The easy and cost effective interworking of Distributed Queue Dual Bus (DQDB) and Asynchronous Transfer Mode (ATM) protocols is of prime importance for the evolution of the broadband integrated services digital network (B-ISDN) and the long-term success of MANs as tributary networks. In this paper, we study several practically useful scenarios for the interworking of ATM Customer Premises Networks (CPN) through a transit DQDB network. Suitable Interworking Unit (IWU) protocols are presented and compared. It is shown that the most advantageous solution in terms of service quality and IWU simplicity and robustness is the use of a Connection Oriented (CO) DQDB service exploiting the Queued-Arbitrated mode of access. Also, the provisions required in the definition of a CO DQDB service are pointed out. Finally, the implementation of an IWU applying the ideas presented is outlined.

Keywords: interworking, ATM, DQDB signalling, AAL compatibility, cell/slot relay, internetwork VCC

The present situation of the international communication environment is characterized by a diversity of technologically dissimilar and administratively autonomous subnetworks. Notwithstanding the continuous efforts for integration as exemplified by ISDN, it is realistic to expect that the heterogeneous environment will persist because the reasons that created it remain:

- diversity of needs and applications served
- evolution in transmission technologies
- multiplicity of administrative authorities
- historical reasons, i.e. the inheritance of technically superseded but still economically viable installations, including terminals.

The continuing existence of this heterogeneity creates a strong incentive for interoperability between the diverse subnetworks with the varying protocol suites and implementation technologies.

Since the ATM concept is standardized as the transfer mode for the future public B-ISDN\(^1\), non-ATM networks covering different geographical areas and applications (e.g. LANs, PBXs, MANs) cannot remain isolated and unable to take advantage of ATM's potential.

The ATM concept together with resource allocation associated mechanisms (for a survey of policing mechanisms for congestion control, see References 2 and 3) is very advantageous particularly for bursty traffic, but the present state of the CCITT standards is not sufficiently detailed for implementation. However, some proposed protocols compatible with ATM are available from IEEE, ANSI and research laboratories working in high speed LANs and MANs. These are mainly the protocols related to the DQDB proposed standard as appears in the reports of the IEEE 802.6 committee\(^4\), as well as the Switched Multi-megabit Data Service (SMDS) of Bellcore\(^5,6\), the Cyclic Reservation Multiple Access\(^7\) and the Distributed-Queue Multiple-Access of IBM\(^8\). The majority of these protocols are related to Connectionless Service (CL) offered to business customers. The connectionless service, which allows the transfer of information among service users without the need for end-to-end call establishment procedures\(^9\), does not in general offer the grade of service provided by Connection Oriented (CO) services.

It is expected that the penetration of B-ISDN infrastructure will start with CL services offered to business customers. Anticipating that, ETSI is adopting some of the above MAN standards with certain modifications, with the intention of using MANs as a starting point for the evolution to B-ISDN. Thus the concept of MAN compatibility with B-ISDN (or in
other words, the easy interconnection of MANs and B-ISDN is considered as a stepping stone for B-ISDN. It is natural, then, that the broadband evolution scenarios envisage the development of MAN islands before the widespread availability of ATM. Consequently, a lot of interest is directed at providing the capability to interconnect the initially isolated MANs via the public ATM network.

The opposite situation (i.e. the need to interconnect ATM equipment through MAN subnetworks) is less frequent. However, this case presents appreciable promise as a potential solution for special cases that arise in the evolution of the global broadband network, as well as in the eventual situation where MANs will remain as access networks for ATM equipment.

One situation where interconnection of ATM users through the DQDB MAN will be beneficial appears in the interim stage when the evolving public B-ISDN is still unavailable, whereas Customer Premises Networks (CPN) are increasingly turning to providing broadband services. By the term CPN we indicate any kind of installation located between Terminal Equipment (TE) and the public network access interface. It is natural to expect that the pace of expansion of the public ATM-based B-ISDN will not match the installation speed of private CPNs enriched with ATM functionality (ATM CPNs). Apart from the usual reasons relating to the inertia of the big public operators, there is the incentive of guaranteed high traffic within private business customers which will motivate the early introduction of ATM functionality in CPNs, not unlike the present situation accompanying the introduction of the N-ISDN. Installation of N-ISDN PBXs is burgeoning despite the slow introduction of public N-ISDN. There is every reason to expect that the same will happen with the introduction of B-ISDN. The integration provided by the latter will prompt private corporations to invest in ATM technology rather than keep separate PBXs and patch up the interconnection of LANs with ad hoc fibre optic links. As broadband needs increase, and in anticipation of the eventual availability of the public ATM-based B-ISDN, this trend will build up.

The early introduction of MANs will relieve the need for intercommunication of temporarily isolated (regarding their broadband needs) ATM CPNs in high traffic metropolitan areas (Figure 1) originally for CL services. These MANs, which are used as access facilities, will represent an appreciable investment that we must endeavour to incorporate into the eventual B-ISDN landscape permanently, in the role of gathering networks by incorporating CO services as well.

ABBREVIATIONS

<table>
<thead>
<tr>
<th>AAL</th>
<th>ATM Adaptation Layer</th>
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<tr>
<td>ATM</td>
<td>Asynchronous Transfer Mode</td>
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<tr>
<td>B-ISDN</td>
<td>Broadband Integrated Services Digital Network</td>
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<td>BOM</td>
<td>Beginning of Message</td>
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<td>BVC1</td>
<td>Broadcast VCI</td>
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<td>BWM</td>
<td>Bandwidth Manager</td>
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<tr>
<td>CEP</td>
<td>Connection End-point</td>
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<tr>
<td>CF</td>
<td>Convergence Function</td>
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<tr>
<td>CL</td>
<td>Connectionless</td>
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<td>CLP</td>
<td>Cell Loss Priority</td>
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<tr>
<td>CLSF</td>
<td>Connectionless Service Functions</td>
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<td>CO</td>
<td>Connection Oriented</td>
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<td>COCF</td>
<td>Connection Oriented Convergence Function</td>
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<tr>
<td>CPN</td>
<td>Customer Premises Network</td>
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<td>CS</td>
<td>Convergence Sublayer</td>
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<tr>
<td>DA</td>
<td>Destination Address</td>
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<tr>
<td>DMPDU</td>
<td>Derived MAC PDU</td>
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<tr>
<td>DQDB</td>
<td>Distributed Queue Dual Bus</td>
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<tr>
<td>GFC</td>
<td>Generic Flow Control</td>
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<td>HOB</td>
<td>Head of Bus</td>
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<tr>
<td>ICF</td>
<td>Isochronous Convergence Function</td>
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<tr>
<td>IMPDU</td>
<td>Initial MAC PDU</td>
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<tr>
<td>IWU</td>
<td>Interworking Unit</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
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<tr>
<td>LAP-D</td>
<td>Link Access Procedure on the D-channel</td>
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<tr>
<td>LLC</td>
<td>Logical Link Control</td>
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<tr>
<td>LME</td>
<td>Layer Management Entity</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MAN</td>
<td>Metropolitan Area Network</td>
</tr>
<tr>
<td>MCF</td>
<td>MAC Convergence Function</td>
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<tr>
<td>MID</td>
<td>Message Identifier</td>
</tr>
<tr>
<td>MLAP-D</td>
<td>Modified LAP-D</td>
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<tr>
<td>PA</td>
<td>Pre-arbitrated</td>
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<tr>
<td>PBX</td>
<td>Private Branch Exchange</td>
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<td>PCI</td>
<td>Protocol Control Information</td>
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<td>PDU</td>
<td>Protocol Data Unit</td>
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<td>PT</td>
<td>Payload Type</td>
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<tr>
<td>PVC1</td>
<td>Permanent VCI</td>
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<tr>
<td>QA</td>
<td>Queued Arbitrated</td>
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<tr>
<td>QoS</td>
<td>Quality of Service</td>
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<tr>
<td>SA</td>
<td>Source Address</td>
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<tr>
<td>SAP</td>
<td>Service Access Point</td>
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<tr>
<td>SAR</td>
<td>Segmentation and Reassembly</td>
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<td>SP</td>
<td>Segment Priority</td>
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<tr>
<td>ST</td>
<td>Signalling Termination</td>
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<tr>
<td>SVCi</td>
<td>Signalling VCI</td>
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<tr>
<td>SVClup</td>
<td>Signalling VCI upstream</td>
</tr>
<tr>
<td>TE</td>
<td>Terminal Equipment</td>
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<tr>
<td>TEI</td>
<td>Terminal Endpoint Identifier</td>
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<tr>
<td>UNI</td>
<td>User Network Interface</td>
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<tr>
<td>VCC</td>
<td>Virtual Channel Connection</td>
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<tr>
<td>VCI</td>
<td>Virtual Channel Identifier</td>
</tr>
<tr>
<td>VPC</td>
<td>Virtual Path Connection</td>
</tr>
<tr>
<td>VPI</td>
<td>Virtual Path Identifier</td>
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ATM traffic transfer via QA DQDB: I S Venieris et al.

Figure 1  Evolution scenario leading to the interconnection of ATM CPNs through MANs

Hence the use of the DQDB MAN as the transit network for ATM traffic appears not only as a stepping-stone in the evolution, but also as a more permanent solution. In addition, it presents considerable practical and theoretical interest. In this paper, the interconnection implications on the protocols as well as the functionality of the IWU are investigated. It will be shown that the introduction of CO services to DQDB is the most advantageous solution. We start our study by overviewing the ATM and DQDB protocols, emphasizing the provisions for interconnection in existing draft standards. Interworking issues relating to addressing, signalling, bandwidth management, etc. are extensively discussed, and lead to a comparative examination of interconnection alternatives, where suggestions regarding protocol compatibility for efficient and robust relaying are given. A functional analysis of the interworking unit for each scenario is presented, and possible implementation techniques are outlined. Finally, the conclusions of this study are summarized.

ATM AND DQDB STANDARDS: PROVISIONS FOR INTERWORKING

A study of the standards defining the two network types reveals intentional compatibilities which facilitate the interworking, with the most obvious being the equal size of the ATM cell to the DQDB slot.

ATM mainly provides labelled multiplexing of ATM cells using the corresponding Virtual Channel Identifier (VCI) and Virtual Path Identifier (VPI) subfields of the ATM header. The ATM cell consists of a 5-octet header field and a 48-octet information field. The payload of the ATM cell includes control information of the upper layer protocol, widely known as ATM Adaptation Layer (AAL). The basic function of AAL is to guarantee the proper common use of ATM for services with different Quality of Service (QoS) requirements and varying traffic profiles. To avoid a large number of service specific AAL protocols, AAL is further sublayered to the Segmentation and Reassembly (SAR) sublayer and the Convergence Sublayer (CS)\textsuperscript{15}. In addition, AAL users are grouped into four different service classes with reference to their AAL protocol requirements. For each class an SAR protocol type is currently proposed\textsuperscript{15}. Functions of SAR and CS protocols pertaining to the interworking are discussed in the relevant sections below.

One of the main advantages of ATM is the efficiency in bandwidth utilization resulting from the statistical multiplexing of several individual sources. However, to fully exploit the benefits of statistical multiplexing even for bursty information, new kinds of bandwidth management and traffic control operations are required so that the QoS requirements of different services are preserved\textsuperscript{16}.

By definition, ATM is a CO technique\textsuperscript{17}, i.e. requiring the set-up of an ATM virtual connection between origin and destination before the actual transmission of the cells takes place. Cells of a particular connection are identified by their VCI, VPI values. However, the CO ATM can also be used for CL services by means of a particular type of CL AAL protocol, namely AAL type 4\textsuperscript{15}.

The DQDB MAN is in a more advanced stage of standardization. The IEEE 802.6 proposed standard fully describes a connectionless transport mechanism with a MAC (Medium Access Control) sublayer different to the other 802.x networks. However, it provides services to the same LLC (Logical Link Control) sublayer, i.e. IEEE 802.1.

The medium consists of a dual bus accessible by two methods:

- In the Pre-Arbitrated (PA) access, slots (the basic data units in DQDB) are a priori assigned so that isochronous traffic can be carried without encountering variable delay.
- In the Queued Arbitrated (QA) access, slots are not preassigned; instead, access is determined by means of a queueing mechanism for outstanding slots. The queue is logically global within a MAN, though maintained in a distributed manner. The QA mechanism is inherently effecting statistical multiplexing by means of its access algorithm. In DQDB, unused QA slots are available to users who happen to be in a bursty situation. This in essence is the same concept with the statistical multiplexing in ATM networks, where bursty situations are accommodated by virtue of the exploitation of possible silent periods experienced in active calls. The imperfections of the DQDB access protocol, particularly under heavy load even with the introduction of the bandwidth balancing mechanism, somehow differentiate this method from statistical multiplexing of the ATM technique. This, however, does not destroy the validity of the argument, nor the useful exploitation of the fact for the interworking of the two techniques.

To adapt the above two access methods to the higher layers, the following three Convergence Functions (CF) are provided in DQDB:
**MCF (MAC Convergence Function)**

This CF enables the DQDB to provide the service expected by the LLC 802.1 standard. It employs the incorporation of the destination and source addresses into the IMPDU (Initial MAC PDU) to effect routing without previously setting-up a connection. No switching based on VCI translation is performed. Thus within DQDB, the functionality of the VCI resource is limited to a mere indication of the kind of service, i.e. 'connectionless'.

**COCF (Connection Oriented Convergence Functions)**

These CFs have not been defined yet in the standard. However, provisions are contained for their future definition. In this case virtual DQDB connections identified by specific VCIs are established using signalling procedures. Thus a CO service is obtained. The signalling requirements are further discussed below.

**ICF (Isochronous Convergence Function)**

In this CF preassigned slots marked by the node which is head of bus carry isochronous service octets at defined offsets. These slots are issued every 125 µs and are accessed using the PA method. Thus a CO service is provided which in addition preserves the timing relationship of the octets.

The first two alternatives form the basic DQDB transport mechanisms on which all further investigations for the interworking will be based. The third method devoted to support isochronous characteristics using the ICF (and hence the PA method) may be useful only for services belonging to class A, i.e. constant bit rate, CO services that require timing relation between source and destination. It is important, however, to stress that in ATM the isochronous services (or the services of class A in ATM terminology) are supported by end-to-end synchronization functions provided by the AAL protocols of the transmitter/receiver (see SAR type 1 of CCITT draft rec. I.36315). The ATM by itself does not provide any service synchronization functionality. Hence, similar to ATM, the QA method can also support the isochronous traffic originating and destined to ATM users provided that these users support the required synchronization functionality (the observance of maximum limits for the transit delay and the cell jitter is, of course, required). Use of the ICF clearly is one alternative. However, in this study exploiting the fact that DQDB is just a transit network and the existence of end-to-end ATM service synchronization, we investigate the use of the QA mode of access for all traffic classes. As will be shown in the implementation section, the direct translation of cells into DQDB slots (and vice versa) is so fast that obviously no appreciable processing delay is introduced by the IWU. Furthermore, the method of allocating QA slots to DQDB connections driven from an overall bandwidth management policy, proposed in the relevant section below, guarantees that the access of a CO service to the DQDB resources will experience delay which does not affect the QoS.

Comparing the structure of both the DQDB slot and the DMPDU (Derived MAC Protocol Data Unit), we can identify similarities to the ATM cell and the SAR PDU types 3 and 4, respectively (same length, same CRC coding, similar subfields). Also, a similar structure to that of the IMPDU (Initial MAC Protocol Data Unit) is under consideration for the aggregated PDU of CLNAP (Connectionless Network Access Protocol) and CS type 4 (Convergence Sublayer)14. Hence, there is an intentionally arranged correspondence of sublayers, as shown in Figure 2. Considering the interworking between the DQDB MAN and the ATM, these PDU commonalities must be fully exploited so as to provide the most economical and reliable implementation.

The compatibility between the CLNAP + AAL type 4 and MAC PDUs is crucial for the ATM–DQDB interworking when relay of CL traffic originated from an ATM-TE is performed at the DM or IM level of a DQDB node. This is the case for the DQDB supporting CL services (see MCF above). The same CL DQDB mechanism may also be used for the transfer of CO traffic originating from an ATM-TE, as well be elaborated below. The problem in this case is the lack of a Destination Address (DA) field in the PDUs which support CO services (no CLNAP is present). This is because in CO services routing is based on the VCI of the ATM cell which is allocated via signalling (the ATM manner). Hence, the ATM-DQDB IWU will be responsible for reconstructing the ATM traffic in DQDB format. This implies that the IWU will relay the ATM information on top of the AAL/IM. This is also the case when traditional LANs are interconnected through an ATM network16,18. In the following we preserve a simple IWU which relays on the ATM cell/QA slot level by the introduction of signalling capability in DQDB. This results in the allocation of DQDB VCIs for each connection. These VCIs are now used to route QA slots inside DQDB, extending the concept of VCC inside DQDB as well. So now, the QA slot payload is not accessed and CLNAP + AAL and MAC PDU compatibility is no longer a strict requirement.

**INTERWORKING ISSUES**

The set-up of the interconnection is shown in Figure 3. An end-to-end connection is provided to subscribers of ATM CPNs through the DQDB transfer services. The ATM CPN can include a large spectrum of configurations ranging from simple passive to intelligent interconnected subnetworks, exhibiting at the B-ISDN access interface ATM functionality (Tb reference point)8. To connect the private NT2 to the MAN network, an IWU is installed, which is connected to the NT2 on the one side and to the DQDB dual bus on the
Figure 2 Correspondence of sublayers

other. The IWU also performs the normal DQDB node functions. According to the interconnection scenarios presented below, its protocol stack extends up to sublayers DM or IM (see Figure 2). Therefore, the IWU can be considered as a bridge or a combination of bridge and router (brouter).

Signalling

Signalling between the ATM-TE (ATM Terminal Equipment) and NT2 will take place according to the normal ATM signalling procedures currently under standardization by CCITT. We will assume that separate VCIs are used for signalling connections. This is in line with CCITT draft recommendation I.311, according to which signalling messages belonging to the same signalling connection are conveyed by ATM cells marked with the same SVCi (Signalling VCI) value. In OSI terms, signalling messages issued from different users enter the ATM layer through different SAPs (Service Access Points) or different CEPs (Connection End-Points) of the same SAP, which correspond to the use of different SVCIs for cell routing.

The allocation, checking and removal of SVCIs (Signalling VCIs) per signalling connection at the UNI (User Network Interface) is undertaken by the ATM Layer Management Entity (ATM-LME). Each ATM-LME provides its services by using the metasignalling protocol. It communicates with NT2 through a metasignalling PVC (Permanent Virtual Channel). The PVC identifier (PVCi) has a standardized value. The Metasignalling Protocol is based on the TEI (Terminal Endpoint Identifier) assignment protocol of ISDN. A user wishing to initiate a signalling process with the network issues a metasignalling message requesting allocation of a signalling VCI. This single cell message is conveyed by an ATM cell marked with the metasignalling PVCi. A reference number used as a temporary identification of the calling user is contained within the metasignalling cell payload. After receipt of the metasignalling request the network issues a metasignalling indication, which is conveyed by a cell marked with the preassigned BVCI (Broadcast signalling VCI). All ATM-TEs connected to the particular UNI receive the metasignalling cell, but only the calling ATM-TE recognizes the reference number which is also contained in the metasignalling cell payload. The metasignalling cell payload contains the values of the SVCiup and SVCId (upstream and downstream signalling VCI), which are to be used for signalling between the calling ATM-TE and the network, across the UNI. All signalling messages issued by the calling ATM-TE are conveyed with signalling cells marked with the SVCiup. The calling ATM-TE receives signalling cells, which carry the SVCi up value.

When using the CL DQDB services, signalling between ATMP CPNs is, of course, transparent for the transit network, and is handled as any other data traffic. However, when using the CO services of DQDB, signalling will take place between the ATM CPN and suitable entities in the DQDB subnet, via the IWU.

Since the CO service of DQDB has not yet been specified in the standard, we will make use of the reasonable assumption that the CO signalling protocol will be in line with the guidelines presented in Appendix A of the IEEE 802.6 standard with reference to the PA isochronous functions. Furthermore, we assume that this signalling protocol will be compatible with that adopted in ATM.

The existence of the following entities in analogy to those suggested for the PA functions is assumed in this paper:

- A VCI server for QA access, responsible for the allocation of DQDB VCIs to new DQDB connections.
- A Signalling Termination (ST). This is the entity which executes the DQDB signalling protocols, and its protocol stack includes a modified Q.931 (MQ931) protocol for layer 3 and a modified LAP-D (MLAP-D) on the top end of layer 2. With the term modified we indicate protocols which are developed with the corresponding standards as starting points, which is the line followed in the RACE project.
- A Bandwidth Manager (BWM). This entity is responsible for monitoring bandwidth usage and allocation of bandwidth to new DQDB connections.

Figure 3 Interconnection of ATM CPNs through a DQDB MAN
In addition, the IWU must possess a policing function operating along the lines of policing currently under study for ATM, e.g. leaky bucket or similar. The ST will accept or reject calls in consultation with the BWM, which executes the call acceptance algorithm. Since any node has first to communicate with ST to apply for resources, we propose a procedure similar to that of ATM metasignalling, i.e. we propose the use of a pre-defined ‘metasignalling’ upstream VCI on which any node can send requests for allocation of Signalling VCIs (SVCI) to the ST and a pre-defined broadcast downstream VCI on the opposite bus on which the ST responds. A reference number included in the metasignalling cell is used in the ST response to identify the node to which two SVCIs (one for upstream and one for downstream) are allocated. The set-up request is then sent on the SVCIdup (SVCI upstream) incorporating request parameters (bus no., average rate, peak rate, etc.). The ST checks the availability of resources with the BWM and responds with a message sent on the SVCId (SVCI downstream). The ST call acceptance message contains the values of the DQDB VCIs which will be used for the user information transfer. These DQDB VCI values are allocated by the VCI server for QA access. In conclusion, the IWU is capable of performing metasignalling protocols in both directions: towards the ATM CPN as any other CPN subscriber, and towards ST as a CO DQDB service user.

**Bandwidth management**

An important issue is bandwidth negotiation, allocation and policing. When DQDB supports CO services, in addition to the isochronous and CL services we need a method to divide the available bandwidth among the supported services. The amount of bandwidth devoted to each CO service should be allocated dynamically according to the traffic load. In this way, we take advantage of the statistical multiplexing effected by the QA mechanism. A mechanism for bandwidth management in a DQDB supporting CO, isochronous and CL services is described below.

First, the Head Of Bus (HOB) will mark (as already foreseen by the standard) as PA enough slots to accommodate the isochronous PA DQDB connections. The HOB will also put the VCI values to these PA slots intended for isochronous traffic. The rest of the slots are marked by the HOB as QA. Since the CO services using the QA mode should have a guaranteed bandwidth as agreed during connection set-up, a percentage of slots corresponding to the aggregate effective bandwidth of the established connections should be inaccessible to CL traffic. One way to mark the QA slots intended for CO traffic is to set to 0 the four extra bits of the DQDB VCI (then 16 bits are available for the VCI value, as is the case in the ATM cell). These slots are then seized by the nodes supporting a CO service and the specific 16 bit VCI values are assigned. The reverse marking (four ‘1’) is done by the HOB to the rest of the QA slots which are also available for CL traffic.

However, to allow the statistical multiplexing to work more efficiently, overspilling of CO traffic into the bandwidth intended for CL traffic should be allowed. This corresponds to the Movable Boundary scheme presented by Sykas et al. Thus a minimum amount of bandwidth, based on the negotiated average of the current connections, is exclusively allocated to the CO service (i.e. the QA slots that carry the four ‘0’s) to guarantee the required QoS. In addition, bursty situations with instantaneous bandwidth needs above that are accommodated by allowing access of CO services to the bandwidth of the CL services (i.e. to the QA slots that carry the four ‘1’s). On the other hand, CL services are restricted to the use of their own bandwidth. To prevent CO service users from exceeding the negotiated parameters, the policing mechanism must be relied upon. Policing units cannot be inserted in the DQDB buses and must be included in the IWU. The policing units will monitor the traffic per connection, as well as the total ATM traffic injected into the IWU against the agreed parameters.

**PDU mapping**

Attention must be paid to the difference in certain header functions, despite the same size of ATM cell and DQDB slot. Recall that the first byte of the QA slot header (Access Control Field) is used to manage the slot access mechanism, whereas in ATM it provides 4 bits for the still unspecified Generic Flow Control (GFC) and 4 bits partially specifying the VPI. Another difference exists in the last field. In ATM the Header Error Control covers all the rest of the header (4 octets), whereas in DQDB it covers the three middle octets. However, there is no real loss of compatibility here, since the recalculation of the CRC at the relay verifies the integrity of the arriving header.

In general, there is no problem with the header interworking provided the GFC mechanism currently under study will not introduce incompatibilities and will permit the DQDB MAN to be a subset of B-ISDN. The rest of the functions are mapped as follows:

- The 24 bit VPI + VCI value of the incoming ATM cell is translated into a 20 bit DQDB VCI, which is the default CL VCI or a CO VCI obtained by DQDB signalling procedures.
- The 2 bit Payload Type (PT) has not been defined yet in both the ATM and DQDB standards. Its default value (00) is transferred transparently. Since no other values have yet been defined, we use the default value even in the case of signalling. We expect, however, that a specific PT value is going to be standardized for signalling use when the COCF specification is complete. PT may be used to route
signalling cells to the Signalling Termination, VCI server, etc.

- The 1 bit Cell Loss Priority (CLP) of the ATM cell is mapped to the default value of the Segment Priority (SP) of the QA slot. This is because the values of SP are not yet defined. However, from a functional point of view, the aim of CLP and SP is common, i.e. to avoid and control congestion. To preserve the required QoS of the ATM-TE user within the DQDB network, it is apparent that ATM cells sensitive to cell loss must be converted to QA slots with high segment priority.
- The 4-bit GFC is not used, thus the GFC default value (0000) is not coded within the QA header.

Addressing

A significant difference between the CL MANs and ATM stems from the fact that in the former, addressing is handled in the IM sublayer, whereas in the latter it resides above the AAL sublayer. The impact of this on the interworking depends on whether the CL or the CO DQDB service is used. In the CL DQDB, where routing is based on the DA and MID, address translation is repeated for every PDU. In contrast, in the CO DQDB address translation is performed by the ST once for every connection during the set-up phase. Subsequent signalling and user information are routed at cell/slot level on the basis of VCI mapping resulting in a more simplified IWU.

In either case, a method is needed to identify the IWU through which the destination ATM-TE can be reached based on the information provided by the coding of the ATM-TE address contained in the pertinent field of the CS type 4 PDU or the set-up message. Furthermore, once the DQDB address of the IWU is found from address correspondence tables, it may provide a way to reach the IWU but may not contain information for further routing to the particular ATM-TE in the destination CPN. In the following we investigate ways to overcome these problems which apply to both the CO and CL DQDB cases, with the understanding that in the CO case they refer to routing the call set-up via the ST but in the CL case to every CL PDU.

A very elegant and simple way to route across diverse subnetworks is possible when a hierarchical addressing scheme universally administered is employed. If this is the case, the ATM-TE address indicates not only the subnetwork (the CPN in this case) and the second level the address of the particular ATM-TE. As a result, we can place the 60 bit addresses of the ATM-TE in the pertinent fields of the DQDB PDUs and still the IWU receiving functions can recognize that the PDU is addressed to it.

The hierarchical addressing scheme has one more advantage: it allows easy and quick decoding of the PDU address obviating the time consuming reading of tables by the IWU to determine if the full address is one belonging to the ATM CPN (as is the case with LAN bridges). A hierarchical addressing scheme along the lines presented by Parulcar and Turner allows the IWU to immediately decode the first field, and if there is a match to advance the received PDU to the ATM CPN.

However, E164 addressing is not mandated by the IEEE standard, and may not be supported in a private MAN. In such a case the ATM addresses are not recognized inside DQDB, and we have to devise other methods to convey to the receiving ATM CPN the address of the destination ATM-TE.

One solution is to employ address mapping, i.e. each ATM-TE address served by the IWU is mapped to a 'proxy' locally administered 48 bit (or 16 bit) DQDB compatible address which the receiving IWU can recognize and replace with the proper ATM address before forwarding the corresponding message to the adjacent NT2 unit. The IWU (or the ST in the CO DQDB case) has to maintain an address correspondence table providing the mapping of the ATM-TE addresses of the ATM CPN to the proxy DQDB 48 bit addresses.

The creation and maintenance of the address correspondence tables is a significant complication providing a strong incentive for the support of E164 addresses when DQDB is used to interconnect ATM CPNs. Of course, this is always the case with public MANs.

INTERCONNECTION OPTIONS

In this section a comparative presentation of interconnection scenarios will highlight the benefits of the introduction of a CO DQDB service to interworking with the ATM. Our considerations influence the implementation of an IWU which will be functionally described in the following section.

The impact of each alternative decision on every aspect of the interworking must be carefully considered, and the benefits of each choice balanced against often conflicting design targets. The main design objectives are:

- exploitation of the existing provision for interworking in the standards
- increased flexibility against a background of still evolving standards
- minimization of the implementation complexity.
CO ATM traffic through a CO DQDB

An IWU satisfying the above requirements is presented in Figure 4. In this scenario an end-to-end B-ISDN CO service is provided through a CO DQDB network. The IWU takes part in the exchange of signalling information for the purpose of establishing an end-to-end Virtual Channel Connection (VCC) throughout the two differing subnetworks, i.e. the introduction of signalling into DQDB also extends the VCI concatenation into the MAN. The allocation of a CO DQDB VCI which unambiguously identifies the particular connection (not just the service as is the case with the default CL VCI presently standardized by the IEEE) enables the relay of ATM cells in the user plane through the transit DQDB without reassembly.

Regarding signalling messages, there is, of course, the need for the IWU to modify certain fields containing the VCI values allocated by each subnetwork. In B-ISDN signalling protocol standardization there is no consensus yet on whether VCI allocation will take place with the ‘Bearer Connect’ or with the ‘Allocate’ message. There is even a possibility that users will allocate VCIs from a pool of VCIs provided to them. In any case, the IWU can always identify the required messages by checking the ‘Message Type’ information element which is always coded at the same position of a BOM (or SSM) segment. It can therefore access the VCI value in the ‘Connection Identification’ information element, thus obviating the need to reassemble even those signalling messages whose contents may need modification by the IWU protocols. One of them is the ‘Call Set-up’ message which must be identified for the IWU to initiate a metasignalling procedure with the ST, which will result in the allocation of DQDB SVCIs. Thus the complexity of the IWU can be kept to a minimum, avoiding the true activation of Layer 3 functions even for the control plane.

In the case of a non-uniform addressing scheme, there exists the additional problem of identifying the destination ATM-TE (as well as the particular connection in case of multiconnection service), since this information cannot be extracted from the DA_DQDB any more. This function will now be performed by the ST, which will now keep and update the address correspondence tables. The same method of the proxy addresses can be used, but this time the table maintenance is assigned to the ST, thus reducing the cost of the IWU (of course, in the case of a uniform addressing scheme these tables are redundant).

CO ATM traffic through a CL DQDB

When the CL DQDB service which corresponds to the current status of IEEE standards is used, the IWU complexity increases significantly, as can be seen in the protocol stack of Figure 5. Note that we are forced to perform a relay function on top of the CS/IM sublayer instead of the ATM/QA sublayer. The reason for this is the absence of a suitable routing entity, i.e. a way for the identification of the destination of PDUs. The segmented QA slots in the previous case could be routed by virtue of their VCI. However, now the VCI simply identifies the kind of service, i.e. CL service. Routing can now only be based on the DA field of the BOM segment of an IMPDU. As for the other segments, these will be identified by their MID value according to the usual CL DQDB protocol. Therefore, it is now unavoidable that the IWU must reassemble the ATM cells with the same ATM VCI value messages so that it can receive the services of the MCF block with which information is exchanged in the form of IMPDUs. Of course, now it is the IWU which must be able to either map the B-ISDN address contained in the call set-up message issued by the ATM-TE to the MAN proxy address, or encapsulate the 60 bit address into the pertinent IMPDU field and maintain the address
correspondence tables, which adversely affects its simplicity.

The obvious disadvantages of utilizing the CL DQDB service is that the segmentation/reassembly procedure within the IWUs cannot be avoided. This is true even in the case where the service provided by the ATM-TE belongs to the class C service user group, i.e. packet mode, variable bit rate and connection oriented, in which case the SAR-PDU type 3 is compatible to the DMPDU. In this situation, reassembly within the originating IWU is mandatory for coding the DA DQDB and MID, resources absolutely necessary for routing within DQDB.

It is important to note that the use of the CL DQDB service does not take advantage of the similarity of structure between the DQDB slot and the ATM cell. Thus, the implementation of the IWU along these lines results in a waste of resources. This option, however, is preferable for the interconnection of ATM-TEs through ATM incompatible LANs or MANs, and vice versa. In this case, segmentation and reassembly are anyway unavoidable because of the differing frame sizes.

Protocols devoted to interconnection of IEEE 802.3-5 LANs through the ATM network are explained in detail elsewhere \cite{18}.

**CL ATM traffic through DQDB**

So far we have considered an ATM CPN which provides CO services. Since an ATM CPN may include several bridged LANs that support CL service \cite{12}, and as it is the CCITT's intention to provide CL services to the customers of an ATM-based B-ISDN \cite{30}, we here consider the IWU functionality in the case where CL traffic originating from an ATM CPN enters the DQDB MAN. It is apparent that the design of the IWU should primarily focus on the support of CO service used in the majority of the applications, instead of being designed to cater for the small portion supporting the CL service.

In analogy to the mechanisms specified in CCITT Recs. II.327\cite{31} and I.211\cite{30} for CL service support in B-ISDN, the ATM-based CPN can support the CL data transfer either directly or indirectly. The direct case implies the incorporation of Connectionless Service Functions (CLSF) within the CPN. It is a general view that the CLSF will be realized by CL protocols which up to the CLNAP are likely to be DQDB compatible. If this is the case, then relay in the IWU can again be performed on top of the ATM cell/QA slot level similar to the CO DQDB case. The main difference, however, is that routing is now performed not on the incoming cell VCI used to forward the CL ATM traffic of the CLSF to the IWU, but on the DA implied in the BOM segment. It is also expected that the IWU will perform a translation of the SAR type 4 PDU MID to a DMPDU MID which requires a new CRC calculation. Hence, even if relay is performed on a QA slot/ATM cell level, the relay protocol provides upper layer functions.

In case the ATM CPN supports CL data service indirectly, then no CL protocols are provided by the CPN. The CPN uses ATM virtual connections to forward the CL traffic to the IWU, as it does with any other CO traffic. CL protocols are terminated end-to-end, i.e. between the communicating TEs. If we consider the use of semi-permanent CO DQDB connections to support the indirect ATM CL data traffic (as proposed by one of the reviewers), then we have an instance of a simplified CO DQDB. The IWU functionality dispenses with the need for metasignalling, and it is restricted to the translation of ATM to DQDB VCI (absence of signalling overhead) which is performed at the ATM cell/QA slot level without reassembly.

**IMPLEMENTATION ISSUES**

An implementation applying the previously presented protocol interworking solution based on the introduction of a DQDB CO service is outlined below.
The set-up of the interconnection is illustrated in Figure 6. The IWU is incorporated inside the DQDB node as a module attached to its buses, to provide the capability to accept cell-based traffic. The ATM-based CPN is connected through an ATM link to the IWU at the $T_B$ Interface. Note that the IWU directly injects into the QAF block the payload of each cell along with all the parameters normally provided by the COCF block (i.e. DQDB VCI, TX_BUS, ACCESS QUEUE, PT, SP). The QAF and the lower layer functions create a DQDB slot using this information. The IWU also exchanges information with the Layer Management Entity to announce its activation/deactivation, and to request opening of Service Access Points and other management functions.

The IWU Architecture is depicted in Figure 7. It consists of the following functional blocks:

- **ATM I/F** This is the Interface with the ATM stream. This block consists of a cell transceiver which translates the serial bit stream into a byte serial stream. It performs all the required physical layer ATM functions, i.e. cell delineation, scrambling/descrambling, CRC error detection, clock synchronization, etc. It also includes a programmable cell segregator circuit which can direct the cells to different FIFOs according to VCI and SVCIs values. These values are programmed into a special RAM by the Micro Processor Unit (MPU). This VCI programming is part of the establishment of the VCI concatenation by the IWU. However, all user traffic cells (all VCIs) are queued in one FIFO queue, but SVCIs are queued in separate queues since their payload must be easily accessible by the MPU, where user traffic is completely transparent to the IWU.

- **Signalling FIFOs** This is a collection of all the queues belonging to different SVCIs. Each queue is fed by the segregator circuits according to the SVCIs programmed. The buffers are accessed by the MPU, which inspects the Message Type and decides on the action required, as explained below.

- **User Info FIFO** This block temporarily buffers the user information before it is injected into the QAF via the VSB bus. Cells are delayed at least by the time required for the translation of their cell header.
The information exchanges between the IWU (which is a bus slave) and the QAF and LME (which are bus masters) are interrupt driven. When signalling cells arrive from the ATM CPN they are placed in the SIGNALLING FIFO according to their SVCI and the MPU is interrupted. The MPU reads the first cell (BOM) and determines from the Message Type whether it is a Call set-up, in which case it changes the DA and the SA into the values recognizable by DQDB. Other messages are processed accordingly by the MPU.

After translating the header, the MPU places the resulting message in the SIGNALLING mailbox. Now the MPU initiates a metasignalling procedure with the ST by placing the metasignalling segment in the METASIGNALLING MAILBOX and interrupting the QAF. It has placed the vector which identifies metasignalling exchange in the appropriate control register of the VSB I/F. The arrival of the response from the ST is announced by writing the received segment into the METASIGNALLING MAILBOX and interrupting the MPU, which reads the response. The MPU then forwards the Call set-up by interrupting the QAF module and providing the interrupt vector used for signalling exchange. The QAF first reads the address of the mailbox to be used from the appropriate registers residing in the VSB I/F module. The QAF module then reads the first segment and forwards it for transmission. The process is repeated for the number of cells the message consists of, as well as for all subsequent messages.

Once user VCIs have been allocated, the user exchange takes place via the hardware completely transparently to the IWU. The MPU only has to program the appropriate values into the Header Translator, and it does not intervene again until the connection tear-down.

The IWU performs metasignalling protocols with the ATM as do any other ATM subscribers. It also performs metasignalling with the DQDB ST entity as a CO DQDB service user.

**CONCLUSIONS**

The easy and cost-effective interworking of DQDB with ATM is of crucial importance for the evolution of broadband networks and the long-term success of MANs as gathering networks. The three practically useful scenarios for this interworking have been investigated in this paper, with the aim of achieving a robust, future-safe, and simple solution lending itself to easy and cost-effective implementations.

The most significant scenario from the preceding discussion emerges as the provision of CO ATM services through a CO DQDB network. From the ATM user standpoint, this is the most general case since the majority of ATM services are of the CO type.
For MANs to be able to efficiently transfer the basically CO ATM traffic, the definition of CO protocols compatible with ATM is paramount. Use of the current CL MAN service is not considered adequate from a QoS standpoint. As we saw in the interconnection options, without the separation of control and user planes in DQDB, we need to activate higher layer protocols in the IWU which inversely affect the simplicity and robustness of the implementation, and consequently the speed and cost. However, using a CO service along the lines presented above (i.e. compatible with ATM) results in a highly simplified user plane, which means efficient transfer. Remember that in the broadband network the percentage of control information is insignificant compared to the user plane. Thus, the processor-intensive but low bandwidth signalling functions assist in keeping the high bandwidth user traffic transfer simple. The latter are hardware intensive, and their duplication carries a significant cost penalty. That is why Parulcar and Turner take the view that the CO service with its inherent separation of control and user traffic is in general better suited for broadband networks.

One manifestation of this simplicity is the ability to perform the relay at a very low level, i.e. on the ATM cell/QA segment level. The equal size and same format of the cell/slot allow the avoidance of duplication of functions (and therefore H/W) which occurs when the relayed information must ascend and descend a high protocol stack at the relaying unit (i.e. segmentation/ reassembly, successive CRC calculations, etc.). We can also utilize uniformly the VCI resource across the whole connection both through ATM and DQDB, which brings the benefit of lower transit delay and IWU complexity. Both are crucial aspects, since the speeds of transfer approaches the current technology limits for mass produced components. Recall that in the CL DQDB service the functionality of the VCI field is relegated to a mere indication of the kind of service (i.e. connectionless).

As a consequence, the transit delay introduced by the IWU is much lower when using a CO DQDB service. The protocol overhead is only related to the conversion of the ATM cell header to a QA segment header, and vice versa. This is also a result of the introduction of the VCI routing functionality inside DQDB. In addition, this simplifies the usual node processing. When a CO DQDB service is used, the IWU directly injects traffic into the QA functions. The conclusion is that for a small penalty of the call set up a substantial improvement is obtained for the processing delay both in the IWU and the node functions included.

The authors are currently engaged in the definition and development of an IWU for the purposes of interconnecting ATM-TEs through the MAX (Metropolitan Area Communication Subsystem) subnetwork. The IWU will conform to a CO DQDB service.

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