PDUs can be distinguished: Level 1 Link State PDUs (L1-LSPs) and Level 2 Link State PDUs (L2-LSPs). L1-LSPs are generated by L1 Intermediate Systems and flooded throughout the area. The contents of the L1-LSP indicates the state of the adjacencies (ID plus metrics) to neighbour ISs or pseudonodes, and End Systems of the IS that originally generated the PDU. L2-LSPs are generated by L2-ISs and are propagated throughout the Level 2 subdomain (all L2-ISs in a routeing domain). The contents of the L2-LSP indicates the state of the adjacencies to neighbour ISs or pseudonodes, and to reachable address prefixes of the IS that originally generated the PDU. With this information it is possible to calculate shortest paths from the IS to every destination. It is done separately for Level 1 and Level 2 routeing and within a level for every supported metric.

This way, all L1 Intermediate Systems in an area know about the topology of that area. Whenever an L1-IS in an area receives a packet destined for an address he does not know about, he hands the packet over to the nearest L2-IS. The packet is then propagated through the Level 2 subdomain to the L2-IS that advertised the address prefix of the area to which the destination address belongs. When the destination address is not known in the entire routeing domain, the L2-IS forwards the packet to the Boundary Intermediate System (BIS). With Inter-domain routing [15],[12, App. B] the packet will reach the routeing domain to which the destination address belongs.

In OSPF, routing information is exchanged by means of five different Link State Advertisements (LSAs): router links, network links, 2 types of summary links and AS external links. *Router links advertisements* are originated by routers for each area that they belong to and are flooded throughout these areas. Area border routers also flood router links advertisements into the backbone (OSPF's equivalent of IS-IS's Level 2 subdomain). The contents of these router links advertisements indicates the type of attached network of that link, the ID of the entity on the other end, and the cost of using the link for output. Router links advertisements roughly correspond with IS-IS's L1-LSPs. *Network links advertisements* describe all the routers that are attached to a transit multi-access network and are flooded throughout the area containing the network. This advertisement is originated by the Designated Router of this multi-access network (see next item). Each *Summary links advertisement,* originated by an area border router, describes a route plus cost to a single destination external to the area, yet still belonging to the Autonomous System. The destination may be an IP subnetwork or an AS

[8]RMP only supports point-to-point link sets between two routers, i.e. a maximum of two routers are allowed on broadcast networks. OSPF and also IS-IS support point-to-point, broadcast and non-broadcast networks.

- If it receives the LSP from another router before it can transmit the LSP itself, the router clears the flag in memory.

As the IS-IS scheme does not use explicit acknowledgements on the LAN, the Designated Intermediate System periodically transmits a packet known as a Complete Sequence Numbers PDU (CSNP). The CSNP lists the sequence numbers of all the LSPs in the LSP database of the Designated-IS. If a router notices that the Designated-IS has missed an LSP, the router will multicast the lost LSP. If a router notices that itself has missed an LSP, it explicitly requests the LSP from the Designated-IS by means of a Partial Sequence Numbers PDU (PSNP). PSNPs contain the sequence numbers of the LSP numbers for which the requesting router has older information. The concept of Complete and Partial SNPs is also used on point-to-point links (CSNPs only at neighbour initialisation, PSNP as an acknowledgement or request for LSPs).

Field coding:
Another difference between OSPF and IS-IS is that all fields in OSPF are of fixed length, and the packet formats specify which fields are present. In contrast, most fields in IS-IS are of variable length, and are encoded as in Figure 7.3.

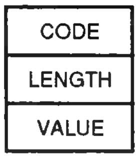

Figure 7.3: *Encoding of variable length fields in IS-IS*

Fixed format fields make it easier for the routers to process packets, and allows more efficient encoding. However, it makes it more difficult to extend the protocol. IS-IS allows fields to be defined in a downward compatible way. IS-IS specifies that a router that does not support a particular type merely skips that field and continues processing the rest of the packet. An example of the difference in field encoding is the coding of the authentication field.

Information authentication is used to prevent hackers from identifying themselves as routers. This way they can not extract traffic from the network and decrease the performance of the routing protocol.

In IS-IS, the value associated with the authentication is of variable length (with a maximum of 254 octets). In OSPF, it is fixed at 64 bits. This way, IS-IS can support future schemes more easily than OSPF does.

7.3. Proposal for the routing protocol

The IS-IS protocol is the one that meets the requirements outlined in Section 6.3 most. ISO proposed this protocol for use in a routing domain consisting of several combined types of subnetworks, like point-to-point links and broadcast subnetworks. Furthermore, it allows the protocol to enhance itself by introducing variable length fields. In the future, several options may be changed or added to the protocol without losing

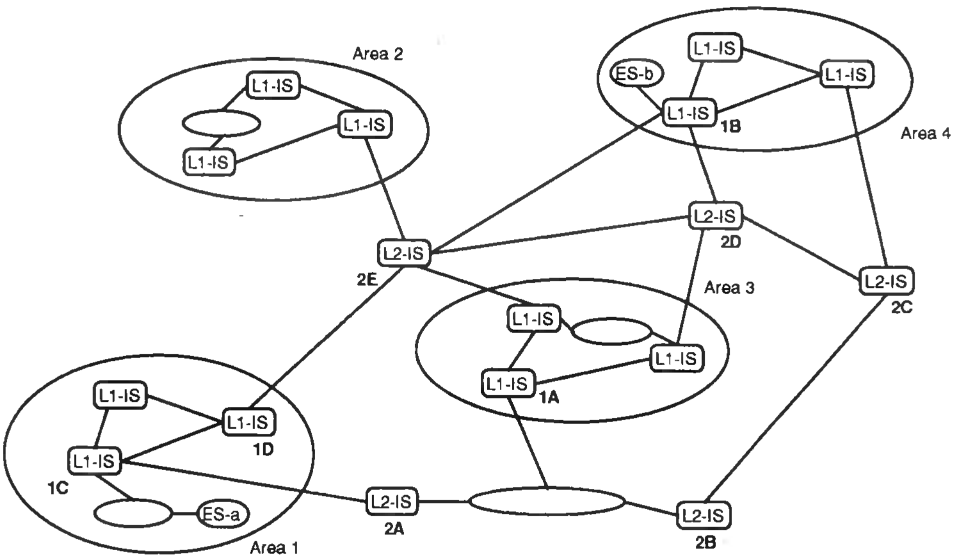

Figure 7.4: *Sample IS-IS installation*

It would be nice to include some of the OSPF routing qualities as an extension of the IS-IS protocol to prevent this kind of situation. As was stated, OSPF optimises routing whereas IS-IS minimises bandwidth use together with minimising processing time and memory use in the routers (ISs). This extension combines the better qualities of both routing protocols in a sense that it performs better at routing than IS-IS does with a lower bandwidth and processing overhead than OSPF.

The extension consists of feeding Level 2 link state packets (L2-LSPs) into the areas for use by the L1s. As the contents of these L2-LSPs reflect the topology of the L2 subdomain, the L1s now are able to choose the optimal L2 for the transfer of packets to a specific area. Now lets see how this works in our situation.

Suppose that this Level 2 routing information is fed to all Level 1 Intermediate Systems in area 1. Now, 1C will learn from every L2 in the routing domain who his neighbours are and what address prefixes he can reach. With this extra information, 1C can calculate that area 4 is 4 hops away when relaying through 2A. However, he will also learn that area 4 is 3 hops away when relaying packets through 2E. This way, routing has a better performance at the expense of adding extra functionality to L1 and L2s together with an increase in bandwidth use in areas, and an increase in memory use and processing time in the L1s. This increase is not as drastic compared to using OSPF for the routing protocol since OSPF also feeds routing information from outside the routing domain inside the domain and even inside the areas.
Note: in this section, the number of hops is chosen as routing metric for simplicity reasons. However, the optimisation is applicable to any metric like for example delay, error rate or monetary cost.

Conclusively, we may say that feeding Level 2 routing information into the areas increases the performance of the routing protocol at the expense of bandwidth use, memory use and processing time in the L1s. The extra functionalities in the Intermediate Systems for this extension are:

use 2E when forwarding data to area 4. The same calculation is repeated in every L2 for every area to which it is attached and for each destination area.

With this implementation, a problem may arise when the L2s do not correctly synchronise. Suppose that 2A calculates the best L2 for area 1 when forwarding data to area 4 and finds that 2E is the best L2. 2E, however, finds for some reason that 2A is the best. If these L2s do not properly synchronise, each of these L2s may introduce the other to the L1s in area 1 as the best L2 for reaching area 4. The L1s may get confused by these contradictory advertisements. The L2s drop any incoming packet because they do not consider themselves to be the best L2 for source-area 1 and destination-area 4. As a result, no packets can leave area 1 with destination area 4. To overcome this problem, the Level 2 Intermediate Systems MUST accept any packet from area 1 destined for all other areas, even when the L2 is not considered to be the best L2. This problem may temporarily decrease the performance to the level of native IS-IS, but only until synchronisation is restored.

The extra functionalities in the Intermediate Systems for this implementation are:

Extra functionalities in Level 1 Intermediate Systems

- Accepting and forwarding best-L2 information.
- Maintaining Destination area - Level 2 IS table.

Extra functionalities in Level 2 Intermediate Systems

- Processing Level 2 link state packets (calculation of best L2 for destination area).
- Synchronising this calculation with other attached L2s.
- Forwarding results to Level 1 Intermediate System neighbours.
- Forwarding packets from the attached area, even when not considered best L2.

Implementation 2: Level 1 link state packets are available to the Level 2 ISs

With the previous implementation, it is possible that several L1s in an area now choose a worse route to another area. This is due to the fact that the L2s do not know what the topology inside the area looks like. To clarify this problem, consider the situation of Figure 7.5 which is a little different from Figure 7.4.

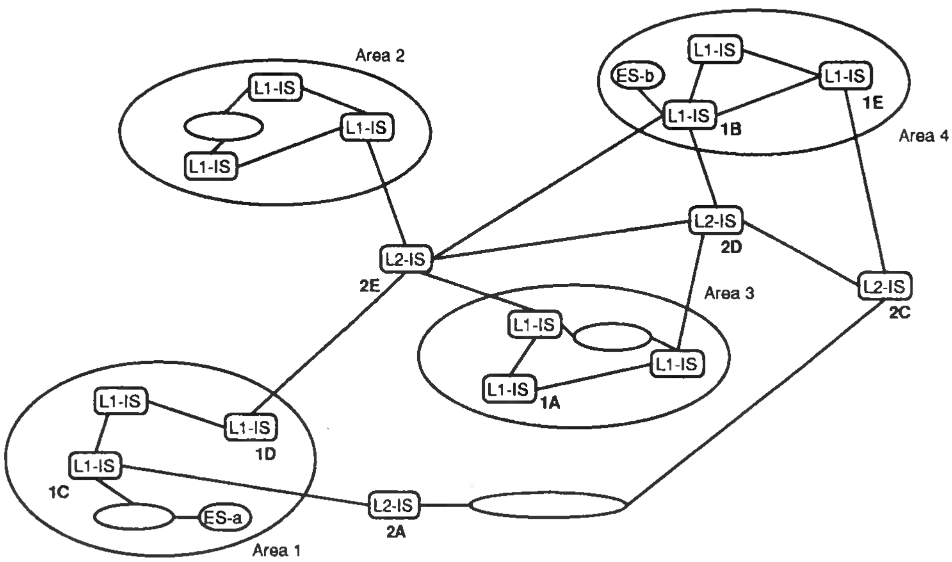

Figure 7.5: *Implementation 1 problem: worse route*

best path to area 4. 1C now knows that 2A is able to reach area 4 in 2 hops and that 2E can reach area 4 in 1 hop. It also found out using normal Level 1 routing that 2A can be reached in 1 hop and that 2E can be reached in 3 hops. Adding these hop-counts, 1C finds that the best path to area 4 is through 2A since it requires 1 less hop (3 in stead of 4 when using 2E).

Thus, using this extension to the native IS-IS protocol, it is possible to achieve a better routing performance at the cost of adding only minor functionality to the Level 1 and Level 2 Intermediate Systems. These extra functionalities are:

Extra functionalities in Level 1 Intermediate Systems

- Accepting and storing hop-count information.
- Forwarding of hop-count information to other Level 1 Intermediate Systems in the area.
- Processing of Level 1 link state packets & hop-count information (calculation of best L2 for destination area).
- Maintaining Destination area - Level 2 IS table.

Extra functionalities in Level 2 Intermediate Systems

- Forwarding hop-count information to Level 1 Intermediate System neighbours.

Designing a well-dimensioned Level 2 subdomain

This is in fact not a real extension of the protocol, but just a means to increase the performance while not deviating from the standard. Consider for example the installation of Figure 7.4 again. As can be seen from the picture, there is minor connectivity in the Level 2 subdomain.

When a Level 1 Intermediate System (L1) 1A in area 3 has data to send to a destination in area 2, it forwards this data to the nearest L2 (in this case 2B). Consequently, the path towards area 2 will cross the L2s: 2B, 2C, 2D and 2E before reaching the desired area. A redimensioning of the Level 2 subdomain, so that there is a connection between the L2s 2A and 2E, would result in a shorter path between the connectionless service users in the areas 2 and 3. This is just a simple example, but it clarifies the importance of a well dimensioned Level 2 subdomain.

The extra functionalities in the Intermediate Systems for this 'extension' are:

Extra functionalities in Level 1 Intermediate Systems

- None

Extra functionalities in Level 2 Intermediate Systems

- None

Considering these extensions, it can be concluded that there are several options for improving the performance of the native IS-IS routing protocol. One needing more extra functionalities in the Intermediate Systems than the other.

The most effective way of improvement was to feed all Level 2 routing information into the areas for use by the Level 1 Intermediate Systems. With this extension, all L1s in the routing domain known about the entire topology of this domain and are therefore able to choose the optimal path to all destinations. It, however, also has a major drawback i.e. the impact on the L1s and the bandwidth needed. L1s must accept, store, forward and process Level 2 link state packets in order to find these paths,

8. INTERWORKING CONSIDERATIONS

This chapter describes problem areas for the IS-IS routing protocol when it is used in the actual ATM/DQDB environment. Impacts on the interworking unit considering addressing, priority for routing packets and routing information discrimination are identified and solutions are given.

The section on addressing serves as an input to the RACE project COMBINE (COMposite Broadband INterworking and End-to-end models) to form the Deliverable 5, a report from RACE to the European Community.

8.1. Routing and addressing

One of the major interworking problem areas inside an internetwork composed of ATM-based subnetworks and DQDB Metropolitan Area Networks is the addressing on DQDB. Inside the ATM subnetworks, E.164 numbering [13] will be used as is recommended by CCITT. The structure of an E.164 address is given in Figure 8.1.

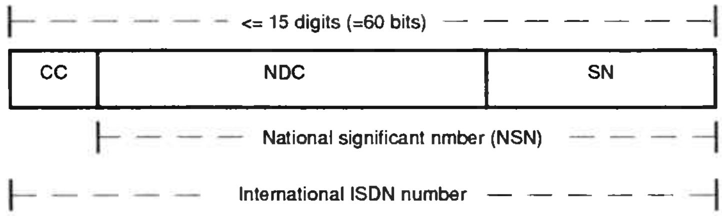

Figure 8.1: *Structure of an E.164 address.*

The international ISDN number is composed of a number of variable length fields, like the Country Code (CC), the National Destination Code (NDC) and the Subscriber Number (SN). The NDC and SN fields together are called the National Significant Number (NSN). The total length of the international address may not exceed the length of 15 digits (= 60 bits). The country code is used to select the destination country (or geographical area) and the NSN selects the ultimate subscriber in a particular destination network.

In DQDB, however, additional addressing schemes are used. The DQDB standard [2, pp. 169-172] supports 60 bit individual and group addresses in addition to 16 and 48 bits MAC addresses. The 48 bits, universally administered MAC addresses are mandatory, whereas the other addressing schemes are optional. The structure of the source and destination address fields in the Initial MAC PDU (IM-PDU) are given in Figure 8.2.

introducing some priority mechanism or by reserving separate lines to the CLS for the exchange of routing information. Priority mechanisms are dealt with in the next section.

Besides maintaining connection(s) to the connectionless server, the interworking unit (IWU) could as an extra be provided with some functions normally residing in the connectionless server. This way, the server is relieved of some of its functions leaving more time for other (more important) engagements. Some of these functions that may reside in the IWU are: source address validation (public IWU only), destination address screening and local traffic discarding.

Using other addressing schemes on the DQDB MAN

This situation will most likely occur when a privately owned DQDB MAN wants to connect to the connectionless service of the B-ISDN network. The MAN may use 16 bit addresses, which are only unique on that specific MAN; 48 bit universally administered addresses, which are globally unique; or 60 bit privately administered addresses, which will probably not be globally unique.

Since there is no guarantee of world-wide uniqueness for 16 or 60 bit privately administered addresses these addresses may not be used for the routing protocol. Therefore, these addresses can not be used for communications outside the MAN (not even for communications between users on different DQDB MANs only). 48 bit universally administered addresses could be used for the routing protocol. This, however, is not recommended because of the considerable overhead it would give due to the lack of hierarchy in the address space, resulting in larger routing tables, and the use of an extra address type. Thus, the interworking unit must perform the mapping of 16, 48 or 60 bit privately administered local addresses on to unique E.164 addresses for communications with users in the B-ISDN. For local communications it is still possible to use the local addressing scheme. The mapping of the address spaces can be done as follows:

On receipt of an IM-PDU, the interworking unit first looks at the destination address. It will discard any address type not equal to E.164 addresses since they can only be used locally. It will also discard local E.164 addresses using the local traffic discarding mechanism. Second, the IWU maps the local source address on to its corresponding E.164 address for outside communications and inserts it in the Source Address field of the IM-PDU. If present, it recalculates the optional CRC32 field. This poses no problem when the interworking unit is working in message mode. In streaming mode, the recalculation of the CRC32 must be done based on the successive SAR-PDUs. Whether or not this is done by using a CRC-buffer or by buffering the whole IM-PDU just for recalculation needs further study. On receipt of an CLNAP-PDU, the interworking unit replaces the E.164 destination address with the local address of the MAN node. Again, recalculating the CRC32 (if present).

8.1.2. Communication between DQDB connectionless service users on separate MANs

In this scenario, a DQDB node wants to communicate with a connectionless service user on another DQDB MAN. This way, the B-ISDN just serves as a backbone network for the interconnection of all MANs. Again starting from the fact that all address spaces may be used on the MAN, we can already rule out the use of 16 or 60 bit privately such as address mapping or CRC32 recalculation, is needed in the IWU. The only consequence of this solution is that the source DQDB node needs to know which remote IWU serves the 48 bit destination address. For the routing protocol, the advantage is the fact that only the E.164 addresses of the IWUs are exchanged, resulting in a lower bandwidth use for the exchange of routing information and a lower processing overhead. The disadvantage is that no status information of DQDB nodes is available, since no 48 bit addresses are recognised.

4. *Including of the 48 bit addresses after the header extension field*: In this solution, there is also a need for introducing a new address type. The sending and receiving DQDB node need to know where to find the 48 bit source and destination addresses in the IM-PDU payload. As with option 3, no extra functionality is needed in the IWU. However, since the 48 bit addresses may not be known to the DQDB node until the second SAR-PDU arrives, every node on the MAN must buffer at least all BOM SAR-PDUs before he knows if he does or does not need to reassemble the IM-PDU. Another disadvantage of this solution is that again no status information of DQDB nodes is exchanged by the routing protocol.

Using E.164 addresses on one MAN and 48 bit addresses on the other MAN

This is a situation that can only be solved using address mapping. If the initiating node uses a 48 bit address, communication is straightforward. The interworking unit changes the 48 bit source address to its corresponding E.164 address and leaves the E.164 destination address intact. In the process, it recalculates the optional CRC32. The destination uses the mapped E.164 for reply. If the initiating node uses an E.164 address, communication is more complicated. Now, the 48 bit destination address needs to be mapped. Since there are far more destination addresses than there are source addresses, this leads to considerable address tables in the interworking units.

Interconnection of private MANs

In this situation two or more private DQDB MANs on different locations need to be interconnected using the B-ISDN network as a backbone. Here, all address types may be used on the assumption that these addresses are unique in the interconnected DQDB network. The interworking unit just serves as one half of a remote bridge. It scans all IM-PDUs on the local MAN looking for a destination address not present on his MAN. On receipt of such a PDU, it encapsulates the PDU in a CLNAP-PDU and forwards it to the connectionless server. The CLNAP-PDU will find its way to the destination IWU using the routing function of the B-ISDN network providing the connectionless service. On arrival, the destination IWU decapsulates the IM-PDU and forwards it on to his MAN.

8.1.3. Conclusions on addressing

Addressing in the ATM/DQDB internetwork is made very complex, due to the multiple addressing schemes that are allowed on DQDB MANs. These MANs support the use of 16 bit and 60 bit privately administered addresses beside 48 bit and E.164 universally administered addresses, whereas B-ISDN only supports the E.164 address type. For communication between arbitrary connectionless service users (DQDB or B-ISDN), the use of 16 or 60 bit privately administered addresses on DQDB MANs must be ruled out. These address types can not be used because of their inability to be globally unique. 48 bit universally administered addresses can be used for the routing protocol.

therefore recommended to have a permanent connection to the connectionless server for the exchange of routing information. On receipt of a link state packet, the interworking unit need not have to build a connection to the connectionless server in the ATM network. It must already be present at that time, resulting in a minimal delay. Two different ways of exchanging routing information with regard to user data traffic can be distinguished. It is depicted in Figures 8.3a and b.

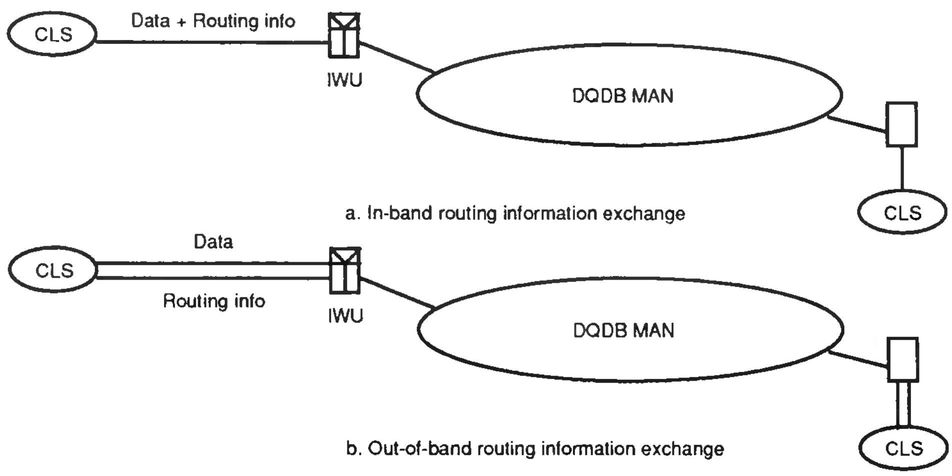

Figure 8.3: *Two ways of exchanging routing information*

1. *In-band routing information exchange:* In this situation, the routing information is exchanged on the same connection where user data is exchanged. Here, one permanent connection is set up between the interworking unit and the connectionless server (router), where user data and link state packets are multiplexed. However, in case of congestion a mechanism must provide a way of giving priority to the LSPs. This can be done by setting the Higher Layer Protocol Indicator (HLPI, present in both CLNAP-PDU and IM-PDU) to indicate a routing protocol packet.
2. *Out-of-band routing information exchange:* In this situation, the routing information is exchanged on a separate connection to the connectionless server, resulting in two connections between the interworking unit and the connectionless server. In order for the routing protocol to meet the requirement on stability and fast adaptation, a connection with the highest peak rate is recommended. Solution 2 needs no priority mechanism at the cost of keeping an extra connection to the connectionless server. Again, the HLPI can be used to identify a routing protocol packet.

Figure 8.4 shows a possible way of implementing the described priority mechanism in case of in-band routing exchange. A pre-processor identifies the payloads of the CLNAP-PDU or IM-PDU and forwards every corresponding SAR-PDU to the appropriate queue. The main-processor services the data-queue as long as there is no data in the routing queue. Whenever there is data present in the routing queue it is handled immediately by the main-processor.

However, this does require the possibility of discriminating the routing packets from other (user-data) packets by the addressed routers. This may not be possible for every data-link layer used in the internetwork. When this is the case, the data-link implementation must be modified to recognise a new type of packet. If this is impossible due to the fact that there is no more room in the packet type field, the implementation will be incapable of ensuring priority service for the critical control traffic. As a result, the routing protocol will have a lower performance. Furhermore, it is not possible to address one specific router on a multi-access network (LAN/MAN). This is why IS-IS uses no acknowledgements on these networks as OSPF does (see section 7.2).

Below, two scenarios are given for both the DQDB and the ATM data link layer, in which routing protocol packets must be discriminated from user-data packets. The first scenario examines if it is possible to recognise routing packets at the data link layer on both networks, the second examines if it is possible to use network addresses for discrimination.

Routing packet discrimination at the data link layer on a DQDB MAN
This scenario will study the possibility of discriminating routing protocol packets at the data link layer on DQDB MANs. When IS-IS's native approach is used, no specific addressing of destinations on the MAN is possible. In stead, all routers accept data link cells with the packet type set to indicate a payload containing routing information.

On DQDB MANs, a data link cell equals a DQDB slot consisting of a DQDB slot header and an information payload (see Figure 3.3, pag. 15). Thus a way must be found for the header to indicate a payload containing routing information. The only way this can be done is to set the Payload Type field to a specific value. The DQDB standard states that the two bit Payload Type field indicates the nature of the data to be transferred. For the default connectionless VCI (VCI = all ones), only one value ("00") is valid indicating user data. Payload Type use for other VCI values is still under study.

With this in mind, there is only one way of routing packet discrimination on DQDB MANs at the data link layer: the use of a not yet defined Payload Type value together with a new VCI value for the connectionless service. This is fully in agreement with the standard, since it comments that the Payload Type field is intended to differentiate user and network information. When this solution is used, routers check every DQDB slot for the new connectionless VCI value and Payload Type indicating routing information. Normal DQDB nodes using the connectionless service just check for the default connectionless VCI value and look in the payload if their network address is present.

Routing packet discrimination at the network layer on a DQDB MAN
In this scenario, the native IS-IS approach is not used. In stead, routers are addressed using their network addresses. In case of propagating routing information to all routers on a MAN, 48 bit or 60 bit group addressing may be used. This is a more flexible means of discriminating routing protocol information because it independent of the data link layer used. Furthermore, routers can be addressed not only as a group but also individually. Here, no new VCI value for the connectionless service on DQDB MANs is needed. The routers (IWUs) just look for the default connectionless VCI and consequently look for the network destination address and the Protocol Identification field in the payload of the first DM-PDU. If it matches their own address, the payload is

9. CONCLUSIONS & RECOMMENDATIONS

Conclusions:

- *The OSPF based proposed routing protocol for SMDS can be used in the ATM/DQDB environment, but IS-IS is a better alternative for intra-domain routing.*

  OSPF feeds routing information from outside the areas and even from outside the domain into these areas for route calculation. IS-IS does not. The advantage of IS-IS is therefore minimal use of bandwidth in the areas, minimal use of processing time in the Intermediate Systems and the virtual independence of the protocol on network growth. This protocol has the additional advantage of using variable length fields that are skipped by not compatible routers. This way, IS-IS is able to extend itself without major changes to existing hard- and software in the routers. The disadvantage is that the route calculation can not be as optimal as in OSPF.

- *For a good performance of the IS-IS routing protocol, it is necessary to dimension the level 2 subdomain properly.*

  Level 1 Intermediate Systems have no choice in level 2 routers when forwarding data to other areas or other domains. Therefore it is necessary to dimension the level 2 subdomain properly to obtain the least number of hops between areas.

- *To increase the performance of IS-IS, hop-count feeding or level 1 IS selection by level 2 ISs should be introduced.*

  Hop-count feeding lets level 1 routers calculate the best level 2 router when forwarding data to a specific destination area, in stead of just choosing the nearest level 2 router. With level 1 IS selection by level 2 ISs this calculation is performed by level 2 routers, after which the results are forwarded to all level 1 routers in the attached areas.

- *To overcome addressing problems in the ATM/DQDB internetwork, it is recommended to use E.164 addresses on DQDB MANs or perform the mapping of local address types to E.164 addresses in the InterWorking Unit.*

  On DQDB MANs 16 bit and 60 bit privately administered addresses together with 48 bit and E.164 publicly administered addresses may be used. ATM uses E.164 addresses. When DQDB connectionless service users want to communicate with users on other MANs or on B-ISDN networks, E.164 addresses must be used for routing and addressing.

Recommendations:

To further improve the provision of connectionless services on the B-ISDN/DQDB-MAN internetwork and especially the routing protocol, additional work may be done in the following areas:

- *Group addressing*: one of the functionalities of the connectionless servers is the forwarding of packets from one source to multiple destinations. It needs further study if this is implemented using Group Address Agents or in any other form and how this influences the routing protocol.
- *Routing protocol optimization*: it needs further study if the (extended) IS-IS protocol can be enhanced to take into account the number of hops a packet must traverse in the destination area (e.g. by means of route-recording or backward learning).
- *Performance aspects*: the (extended) IS-IS routing protocol should be modelled in a computer program to investigate the performance of the protocol in the actual B-ISDN/DQDB-MAN environment, especially the convergence speed and stability.
- *Inter-domain routing*: for interconnecting routing domains belonging to the same service provider or to different service providers, a routing protocol needs to be defined for the calculation of best paths between these domains. As a basis may serve the ISO Inter-Domain Routing Protocol (IDRP, [15]).

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