Future trends in digital telecommunication transmission networks

New technology is needed by digital transmission networks for the increased bandwidth, performance and reliability requirements of existing and future telecommunication services, such as broadband ISDN. Increased flexibility, automation and control are also major issues being addressed. The combination of these factors has led to the development of synchronous digital heirarchy (SDH) networks to replace existing asynchronous networks during the 1990s. These issues are reviewed and further developments to bandwidth-transparent optical networks indicated for the twenty-first century.

by I. Hawker

Principal abbreviations

AU	administrative unit
MTN	managed transmission network
mux	multiplexor
RCU	remote concentrator unit
SDH	synchronous digital heirarchy
STM	synchronous transport module
Telco	telecommunications company
TON	transparent optical network
TU	tributary unit
VC	virtual container
WDM	wavelength division multiplexing

1 Introduction

Digital telecommunication networks are expanding rapidly in terms of the range of services offered (speech, data, mobile, video etc.) and the volume of traffic transported (10–50% per annum). To operate these growing networks efficiently, and to meet the quality of service (QoS) demanded by customers, it is necessary to provide greater bandwidth and make increasing use of automation (network intelligence), for example in provisioning and maintenance operations. The networks must also be designed for greater performance and reliability.

For example, the British Telecom (BT) public switched telephone network (PSTN) has undergone considerable automation with the introduction of

(*a*) about 300 processor exchanges controlling 5000 remote concentrator units interfacing with customer sites
(*b*) intelligent network databases (INDBs) for provision of advanced customer services and
(*c*) dynamic alternative routing (DAR) to automatically route customer calls and to minimise congestion (call blocking) at busy periods.

By contrast, digital transmission bearer networks are manually driven with capacity configuration using manual crossconnects (high granularity 2/8/34 Mbit/s switches in the transmission path) and multiplexors to combine 2 Mbit/s streams from digital exchanges onto a higher order 140/565 Mbit/s transmission network. These networks are often supported by various independent management systems.[1]

Recent developments have seen the introduction of optical digital transmission systems up to 565 Mbit/s. However, in addition to bandwidth, future enhancements are also aimed at:

- the introduction of more flexibility and control for improved capacity utilisation and faster response to network events
- network restructuring, with longer optical transmission spans to reduce multiplexing hardware and improve performance
- greater automation to reduce manual intervention and to minimise operating and maintenance costs
- great reliability.

In this article the structure and operation of telecommunication transmission networks is outlined together with the role played by the flexible SDH (synchronous digital hierarchy) networks planned for the 1990s.[2] Further developments to bit rate transparent optical networks (TONS),[3,4] in which all crossconnects and multiplexors (muxs) are optical, are also described.

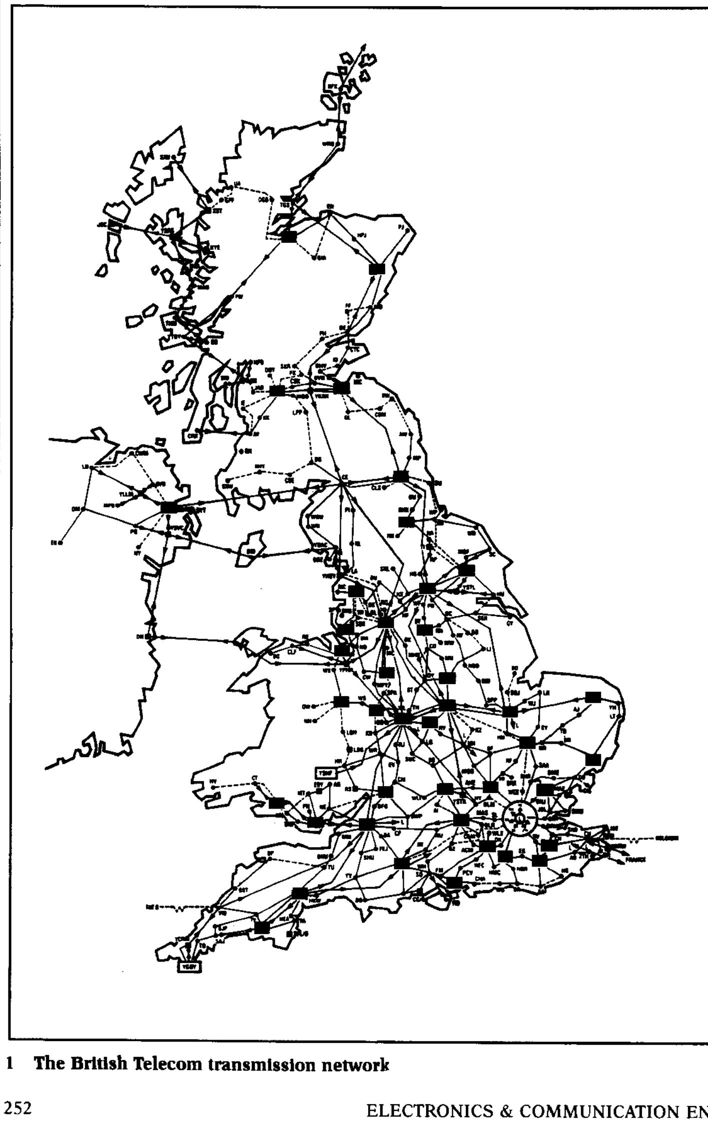
2 Existing digital telecommunication transmission networks

Generally, digital transmission networks are divided into *access* and *core* regions. Access incorporates distribution from the residential or business user to the local digital exchange, whereas the core contains both transmission and 64 kbit/s switching (a voice circuit being 64 kbit/s). For example, the BT network is divided into an outer core of *processor* (main) exchanges and their remote concentrator units (RCUs), and an inner core of about 55 fully interconnected trunk exchanges linked by 140/565 Mbit/s digital transmission systems.

Current transmission technology is plesiochronous (nearly synchronous), whereby separate (nominally equal) clocks drive each multiplexor in the network independently, with bit stuffing to equalise all input signal rates prior to bit interleaving to a higher transmission rate. In a 140 Mbit/s data stream, bit stuffing will generally have occurred at 8, 34 and 140 Mbit/s resulting in a complex data structure from which it is very difficult to extract lower order tributary rates. For example, to extract a 2 Mbit/s data stream requires demultiplexing of the entire 140 Mbit/s signal and a correspondingly large amount of demultiplexing hardware.

The BT inner core network topology (Fig. 1), although primarily optical, has developed using short-haul coaxial systems (supplemented by some long-haul radio) with intermediate multiplexors for flexibility. As with other Telcos (telecommunication operating companies) performance is determined by the following factors:

- short-haul topologies lead to considerable hardware on digital paths
- use of plesiochronous hardware leads to inefficient multiplexor chains
- the resulting inflexibility can lead to a high proportion of expedient non-shortest path routings and inefficient utilisation of plant
- the absence of accessible overhead channels in the frame structure, together with hardware inflexibility, makes control and monitoring difficult, leading to increased operating costs
- lack of flexibility makes it difficult to groom (concentrate) traffic for maximum fill and to provide 'visibility' of services at the transmission level, whereby performance can be more easily matched to individual service targets.
- lack of flexibility makes it difficult to optimise protection strategies within the network. In current networks protection usually consists of standby line systems (i.e. 1+1 or 1+*N*) with automatic switchover in the event of system failure
- lack of standards for control and signalling leads to a proliferation of management systems and greater operating costs.



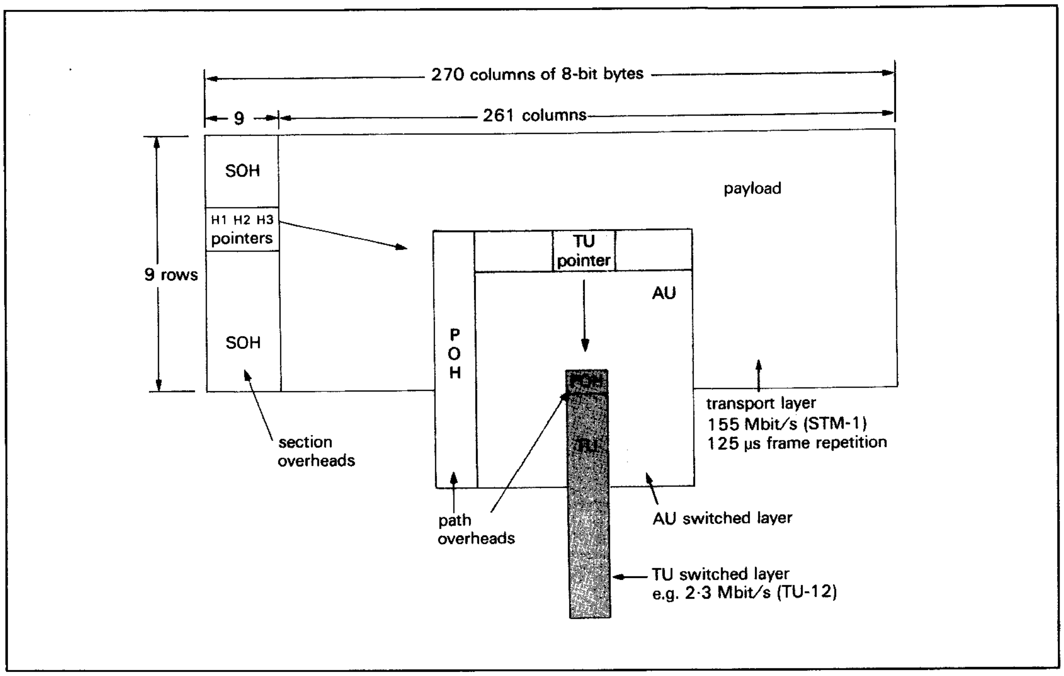
1 The British Telecom transmission network

These limitations tend to negate the vision of 'end-to-end' control and monitoring of digital paths, increased automation and reduced response times. A new approach is needed which makes better use of technology and integrates the required functionality into unified management support systems. These requirements have lead to the development of SDH transmission networks in line with similar international initiatives for standardising management systems and signalling.

3 SDH networks

International standards

The SONET (synchronous optical network) concept was introduced in 1986 when ANSI (American National Standards Institute) determined to establish transmission standards so that telecom operators could interface using standard frame formats and signalling protocols. The concept also included network flexibility and overhead channels (within the digital frame structure) to carry control and performance information between network elements (line systems, multiplexors etc.) and control centres. It embodies the capability of a managed transmission network (MTN) with centralised management and devolved control

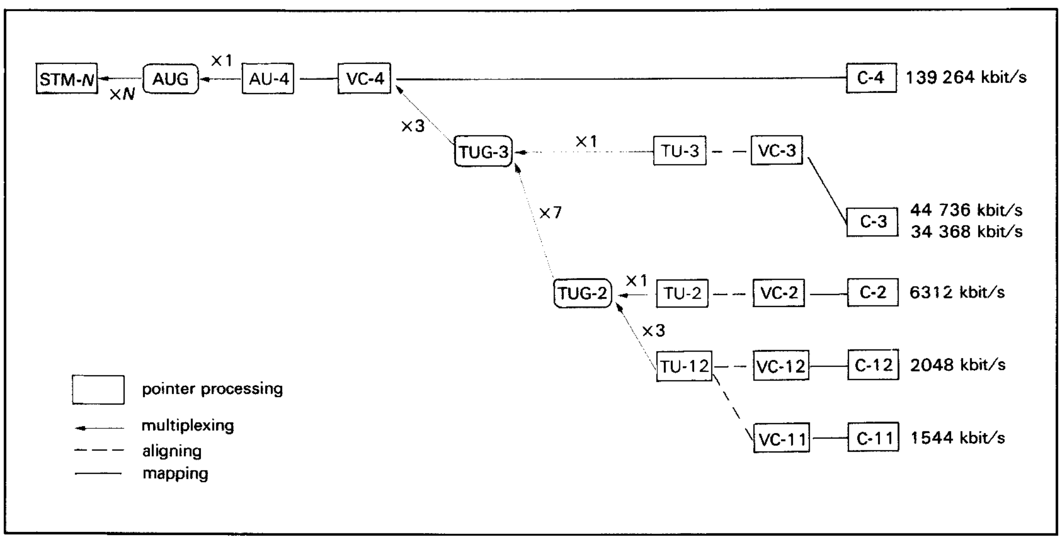


2 SDH frame structure

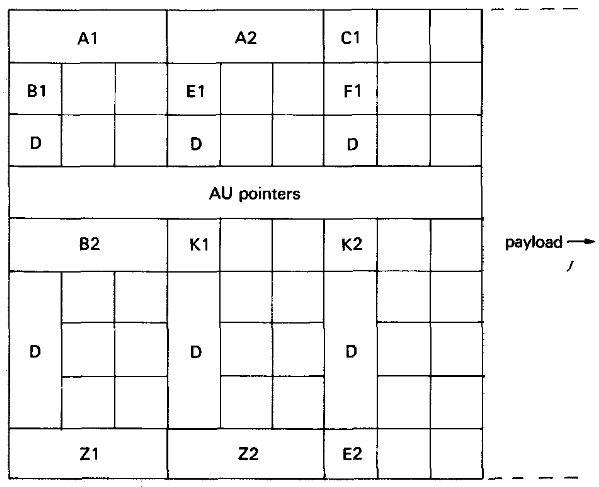
(by software download) for increased automation and reduced response time.

In 1988 these concepts where adopted by CCITT (International Telephone and Telegraph Consultative Committee) and ETSI (European Telecommunications Standards Institute) and renamed SDH with the aim of agreeing world standards for transmission covering optical interfaces, control aspects, equipments, signalling etc. Bit transport rates start at 155 Mbit/s with a hierarchy to 622 Mbit/s, 2488 Mbit/s and beyond. The standards have now (1990) reached the stage where manufacturers can produce hardware, with outstanding issues being concerned mainly with signalling and control.

For example, further work is ongoing in object-oriented information modelling for flexible re-usable management software, whereby the functionality and relationship between network elements is represented, within the control computer at the management centre, by lines of code. Reconfiguration of equipments or alarm thesholds is achieved by running suitable applications to produce the required message sets to



3 Multiplexing structure adopted by ETSI
C = container; VC = virtual container; TU = tributary unit; TUG = tributary user group; AU = administration unit; STM = synchronous transport module



A1 A2 framing bytes
B1 B2 error bytes
C1 STM-1 identifier within STM-*N*
D 12 data communications channels (signalling)
E1 E2 maintenance channels
F1 network operator user channel
K1 K2 automatic protection switching
Z1 Z2 spare bytes

4 Section overhead bytes

reconfigure the network elements. For ease of interworking between operators, objects and message sets must be agreed and incorporated into international standards.

Network flexibility

Network flexibility implies the ability to rapidly reconfigure network capacity from a control centre in order to:

- improve capacity utilisation by maximising the number of 2 Mbit/s channels transported in the higher order system
- improve the availability of digital paths by centrally allocating spare capacity and protection schemes to meet service requirements
- reduce maintenance costs by remotely diverting traffic away from failed network elements
- provide 'service visibility' whereby capacity is allocated and managed for individual services
- reduce response time
- provide easier growth with temporary diversion of traffic around the affected areas.

Flexibility can be achieved by use of automatic SDH crossconnects and 'drop and insert' multiplexors. Automatic crossconnects will replace existing manual crossconnects and allow remote reconfiguration of capacity within the network at 2 Mbit/s and above, whilst 'drop and insert' multiplexing refers to the ability to extract or insert individual channels without the need to demultiplex the entire high-order signal (thereby reducing by a factor of three the amount of multiplexing hardware needed and reducing hardware costs).

SDH frame structure

The benefits of SDH are related to the regular frame structure defined by the standards. Digital data streams are made up from frames containing a nominal number of bits (or bytes), with each frame having a fixed sequence frame alignment signal (FAS) which, when recognised by the receiver electronics, identifies the positions of all individual data streams within the frame. Frame structures currently used in plesiochronous transmission equipments are formed by bit-interleaving lower order tributaries with bit stuffing at each level, resulting in very complex structures at 140 Mbit/s. However, the SDH frame structure (Fig. 2) is very much simpler and incorporates the following features to simplify 'drop and insert' and crossconnect functions:

- a modular structure made up from SDH tributaries
- extensive overheads for monitoring and control
- byte interleaving with direct visibility of 64 kbit/s channels
- byte stuffing to improve robustness against loss of synchronisation
- standard mappings for all common data rates into the SDH frame format
- the ability to map other signal rates into SDH by concatenation of standard modules.

A 155 Mbit/s transport module (STM-1) is made up from $9\times270\times64$ kbit/s channels with 9×9 of these dedicated to section overheads. The bit rate is higher than the equivalent capacity 140 Mbit/s plesiochronous rate owing to the addition of these easily accessible overhead bytes. Higher order systems are formed by byte interleaving $N\times155$ Mbit/s channels (e.g. STM-16 = $16\times155{\cdot}5$ Mbit/s = 2488 Mbit/s).

The frame structure also incorporates two smaller network modules: the AU (administrative unit) and TU (tributary unit). The TU is a standard tributary plus additional SDH overheads for performance monitoring within the SDH environment, whilst the AU is a larger unit consisting of TUs routed together as a block (e.g. for restoration). These units may be dropped or inserted from the data stream and networked as units of capacity between transmission nodes.

Multiplexing of tributary rates into the SDH frame is shown in Fig. 3. Narrow and broadband digital streams are mapped into fixed rate containers (C-12, C-4 etc.) using conventional bit stuffing, and path overheads are added to each container to form virtual containers (VCs). Phase information is then added to form TUs (SDH tributary units) which are grouped into tributary user groups (TUGs). The position of each VC within the frame is obtained by reading the pointer bytes within the TU header. Similarly, path overheads are added to each TUG to form a higher order VC, such as VC-4. Further addition of phase information produces the AU, whose location within the frame is indicated by AU pointer bytes within the STM overhead.

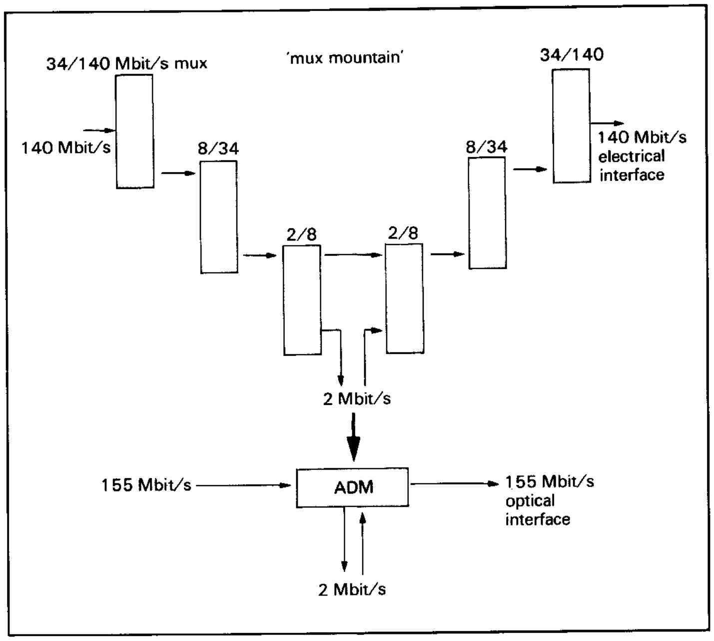
A useful feature of SDH is that the frame format allows simultaneous transport of both narrow (e.g. 2 Mbit/s) and broadband (e.g. 45/140 Mbit/s) services within a 155 Mbit/s or $N \times 155$ Mbit/s transport module. Commonly used tributaries translate directly into SDH format whilst others may be mapped into concatenated TUs or AUs.

Overhead channels for management and performance monitoring are provided for STMs, AUs and TUs. The STM overhead channels (Fig. 4) manage digital sections between network elements and are either allocated for specific purposes such as control, protection or alarms, or reserved for operator or national/international use. AU and TU overheads are concerned mainly with alarms and performance monitoring of these networked units.

Network synchronisation

SDH networks are intended to operate synchronously: network elements are linked to a master reference clock via a synchronisation hierarchy (this could be the same hierarchy as used for synchronising digital exchanges). This will greatly reduce the frequency of stuffing compared to plesiochronous operation and should improve performance. SDH networks are also robust against loss of synchronisation, which would simply increase stuffing rates whilst maintaining normal operation.

Synchronisation of incoming streams to the local clock is achieved by adding or removing a byte (or bytes) from each stream as required. The H3 pointer byte (see Fig. 2) is either overwritten with data (negative stuff) or extended into the payload area (positive stuff). This operation changes the position of the AUs within the frame and the pointer bytes H1 and H2 are updated (hence the term 'pointer processing'). Byte stuffing will necessarily introduce more jitter into data streams than existing bit stuffing schemes, and this will affect future specifications for timing utilities within digital exchanges.

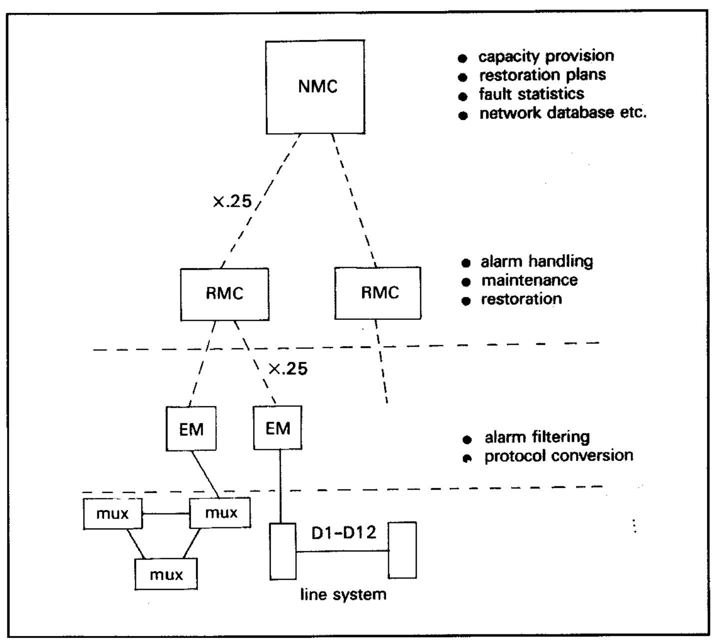


5 The SDH add-drop multiplexor (ADM) replaces the plesiochronous 'mux mountain'

SDH equipments

SDH equipments fall into three broad categories — multiplexors, crossconnects and element managers — all of which will be software configurable and controlled locally or remotely as required.

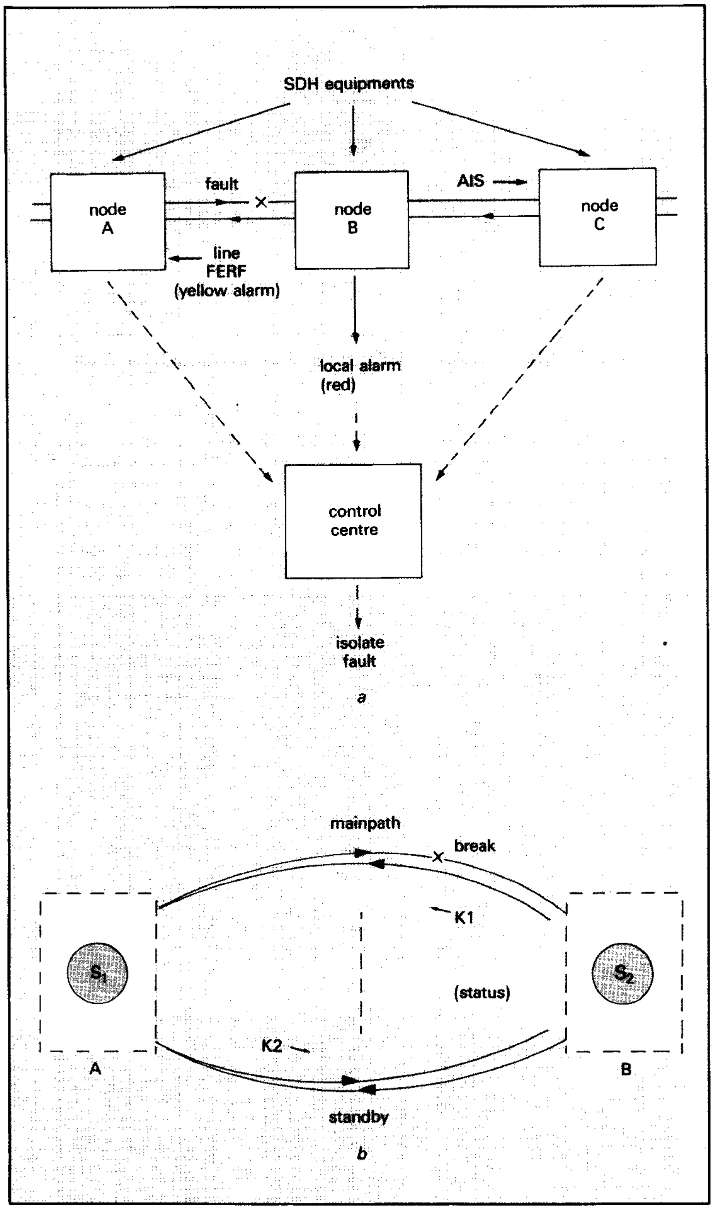
The SDH multiplexor provides access for plesiochronous signals onto the SDH network and replaces the asynchronous 'mux mountain' (Fig. 5). This results in reduced hardware on digital paths and better performance. Various types of multiplexor will be used



6 Control of an SDH/MTN
NMC = network management centre; RMC = regional management centre; EM = element manager

including terminal multiplexors, 'drop and insert' multiplexors and broadband multiplexors. Terminal multiplexors will be used to terminate line systems (replacing conventional line terminating equipments and multiplexor chains) whilst 'drop and insert' multiplexors will be used mainly in multiplexor rings linking exchanges. Broadband multiplexors will combine higher order STM optical signals.

The SDH crossconnect replaces manual crossconnects and will be used for remote network configuration, protection and traffic concentration (grooming). Various equipments have been specified by Telcos including AU broadband crossconnects, narrow-band TU crossconnects and combined AU/TU crossconnects. As with multiplexors, applications are envisaged in providing transmission network flexibility both within and between digital exchanges. Because of the large concentration of traffic in this equipment it will probably be duplicated for protection.



7 (a) Fault isolation; (b) automatic protection switching
FERF = far-end return fail; AIS = alarm inhibit signal; K1 = send fault status to far end and actuate protection switch S_1; K2 = return protective status to near end and activate protection switch S_2

Control of SDH networks

The control of the SDH/MTN will be software based and aimed at automating operational procedures and minimising response times. International standards will be adopted for management architectures and signalling protocols to simplify interconnection of Telcos. In addition, closed user groups (CUGs) may be set up as required to support private networks managed within the SDH/MTN environment.

A management hierarchy will typically have three layers (Fig. 6):

(*a*) a *network management* layer for centralised or devolved control of OAM&P (operations, administration, maintenance and provisioning) functions. For example, circuit provision, monitoring and network statistics could be centrally controlled whilst maintenance, alarm handling and protection are devolved to regional centres.

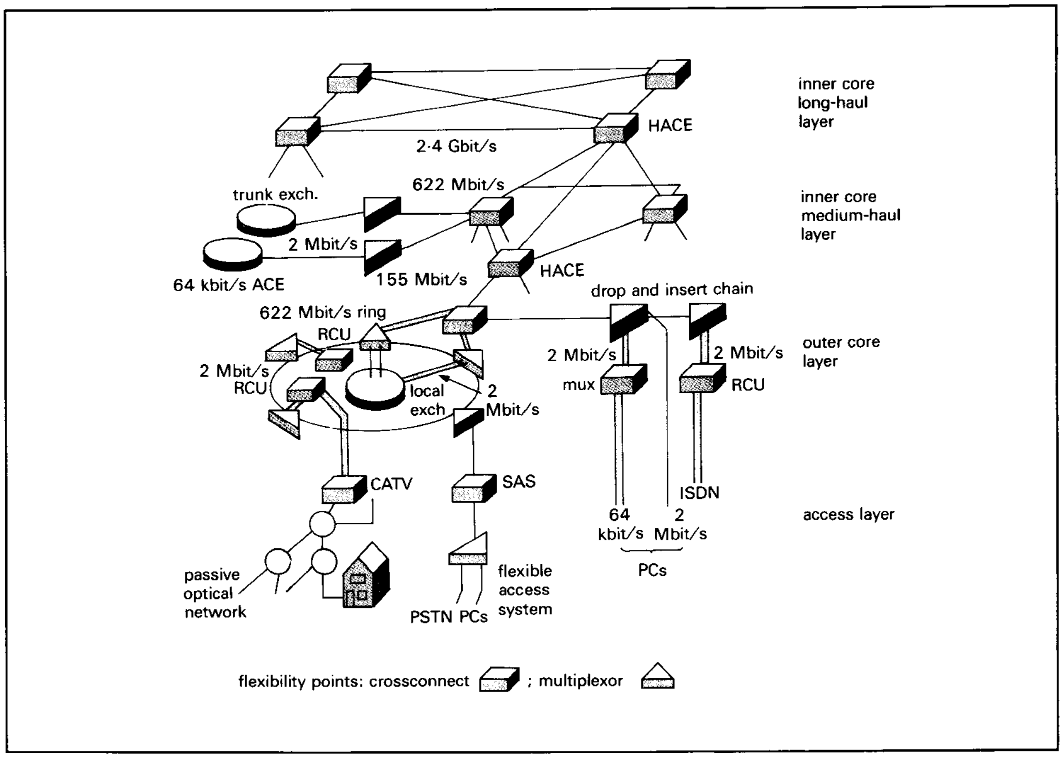
(*b*) an *element management* layer with large numbers of element managers (EMs) directly controlling equipments in their catchment area. Functionality will be devolved from the management centre as required and will include protection plans, alarm filtering, protocol conversion, etc. aimed at minimising the network response time and the volume of information flowing into the management centre.

(*c*) a layer of network elements comprising the transmission network. These elements will have local processors and will become increasingly more intelligent as applications are downloaded from the management centre.

At the network element level SDH overheads provide a convenient medium for rapid transport of control information, whereas at higher levels a separate data network may be provided for security reasons.

Operational features

Operational features of an SDH/MTN, such as fault location/

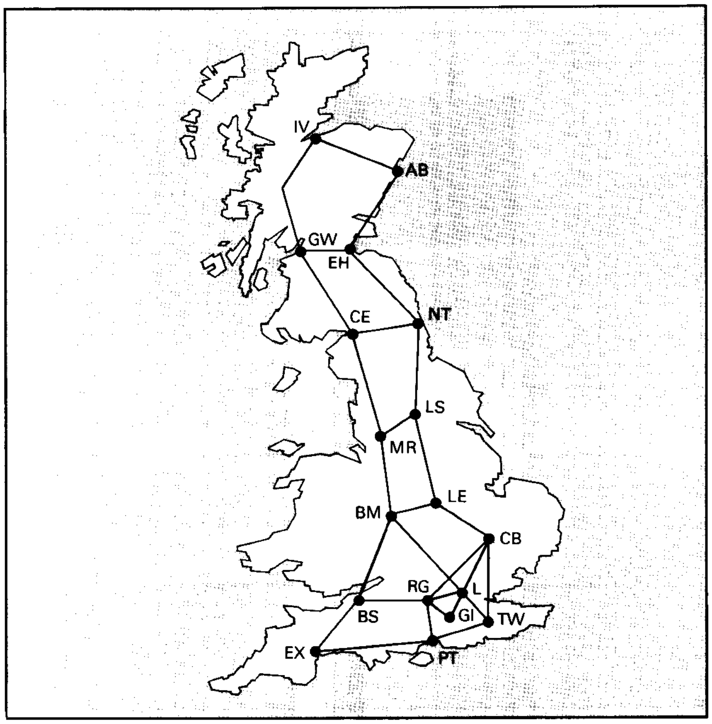


8 Possible future MTN/SDH network hierarchy
ACE = automatic crossconnect equipment; HACE = high-order automatic crossconnect equipment; PC = private circuit; SAS = service access switch; CATV = cable TV

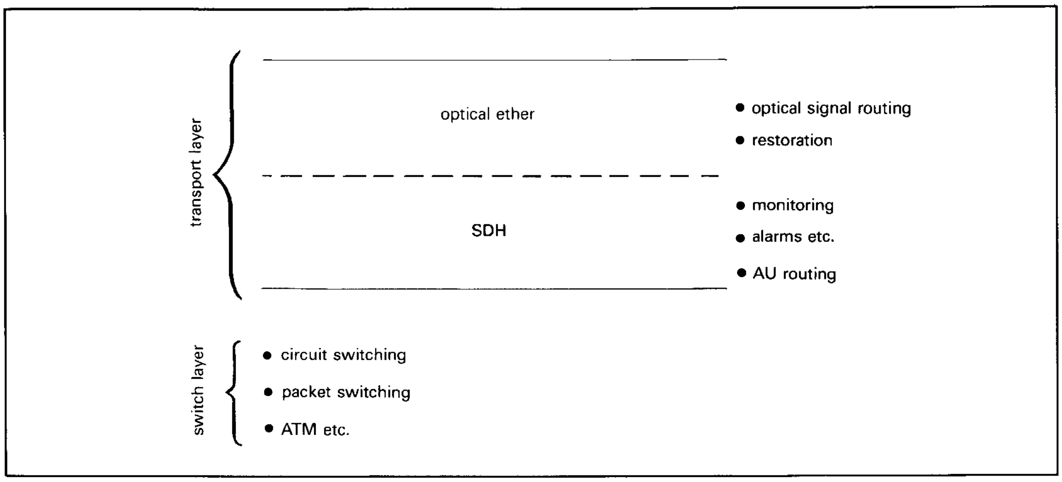
identification, performance monitoring and restoration, will be much improved compared with existing plesiochronous networks. Two examples are chosen to illustrate this, covering fault isolation and automatic protection switching.

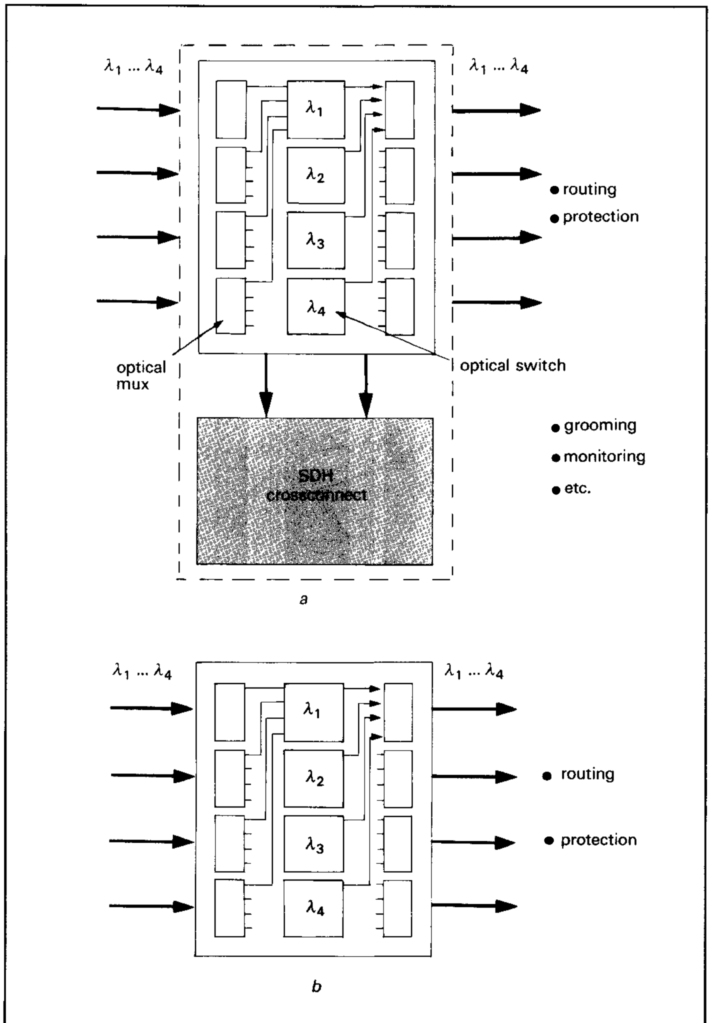
For example, a circuit break between transmit node A and receive node B (Fig. 7*a*) will result in loss of signal at B, a red alarm indication of the fault status to the control centre via the element manager, and a yellow alarm to node A (using the G1 overhead byte) to indicate a downstream fault. Node A then flags the control centre, which now has knowledge of the location and status of the fault. Should the return leg be affected the yellow alarm is sent via a protection channel.

The above break may be accompanied by fast protection switching (Fig. 7*b*) whereby fault status information is returned to A (on the K1 byte), where a protection switch is activated. The make-good is completed by activating the protection switch at B on receipt of an acknowledgment from A (over the K2 byte).



9 Inner core long-haul network





11 (a) Wavelength routing/SDH crossconnect; (b) simple wavelength routing crossconnect

Each of these functions is programmable by software download from the management centre, so that network functionality and automation can evolve to meet changing requirements.

Network topologies

With the introduction of SDH the opportunity may be taken to modify network layers and topologies to those better suited to long-haul resilient networks. If the number of transmission nodes is >100 then a new long-haul network of large crossconnects would be considered to reduce the number of nodes on digital paths (Fig. 8). Long-haul topologies would be chosen for diversity to ensure resilience of the transmission network (Fig. 9). Medium-haul layer crossconnects link trunk exchanges using topologies chosen for diversity with at least dual access to higher order nodes. Outer core topologies would be mainly rings of SDH multiplexors linking local exchanges and RCUs.

Access regions may remain principally star topologies with increasing use made of rings for resilience where possible. The use of SDH equipments in the access layer, with the benefits of end-to-end management of digital paths and broadband interfaces to the customer, depends largely on the availability of cheaper SDH equipments with reduced functionality. SDH seems likely to be introduced initially for large business users.

Support of multiservice networks

It is clearly important for the SDH/MTN to support the transport of possible new digital formats, for example ATM (asynchronous transfer mode), in which all services are transported together in fixed-length slots and switched using a common multiservice switch. Mappings to allow this are being examined in ANSI and CCITT.

Risks associated with software

The price paid for increased functionality and automation of transmission networks is the requirement for large quantities of software. Unlike hardware, software failures can simultaneously affect almost every network element, making software reliability a major issue. Whereas it should be possible to minimise software faults by, for example, automatic code generation and rapid prototyping on test beds, problems are still possible from combinations of events unforeseen in the original software specification.

The SDH/MTN is designed to be future proof in terms of bit rate and node functionality (achieved by software download). Further developments to new technologies must incorporate management capability and offer considerable advantages in terms of bandwidth and operating costs. It is important to consider these options since they incorporate a longer term vision of cheap 'unlimited' bandwidth to the customer.

4 Transparent optical networks

The transparent optical network (TON) is a concept whereby the large bandwidth inherent in optical transmission elements is realised by removal of the electro-optic 'bottle-neck' present in today's equipments. Systems have been demonstrated between local exchange and customer for combined TV/telephony distribution and applications within the central-core network are bound to follow.

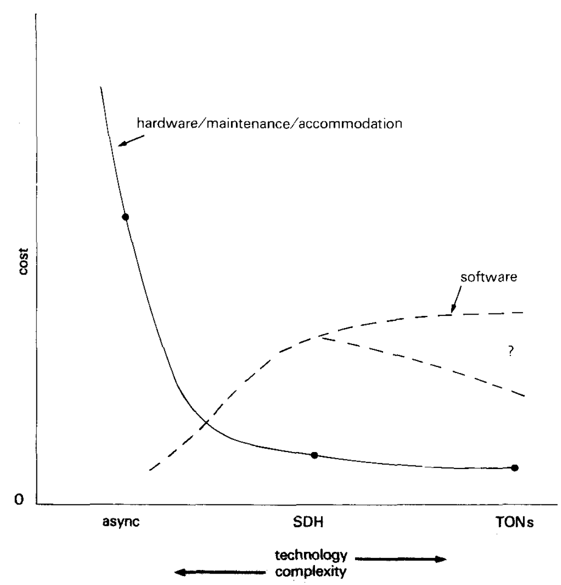
The transport layer would be split into an optical layer for simple routing and restoration (using optical crossconnects and multiplexors) and an SDH layer (Fig. 10) for monitoring, alarm generation etc. This would allow for the early introduction of TONs as dumb elements controlled by the MTN, with increased functionality being added later as optical processing and monitoring are developed. TONs could be introduced in stages as indicated below.

Wavelength division multiplexing (WDM)

WDM can be used to greatly enhance cable capacity by transporting traffic using several wavelengths in the same fibre. Currently the technique is used only for special systems (e.g. submarine cable), but commercial systems with up to ten channels should be available during the 1990s and, eventually, with as many as 100 channels when coherent technology is used. Protection of these cables will be essential, 1+1 automatic link or network protection schemes being likely.

Wavelength routing

Having increased cable capacity with WDM a further step is to open up this capacity over entire routes by introducing transmission nodes with optical crossconnect facilities. Capacity would be allocated to wavelengths switched at optical crossconnect sites to route traffic between



12 Cost of ownership

destinations, with capacity restoration provided over diverse routes. Wavelengths could be re-used and the technology introduced initially using a small number of wavelengths. These could later be increased to support greater capacity and flexibility with limited change to the transmission infrastructure.

Implementation of this technology into the SDH/MTN would include:

- combined wavelength routing and SDH crossconnects (Fig. 11*a*) introduced into both the long- and medium-haul layers of the core network
- simple wavelength routing crossconnects (Fig. 11*b*) introduced into a single layer of the MTN for traffic routing and restoration in the optical path, with SDH equipments retained in other layers for traffic grooming, monitoring and control purposes
- simple wavelength multiplexors in the outer core linking exchanges with SDH retained in other layers.

All of these applications are likely as a natural development of SDH to far greater capacity from the year 2000 on.

5 Cost of ownership

A major factor in the use of new technology is the cost of ownership: the costs of installation, operation, maintenance, growth and eventual replacement. These costs are related to the total network plant and the associated maintenance, and should continue to fall with migration from asynchronous to SDH to TONs (Fig. 12). However, trends in software management costs are uncertain since software is likely to increase with each new application, although simpler TON hardware should reduce software complexity at the network element level.

The cost of planning should also decrease compared to today's networks, owing to the flexibility of SDH to meet unexpected demands and the easier bandwidth upgrading of TONs without the need to introduce additional cables and ducts. Equally, it should also be possible, with SDH and TON technology, to reduce contingencies and the quality of plant held in stores.

6 Conclusion

Trends in digital telecommunication networks are towards greater bandwidth, flexibility, management, automation and reliability. The replacement of asynchronous by SDH technology during the 1990s should meet these requirements, with migration to TONs after the year 2000 opening up the enormous bandwidth inherent in optical transmission and minimising planning and operational costs.

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