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MODELLING OF NEW SERVICES IN COMPUTER AND COMMUNICATION NETWORKS

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ABSTRACT

The introduction of digital networks and new services for communication, information processing and storage poses a large number of new problems for traffic engineering and network planning. Bases of the performance evaluation is the modelling of new services and of new network functions. The paper aims at first at the characterization of service attributes and network capabilities which are being related to the protocol architecture and to standardization work. In the final part, a set of traffic models is discussed which refer to workload characterization, protocols, and switching networks.

1. INTRODUCTION

Communication networks of the past have developed individually and were characterized through one dominating service as, e.g., voice telephony, telex, or data transmission. The network technology has been optimally adapted to the purpose of the dominating service and network or service transitions were not possible.

Through the advances of digital transmission, microcomputer control and software technology future communication networks will be able to support a wide spectrum of services. Bases of this development are cheap hardware components for transmission and control and the international standardization of services and protocols; the latter has been greatly enhanced by the introduction of the ISO Basic Reference Model for Open Systems Interconnection. Administrations of many countries plan for the Integrated Services Digital Network (ISDN) which will include, in its final stage, services with different switching principles as circuit and packet switching, different transmission speeds as narrow band voice and broad band video, and different connection configurations as point-to-point, multipoint, and broadcast.

Besides the functional differences between the various services their dynamic properties with respect to resource demand are quite different. These properties differ in their signalling procedures, transmission bandwidths, storage requirements, subscriber behaviors, interarrival and holding times and need new traffic models to support adequate traffic engineering procedures.

This paper aims at an overview on new services and an introduction of a conceptional view of the modelling approach. This conceptional view includes the user's perspective in terms of reference points and service attributes as well as the network's perspective in terms of network resources and functional capabilities. In the final part, we refer to a set of particular traffic models covering various aspects of new services and networks.

2. SERVICES, NETWORKS AND PROTOCOLS

2.1 GENERAL SERVICE CONPEPT

The communication between different application processes (users, terminals, end systems) is logically structured into functions with a layered architecture. The principles of this architecture are defined by the well known Basic Reference Model for Open Systems Interconnection |1|. The layering concept partitions the system functions into subsets of manageable pieces which are ordered in a hierarchical manner as shown in Fig. 1 for the general case of a level N.

The (N+1)-Entity is the service user of the functionality (service) of the (N)-Entity. The (N)-Entity is a service provider for the (N+1)-Entity. The services of the (N)-level are controlled by a quadruple of (N)-Service Primitives REQUEST, INDICATION, RESPONSE and CONFIRMATION. The adjacent layer communication is exectuted by the exchange of (N)-Service Data Units, (N)-SDU.

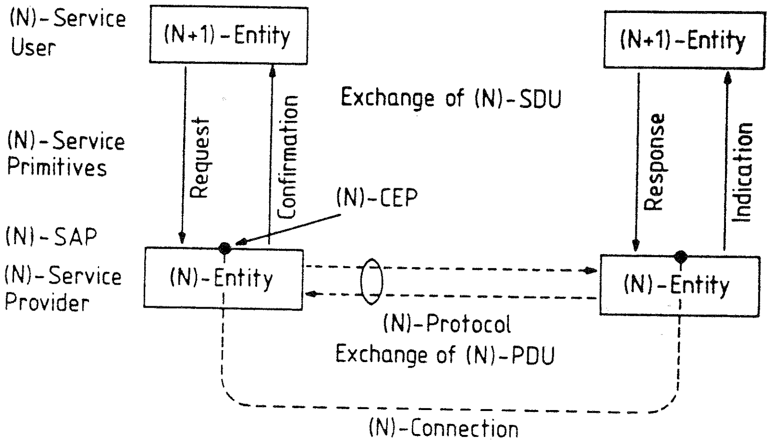


Figure 1
Generic Service Concept

The communication between peer (N)-Entities is governed by a set of well-defined procedures, the (N)-Protocol. The protocol uses a number of particular protocol elements which are encoded by (N)-Protocol Data Units, (N)-PDU, which consist of (N)-User Data and the (N)-Protocol Control Information, (N)-PCI. The exchange of (N)-PDU's can be greatly enhanced by the establishment of one ore more (N)-Connections between the (N)-Entities; connections are identifieable by (N)-Connection End Points and their corresponding addresses (identifiers). Connections may support the communication through functions as sequence control, flow control, or error recovery.

Within each of the architectural layers particular problems have to be solved as addressing, connection management (establishment, multiplexing, splitting) data unit management (segmenting, blocking, concatenation), and control of the protocol function. The Basic Reference Model defines 7 fundamental layers which can be further subdivided for particular services or network types:

7	A	Application
6	P	Presentation
5	S	Session
4	T	Transport
3	N	Network
2	DL	Data Link
1	Ph	Physical

Layers 1-4 refer to the communication functions whereas layers 5-7 belong to the processing and storing function of the end systems. The lower layer functions and protocols are basic for use of many application services; their standardization has reached a quite stable state. The higher layer functions (HLF) are much application-dependent and their standardization is still subject of international standardization bodies.

2.2 APPLICATION SERVICES

The classical services as Voice or Telex have been largely complemented by computer- and communication-oriented services, see Table 1.

Voice	Single Connection Conference Connection Voice Mail
Text	Telex Teletex Text Mail
Facsimile	Telefax Fax Mail Text-Facsimile (Textfax) Textfax Mail Electronic Mail Document Interchange
Video	Videotex Videophone Videoconference
Data	Data Base Access File Transfer, Access and Management Job Transfer Teleaction Message Handling

Table 1. Survey of Computer and Communication Services

Application services differ in their characteristics with respect to network access, information transfer, or supplementary service functions which are generally called as Service Attributes. Table 2 gives a survey of certain attributes .

2.3 INFORMATION FLOWS AND COMMUNICATION CONTEXTS

Networks supporting a large number of services are characterized by various flows of user and control informations. For the modelling of the information flows specific Reference Points are considered as, e.g., Terminal Endpoints (TE), Network Terminations (NT), Exchange Terminations (ET), or Network Interworking Units (Gateways). Fig. 2 shows the general configuration as recommended by CCITT for the ISDN. The performance of the information flow can be quantified by consideration of the relationships between protocol entities of the various communication contexts |2|.

Criterion	Service Attributes		
Switching	Circuit-Switched	Packet Switched	Non-Switched
Configuration	Point-to-Point	Point-to-Miltipoint	Broadcast
Connection	Connection-Orient.	Connectionless	
Conn. Establishm.	Demand	Reserved	Permanent
Signalling	In-Band	Out-Band	Common Channel
Bandwidth/ Throughputrate	Constant	Variable	
Protocol Parameter	Fixed	Negotiation at Subscription	Negotiation at Connection Establ.
Communication	Dialogue	Request	Distribution
Delivery	Immediate	Delayed	Specified Time
Suppl. Functions	Reverse Charging	Redirection	Call Back

Table 2. Survey Service Attributes

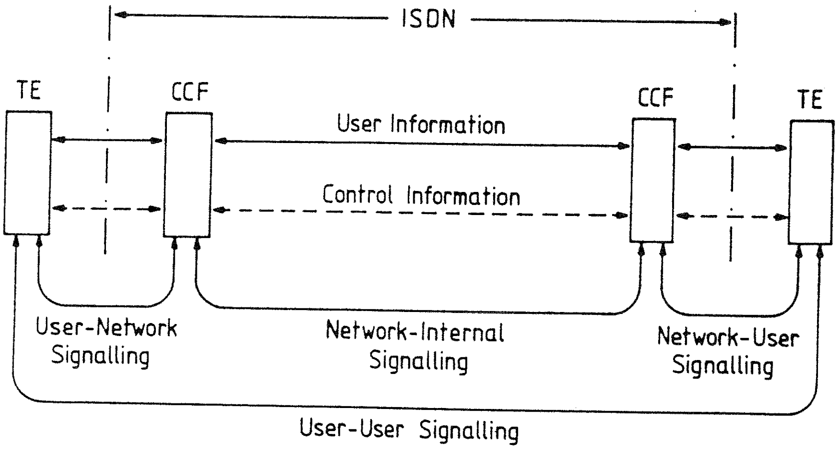


Figure 2
Information Flows and Communication Contexts
TE Terminal Equipment
CCF Connection Control Functions

2.4 NETWORK ACCESS AND NETWORK CAPABILITIES

The future networks for integrated services will have a number of capabilities as indicated in Fig. 3 and Table 3.

Particular interest has been paid to the Customer Access which allows the connection of multiple ISDN-equipments (TE1) as well as non-ISDN-equipments (TE2) through Terminal Adaptation (TA). Packet switching access can be provided through the D-channel (p-data) or through a switched B-channel to the destination,or to the ISDN-internal PS-facilities.

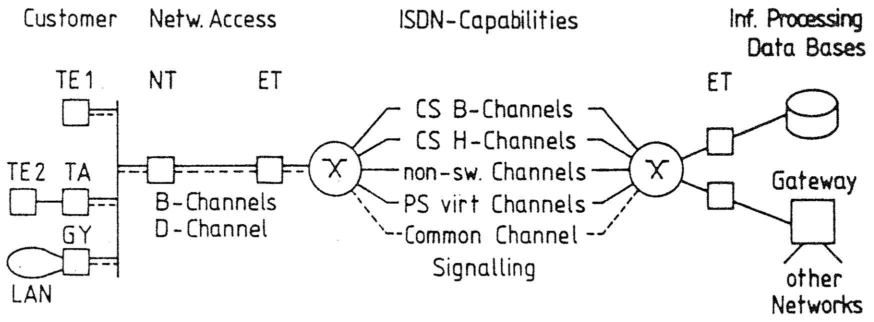


Figure 3
ISDN Basic Structure and Capabilities

Information Channels	B-channel	64	kbps	(CS or non-switched)
	HO-channel	384	kbps	(CS or non-switched)
	H11-channel	1536	kbps	(CS or non-switched)
	H12-channel	1920	kbps	(CS or non-switched)

Signalling Channels	D16-channel	16	kbps	(D-channel Protocol)
	D64-channel	64	kbps	(D-channel Protocol)
	E-channel	64	kbps	(No.7 Sign. Protocol)
Switching	Circuit Switching			(CS)
	Packet Switching			(PS)
	Non-switched			
Signalling	Separate channel for Basic Access			(D-channel)
	Common channel for Network Control			
Customer Access	Basic Access			(e.g. 2B + D16)
	Primary Rate Access			(e.g. 30B + D64)
Terminal Equipment	TE 1 ISDN-compatible			(D-channel Signalling)
	TE 2 non-ISDN			(V.24, X.21, X.25,...)
	through Terminal Adaptor TA			
Processing/ Storing	Network Data Bases			
	Information Storage and Processing Facilities			
Network Transitions	Interworking with other Public and Private Networks through Gateways			

Table 3. ISDN Capabilities

2.5 PROTOCOLS

The exchange of informations between users, application programs or any particular level entities is controlled by a set of rules subjected to a protocol definition. Based on the layered protocol architecture of the ISO/CCITT OSI Basic Reference Model |1|, CCITT has developed a generalized model for ISDN protocols. Whereas for packetized communication control and user information are combined in the respective PDU's, circuit switched communication with separate signalling channels and networks need a multidimensional approach where different Protocol Planes are distinguished for User, Control and System Management informations.

The multiple plane protocol architecture is illustrated in Fig. 4 for a CS-connection through an ISDN with D-channel signalling for the network access and No. 7 common channel signalling network for network-internal signalling.

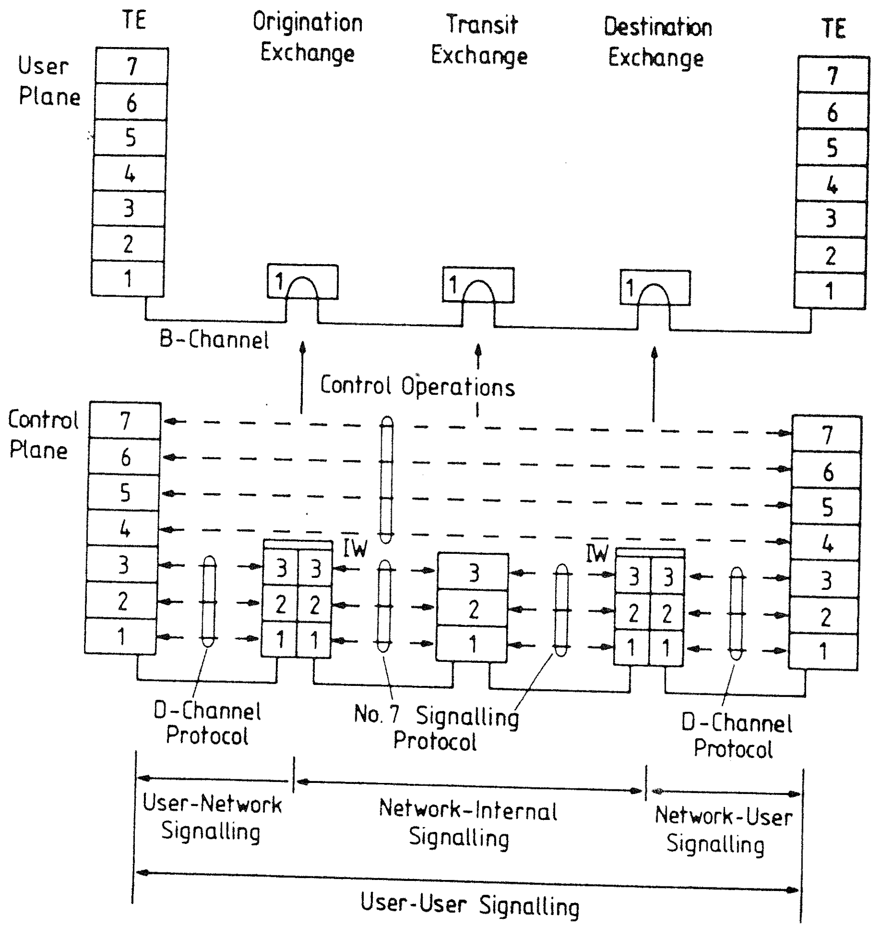


Figure 4
CS Connection through ISDN

The relevant standards of CCITT are defined in the I-series for ISDN, particularly I 431, I 441 and I 451 for levels 1,2 and 3 of the D-channel protocol, and in the No. 7 Signalling System, see Section 2.6. Both the D-channel and No. 7 signalling protocols have been developed for their particular purposes, the control of the network access and network-internal control. Therefore, they differ considerably and an interworking is necessary at the origination and destination exchanges. For the higher layers 4-7 this concatenation of the signalling systems is not visible.

Similar interworking functions appear in a wide variety for the interconnection of different network types as, e.g.,

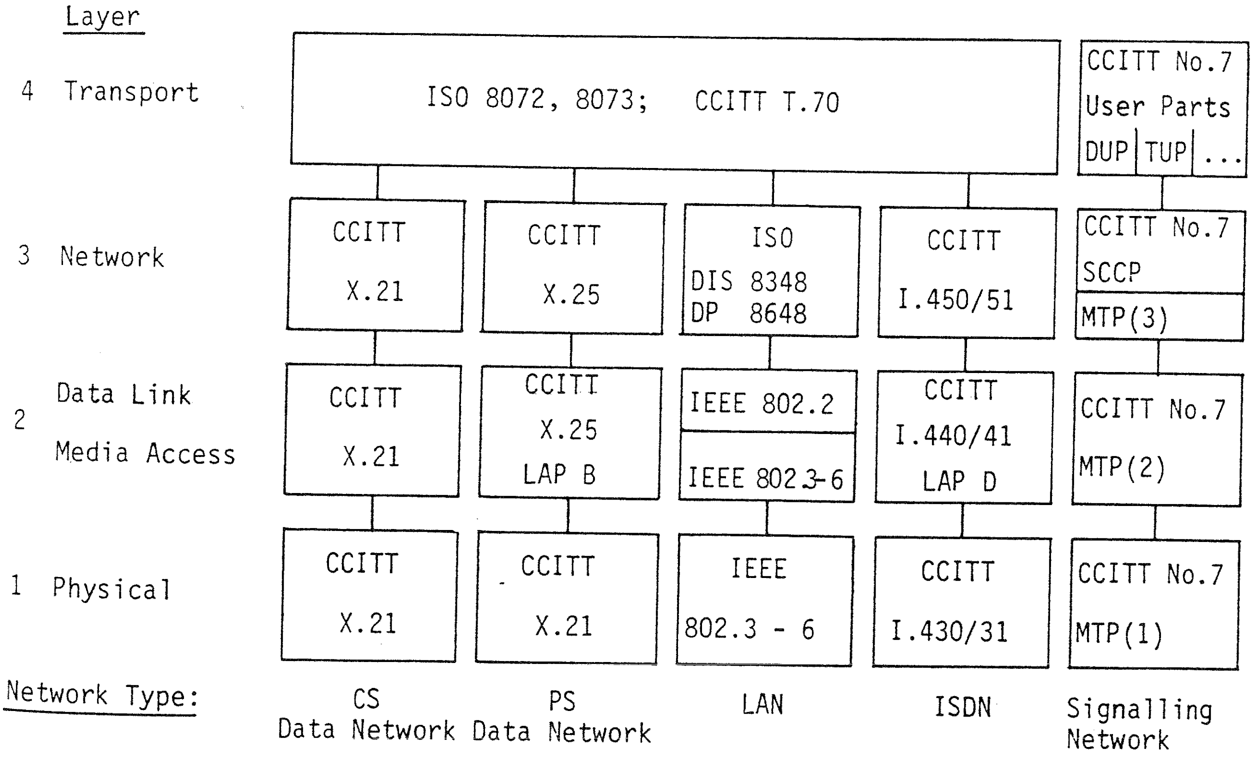
LAN - WAN with CS or PS
LAN - ISDN
LAN - PABX
LAN - LAN with different protocol architectures
WAN - WAN with different protocol architectures.

The basic protocol structure for interworking can be developed in a similar way as shown in Fig. 4. Examples for PS-communication through D- and B-channels are included in the CCITT I-series recommendations and in |3|. Interconnection scenarios between PS data networks with connection-oriented and connectionless services are also subject of ECMA standardization activities |4|.

2.6 STANDARDIZATION

The extension of network capabilities and services implies a detailed structuring of network functions and application processes. This is reflected by the intensive activities of international standardization bodies ISO, CCITT, ECMA, IEEE and IEC. Through these activities a set of services and protocols have been standardized (or are in progress of standardization) as a necessary prerequisite for the development of networks and terminal equipment.

Standards may be classified into two classes: lower layers for communication-oriented functions and higher layers for processing- and storage-oriented functions. The lower layers 1-3 differ substantially due to the different network and access properties; their corresponding standards are referred to in Fig. 5. Level 4 (Transport) is generally considered as a network-independent layer where connections between end systems are provided irrespective from the underlying special network type. For references to these protocols see |5-11|.



Layer	CS Data Network	PS Data Network	LAN	ISDN	Signalling Network
4 Transport	ISO 8072, 8073; CCITT T.70				CCITT No.7 User Parts DUP | TUP | ...
3 Network	CCITT X.21	CCITT X.25	ISO DIS 8348 DP 8648	CCITT I.450/51	CCITT No.7 SCCP MTP(3)
2 Data Link Media Access	CCITT X.21	CCITT X.25 LAP B	IEEE 802.2 IEEE 802.3-6	CCITT I.440/41 LAP D	CCITT No.7 MTP(2)
1 Physical	CCITT X.21	CCITT X.21	IEEE 802.3 - 6	CCITT I.430/31	CCITT No.7 MTP(1)

Figure 5
Survey of Standards for Communication-Oriented Protocol Layers

The higher layer protocols differ mainly because of the different application services. Fig. 6 gives a survey of their corresponding standards |12-18|.

In the CCITT-Recommendations on ISDN the functional capabilities are subdivided according to Low Layer Capabilities which refer to the Communication Path covering levels 1-3 (Bearer Services) and Higher Layer Capabilities which refer to Information Processing and Storage covering levels 4-7 (Teleservices).

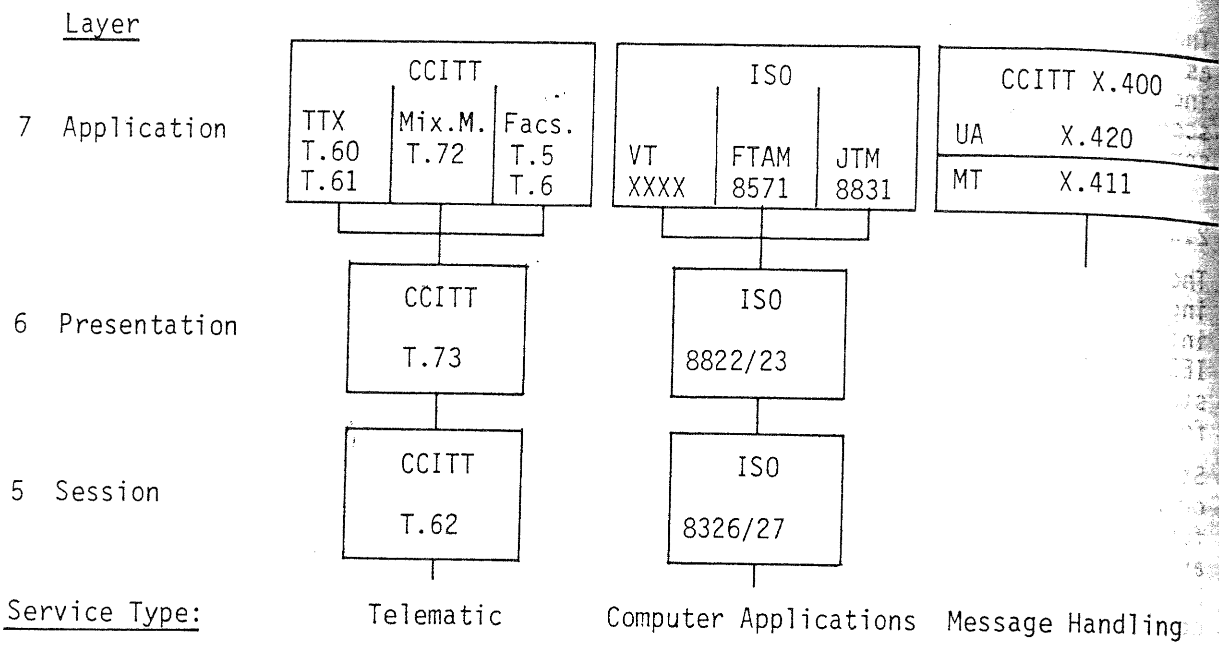


Figure 6
Survey of Standards for Processing- and Storage-Oriented Protocol Layers

3. MODELLING

Modelling of communication protocols is understood in a wide sense comprizing (a) formal specification techniques for protocol mechanisms (as finite state machine, Petri Net models, formal language models) and techniques for formal verification and conformance testing based upon such models, and (b) quantitative techniques to evaluate the traffic performance through simulations and mathematical analysis (as queuing networks and service systems), see, e.g., [19]. Both techniques have some common features but differ substantially in their aims and approaches:

a) Formal Specification	b) Performance Evaluation
- logical function	- dynamic behavior
- completeness	- stochastic workload
- free of contradiction	- performance in terms of throughput and delay
- independent from implementation	- dependence from implementation
- deterministic evaluation	- probabilistic evaluation
- conformance testing	- benchmark measurements

Techniques and tools of both modelling approaches are commonly used in the course of standardization and implementation of protocols and communication systems.

In this paper we will mainly focuse on modelling techniques belonging to class b). This field has a long tradition in operations research, traffic engineering and computer performance where a great variety of theories, methods and tools already exist. For the specific field of computer communications networks, we refer to various excellent surveys [20, 21], books, e.g. [22], or conference series [23-25]. This paper aims therefore on some particular problems which have arisen in connection with the event of new services. Herein, we will address three different aspects: Workload models, Protocol models, and Switching networks.

3.1 WORKLOAD MODELS

Within classical performance models, the workload is mainly characterized by

- arrival processes of service requests
- service processes for system resources.

Arrival processes can be described by a properly chosen point process (e.g., Poisson process, renewal process, nonrenewal process) to describe the behavior of a large number of customers and devices, or even the relation between arrival events as in case of repeated call attempts. Cluster effects may also be characterized by batch arrival process. Service processes are usually described by a probability distribution function for the holding time of the resource requested.

Many new services need further specifications with respect to

- structured activities within an established connection to account for, e.g.,
  - full or half duplex transmission
  - session synchronization points
  - dialogues
- data transmission rates for various applications as, e.g.,

• program development	9.6 kbps
• line printing	19.2 kbps
• voice and telematic services	64 kbps
• high resolution graphics	256 kbps
• file transfer	10.000 kbps
• video communication	140.000 kbps

- data volumes and call duration times for the various services, as, e.g.,
  - files, messages, mail, documents
  - virtual calls in PS-networks
  - data link connections for signalling purposes
  - video connections for individual videophone and videoconference applications
- subscriber behavior as, e.g., for
  - repeated call attempts
  - TE busy periods
  - selection of parameters by negotiation
  - peak traffic busy hours
  - advance registration for reservations
  - dependence between grade of service and tariffs.

Many of these workload characteristics are not yet known since the services are not yet introduced or the final networks are not yet in operation. Some first data have been obtained from field measurements, see [26-28]. Generally, there is a great need of further measured data to develop reliable workload models as a basis for traffic engineering in presence of new services. For ISDN-applications, a first approach has been reported in [29] where a service mix has been associated to a "reference equivalent user" for proper dimensioning and planning procedures.

3.2 PROTOCOL MODELS

3.2.1 BASIC STRUCTURE AND METHODOLOGY

A protocol performance model incorporates

- the basic functions of the communicating protocol entities of the considered layer
- the exchange of commands and responses with the higher layer service user entity according to the adjacent layer service primitives
- the establishment of connections and transport of PDU's through the exchange of commands and responses with the lower layer service provider entity.

The basic protocol model structure follows directly from the generic service concept of Fig. 1, see Fig. 7. The model of Fig. 7 is based on a connection-oriented communication mechanism; for a connectionless communication a slightly simplified model can be used |30|. The connection is represented by a pair of transmit (T) and receive (R) queues within the (N)-entities. The exchange of (N)-PDU's follows according to the underlying (N)-peer protocol. The total subsystem of layers ≦ (N-1) is aggregated into a pair of servers for the (N)-transport submodel; the aggregated PDU-transport times T_{AB} and T_{BA} follow from a preceeding submodel analysis. Thus, the analysis of hierarchically layered protocol architectures can be performed recursively level by level, bottum-up. The delays of the level (N) submodel can again be aggregated into an equivalent pair of servers to act as (N+1)-transport submodel.

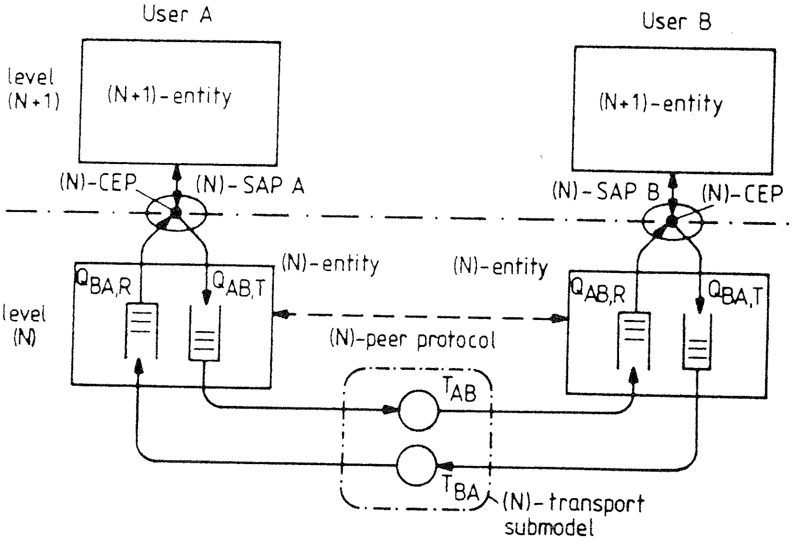


Figure 7
Basic Structure of a Protocol Model

In the sequel we will apply this principle to various application examples of communications-oriented protocol layers (levels 2-4).

3.2.2 SINGLE DATA CONNECTION MODEL

Handshake protocols for error recovery need too much overhead, especially when the propagation delay of the transmission link is high. For this reason, a sliding window protocol is used allowing to proceed to send before an acknowledgement of the preceeding message has arrived. To control this mechanism, both terminal stations of a link use sequence numbers N(S) and N(R) which are incremented cyclically modulo M (M=8 or 128). N(S) indicates the next message (frame) to send where N(R) acknowledges the other station that all frames up to N(R)-1 have been received safely. A station may send as long as its window is opened, the window size W may vary between W=0 and W=M-1 or less.

Besides this sequencing mechanism, the data link protocols feature several other aspects:

- primitives to set-up and take-down a data link connection
- definition of several operational modes as Normal Response Mode (NRM) or Asynchronous Balanced Mode (ABM)
- Recovery mechanisms using checkpointing by poll and final bits (P/F recovery) and time-out.

The performance of a data link, i.e. its maximum throughput and transit delay, depends largely on the data link and protocol parameters as

- transmission speed
- propagation delay
- error probability
- maximum window size
- recovery mechanism

and is subjected to a careful performance analysis. Fig. 8 shows a basic model for an established data link connection for the class of HDLC-ABM procedures, where the level 1 is represented by a transmission channel with errors.

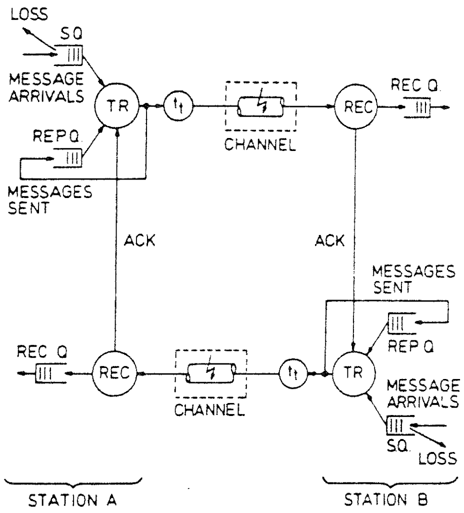


Figure 8
Data Link Model for HDLC-ABM

TR	Transmitter
REC	Receiver
S.Q.	Send-Queue
REP.Q.	Repeat-Queue
REC.Q.	Receive-Queue
ACK	Acknowledgement
t_t	Transmission time/frame

Performance results have been obtained by simulations as well as by analytical studies using a concept of "virtual transmission time" |31-33| . Typical results show a throughput maximum for medium sized frame lengths. The throughput degrades for small frame sizes (window limitation) as well as for large frame sizes (frame errors); the maximum may be far less than 100% depending on factors as error probabilities, window size, and recovery mechanism.

3.2.3 MULTIPLE DATA LINK CONNECTIONS IN LAN's

In Local Area Networks (LAN) many stations share one communication channel. The access to this channel is controlled by a procedure which is usually distributed among all access stations and governed by a Media Access Control (MAC) protocol (level 2a). On top of this MAC-layer, stations may establish DL-connections (or Logical Link connections) among each other. Each of these DL-connections is now additionally affected by the commonly used transmission medium and the particular MAC-protocol as, e.g., CSMA/CD or Token-Passing.

Fig. 9 shows the basic structure of a DL-connection model where one or many DL-connections are established between two stations A and B. This model consists of three submodels:

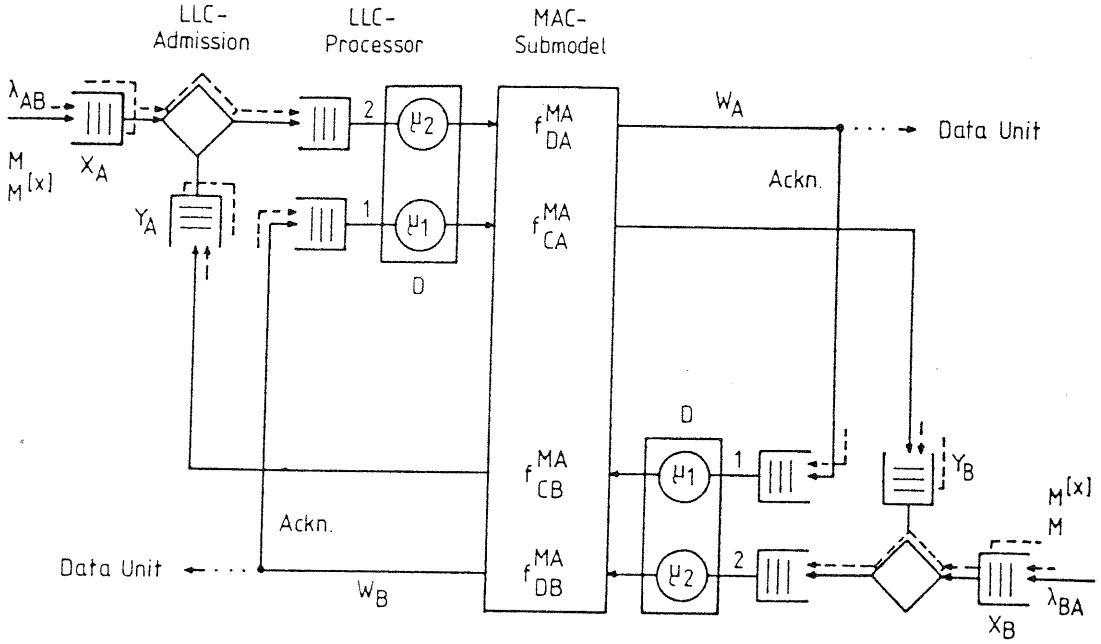


Figure 9
Multiple DL-Connection Model for Local Area Networks

- LLC-Admission Submodel

  The admission of DL-PDU's (frames) from the X-queue depends on the state of credit queue (Y-queue). Each admitted frame reduces the Y-queue by one; if there are no credits available, frames have to wait within the X-queue. Each time a frame has been successfully transmitted, an acknowledgement frame is sent back which increases the Y-queue by one. The total number of frames and acknowledgements within one connection loop, W, defines the maximum window size. This model is a variant of Reiser's suggestion |34|.

- LLC-Processor Submodel

  The LLC processor performs all level 2b (and possibly higher level) functions of a station. The processor model is a priority type model where acknowledgements for the reverse direction of the FDX-DL-connection are treated with higher priority.

- MAC-Submodel

  The MAC-submodel represents the transit delays of the LAN where two basic MAC-PDU types are distinguished: short control (C) messages as for acknowledgements, and long data (D) messages. This submodel is an aggregated model where the influence of all other traffics on the MAC-level are lumped together.

The performance analysis of the multiple DL-connection model is based on successive decomposition and aggregation steps, see |30| .

3.2.4 ISDN BASIC ACCESS SIGNALLING MODEL

Within the future ISDN, multiple terminal equipment is connected to the network through 2 B-channels, where the signalling is executed through a common D-channel. The D-channel is used to set up multiple level 2- and level 3-connections between the terminal equipment (TE 1) and the exchange termination (ET) entity. Each of the level 2-connections (LAP D) operates similarly as an HDLC-procedure; the protocol is more complicated, however, since it has to account for addressing of multiple TE's with changing end points for the attachment of the TE's and for a quick dynamic set up.

The complexity of the corresponding models requires usually a simulation approach; such models allow the additional handling of packetized data transmission over the D-channel, see |35| .

3.2.5 X.25 NETWORK ACCESS

For the access to public PS data networks CCITT has recommended the X.25 interface |6| . Within level 2, the Link Access Procedure for Balanced Mode (LAP B) is used which is similar to HDLC-ABM. Within level 3, multiple virtual connections (N-connections) may be multiplexed, each of them being individually managed with respect to establishment/release, flow-control, and error recovery. This is another example of mutual influence between connections on one level and the interaction between different levels.

The performance can be evaluated on the basis of a detailed queuing model as depicted in Fig. 10, see |36| .

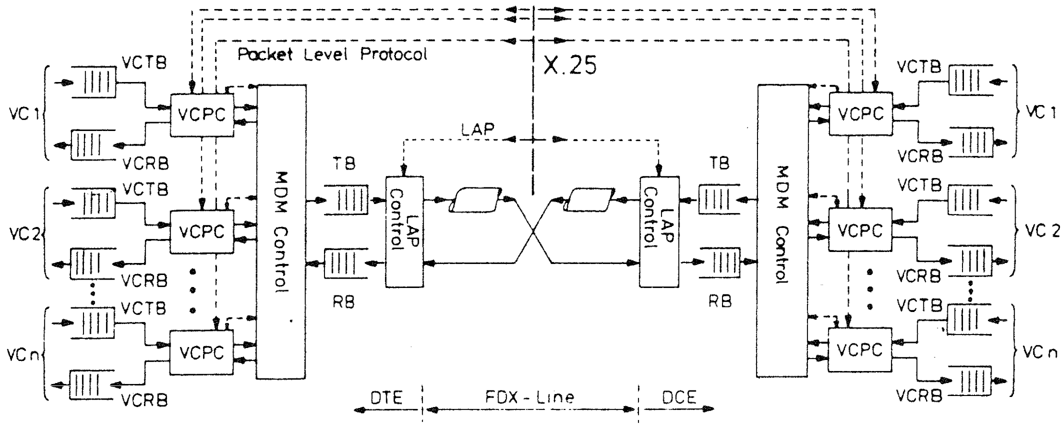


Figure 10
Model of the CCITT X.25 Network Interface

DTE	data terminal equipment
DCE	data circuit terminating equipment
LAP	link access procedure
VC	virtual call or virtual circuit
RB/TB	receive/transmit buffer
VCPC	VC procedure control
MDM	multiplex/demultiplex device

3.2.6 END-TO-END FLOW CONTROL

The transport level comprises all functions related to the end-to-end communication between two user entities through the network. These functions are the set-up and take-down of transport connections, the multiplexing/demultiplexing of several transport connections on one network connection, the splitting/recombination of one transport connection on several network connections, segmenting and reassembling of transport service data units (TSDU) on transport protocol data units (TPDU), the end-to-end flow control and the negotiation on transport service parameters.

A particular model for the end-to-end control through a network is shown in Fig. 11 |37|. The source model consists of two Markovian traffic sources with high (λ_1) and low rates (λ_2). The sink model consists of an arrival storage of maximum capacity S buffers and a Markovian server with service rate μ_S. The traffic flow is controlled by two storage levels L1 and L2: Upon an upward crossing of L1 a control message is sent back to the source to switch from high to low traffic; another control message is applied upon downward crossing of L2 < L1 to switch the source from low to high traffic. The inherent network delays for the control messages and the data units are lumped together in one "infinite server" stage IS with an arbitrary delay distribution with average $1/\mu_N = d$.

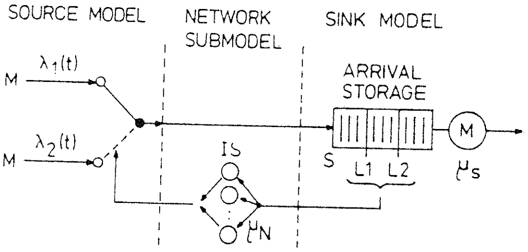


Figure 11
End-to-End Traffic Control Model

This model allows the performance evaluation of end-to-end control schemes particularly the estimation of the influence of larger network delays, finite storage, and control levels. Under larger network delays a stationary analysis may be quite misleading due to the inherent traffic fluctuations resulting from the on/off-control mechanisms. For the nonstationary traffic analysis efficient procedures have been developed, see |37| .

3.2.7 FILE TRANSFER

Among the many applications in data communications, file access and transfer may be mentioned as an example. In this application, users access a data base through a communication network in order to receive larger blocks of data. Based on the particular communication-oriented protocol levels 1-4, this application is largely governed by the higher layer protocols for functions as

- session control
- file access
- intermediate buffering
- overlapped operations.

Modelling of File Transfer connects computer communication models and computer system models. Both submodels are usually optimized for their isolated operation: networks for a more or less continuous flow of data and disk access systems for a block-oriented transmission of data. The interconnection of both submodels results in a number of problems to be handled by the higher level protocols. In particular, different block sizes for file access and network transmission and different transmission speeds within the computer system and the communication network require large buffer spaces and cause large transmission times.

For a more detailed discussion on such questions see |38|.

3.3 SWITCHING NETWORK MODELS

The future ISDN develops from the CS digital telephone network. Within the ISDN the voice communication will still be the dominating service; therefore, the ISDN will be optimized more or less with respect to this dominating service. Other services which require different switching principles or transmission bandwidths give reason for a number of new problems in connection with switching networks.

3.3.1 MULTICHANNEL SWITCHING

Video communication requires bandwidths which are considerably higher as for voice communication. Besides the 140 Mbps rate for a high definition TV quality, lower bit rates may be interesting for certain applications or for economic reasons. Particularly, applications which require only a few of basic B-channels could be realized on the basis of the so-called "narrow band ISDN". For a switched point-to-point video communication 6 B-channels (384 kbps) can be used. This application results in a set of new traffic models where different bit rates (i.e. n simultaneous B-channels with n = 1,2,...32) have to be switched through

- single/multi-stage connecting networks with full or limited accessibility and
- long distance trunk groups.

A basic model can be defined which is characterized by

- several arrival classes with different arrival rate
- individual statistics for interarrival and service times.

This model can be modified to include further features as

- maintaining the time slot (channel) order
- packing algorithms based on subgroup divisions
- rearrangement of existing connections, etc.

For further discussions on these problems we refer to |39, 40|.

3.3.2 CONNECTION RESERVATION

Within the future "broadband-ISDN" teleconferencing will be one service additionally to the individual point-to-point video communication. Teleconferences differ from the individual communication with respect to

- predefined time of a broadband connection between two teleconferencing studios
- reservation of communication channels ahead of time to guarantee the connection at the predefined time
- longer holding times.

The procedure for the scheduling of connection reservations depends on parameters as

- the arrival time of the reservation request
- the instant and duration of the requested connection
- the number of requested resources (channels, bandwidth)
- the costs for delaying reservation requests
- the costs for prereserved (blocked) communication channels
- the discretization of time for the reservation procedure.

The many constraints lead to traffic models with a high degree of correlations which cannot be mastered up to now by other means than simulations.

For a more detailed study of these problems we refer to |41, 42| .

3.3.3 BROADBAND NETWORKS

Switched broadband networks allow not only spontaneous or pre-reserved point-to-point connections; they may also be used for switched distribution of particular programs as for educational purposes. Switched boradcast networks can be constructed non-blocking. The cost of such networks can be further reduced by using rearrangement techniques for existing connections.

For a more detailed discussion see |43| .

3.3.4 HYBRID SWITCHING NETWORKS

As it was stated in Section 2.2, new communication services are rather heterogeneous with respect to their resource requirements. Therefore, the integration of such services poses difficult problems as

- interface protocol adaptation
- speed adaptation
- switching principle transition
- interworking of different networks.

Such problems are particularly vital for the interworking of high-speed local networks with narrow-band public networks. The amount opf equipment for protocol conversion, speed conversion and buffering can be greatly reduced when the network itself offers heterogeneous transmission and switching capabilities. Hybrid switching is a basis for the integration of stream-type voice communication with burst-type data communication. Circuit Switching (CS) is more advantageous for stream-type communications whereas the burst-type communications is much better supported by the Packet Switching (PS) principle.

In principle, each of the switching principles can be applied to either communication; voice may be transmitted in a packet mode, and burst data can be transmitted by fast circuit switching. Both, however, have significant drawbacks with respect to losses and variable delays for voice packets or delays through the many connection establishments for burst-type transmissions. Therefore, both variants have only limited applications.

Hybrid switching can be realized in different ways |44| , see Fig. 12.

The various hybrid switching principles differ with respect to their signalling schemes, bandwidth utilizations and traffic performance. The latter one is subject of performance modelling. Some of these schemes have already been analyzed (for references see |44 |.

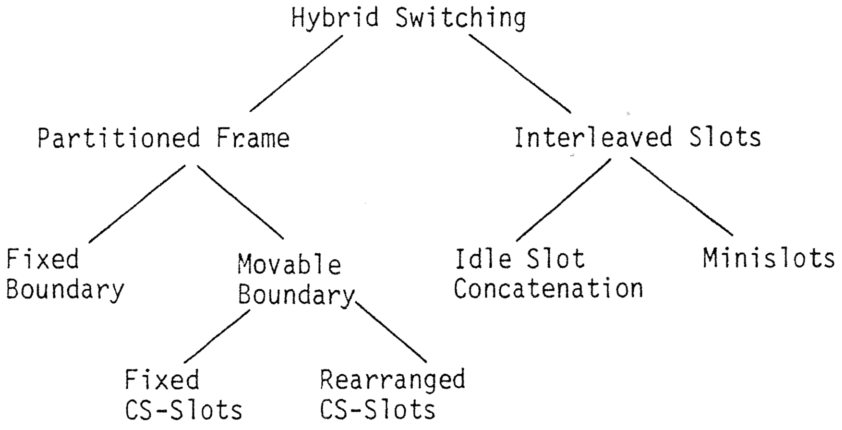


Figure 12
Hybrid Switching Principles

Hybrid switching is usually applied to high-speed bus or ring systems for local area networks. The assignment of the bandwidth of the common transmission medium can be managed in a decentralized, centralized or mixed centralized/decentralized way. Fig. 13 shows a general traffic performance model for a hybrid CS/PS ring for local area networks operating according to the partitioned frame principle.

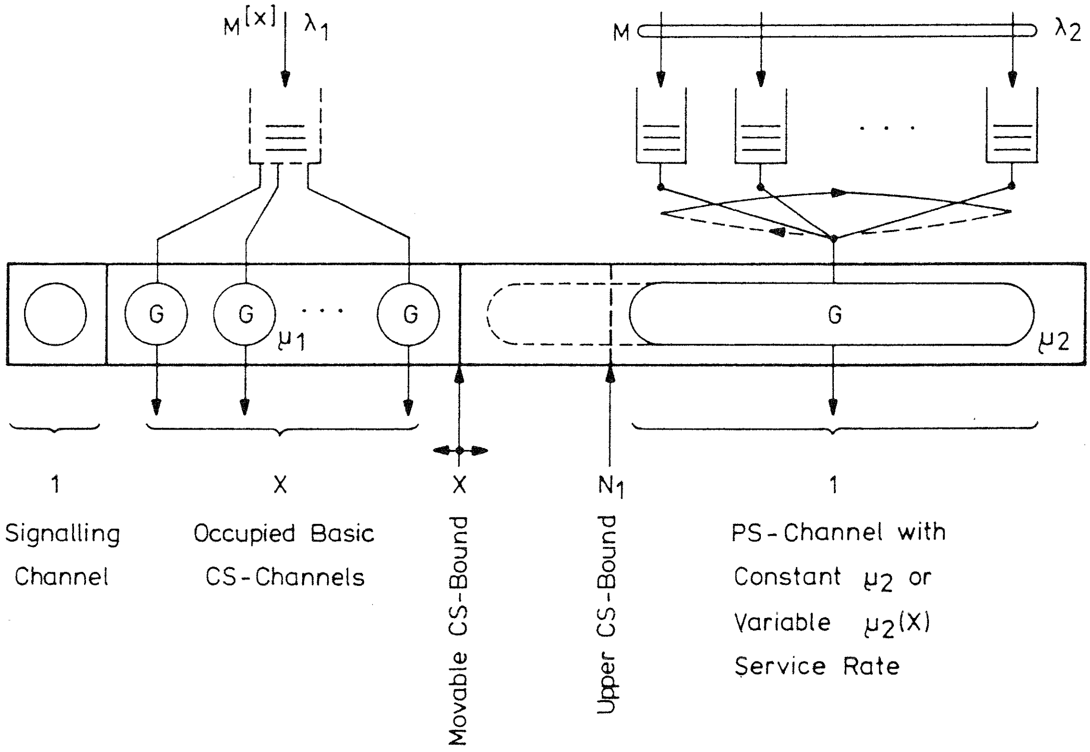


Figure 13
Traffic model for a Hybrid Switching Scheme

The bandwidth of the transmission media is subdivided into one separated server for synchronization and signalling, $X \leq N_1$ basic CS-servers with each 64 kbps transmission rate, and one residual PS-server. The CS-servers are operated either in loss or in delay system mode. The arrival process for new connections may be batch Markov $M^{[X]}$ with arrival rate λ_1. Batch arrivals require also group service, i.e. all occupied basic channels belonging to one connection terminate simultaneously. The service times may be general (G) with service rate μ_1. Contrary to the centrally managed CS-channels, the PS-channel is allocated in a distributed fashion according to the token-passing principle symbolized by a circularly rotating switch. There are as many input queues as access stations each with Markov arrivals of rate μ_2. The PS-server serves one packet transmission time of arbitrary type (G) and service rate $\mu_2(X)$. If a packet transmission is not completed within the current pulse frame, it will be interrupted by the synchronous CS-connections and immediately continued thereafter.

The theoretical analysis of the joint state variables for the number of occupied basic CS-servers and the number of packets in the system has been subject of many recent papers. This process is extremely difficult to analyze exactly. An approximate analysis according to the decomposition principle can be done since the CS-occupations (as for voice) are of low dynamics compared to the highly dynamic packet process |44|. Then, the general model can be decomposed into an independent CS-submodel of the type $M^{[X]}/G/N_1$ with group service and a PS-submodel of the type M/G/1 with regular service interrupts (D) of constant length (D_X); the regular interrupts (D) correspond to the pulse frame length T whereas the interrupt length (D_X) depends in the general case on the actual CS-occupation state X.

CONCLUSION

The introduction of new services and network functions poses many new problems on modelling techniques. This contribution aimed at the identification of some of these new problems. Since the development has not reached a stable point, many more problems can be expected in the future.

Generally, we can conclude that the modelling process leads to rather complicated structures where also new approaches for the performance analysis are required. For this reason, simulation is one of the techniques which are at this time most adequate. Even this technique has significant drawbacks for large model structures so that advanced decomposition and aggregation techniques are necessary. New approaches have to be found to analyze models with multiple interdependencies, many heterogeneous customer classes, synchronization mechanisms extremely large state spaces, large differences in the dynamic behavior of partial processes, time-dependent mechanisms, and the characterization of workload. Some of these approaches have also been addressed recently, see |45, 46|. The analytical and simulative tools have also to be complemented by system measurements and experimental methods as environment simulations.

REFERENCES

|1| ISO 7498/CCITT Recommendation X.200: Reference Model of Open Systems Interconnection.

|2| Potter, R.M.: ISDN Protocol and Architecture Models.
Proc. 11th Int. Teletraffic Congress (ITC), Kyoto 1985.
Elsevier Science Publ. B.V. (North Holland), paper 1.3-4.

|3| Duc, N.Q. and Chew, E.K.: ISDN Protocol Architecture.
IEEE Comm. Magazine, Vol. 23 (1985) 3, pp. 15-22.

|4| ECMA TR/XX: OSI Sub-Network Interconnection Scenarios Permitted within the Framework of the ISO-OSI Reference Model. First Draft (1983).

|5| CCITT Recommendation X.21: Interface between Data Terminal Equipment (DTE) and Data Circuit Terminating Equipment (DCE) for Synchronous Operation on Public Data Networks. Yellow Book, Fasc. VIII.2, Geneva (1980).

|6| CCITT Recommendation X.25: Interface between DTE and DCE for Terminals Operating in the Packet Mode on Public Data Networks.
Yellow Book, Fasc. VIII.2, Geneva (1980).

|7| CCITT Recommendations on ISDN (I-Series).
I.100 Series: General ISDN Concept
I.200 Series: Service Aspects
I.300 Series: Network Aspects
I.400 Series: User-Network Interface Aspects
I.500 Series: Internetwork Interfaces
I.600 Series: Maintenance Principles.
Red Book, Geneva (1985).

|8| CCITT Recommendations on Signalling System No. 7.
Q.701 - Q.710: Message Transfer Part (MTP) and PABX Applications
Q.711 - Q.714: Signalling Connection Control Part (SCCP)
Q.721 - Q.725: Telephone User Part (TUP)
Q.761 - Q.766: ISDN User Part (ISDNUP)
Q.795: Operations and Maintenance Application Part (OMAP).
Red Book, Geneva (1985).

|9| IEEE Project 802. Local Area Network Standards, Rev. D (1982).
IEEE Standard 802.2: Logical Link Control
IEEE Standard 802.3: CSMA/CD Access Method and Physical Layer Specifications
IEEE Standard 802.4: Token-Passing Bus Access Method and Physical Layer Specifications
IEEE Standard 802.5: Token Ring Access Method and Physical Layer Specifications (1985).

|10| ISO DIS 8348: Network Service Definition.
ISO DP 8648: Internal Organisation of the Network Layer.

|11| ISO 8072: Transport Service Definition (1983).
ISO 8073: Connection Oriented Transport Protocol Specification (1983).
CCITT T.70: Network Independent Basic Transport Service for the Telematic Services (1984).

|12| CCITT T.62: Control Procedures for Teletex and Group 4 Facsimile Services (1984).

|13| CCITT T.73: Document Interchange Protocol for the Telematic Services (1984).

|14| CCITT Recommendations
T.60: TTX Terminals
T. 5: Facsimile Terminals
T.72: Mixed Mode Terminals
T.61: TTX Character Set
T. 6: Facsimile Coding.

|15| ISO DIS 8326 and CCITT X.215: Connection-Mode Session Service Definition.
ISO DIS 8327 and CCITT X.225: Connection-Mode Session Protocol Specification.

|16| ISO DP 8822: Connection-Oriented Presentation Service Definition.
ISO DP 8823: Connection-Oriented Presentation Protocol Specification.

|17| ISO DP XXXX: Virtual Terminal Service and Protocol (VT).
ISO DP 8571: File Transfer, Access and Management (FTAM).
ISO DP 8831: Job Transfer and Manipulation Concepts and Services (JTM).

|18| CCITT X.400-Series Message Handling Systems (1984).
X.411: Message Transfer Layer.
X.420: Interpersonal Messaging User Agent Layer.

|19| Sunshine, C.A. (Ed.): Communication Protocol Modelling.
Artech House, Inc., Dedham, MA (1981).

|20| Kobayashi, H., Konheim, A.G.: Queueing Models for Computer Communication System Analysis.
IEEE Trans. Commun., Vol. COM-25 (1977), pp. 2-29.

|21| Reiser, M.: Performance Evaluation of Data Communication Systems.
Proc. IEEE, Vol. 70 (1982), pp. 171-196.

|22| Kleinrock, L.: Queueing Systems.
Vol. 1: Theory, Vol. 2: Computer Applications.
J. Wiley, New York (1975).

|23| Proceedings of the International Teletraffic Congress (ITC),
1 (1955) through 11 (1985), every 3 years.

|24| Proceedings of the International Symposium on Computer Performance ,
IFIP WG 7.3, every 18 months.

|25| Proceedings of the International Seminars on Performance of Data Communications Systems (Paris 1981, Zurich 1984)

|26| Pawlita, P. Traffic Measurements in Data Networks, Recent Measurement Results and some Implications.
IEEE Trans. Commun. Vol. COM-29 (1981), pp. 525-535.

|27| Shoch, J.F, Hupp, J.A.: Measured Performance of an Ethernet Local Network.
Commun. of the ACM, Vol. 23 (1980), pp. 711-721.

|28| Hofstetter, H., Weber, D.: Traffic Models for Large ISDN-PABX´s.
Proc. 11th Int. Teletraffic Congress (ITC), Kyoto 1985.
Elsevier Science Publ. B.V. (North Holland), paper 1.3-3.

|29| Soto, O.G.: On Traffic Modelling and Characterization of ISDN Users.
Proc. Data Commun. in the ISDN Era, Tel Aviv, 1985.
Elsevier Science Publ. B.V. (North Holland), pp. 127-140.

|30| Gihr, O., Kuehn, P.J.: Comparison of Communications Services with Connection-Oriented and Connectionless Data Transmission.
Proc. Int. Sem. on Computer Networking and Performance Evaluation, Tokyo, 1985.

|31| Bux, W, Kümmerle, K. Truong, H.L.: Balanced HDLC-Procedures: A Performance Analysis.
IEEE Trans. Commun., Vol. COM-28 (1980), pp. 1889-1898.

|32| Bux, W, Kümmerle, K. Truong, H.L.: Data Link Control Performance: Results Comparing HDLC Operational Modes.
Comp. Networks, Vol.6 (1982), pp. 37-51.

|33| Goeldner, E.-H., Truong, H.L.: A Simulation Study of HDLC-ABM with Selective and Nonselective Reject.
Proc. 10th Int. Teletraffic Congress (ITC), Montreal, 1983, paper 3.4-5.

|34| Reiser, M.: Admission Delays on Virtual Routes with Window Flow Control.
Proc. Perf. of Data Commun. Systems and Their Applications.
North Holland Publ. Comp. (1981), pp. 67-76.

|35| Fischer, W., Goeldner, E.-H., Berner, W.: Performance of the D-Channel
Protocol - A Simulation Study. Forthcoming paper (1986).

|36| Dieterle, W.: Performance Evaluation of Data Communication Protocols -
Example of a Case Study on X.25.
Proc. Int. Conf. on Computer Commun. (ICCC), Sydney, 1984, pp. 400-405.

|37| van As, H.R.: Modelling and Analysis of Congestion Control Mechanisms
in Packet Switching Networks. 38th Report on Congestion Theory,
University of Stuttgart, 1984, ISBN 3-922 403-48-4.

|38| Meister, B., Janson, P., Svobodova, L.: File Transfer in Local Area
Networks: A Performance Study.
IBM Research Report RZ 1333, 1984.

|39| Ramaswami, V.,Rao, K.A.: Flexible Time Slot Assignment. A Performance Study
for the Integrated Services Digital Network.
Proc. 11th Int. Teletraffic Congress (ITC), Kyoto 1985.
Elsevier Science Publ. B.V. (North Holland), paper 2.1A-3.

|40| Fiche, G., Le Gall, P., Ricupero, S.: Study of Blocking for Multislot
Connections in Digital Link Systems.
Proc. 11th Int. Teletraffic Congress (ITC), Kyoto 1985.
Elsevier Science Publ. B.V. (North Holland), paper 5.4B-2.

|41| Murakami, K., Katoh, M., Abe, S,: Traffic Design for Time Division Wideband
Switching Networks.
Proc. 11th Int. Teletraffic Congress (ITC), Kyoto 1985.
Elsevier Science Publ. B.V. (North Holland), paper 5.4B-3.

|42| Roberts, J.: Teletraffic Model for the Telecom I Integrated Services Network.
Proc. 10th Int. Teletraffic Congress (ITC), Montreal 1983, paper 1.1-2.

|43| Richards, G.W., Hwang, F.K.: A Two-Stage Rearrangeable Broadcast
Switching Network.
Proc. 11th Int. Teletraffic Congress (ITC), Kyoto 1985.
Elsevier Science Publ. B.V. (North Holland), paper 5.4B-4.

|44| Goeldner, E.-H. Kuehn, P.J.: Integration of Voice and Data in the Local Area.
Proc. Data Commun. in the ISDN Era, Tel Aviv, 1985.
Elsevier Science Publ. B.V. (North Holland), pp. 103-117.

|45| Kuehn, P.J.: Modelling and Analysis of Computer Networks - Decomposition
Techniques, Transient Analysis and Protocol Implications.
Proc. Int. Conf. on Commun., Amsterdam, 1984.
IEEE/Elsevier Science Publ. B.V. (North Holland), pp. 1589-1597.

|46| Labetoulle, J.: Performance Evaluation of Telecommunication Networks.
Proc. Int. Conf. on Modelling Techniques and Tools for Performance Analysis,
Paris, 1984. North-Holland, pp. 279-288.