ATM

VOL. 4

Pocket Guide

Wandel & Goltermann

Communications Test Solutions

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Pocket Guide for Asynchronous Transfer Mode and ATM Testing

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Introduction

Multimedia everyone is talking about it, from those fascinated by technology to those who are not. The trend is towards combining sound, images, text and moving pictures in order to teach, entertain or inform. A common experience of multimedia users is that even the latest computers have difficulty keeping pace with ongoing development. This, and the growth in PC networking on a global scale during this decade, has meant that network operators face completely new challenges. Historically, different networks that are based on different technologies have developed practically independently. Thus, on the one hand, we have telephone networks that are suitable for transmitting voice signals and, with corresponding restrictions in bandwidth, facsimile and data signals. On the other hand, networks that are tailored to the special requirements of data transmission have also been developed.
The abbreviation **ATM** stands for **A**synchronous **T**ransfer **M**ode.
The same idea that was behind the development of ISDN (Integrated Services Digital Network) is behind ATM: To provide a network that is capable of handling all current and future applications independently of their bandwidth requirements. The goal was to unite telecommunications with data communications.
Already ATM has shown that it will play a decisive role in coming years in the backbone segment of telecommunications networks. The introduction of new applications such as tele-medicine or video on demand (VoD) services are likely to prove a major influence in further expansion of ATM networks.
This Pocket Guide is intended to give you an introduction to the basics of ATM and then to give some details on various measurement methods.

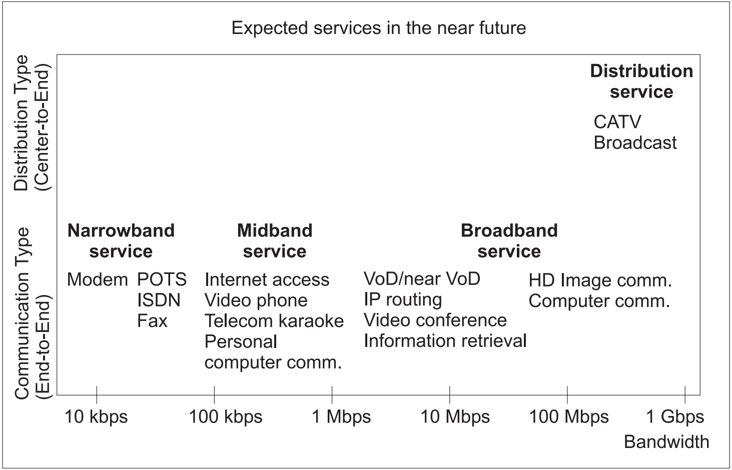


Figure 1: Summary of new services and their bandwidth requirements (Source: Fernmeldeingenieur 5/96)

The ATM market

ATM is probably the most controversial of any communications technology of recent years. Those who support ATM hail it as the future transport network providing guaranteed performance for widely differing services, whereas its detractors point to its complexity and relatively high cost of implementation, which is also reflected in the expected figures for market volume. It is, however, to be expected that solid growth will occur, particularly in the WAN sector. How far ATM will penetrate the subscriber access market remains to be seen.

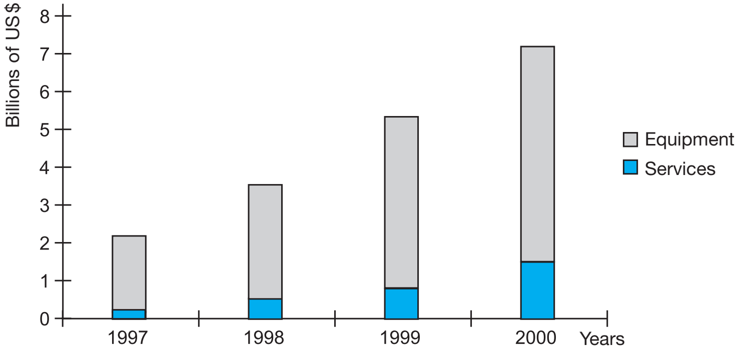


Figure 2: The global ATM market
(Source: Vertical Systems 1997)

Here are a few examples which indicate that ATM is well on the way to becoming a globally accepted technology:
British Telecom is planning an ATM network with 200 ATM switching centers (6/98) to be set up in the next few years. Deutsche Telekom already offers nationwide coverage under the brand name „T-Net-ATM". The next step is that the Global ATM product will be available in 15 countries around the world by early 1999. The Swedish company TELIA and Finnish Telecom are the most advanced in the field. Both these network providers offer IP (Internet Protocol) via ATM.

Why ATM?

Prior to ATM, each application required its own network. The main reason for this development was that the different services placed very different requirements on the transmission medium.
For example, a bandwidth of 3.1 kHz is adequate for transmitting voice signals. The delay in transmitting the voice signals must, however, be small and remain constant. The transmission of data between computers is a completely different story. The bandwidth requirements have grown enormously with the passage of time. As a result, only small quantities of data can be effectively transmitted using the telephone network. The manner of communication between computers is also vastly different to human conversation. Data transfer is characterized by bursts. In other words, there can be a long period of inactivity before data is transmitted for a few seconds at rates of several Mbit/s. The time delay is relatively unimportant. A constant time frame reference between the spoken and the received message is absolutely essential to communications between human beings.

Different technologies were thus employed in order to meet these differing requirements. This has led to time division multiplexing (TDM) on the one hand, used for telephony, and a whole host of standardized protocols on the other hand, these being mainly based on the use of variable length packets. As examples, we may quote X.25, Frame Relay and IP (Internet Protocol).

ATM provides the means to combine pure data networks and pure telephone networks into a single entity. The following advantages result from using ATM:

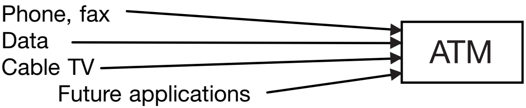
- Integration of various services such as voice, images, video, data and multimedia, with adaptation to the different requirements and traffic profiles.
- Standardization of network structures and components
  This results in cost savings for network providers. ATM allows integration of networks, leading to improved efficiency and management.
- Provision of bandwidth for new technologies such as tele-medicine, tele-learning, internet, video on demand, etc ...

- Transmission that is independent of the medium used
  PDH, SDH, SONET and other media can be used to transport ATM cells. All these transmission methods are transparent to ATM.

- ATM is scaleable, i.e. the bandwidth can be adapted extremely flexibly to meet user requirements.

- Guaranteed transmission quality to match the service required by the user (quality of service, QoS).

  Phone, fax ➡ Digital or analog telephone network
  Data ➡ Data networks such as X.25, Frame Relay, etc.
  Cable TV ➡ CATV networks



- ATM technology can be effectively used in two areas: Subsriber access an long-haul services. This allows costly interfaces to be avoided, and means that the same communications technology can be used throughout, from one subscriber to another.
  Despite these advantages, ATM is making only slow progress against existing LAN technologies.

What is ATM?

ATM (**A**synchronous **T**ransfer **M**ode) is a circuit-switched, cell-switched data communications method. It uses cells with a fixed length of 53 bytes to transmit both user and signaling information. This means that it is distinctly different from packet-switched systems such as X.25 or Frame Relay which make use of data packets of varying lengths. The cells are time-related and thus form a continuous data stream.

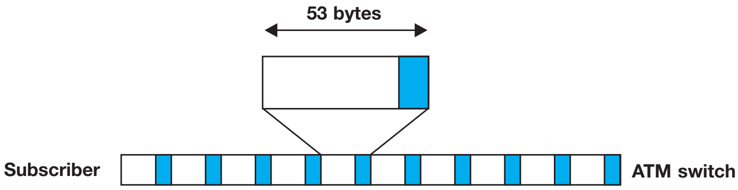


Figure 3: ATM cell stream

Compared with synchronous procedures that have a fixed assignment of timeslots, the cells used by a particular terminal equipment do not have a fixed position in the cell stream. The bandwidth requirements of the source are met by using a corresponding number of cells per unit time.

The illustration of a ski lift serves as an aid to visualizing this process (see Figure 4).

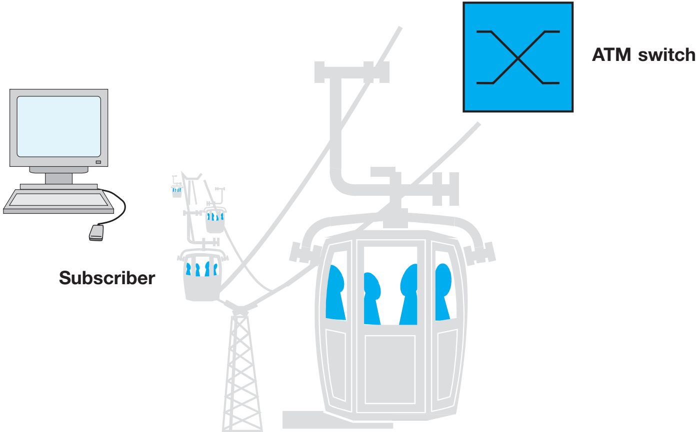


Figure 4: An analogy for ATM: The ski lift

The lifts move in an unbroken sequence from the valley up to the mountainside and back down again. If there are a lot of skiers, practically every lift place will be taken, so the capacity of the ski lift is used completely. If the number of skiers drops, some of the lift places will remain empty.

Bandwidth adaptation in ATM is very similar. A continuous stream of cells moves from the user to the network and vice versa. If there are no data to be transmitted, so-called idle cells are inserted in the stream. These contain no information at all. If the transmission bandwidth requirements increase, the ratio of the used cells to the idle cells will increase. This means that the bandwidth can be very easily adapted.

Standardizing ATM

Standardization of the ATM procedure is being advanced by two bodies. One is the **ATM Forum**, an association of some 700 manufacturers and providers of telecommunications equipment. The other is the international standardization authority known as **ITU-T** (formerly CCITT). Both these bodies work closely together, although it must be mentioned that the ATM Forum reacts much more rapidly to market requirements and new developments in technology. This results in minor differences between the recommendations of the two in some instances.

ATM interfaces

Distinctions are drawn between various interfaces in the ATM network. The interface between the subscriber switch and the terminal equipment is called the **UNI** (**U**ser **N**etwork **I**nterface). The interface between network switches is called the **NNI (N**etwork **N**ode **I**nterface). Separate signaling protocols are defined for both interfaces by ITU-T. The protocol for the public UNI is specified in Recommendation Q.2931. The NNI is defined by Recommendation Q.2764. Both these recommendations are closely based on the ISDN protocols.

Private networks have their own regulations for NNI and UNI. The protocols used are defined by the ATM Forum (private UNI and private NNI).

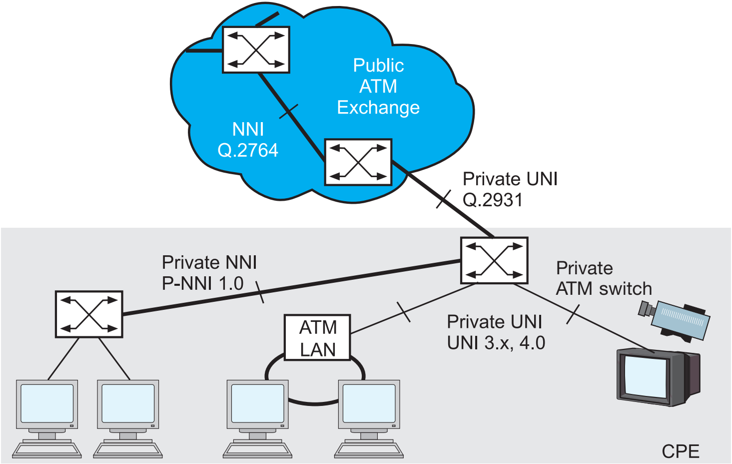
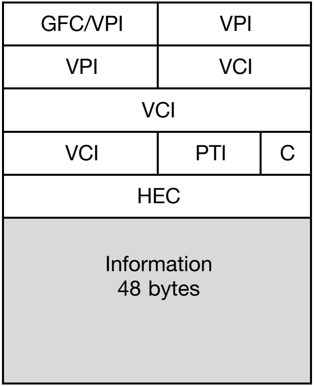


Figure 5: Simplified ATM network structure

It all started with a single cell …

ATM cells are the smallest standardized information units within the ATM network. All user and signaling information must be represented within this cell format. Each cell encompasses a total of 53 bytes, of which 5 bytes make up the cell header, leaving 48 bytes available for the user or signaling information. The information in the cell header is used mainly to direct the cell through the ATM network.



GFC Generic Flow Control
4 bits (to UNI only,
otherwise = VPI)

VPI Virtual Path Identifier,
8 bits (UNI) or 12 bits (NNI)

VCI Virtual Channel Identifier, 16 bits

PTI Payload Type Identifier, 3 bits

C Cell Loss Priority, 1 bit

HEC Header Error Control, 8 bits

Figure 6: The ATM cell format

- **GFC** (**G**eneric **F**low **C**ontrol): This field contains 4 bits and supports the configuration of the subscriber equipment. It is intended for control of a possible bus system at the user interface and is not used at the moment.
- **VPI** (**V**irtual **P**ath **I**dentifier): The VPI contains the second part of the addressing instructions and is of higher priority than the VCI. The VPI collects several virtual channels together. This allows rapid direction of the cells through the network, as the network contains equipment called ATM cross-connects that are capable of switching the cell stream in various directions based on the VPI. The VPI and VCI are assigned by the switching centers when the call is being established.
- **VCI** (**V**irtual **C**hannel **I**dentifier): This field contains part of the addressing instructions. All cells belonging to the same virtual channel will have the same VCI. The virtual channel identifier in each case indicates a path section between switching centers or between the switching center an the subscriber. All these different VCIs together mark the path through the network.
- **PTI** (**P**ayload **T**ype **I**dentifier): This field indicates the type of data in the information field. A distinction is made between network and user information.
- **CLP** (**C**ell **L**oss **P**riority): The content of this field determines whether a cell can be preferentially deleted or not in the case of a transmission bottleneck. Cells with CLP-0 have higher priority than cells with CLP-1.

- **HEC** (**H**eader **E**rror **C**ontrol): This field is provided in order to control and, to some extent, correct errors in the header data that may occur. The HEC is used to synchronize the receiver to the start of the cell. A CRC procedure is used for error detection (cyclic redundancy check). The CRC is based on division of the header field by the generator polynomial $x^8 + x^2 + x + 1$.

What are the different cell codes?

As well as the cells for transmitting payload data and the idle cells already described, further cell types have been defined. There are cells for transmitting signaling information, and so-called OAM cells (operation, administration and maintenance), which can be inserted into the cell stream as required. The latter type of cell carries information for monitoring errors and alarms, controlling network elements and localizing faults.

The so-called unassigned cells should also be mentioned. These are inserted in the cell stream just like idle cells when there is no information that needs to be transmitted. They contain GFC information but are not assigned to a particular connection.

All cells are identified by means of specially reserved combinations of VPI and VCI (see table).

Meaning	VPI	VCI	PTI	CLP
Unassigned cell	00000000	00000000 00000000	Any value	0
Invalid	Any VPI value other than 0	00000000 00000000	Any value	B
Point-to-point signaling	XXXXXXXX	00000000 00000101	0AA	C
Segment OAM F4 flow cell	Any VPI value	00000000 00000011	0A0	A
End-to-end OAM F4 flow cell	Any VPI value	00000000 00000100	0A0	A
VP resource management cell	Any VPI value	00000000 00000110	110	A
Segment OAM F5 flow cell	Any VPI value	Any VCI value other than decimal 0, 3, 4, 6, 7	100	A
End-to-end OAM flow cell	Any VPI value	Any VCI value other than decimal 0, 3, 4, 6, 7	101	A
VC Resource managment cell	Any VPI value	Any VCI value other than decimal 0, 3, 4, 6, 7	110	A
Reserved for future VC functions	Any VPI value	Any VCI value other than decimal 0, 3, 4, 6, 7	111	A

A: May be 1 or 0, depending on the function of the ATM layer

B: The content of this bit has no meaning

C: The transmitting terminal equipment should set the CLP bit to zero. The value may be altered by the network.

Table 1: Combinations of reserved VPI, VCI and PTI values at the Public UNI

The virtual connection, or: How a cell finds its way

ATM is a circuit switched communication procedure, which means that a connection through the network must be established before information can be transferred (just like a telephone connection). The connection through the ATM network is termed “virtual”, since it does not exist physically, but is present only in the form of “routing tables” in the switching centers.

The cells are steered through the network using the information in the VPI/VCI. The information only applies to a section of the connection in each case. The VCI is assigned by the switching center and, together with the VPI, identifies all the cells belonging to a particular connection. When a connection is cleared, the VCI values are made available to the network for use. The VPI values indicate so-called virtual paths, which allow the channels to be collected together. As shown in figure 7, the ATM cross-connects can change the VPI and thus perform a degree of selection. The switching of the cells with the attendant changes in both parts of the addressing information is handled exclusively by the ATM switches.

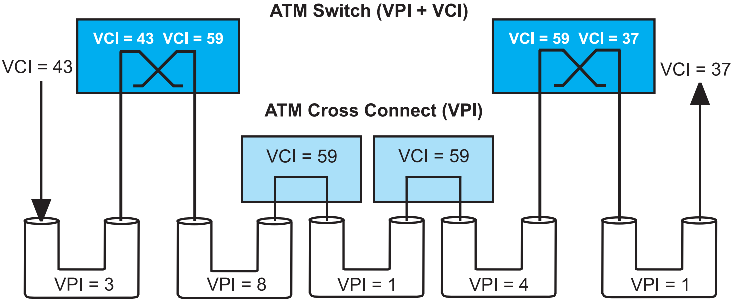


Figure 7: Example of a virtual path

The ATM reference model

The layer model for ATM is composed of four layers based on the principle of the ISO-OSI layer model. To represent ATM exactly, two special ATM layers needed to be defined, namely the ATM layer and the ATM adaptation layer. All the layers are linked together via three communications levels. The structure is shown in figure 8.

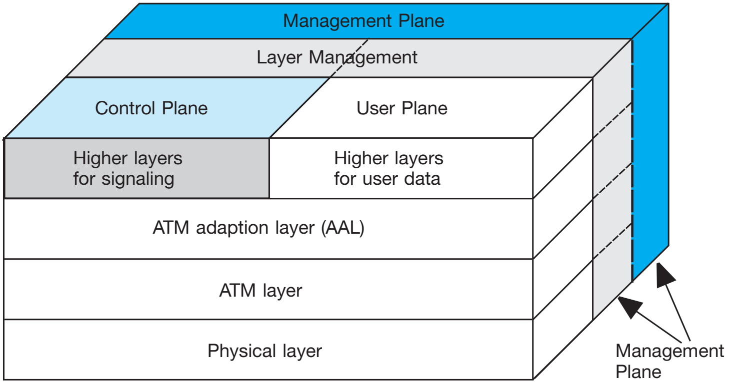


Figure 8: The ATM reference model

The tasks of the three communications planes are described by ITU-T as follows:

- The user plane transports the user data for an application. It uses the physical, ATM and ATM adaptation layers to do this.
- The control plane takes care of establishing, maintaining and clearing down user connections in the user plane. The key word here is signaling.
- The management plane includes layer management and plane management. Layer management monitors and coordinates the individual layer tasks. Plane management handles monitoring and coordination tasks in the network.

Physical layer

The physical layer is the only layer that has a real, physical connection to another system. ATM does not specify a particular transport medium. SDH and SONET are the preferred media in the core segment of the network. These technologies guarantee high bandwidths and low error rates. PDH and asynchronous transmission methods are also used. The xDSL technologies will play an ever increasing role in the access segment. These procedures allow data to be transferred at rates of several Mbit/s using existing twisted copper pairs.

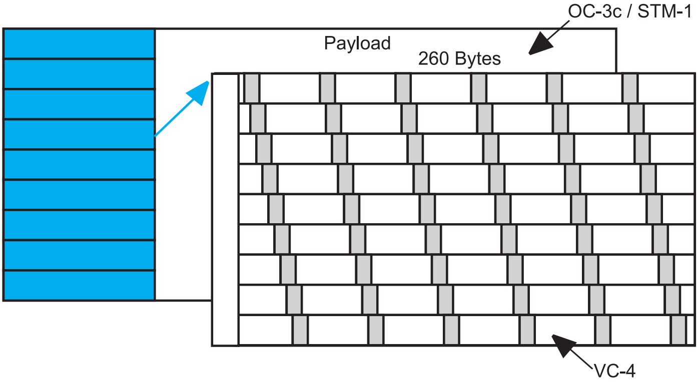


Figure 9: SONET/SDH as physical layer

ATM layer

The main task of the ATM layer is transporting and switching the ATM cells. To do this, it adds the cell headers to the data received from the ATM adaptation layer. These headers contain all the control and addressing information. Cells that are used for special purposes, such as OAM cells, are marked accordingly. The header data is safeguarded against errors using a CRC procedure (cyclic redundancy check), the result of which is transmitted in the HEC. The ATM layer evaluates the VPI/VCI information of incoming ATM cells. The evaluation of the HEC is part of the physical layer.

ATM adaptation layer (AAL)

The ATM adaptation layer, as its name suggests, adapts the data of higher layers to the format of the information field of the ATM cell. This takes place as determined by the services being used. The AAL also reconstructs the original data stream from the information fields and equalizes out variations in cell delay. Matching of protocols for the superior layers also takes place in this layer.
To be able to meet the various requirements that data communications demands, four service classes were created. In turn, these classes are assigned to various service types. Four service types exist, namely: AAL1, AAL2, AAL3/4 and AAL5.
The AAL is divided into two sublayers, the convergence sublayer (CS) and the segmentation and reassembly sublayer (SAR). The SAR sublayer divides or segments the data from higher layers to fit into the information field of the cells, and reassembles the data on the receive side to form the original data. The CS takes care of such functions as identifying messages and regenerating timing or clock information; these functions will vary depending on the service selected.

AAL type 1

This standardized protocol is used for transporting time-critical applications having a constant bit rate (such as voice and video signals) and to emulate PDH paths such as E1 or DS1.

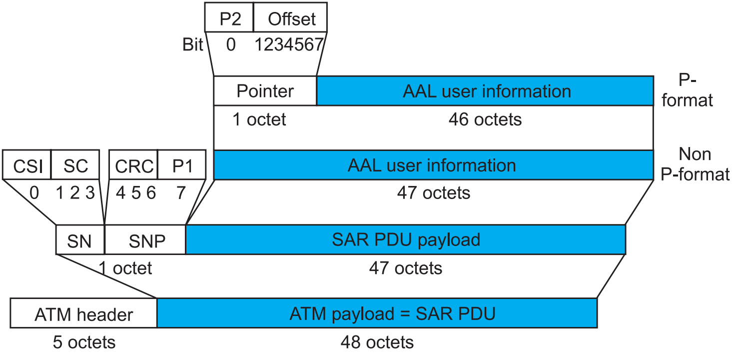


Figure 10: AAL service type 1

AAL type 2

This AAL type is used for time-critical services having a variable bit rate. One example of this is the use of ATM in mobile radio networks.

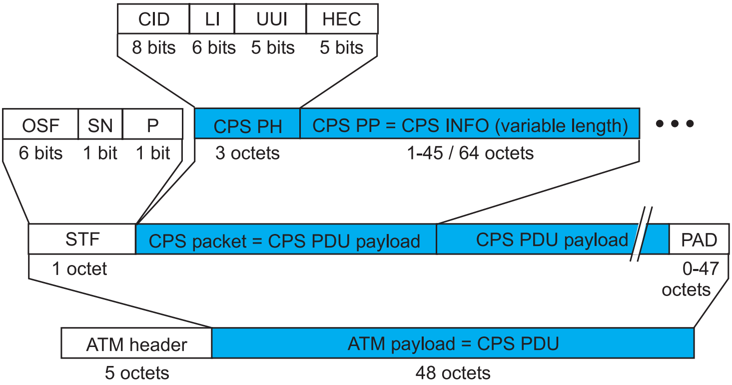
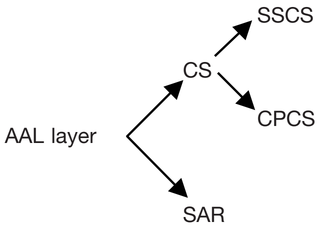


Figure 11: AAL service type 2

AAL type 3/4

The AAL type 3/4 has the task of adapting circuit-switched and circuit-less data communications to the ATM cell format. The area of application is in linking LANs and in transmitting data using ATM. Two further sublayers are used to describe the function. The convergence sublayer is further subdivided into the common part convergence sublayer (CPCS) and the service specific convergence sublayer (SSCS).



Information is added to the data from the higher layers in the SSCS and CPCS as well as in the SAR sublayer. This information is used, for example, to provide user data error safeguards, flow control and to indicate the segmentation.

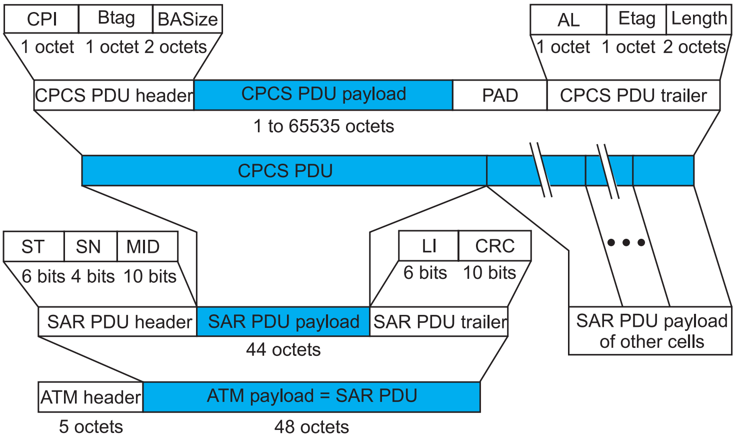


Figure 12: AAL service type 3/4

AAL type 5

AAL type 5 was created for the special requirements of Frame Relay and TCP/IP. It is a slimmed-down version of AAL 3/4.
Data coming from the SSCS is completed with additional information. The padding bytes ensure that the length of the data is always divisible by 4. The CRC field contains the checksum across the entire CPCS PDU. The length field indicates the number of bytes in the SAR PDU (from 1 up to a maximum of 65535). After this, the data packet formed in this way is represented in the SAR layer by segments that are 48 bits long.

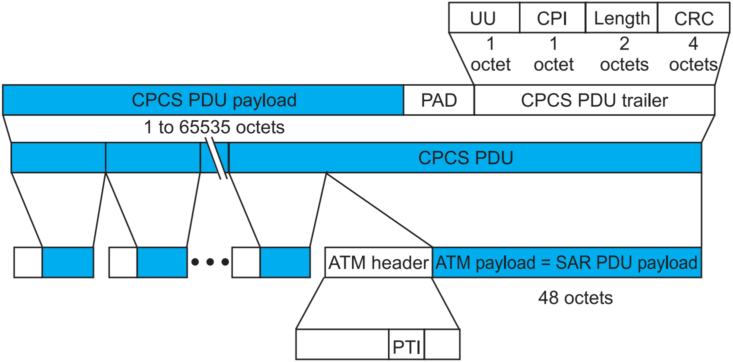


Figure 13: AAL service type 5

Network management with OAM cells

The OAM cells allow the ATM network provider to monitor the network for errors that may occur, to determine the quality of the connection and to configure the performance measurement of an ATM network element from a central location. The cells take the same path through the network as the user cells. They are distinguished by combinations of reserved VCI and PTI values in the header (see under “cell types”). The OAM cell format is illustrated in figure 14.

Cell header	OAM type	Function type	Function-specific field	Reserved for future applications	Error Detection Code (CRC-10)
5 bytes	4 bits	4 bits	45 bytes	6 bits	10 bits

Figure 14: Standard OAM cell format

OAM type: OAM cell type (see table 2)

Function type: Function of OAM cell (see table 2)

Function-specific field: Depends on the OAM cell type (performance management or activation/deactivation)

EDC: Error safeguarding for the payload section using CRC-10.

OAM Cell Type	Value	Function Type	Meaning	Value
Fault management	0001	AIS	Indicate defects in forward direction	0000
		RDI	Indicate defects in backward direction	0001
		Continuity check	Continuous monitoring of connections	0100
		Cell loopback	Check connection/ continuity Localize errors Test connections before putting into service	1000
Performance management	0010	Forward monitoring	On-line quality assessment	0000
		Backward monitoring	Indicate performance assessment in the backward direction	0001
		Monitoring & reporting		0010
Activation/ deactivation	1000	Performance monitoring	Activate and deactivate performance monitoring and continuity check	0000
		Continuity check		0001

Table 2: OAM cell types and function type codes

Five different levels of network management are distinguished. Levels F1 through F3 are assigned to the physical layer, for example SDH or SONET. The information from the physical layer is transmitted using overhead bytes (compare “SDH/SONET Pocket Guide”) The F4 level is used for virtual path connections and level F5 is assigned for virtual channels.

Errors and alarms

One of the practical applications for the OAM cells is for alarm management in ATM networks (see figure 15). If a defect occurs in the physical layer, this is indicated to the VP layer and, as a result, to the VC layer. This causes an OAM cell indicating a VP or VC RDI alarm to be

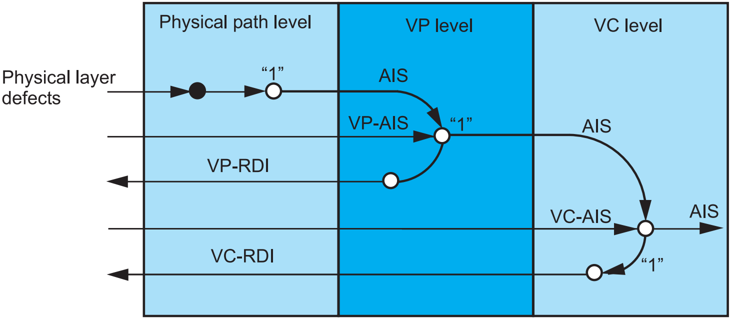


Figure 15: ATM Alarm Management

transmitted in the reverse direction. This signals to the transmitting ATM network element that an error has occurred in the transmit path. This method of alarm management and the criteria for triggering alarms are specified in ITU-T Recommendation I.610.

Table 3: Overview of ATM alarms

Abbreviation	Meaning
VP-AIS	Virtual Path Alarm Indication Signal
VP-RDI	Virtual Path Remote Defect Indication
VC-AIS	Virtual Channel Alarm Indication Signal
VC-RDI	Virtual Channel Remote Defect Indication

Cell synchronization

How does the receiver synchronize to the ATM cell stream? Or, put another way, how does the receiver detect where one cell starts and another cell ends?
The answer is that the receiver attempts to locate the HEC of the cell header by checking the cell stream bit by bit. As already mentioned in the discussion on cell format, the content of the HEC is a CRC of the remainder of the cell header. The algorithm used for producing this check sum is known to the receiver. The received bit stream is thus shifted bit by bit until the check sum for the first four bytes is equal to the fifth byte. This is known as the HUNT state. If correspondence be-

tween the calculated check sum and the HEC is found, the receiver goes into PRESYNCH state. It now only remains to be checked that a bit combination has been detected by chance that happens to correspond to the check sum. For this reason, the data stream is now shifted cell by cell and checked to see that *m* consecutive HECs are correct (*m* is usually set at 6). If an HEC is not correctly detected, the receiver reverts to the HUNT state. Once *m* HECs have been correctly detected, the receiver goes into the SYNCH state, and the cells are detected correctly. If now *n* consecutive HECs are incorrect, the receiver again reverts to the HUNT state (*n* is usually set at 7).

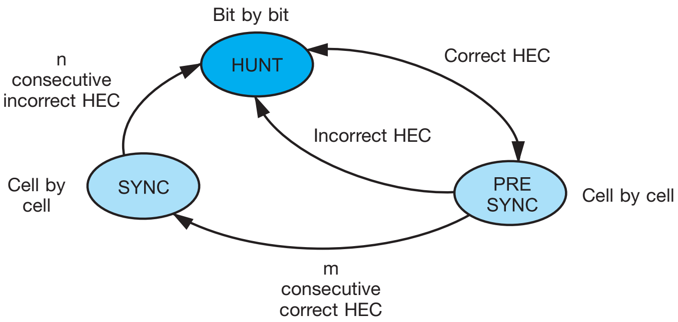


Figure 16: State diagram for cell synchronization

Error detection and correction

The HEC allows detection of errors in the cell header. The algorithm used permits just one error to be corrected. Error evaluation in the receiver operates according to this principle. If an error is detected, it will be corrected and the receiver goes from correction mode into detection mode.
An HCOR alarm (correctable header errors) is triggered. If more than one error is detected in the cell header, the cell will be immediately rejected and the receiver again goes into detection mode.
In such cases, an HUNC alarm (uncorrectable header errors) is triggered. If the receiver is in this state, each subsequent errored cell header will result in rejection of the corresponding cell, even if only one error is present in the header. When a cell without errors is received, the receiver reverts to correction mode.

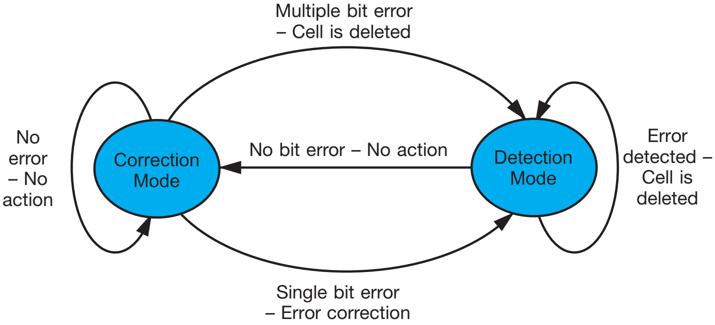


Figure 17: Automatic HEC model for ATM switching equipment

Signaling in ATM

ATM is a circuit switched communications procedure, i.e. a virtual connection must be established before user data is transferred. In PVC (permanent virtual circuit) networks, the connections are analogous to leased lines that are switched between certain users. A change can only be made by the network provider. This type of ATM network often forms the initial stage in the introduction of this technology. Such networks are converted step-by-step into SVC (switched virtual circuit) networks. Users connected to this type of network can set up a connection to the user of their own choosing by means of signaling procedures. This can be compared with the process of dialing a telephone number.

A separate channel is required for transmission of the signaling information. This channel is fixed for end-to-end connections. Cells with VCI-5 are recognized by the switching center as containing signaling information. As has already been mentioned, various logical interfaces are defined for ATM networks. ITU-T and the ATM Forum have specified protocols for these interfaces; these have been published in the form of recommendations and specifications.

Signaling on the UNI is governed by ITU-T Recommendation Q.2931. This recommendation is derived from the ISDN signaling detailed in Q.931. It applies to end-to-end (point to point) connections. The ATM Forum recommendations UNI 3.1 and 4.0 are a subset of Q.2931. They do, however, contain additions covering point to multipoint connections, private addressing and traffic parameters. The NNI is covered by ITU-T Recommendation Q.2764. This recommendation also stems from an ISDN protocol, namely Q.764.

A special AAL known as the SAAL (signaling AAL) has been defined for signaling. The SAAL is defined in ITU-T Recommendation Q.2100 and AAL5. Since signaling data must be secured against errors, a special protocol has also been specified. The service specific convergence sublayer (SSCS) consists of two further sublayers known as the SSCOP (service specific connection oriented protocol) and the SSCF (service specific coordination function) respectively. The SSCOP takes care of safeguarding against errors by operating similarly to the HDLC LAPD protocol in the D channel of ISDN. The SSCF forms the link between the higher layers and the SSCOP.

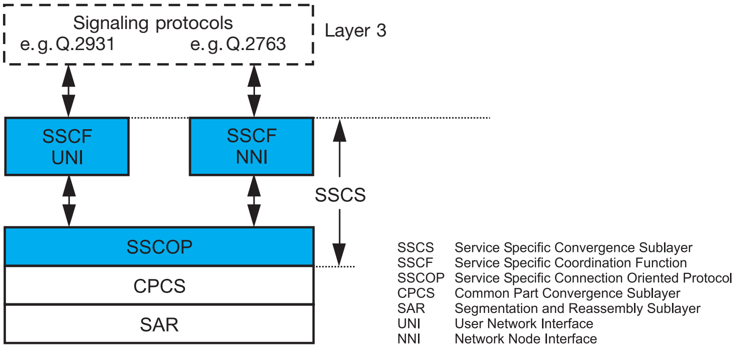


Figure 18: Layer format for the signaling AAL

Actual signaling is done using pre-defined messages that are exchanged between an ATM terminal and the switching center or between two switching centers. The sequence followed during the exchange is also defined. An example of this exchange of messages at the UNI is illustrated in figure 19. A detailed discussion of the signaling is beyond the scope of this publication.

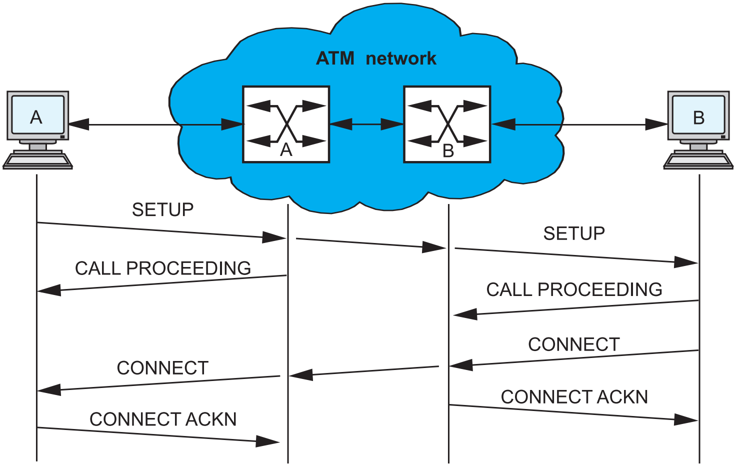


Figure 19: Example of signaling at the UNI (call establishment)

Addressing in ATM networks

Each user in an ATM network having dial-up connections requires an ATM address ("telephone number") to allow contact to be made. ITU-T Recommendation E.164 specifies addresses for (narrow-band) ISDN, including ordinary telephone numbers. The address consists of a maximum of 15 BCD characters. The address is structured in three parts called the regional codes (CC, NDC) and the subscriber number itself (SN). The lengths of the fields vary from one country to another.

CC = Country Code
NOC = National Destination Code
SN = Subscriber Number

Figure 20: ITU-T E.164 address

NSAP address formats: These are 20 bytes in length and are composed from a network specific and a device specific part. To distinguish between the different formats, one byte of the address is reserved for the AFI (authority and format identifier). The device specific part of the address comprises 6 bytes (ESI, end system indicator) and may, for example, contain a 48-bit MAC address (also often called the "hardware address").

Embedded ITU-T E.164 address:

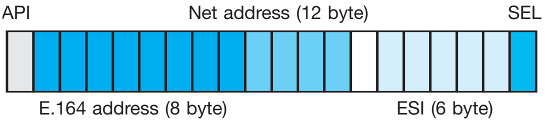


Figure 21: Embedded ITU-T E.164 address

As the E.164 addresses are a maximum of 15 characters, leading zeros are added and padding ("1111" or "F" hex) is inserted into the last octet to bring the length up to 8 octets.

DCC (data code country) and ICD (international code designator) format The AFI determines whether the hierarchy format is DCC or ICD.

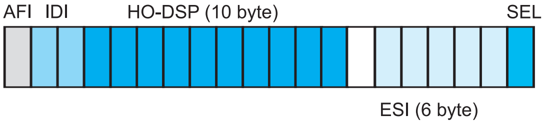


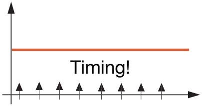
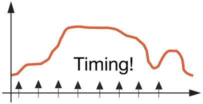
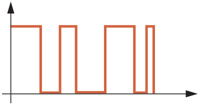
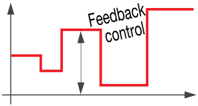
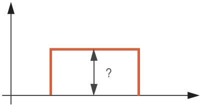
Figure 22: NSAP address (DCC/ICD format)

ATM service categories

As mentioned in the introduction, ATM networks are characterized by the wide range of services that are offered. The designations used by ITU-T and the ATM Forum for the various service types differ. Table 4 gives a summary of those services that are standardized.

Specific applications are, of course, behind these various service categories. It is not always possible to unequivocally state which service category is suitable for a particular application. A summary of suggested service categories for some specific application is shown in table 5.

Table 4: Summary of ATM service categories

ATM-Forum	ITU-T	Possible traffic profile	Description/ Applications
Constant Bit Rate **CBR**	Deterministic Bit Rate **DBR**		Constant bit rate with time reference (real-time) Speech, video
Realtime Variable Bit Rate **rt-VBR**	under study		Variable bit rate with time reference (real-time) Compressed video/audio
Non realtime Variable Bit Rate **nrt-VBR**	Statistical Bit Rate **SBR**		Variable bit rate without time reference File transfer
Available Bit Rate **ABR**	Available Bit Rate **ABR**		Resource-dependent bandwidth-allocation, network has interactive control
Unspecific Bit Rate **UBR**	–		No guarantee for traffic and QoS parameters

	CBR	rt-VBR	nrt-VBR	ABR	UBR
Critical data	●●	●	●●●	●	○
LAN interconnect	●	●	●●	●●●	●●
WAN transport	●	●	●●	●●●	●●
Circuit emulation	●●●	●●	○	○	○
Telephony, Video-conferencing	●●●	○○	○○	○	○
Compressed audio	●	●●●	●●	●●	●
Video distribution	●●●	●●●	●	○	○
Interactive multimedia	●●●	●●●	●●	●●	●
●●● Optimum; ●● Good; ● Fair; ○ Not suitable; ○○ Under review					

Table 5: ATM service categories and applications (Source: ATM Forum)

Traffic contract

ATM services are classified according to various criteria:

- Type of service, characterized by the traffic parameters
- Service quality, characterized by the QoS parameters

The primary characteristics must be agreed upon in the form of a traffic contract before communication starts.

Traffic parameters
The traffic parameters define the type of service:

Peak Cell Rate (PCR): This defines the maximum bit rate that may be transmitted from the source.
Cell Delay Variation Tolerance (CDVT) peak: This is the tolerance in cell delay variation referred to the peak cell rate.
Sustainable Cell Rate (SCR): This is the upper limit for the average cell rate that may be transmitted from the source.
Cell Delay Variation Tolerance (CDVT) sustained: CDVT referred to the sustainable cell rate.
Maximum Burst Size (MBS)/Burst Tolerance (BT): Maximum time or number of cells for which the source may transmit the PCR.
Minimum Cell Rate (MCR): Minimum cell rate guaranteed by the network (for ABR).

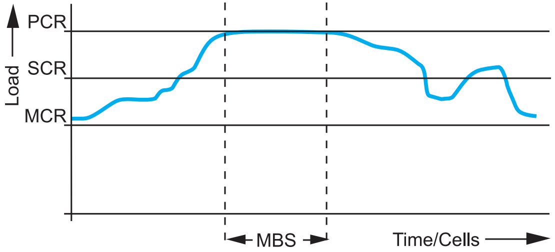


Figure 23:
ATM traffic parameters

Note: The traffic parameters in the traffic contract are only indirectly related to the source parameters of terminal equipment. The source parameters reflect the transmission behavior of the ATM terminal equipment; they should not exceed the traffic parameters.
It is often not necessary to use all the parameters to define a service category. For example, CBR is completely defined by specifying PCR and CDVT peak (also see table 6).

Attributes	**CBR**	**rt-VBR**	**nrt-VBR**	**UBR**	**ABR**	**Parameter class**
CLR	defined	defined	defined	not defined	defined	*QoS*
CTD and CDV	CDV and Mean CTD	CDV and Max CTD	only Mean CTD	not defined	not defined	*QoS*
PCR and CDTV	defined	defined	defined	defined	defined	*Traffic*
SCR and BT	not usable	defined	defined	not usable	not usable	*Traffic*
MCR	not usable	not usable	not usable	not usable	defined	*Traffic*

Table 6: Service categories and their parameters

Quality of service (QoS) classes

The QoS classes are independent of the service. The following classes have so far been defined:

Class 0: Unspecified
Class 1: Circuit emulation, CBR video
Class 2: VBR audio and video
Class 3: Circuit-switched data traffic
Class 4: Circuitless data traffic

The classes are differentiated by specifying different values for the following parameters:

- CTD
- CDV
- CLR (differ for cells with CLP-0 and CLP-1)

Even narrower classifications may be used in the future.

Traffic management

To ensure that a given quality of service is maintained for all ATM services, it is important that the network does not become overloaded. The individual connections must also not influence each other to the extent that a reduction in quality occurs. Control and regulation mechanisms have been introduced to allow the different virtual channels to work together smoothly. These measures are collectively known as "traffic management".

Traffic management functions

- **Connection admission control (CAC)**
  Checks during the signaling procedure whether a connection can maintain the requested QoS and does not adversely affect the QoS of existing established connections within the framework of the traffic contract.

- **Usage parameter control (UPC) or policing**
  This monitors that the parameters agreed to in the traffic contract are being adhered to. Cells that do not conform are tagged accordingly (CLP-1).

- **Cell loss priority control**
  Ensures that tagged cells (CLP-1) are rejected if the need arises.

- **Traffic shaping**
  This is performed by terminal equipment and some network elements to ensure that the transmitted cell stream conforms to the traffic contract at all times.

- **GCRA (generic cell rate algorithm) also known as the "leaky bucket" algorithm.**
  This algorithm is employed by UPC as well as traffic shaping. The PCR, SCR and MBS parameters are controlled with the aid of the GCRA. The principle can be illustrated by a leaky bucket. Assume that the bucket is full of ATM cells. The leak in the bucket is just large enough to ensure that the bucket does not overflow when ATM cells conforming to the standard are received.

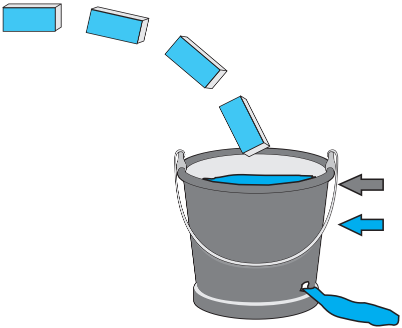


Figure 24: Illustration of the "leaky bucket" algorithm

The cells are tagged (CLP-1) if they are filled above a certain capacity. In the algorithm, this is done by using a cell counter to represent the bucket. This counter is incremented by one for each incoming cell. The "leak rate" in the algorithm is the decrement rate which reduces the counter value by one at certain intervals. This rate is given by the cell rate under consideration (e.g. 1/PCR) and is governed by the minimum distance between two consecutive cells. The bucket volume is analogous to the cell counter range, which is represented by the permissible time tolerance for the incoming cells. This value is determined through the traffic contract or is set by the network provider and is called CDVT (cell delay variation tolerance). If the counter exceeds a certain value, the cells are assumed not to conform to the contract. To counteract this, non-conforming cells can now either be tagged (CLP-1) or dropped. The algorithm is called “dual leaky bucket” if several parameters (e.g. PCR and SCR) are monitored at once, or “single leaky bucket” if only one parameter is monitored.

ATM measurements

ATM is designed to transmit a wide range of different services and to guarantee a specific level of quality for the transmission. The resulting bandwidths are very large and the services themselves place different demands on the system. These facts, coupled with the large number of interfaces to other technologies and protocols, mean that there is an extremely wide field of applications for ATM measuring equipment.
Testing is an important part of the “life cycle” of every ATM network element. The aim in each case is to guarantee correct function and to reduce operating costs. The highest efficiency possible for ATM networks can be best achieved through a combination of network management systems and external measuring equipment.
The measurement tasks can be broadly split into the two application areas: Telecommunications (MAN, WAN) and data communications (LAN).

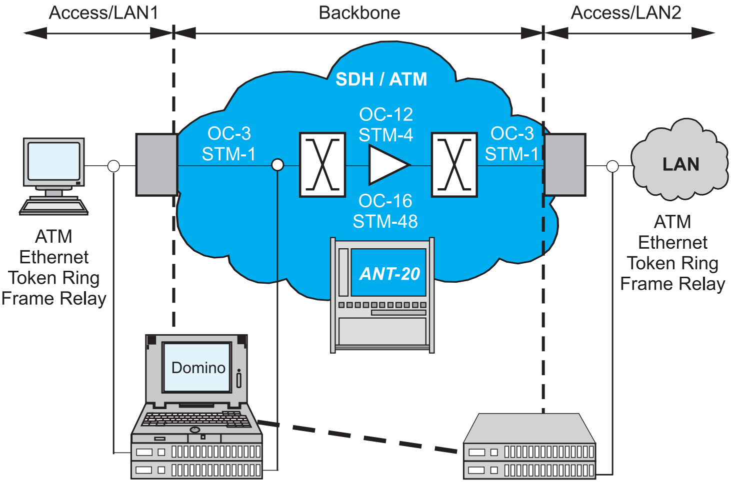


Figure 25: Fields of application for ATM measuring equipment

An overview of the wide range of test tasks is given below.

Physical layer

- Ensuring correct operation of the transmission layer (SONET, SDH, ADSL, etc.)

ATM layer

- Performance analysis (quality of service)
- Sensor tests (alarms)
- OAM management
- Traffic management (usage parameter control, etc.)

ATM adaptation layer

- Test for error-free operation

Analysis and troubleshooting within the services and applications used, internetworking

- SVC signaling tests
- Services: ILMI, LANE, MPOA, etc.

Monitoring

- Determining system loading and traffic profile

Some of these measurement tasks are explained further in the following sections to give you an idea of the kinds of measurement involved.

How tests are made

ATM measurements can be made in two different ways:

1. Out-of-service
As the name suggests, these measurements require interruption of actual traffic. For this reason, these tests are mainly used during production, installation and verification, and when major faults occur that involve an ATM system that is already in operation. Single ATM channels can still be tested in the Out-of-service mode even if the entire system already runs.

2. In-service
These measurements are mainly used for monitoring traffic. They allow determination of the performance of the ATM network and statistical evaluations can be made to determine the network loading. It is possible to connect the test equipment to the network such that the traffic flow is not affected or impeded. This can be done using optical splitters which tap off a small part of the optical power from the signal for measurement purposes. Another possibility is to use test equipment in so-called “through” mode, where the signal passes through the test instrument. The signal itself can, however, be affected by this process. The third possibility is to make use of test points that are built in to the system by the ATM equipment manufacturers.

Quality of Service

QoS parameters (what is measured?)
The following parameters are defined in ITU-T Recommendation I.356, representing the results of a QoS test:

$$\text{Cell loss ratio (CLR)} = \frac{\textit{number of cells lost}}{\textit{total number of cells transmitted}}$$

$$\text{Cell error ratio (CER)} = \frac{\textit{number of errored cells}}{\textit{total number of cells transmitted (including errored cells)}}$$

$$\text{Cell Misinsertion rate (CMR)} = \frac{\textit{number of wrongly inserted cells}}{\textit{time interval}}$$

Cell transfer delay (CTD) is the time between t2 and t1 of a test cell, where
t1 = time the cell enters the device under test
t2 = time the cell leaves the device under test

Mean cell transfer delay (MCTD) is the arithmetical mean of a certain number of CTD values.

Cell delay variation (CDV) is the degree of variation in the cell transfer delay (CTD) of a virtual connection. By defining the quality of service, it is possible to offer different levels of service, e.g. by different guaranteed maximum cell loss rates. This gives service providers a means for structuring the charges made for the service, but it also means that the service provider must be able to demonstrate the QoS to the user

QoS measurement to ITU-T O.191 (how is the measurement made?)

In Recommendation O.191, the ITU-T has specified measurement methods that can be used to demonstrate the QoS in the ATM layer. This replaces the manufacturer-specific and often insufficient methods that have been used in the past.

Recommendation O.191 basically describes a diagnostic model for performance analysis in which test cells are transported over an agreed virtual connection. The procedure is an out-of-service measurement. Important: The O.191 measurement tests performance on a cell-by-cell basis, i.e. in the ATM layer. The function and performance of the individual AALs must be considered separately.

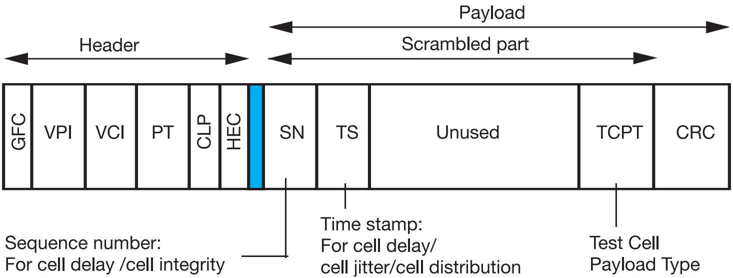


Figure 26: Basic test cell format

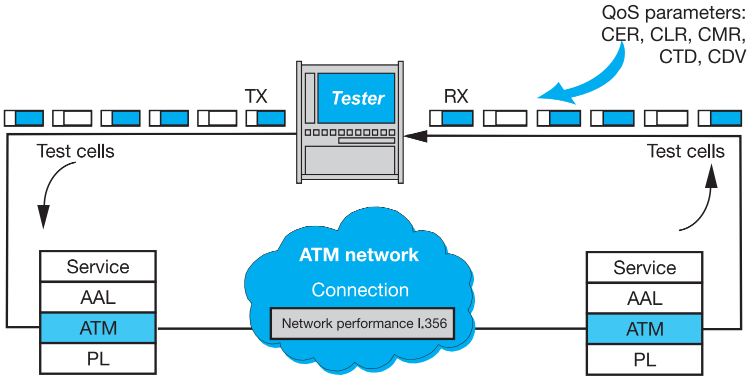


Figure 27: Measuring the QoS parameters as per ITU-T O.191

Usage parameter control test

Usage parameter control (UPC) functions are intended to prevent non-conforming ATM traffic from one user affecting other users. The availability and quality of UPC functions is therefore an important factor when selecting ATM switches for use in the network. UPC, also known as policing, is an important part of traffic management. During acceptance testing, a check is made to see how well the policing functions are supported by the ATM switch.

The simplest way to do this is by means of a self call in two stages: An ATM test channel together with all parameters (traffic contract, connection type, etc.) is established first. Once the connection is successfully established, the second step tests the reaction of UPC. This is done by specific manipulation of the transmission behavior of the test instrument (conforming/non-conforming traffic).

Step 1:

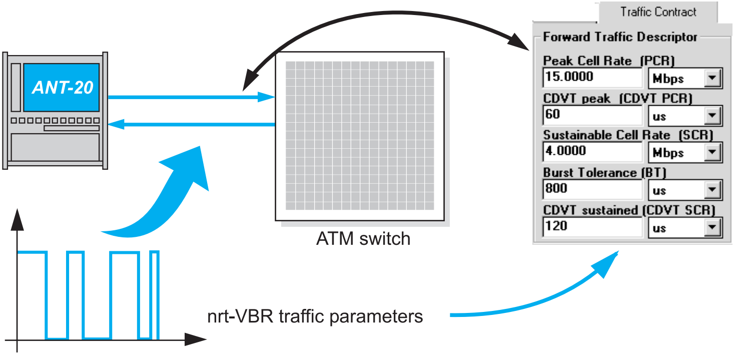


Figure 28: Setting the traffic contract parameters

Step 2:

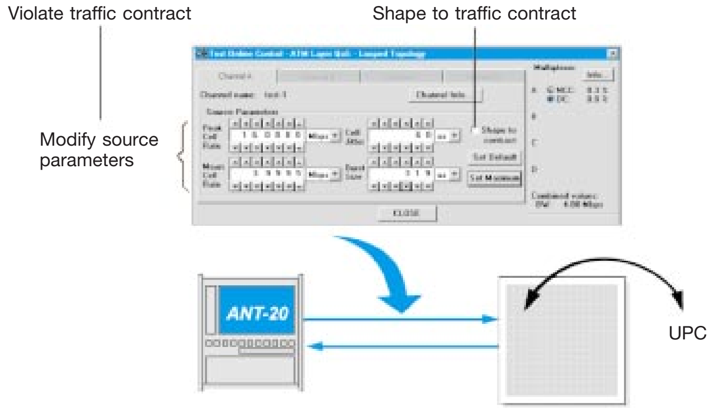


Figure 29: Checking the source parameters in real time

Channel transparency test

A complete bit error ratio test across an ATM channel has many uses. Among other things, it shows whether an established connection is without errors. An AAL-0 BERT tests the entire ATM channel payload by means of a bit sequence. In contrast, an AAL-1 BERT tests the AAL-1 PDU.
The example shows the channel under test alongside other established ATM connections.

In this case, the test channel is a unidirectional permanent virtual channel connection (PVCC). The test equipment checks whether the received bit sequence corresponds to the one that was transmitted. It is possible to test whether a loop is really present in the ATM switch by inserting specific errors into the pattern.

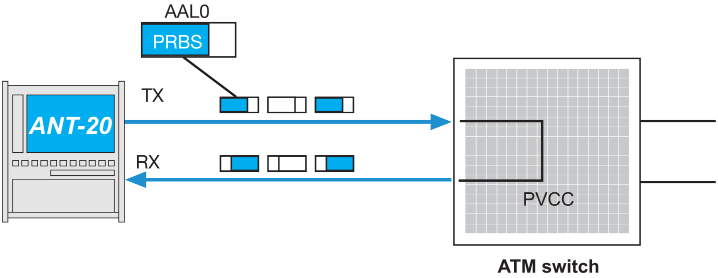


Figure 30: ATM BER test

Sensor test: Loss of cell delineation

As already detailed in the section on "Cell synchronization", the principle of ATM switch synchronization to an incoming cell stream can be described with the aid of a state diagram. The LCD alarm indicates to the network provider that this synchronization has been lost. The aim of the measurement is to cause the ATM switch to lose synchronization in a specific manner and to test whether synchronization is restored. A sequence of 7 consecutive errored cell headers is transmitted to the switch for this purpose. This should cause an LCD alarm to be triggered. If the transmission of errored cells is now stopped, the switch should re-synchronize.

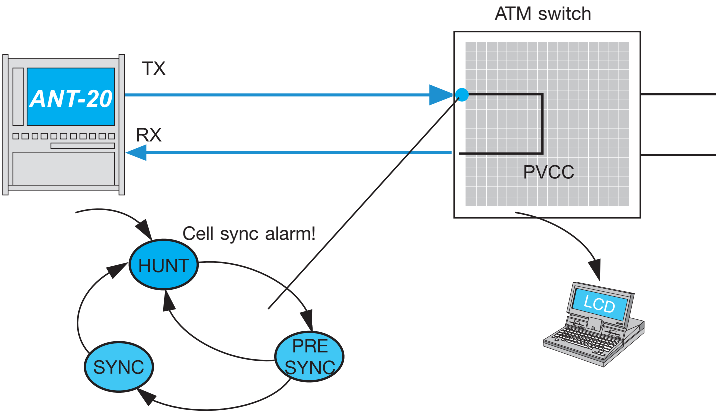


Figure 31: Testing the ATM synchronization process

Interworking tests

Interworking tests make sure that the interfaces between the various technologies within a network function smoothly. This is of particular importance when ATM services are being introduced. Protocol testers are used for these tests. These instruments allow decoding of the complex telecommunications protocols. The protocol testers should have at least two ports to enable them to monitor at least two circuits simultaneously. This is the only way in which effective conclusions can be drawn between cause and effect. The exchange of signaling information described in the section on "ATM signaling" is an example that well illustrates this requirement.
Protocol testers can operate just like a network element. This behavior is called emulation. An emulation test allows network elements to be checked for conformance to the protocol that is in use.

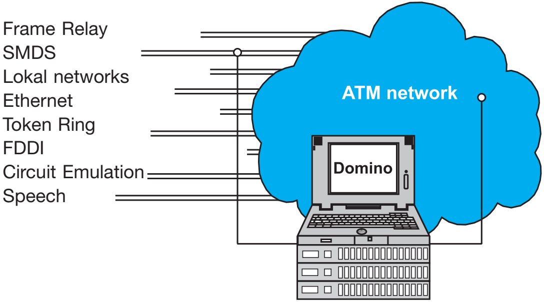


Figure 32: Interworking test with the aid of a protocol analyzer

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Further reading

- Application Note "Can you be sure that there are no weak links"
- "Test solutions for digital networks" by Roland Kiefer, Hüthig 1998, ISBN 3-7785-2699-5

Useful web addresses:

ATM Forum:	http://www.atmforum.com
ITU-T:	http://www.itu.ch
Wandel & Goltermann:	http://www.wg.com
Wavetek:	http://www.wavetek.com

List of abbreviations

A	AAL	ATM Adaptation Layer
	AAL-1	ATM Adaptation Layer Type 1
	AAL-2	ATM Adaptation Layer Type 2
	AAL-3/4	ATM Adaptation Layer Type 3/4
	AAL-5	ATM Adaptation Layer Type 5
	ABR	Available Bit Rate
	ACM	Address Complete Message
	ACR	Allowed Cell Rate
	AIR	Additive Increase Rate
	AIS	Alarm Indication Signal
	ANSI	American National Standars Institute
	ATM	Asynchronous Transfer Mode
B	B-ICI	B-ISDN Inter Carrier Interface
	B-ISDN	Broadband ISDN
	BER	Bit Error Rate
	BISUP	Broadband ISDN User Part
C	CAC	Connection Admission Control
	CBR	Constant Bit Rate
	CCR	Current Cell Rate
	CDV	Cell Delay Variation
	CDVT	Cell Delay Variation Tolerance
	CER	Cell Error Ratio
	CLP	Cell Loss Priority
	CLR	Cell Loss Ratio

	CMIP	Common Management Interface Protocol
	CMR	Cell Misinsertion Ratio
	COM	Continuation of Message
	CPCS	Common Part Convergence Sublayer
	CPE	Customer Premises Equipment
	CRC	Cyclic Redundancy Check
	CS	Convergence Sublayer
	CTD	Cell Transfer Delay
D	DBR	Deterministic Bit Rate
	DSS2	Digital Subscriber Signaling #2
E	EOM	End of Message
	ETSI	European Telecommunications Standards Institute
F	FDDI	Fiber Distributed Data Interface
	FEBE	Far End Block Error
	FEC	Forward Error Correction
G	GCRA	Generic Cell Rate Algorithm
	GFC	Generic Flow Control
H	HEC	Header Error Control
I	ILMI	Interim Link Management Interface
	IISP	Interim Inter Switch Protocol
	IP	Internet Protocol
L	LAN	Local Area Network
	LANE	LAN Emulation
	LOC	Loss of Cell Delineation
	LOF	Loss of Frame
	LOS	Loss of Signal

M	MAN	Metropolitan Area Network
	MBS	Maximum Burst Size
	MCR	Minimum Cell Rate
	MCTD	Maximum Cell Transfer Delay
	MIB	Management Information Base
	MPOA	Multi Protocol over ATM
N	NNI	Network Node Interface
O	OAM	Operation Administration and Maitenance
P	PCR	Peak Cell Rate
	PNNI	Private NNI
	POH	Path Overhead
	PRBS	Pseudo Random Bit Sequence
	PVC	Permanent Virtual Circuit
	PVCC	Permanent Virtual Path Connection
Q	QoS	Quality of Service
S	SAAL	Signaling ATM Adaptation Layer
	SAR	Segmentation and Reassembly
	SBR	Statistical Bit Rate
	SCCP	Signaling Connection and Control Part
	SCR	Sustainable Cell Rate
	SDH	Synchronous Digital Hierarchy
	SMDS	Switched Multi-Megabit Data Services
	SN	Sequence Number
	SONET	Synchronous Optical Network
	SSCF	Service Specific Coordination Function
	SSCOP	Service Specific Connection Oriented Protocol

	SSCS	Service Specific Convergence Sublayer
	STM	Synchronous Transport Module
	STS	Synchronous Transport Signal
	SVC	Switched Virtual Circuit
T	TCP	Transmission Control Protocol
	TM	Traffic Management
U	UBR	Unspecified Bit Rate
	UNI	User Network Interface
	UPC	Usage Parameter Control
V	VBR	Variable Bit Rate
	VC	Virtual Channel
	VC	Virtual Container
	VCI	Virtual Channel Identifier
	VP	Virtual Path
	VPI	Virtual Path Identifier
W	WAN	Wide Area Network

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