SIGNALING

Signaling protocols are used to support real-time control procedures in telecommunication networks. These procedures include users requesting services from a network and network elements interacting with each other to fulfill user service requests. Examples of such services include simple connection services, such as establishing a point-to-point connection between users, and more complex value-added services that may be provided in addition to connection services. Examples of value-added services include validating credit-card numbers for credit-card calls and translating 800 numbers. Signaling protocols, and the control procedures that they support, are defined in standards to allow equipment from different vendors, and networks from different providers, to interoperate and provide end-to-end service among users attached to different networks. The major international standards body that defines signaling protocols and procedures is the International Telecommunication Union (ITU), formerly known as CCITT. Other various national and commercial standards bodies also exist.

Control procedures and signaling protocols are divided into two main areas—access signaling and signaling between network elements. Typical access signaling occurs between a subscriber and its access network over a point-to-point signaling link. Signaling within and between modern networks is carried out over separate signaling networks that connect various network elements.

Signaling protocols support call processing and service processing applications. The call processing application executes on end devices and on network switches. Service applications may execute on end devices or network switches, but most typically execute on processors located in the network that may be accessed by switches. Signaling protocols are defined for the physical layer, link layer, network layer, transport/session layer, and application layer. Nodes in which the application layer signaling protocols are terminated are called *signaling points* and perform the call and service processing applications.

Over the years signaling protocols and procedures have evolved from supporting analog telephony networks (1) to integrated services digital networks (ISDNs) (2). More recently, signaling procedures have been defined to support mobile users and to support advanced services on broadband ISDNs (B-ISDN) (3). To illustrate the purpose and structure of signaling networks, protocols, and procedures, ISDN signaling is ideal. Signaling for B-ISDN is based, in concept, largely on the ISDN signaling model.

ISDN SIGNALING ARCHITECTURE

In this section, the signaling architecture of modern ISDNs is described. A simplified view of the current signaling architecture for ISDN is shown in Fig. 1. Subscribers signal into the network to request calls (services and connections) across the user-network interface (UNI) by using the Digital Subscriber Signaling System No. 1 (DSS1) (4,5) protocol suite. Access signaling is performed over a dedicated point-to-point signaling link called the D-channel. The D-channel, and the entire DSS1 protocol suite, is terminated on the access switch to which the subscriber customer premises equipment (CPE) is connected. The access switch and CPE each execute peer call-processing applications. The call-processing application executing on the CPE is often trivial, whereas the call processing application executing on the access switch is typically complex. The user information, such as voice, travels over a separate logical channel, called the B-channel.

Within networks, nodes signal to each other across the network node interface (NNI) using the Signaling System No. 7 (SS7) (6) protocol suite. This signaling takes place over a separate common channel signaling network. Application layer signaling messages are routed to, and processed in, the switches that will eventually support the connection carrying the user information. In addition, switches may signal to other network processors, called network control points (NCPs), to request service processing, for example a credit-card validation for a credit-card call. The switches and NCPs are signaling points which execute the call processing and service applications.

The common channel signaling network over which various network elements communicate is made up of packet switches called signaling transfer points (STPs). The common channel signaling network is configured in a highly reliable configuration; as shown in Fig. 1, each signaling point is dual-homed to the common channel signaling network, and STPs are connected in a quad arrangement. This structure eliminates any single points of failure. The common channel signaling network is largely self-managing; that is, the protocols that operate on this network continually monitor network performance and automatically react to network failure, congestion, or errored conditions. In some cases, signaling points may have signaling links connecting them directly.

There are three routing modes defined for signaling messages on the common channel signaling network. For associated signaling, messages are sent on links directly connecting the corresponding signaling points. Nonassociated signaling includes intermediate nodes, such as STPs. For quasi-associated signaling, intermediate nodes are included, but the path taken by signaling messages is predetermined and fixed.

ACCESS SIGNALING

Access signaling is used by a subscriber to request service from a network and by the network to indicate incoming service requests to a subscriber. Typical access signaling occurs

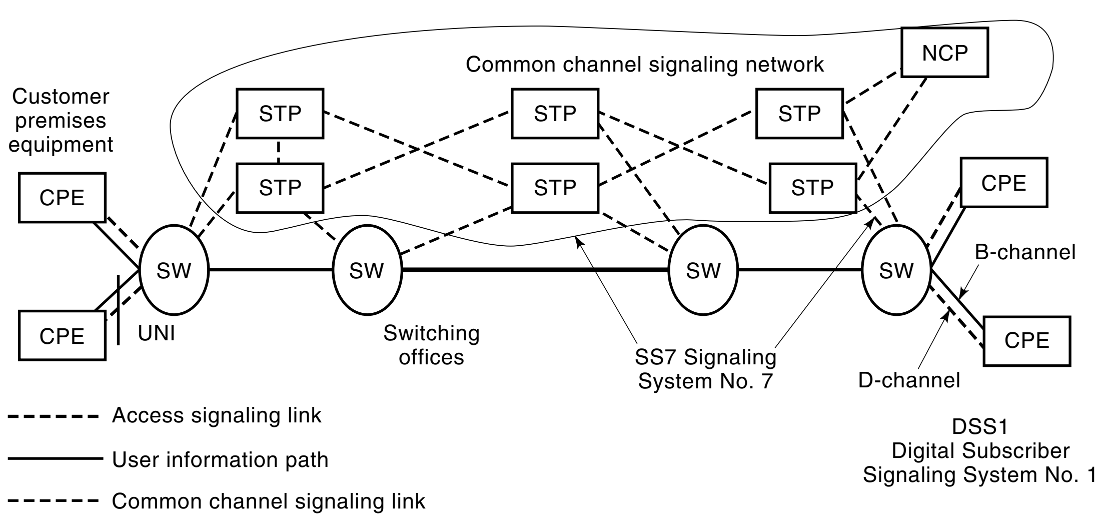

Figure 1. Current signaling architecture.

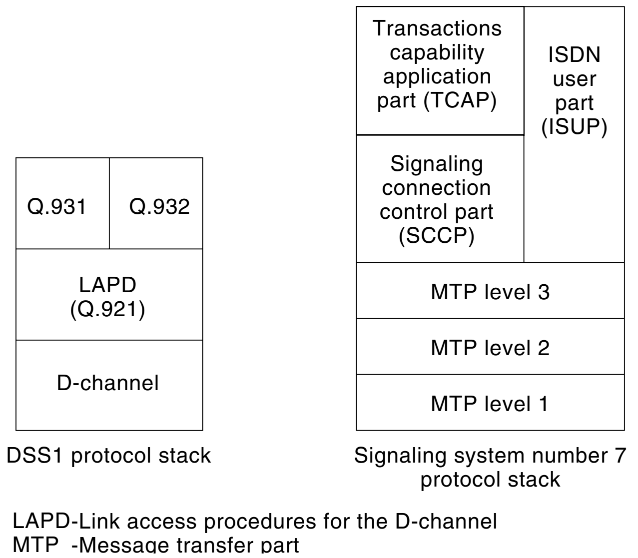

Figure 2. ISDN signaling protocol stacks.

between a subscriber and its access switch. For analog telephone networks, signaling is performed using tones. For digital networks, such as ISDN, access signaling is message based; that is, messages are passed between the subscriber CPE and the access switch. The interface between the user and the network is called the user-network interface (UNI). For ease of understanding, we discuss ISDN access signaling here.

As shown in Fig. 1, subscribers signal into the network using the DSS1 protocol suite. Figure 2 shows the ISDN signaling protocol stacks. The DSS1 link layer protocol, called LAPD (7), provides a point-to-point link between a subscriber and its access signaling point, typically its access switch. Two application layer protocols reside above LAPD—Q.931 (4) and Q.932 (5). Q.931 is used to control circuit-mode connections, packet-mode access connections, and temporary signaling connections. The most common type of connections supported are circuit-mode connections which are used for voice and voice-band data communications. Q.932 is used to control supplementary services.

A typical end-to-end signaling flow for basic call establishment is shown in Fig. 3. The access signaling messages are shown in italic letters. Table 1 summarizes the key signaling messages for call establishment and their use. Note that these messages are part of the Q.931 protocol and are used to control circuit-mode connections. Each Q.931 message contains parameters called *information elements* that are used to characterize the requested call or services being requested.

Table 1. Q.931 and Q.932 Signaling Message Summary

Message Name	Calling Party	Called Party
SETUP	Generated to establish a call; contains all or part of the called party number; may also contain service invocations.	Indicates an incoming call; may contain the calling party number.
SETUP_AK (optional)	Indicates that the network has received the SETUP message but is expecting more information; used if only part of the called party number is included in the SETUP message.	Similar meaning to calling party.
INFORMATION (optional)	Contains additional information required to complete the call, such as the remainder of the called party number if it is not fully included in the SETUP message.	Similar meaning to calling party.
CALL PROCEEDING	Indicates the network has received all information required to process the call and is accepting no more information.	Similar to calling party.
ALERTING	Indicates the remote party has received the call, e.g., the remote phone is ringing.	Indicates the local phone is ringing.
CONNECT	The remote party has answered the call.	The local party has answered the call.
CONNECT_AK	Indicates the connection is active.	Indicates the connection is active.
FACILITY (optional)	Used to invoke a value-added service; based on ROSE; can be used as part of a Q.931 message or as a Q.932 message.	Indicates service invocation.

Analogous messages are used to control packet-mode access connections. The flow of Fig. 3 is more fully described after the discussion of the network signaling in the next section.

In addition to the information elements related to simple communication services, Q.931 messages may also contain an

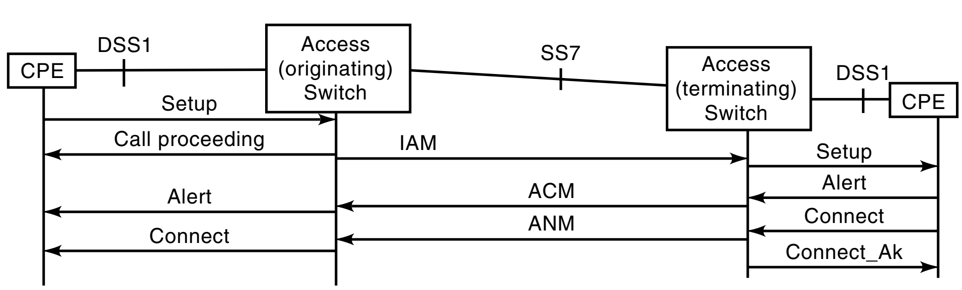

Figure 3. ISDN message flows.

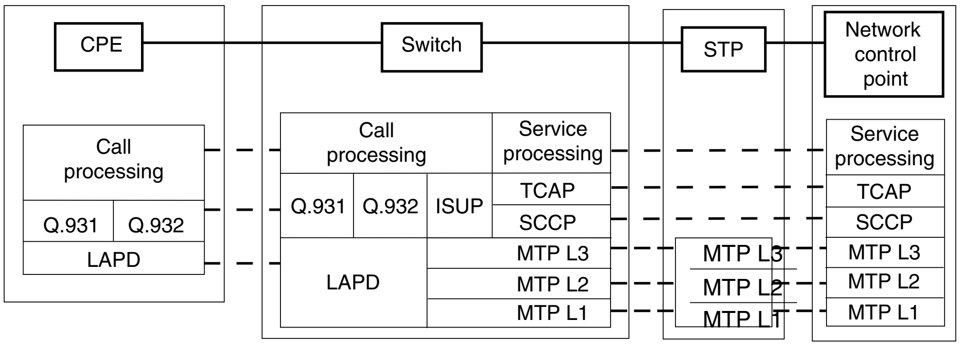

Figure 4. Network protocol configuration.

information element that invokes a service. This information element, called the FACILITY information element, is based on the OSI remote operations service element (ROSE) (8). A subscriber may invoke a service operation, and will be returned either the results or a failure notification for the service request.

Q.932 also uses the FACILITY information element in a dedicated message to provide service control. In addition, Q.932 defines messages specifically for providing such services as placing calls on hold.

NETWORK SIGNALING

Signaling between network nodes, such as between switches and between switches and NCPs, is carried out using Signaling System No. 7 (SS7) protocols (6). The full SS7 protocol stack is shown in Fig. 3. The lower three layers of the protocol stack, message transfer part level 1–3 (MTP L1–3) (9), are collectively called the network services part. The network services part is responsible for routing, monitoring network link performance, and network level signaling network management. The ISDN user part (ISUP) (10) is an application layer protocol that supports basic and supplementary telephony service. The signaling connection control part (SCCP) (11) provides expanded addressing and various grades of delivery service to network-based applications. These applications are typically provided through the transactions capability application part (12), a ROSE-based session layer protocol.

Figure 4 shows a simplified network configuration and the protocol stacks that reside on each network element. The dashed lines show peer signaling relationships. Notice that the signaling points, the CPE, switch, and NCP, all terminate application layer signaling protocols, whereas the STPs only contain the signaling protocols that provide reliable message transfer.

Network Services Part

The lower three layers of the SS7 protocol stack, collectively called the network services part, include message transfer part levels 1, 2, and 3. MTP level 1 is responsible for the signaling data link function, and corresponds to the OSI physical layer. Link bit rates are defined for 64 Kbps by the ITU; the minimum bit rate to support telephony is 4.8 Kbps.

MTP level 2 (MTP L2) is responsible for signaling link functions, and corresponds to the OSI link layer. It provides reliable point-to-point service between two connected signaling nodes. MTP L2 frames contain forward and backward sequence numbers which are used to detect lost frames. For error recovery, MTP L2 uses two methods. In the basic method, negative acknowledgments are generated if a missing MTP L2 is detected by a receiver. When the MTP L2 receiver detects a negative acknowledgment, it rolls back its local transmitter to the lost frame, and performs go-back-N retransmission. On signaling links with long delays, such as satellite links, preventive cyclic retransmission is used. In this scheme, if an MTP L2 transmitter is idle, it retransmits all unacknowledged frames. In this way, extra link bandwidth is used to retransmit frames that *might* be lost, hence the term preventive retransmission.

MTP L2 continually transmits frames, even when signaling points have no data to send. This is done so that MTP L2 may monitor link error rates. This is discussed more fully in the signaling network management section.

MTP Layer 3 (MTP L3) is responsible for signaling message handling and signaling network management. Signaling network management is discussed in a subsequent section. Signaling message handling is broken into three functions: discrimination, routing, and distribution. To perform these functions, MTP L3 processes the MTP L3 header which contains an origination and destination point code. This header is shown in Fig. 5. The point codes are the addresses for the message of sender and receiver, respectively.

The discrimination function determines if a packet is meant for the current local node, or if it must be forwarded to a subsequent node. The destination point code in the message is compared to the address of the local node to make this determination.

If the message must be forwarded, the routing function is performed. MTP L3 provides connectionless routing. It examines the originating and destination point codes and determines the next hop to which the message should be sent. In

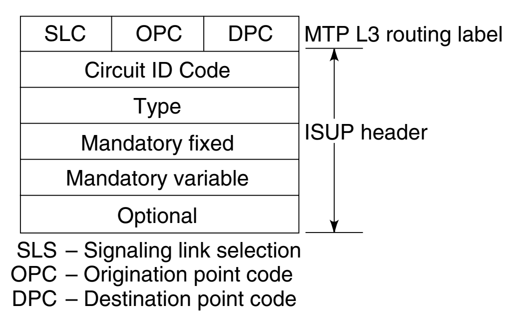

Figure 5. MTP L3 and generic ISUP header.

addition, a signaling link selection (SLS) parameter may be used to indicate a particular signaling link that should be used to carry the message.

If the message is local, the distribution function takes place. This entails sending the payload of the MTP L3 message to the proper higher layer protocol executing on the signaling point. This is performed by inspecting the service information octet which is part of the MTP L3 message.

ISDN User Part

ISUP (10) is an application layer protocol that supports telephony services, such as connection establishment and release, and supplementary services (also known as value-added services), such as call forwarding. ISUP messages are processed in switches that will ultimately carry the connection being established. ISUP interworks with the access signaling protocols, such as Q.931.

The generic format for an ISUP message is shown in Fig. 5. The circuit identification code (CIC) indicates the circuit to which the message applies. For example, messages used to establish a connection contain the CIC of that connection. The type field indicates the message type, and hence its function. The remaining parameters in the messages can be classified as one of three types. Mandatory fixed parameters are required for a particular message, and have a fixed length. Mandatory variable parameters are also required for a particular message, but are of variable length. The remainder of the components are optional. These parameters often carry information pertaining to services that may not be active on every call. Table 2 summarizes key ISUP messages used in connection establishment.

Call Establishment Example

Figure 3 shows a sample flow of ISDN signaling for establishing a call, illustrating the use of the Q.931 and ISUP messages and their interworking (ISUP messages are shown in boldface). The Q.931 SETUP message sent into the network requests that a call be established to a destination number contained in the message. This message also includes the following information elements:

1. Bearer capability describes the bearer services that must be provided for the call by the network, e.g., 3.1 kHz audio.
2. Lower layer compatibility is used to ensure user-to-user compatibility.
3. Higher layer compatibility is used to ensure user-to-user compatibility concerning the application supported on the call, e.g., group IV fax.

Table 2. Key ISUP Messages

Message Type	Usage
Initial Address Message (IAM)	Seizes a trunk over which connection is carried; contains CIC, routing, and services information.
Address Complete Message (ACM)	Indicates remote end has received sufficient information to process the call; may contain an indication that the remote terminal is alerting.
Call Progressing (CPG) (optional)	May be used to indicate the remote terminal is alerting.
Answer (ANS)	Indicates remote terminal has answered the call.

The originating switch then receives the SETUP message, determines the next hop switch, and sends an initial address message (IAM) to that switch. IAM seizes a trunk between the switches over which the user information will be carried. The terminating switch determines that it directly serves the destination party and generates a SETUP message to the destination. The SETUP message sent to the called party indicates an incoming call has arrived.

The Q.931 ALERT message indicates that the called party has received the call and the phone is ringing. The terminating switch receives the ALERT messages and generates an ACM message to the originating switch to indicate that the remote phone has been contacted and is ringing. When the remote terminal answers the call, a Q.931 CONNECT message is sent to the terminating switch. This message may include different values for the bearer capability and lower layer compatibility information elements than contained in the original SETUP message. This is how the called party negotiates these values with the calling party. The terminating switch generates an ANM to indicate to the calling party that the call has been answered. The CONNECT message returned to the calling party contains the bearer capability and lower layer compatibility information elements sent by the called party in its CONNECT message.

ISUP also supports supplementary services, and thus optional parameters in the ISUP messages are used to carry service information. For example, ISUP supports the call-forwarding service. Consider the case of call forwarding on busy, in which a call routed to a terminating point is forwarded if the destination subscriber is already involved in a call. In this case, the call is forwarded to a predefined destination. The IAM messages that are used to extend the connection carry parameters that indicate the original destination number, the number to which the connection is being forwarded, and the number of times a connection has been forwarded. Other services supported by ISUP include calling line identification (ID)/calling line ID restricted and closed user group, which is used to support virtual private networks.

Signaling for Network-Based Services

In addition to basic connection and supplementary services provided by ISUP, network nodes signal to NCPs to receive value-added services, such as 800-number translations, and credit-card validations. Signaling to NCPs is carried out using TCAP (12) over SCCP (11).

SCCP provides the services of the upper half of the OSI network layer. SCCP provides addressing that is expanded beyond MTP L3 through the inclusion of a subsystem number (SSN). The SSN and DPC together are used by SCCP to determine the local user (application) on a node that must receive an application layer protocol message. SCCP also provides global title translation. This entails translating logical identifiers called global titles, to destination point codes to which signaling messages may be routed. SCCP provides four classes of service: basic connectionless, sequenced connectionless, basic connection-oriented, and flow controlled connection-oriented.

TCAP is a session layer protocol that supports client–server operations between network signaling points and NCPs. TCAP consists of two sublayers. The transaction sublayer manages the dialog between communicating peers. There are four transaction sublayer messages. The BEGIN message opens a dialog between communicating peers. The CONTINUE message is used for ongoing communication. The END message closes the dialog. For a single message transaction, a UNI (for unidirectional) message is used.

The TCAP component sublayer is closely based on OSI ROSE. There are four main components in this sublayer. The invoke component remotely activates an operation. This component includes an operation type and any data required for the execution of the operation. This component receives one of four component responses. A return result component signifies the successful operation, and contains any information to be returned by the operation. If the information cannot be contained in a single return result component, several return result components are used, the last being called a return result last component. If the operation could not be completed, a return error component is received which contains a cause for the error. If the receiving node cannot process the operation, it may also return a reject component. Every operation invocation is given a unique identifier so that requests and responses can be correlated and so that different operations may be linked.

The component sublayer defines four classes of operation. Class 1 requires that both success and failure of the operation be reported; class 2 requires that only failures be reported; class 3 requires that only operation success be reported; and class 4 requires no response.

Figure 6 shows the flow for a TCAP transaction. In this example, a switch is requesting a credit-card validation. The transaction sublayer BEGIN message opens the dialog between the switch and the NCP that provides credit-card translation service. This message contains the invoke component which is defined as verify-credit-number. The credit-card number is included as a parameter in the component. This invocation is identified as invocation number 1. The NCP requests that the user-specific personal identification number (PIN) be collected. It does this by invoking an operation in the switch. This operation, called collect-PIN, is sent in a CONTINUE message. It is numbered component 2. This invocation is linked to the first invocation so that the switch may correlate this operation invocation with the invocation 1 that it had previously made. The switch returns the PIN in a return result component in a transaction sublayer CONTINUE

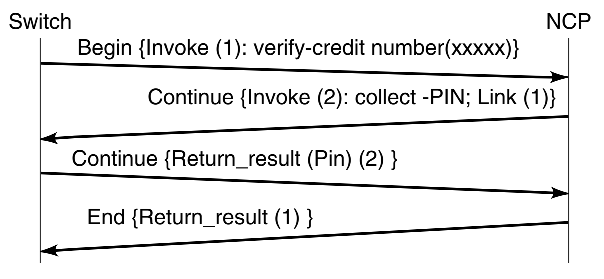

Figure 6. TCAP flow.

message. The NCP then verifies the credit-card number and PIN, and returns the result to the switch in the return result component. This component is sent in the END message that closes the dialog.

SIGNALING NETWORK MANAGEMENT

The performance of the common channel signaling network is self-managed by the SS7 protocols, specifically MTP L2 and L3. MTP L2 monitors link error rates, and reports any problems to MTP L3. MTP L3 is then responsible for taking action to ensure that a high level of signaling performance in maintained.

MTP L2 has three defined frame types. A message signal unit is used to transport MTLP L3 payloads. Link status signal units are used to indicate the current status of a signaling link. They may be sent when a link is flow controlled and no new data should be transmitted. Fill-in signal units (FISUs) are sent when the link would otherwise be idle; that is, there is no layer 3 payload to send.

By continually transmitting frames, MTP L2 can monitor the error rate on the signaling link by checking the cyclic redundancy code (CRC) in each frame. MTP L2 uses a leaky bucket mechanism to determine when notification of a faulty link should be reported to the higher layer protocol, MTP L3. Initially, MTP L2 sets a COUNT variable to 0. Every time an errored frame is detected, the COUNT variable is incremented. Every time 256 consecutive frames are received correctly, the COUNT variable is decremented unless it is already at 0. If the COUNT value exceeds 64, MTP L2 reports the problem to MTP L3. MTP L3 reacts to the reports from MTP L2 by rerouting signaling traffic.

MTP L3 manages signaling links, routes, and traffic. It is responsible for recovering from network failures and congestion. The differences between link management and route management are shown in Fig. 7. Several signaling links are grouped to form a link set. A link set has a common route. If a link becomes unavailable, MTP L3 performs a link changeover which entails switching signaling messages from one link to another in the same set. Therefore, the signaling route stays the same. Links may become unavailable because of high error rates detected by MTP L2, excessive time for MTP L2 to realign or achieve synchronization, or because of a failure at the far-end singling equipment. To perform a link changeover, MTP L3 first retrieves outstanding data from the lower layer protocol, and then sends the data on the new link. This ensures ordered data delivery.

If a link set fails, MTP L3 may perform a route changeover. In this case, signaling traffic is taken off of the failed link set and sent on a new link set, and hence, different route as shown in Fig. 7. The status of a route may be available, unavailable, or restricted. A route is unavailable if a destination can no longer be reached on that route, perhaps because of a configuration problem or intermediate component failure. A route is restricted if there is difficulty in reaching the destination, perhaps because of congestion. The route changeover mechanism is similar to the link changeover mechanism; MTP L3 data are retrieved and sent on the new link set.

MTP L3 traffic management is responsible for load sharing. If a link is becoming overloaded or congested, MTP L3

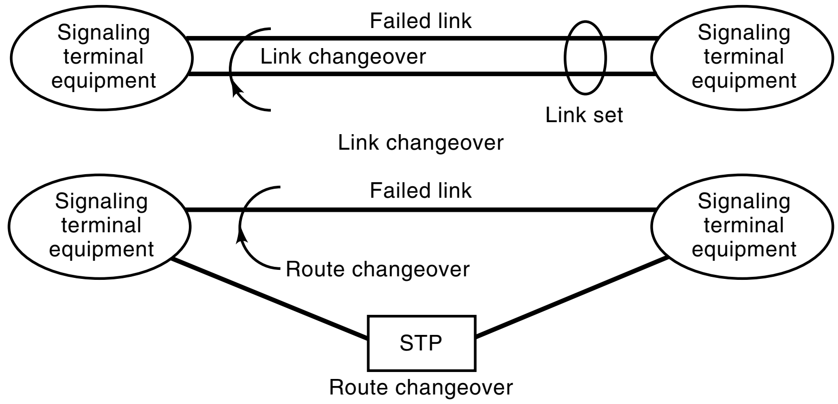

Figure 7. MTP L3 link and route management.

will change the route of some existing traffic and route new traffic on a new link or link set.

SIGNALING FOR B-ISDN

B-ISDN is based on asynchronous transfer mode (ATM) (13) transport technology. The goal of B-ISDN is to support integrated services by providing connections of different quality of service (QoS) supporting different traffic types. QoS can specify bit rates, loss tolerances, and delay budgets. Traffic types can be variable bit rate, constant bit rate, or available bit rate. Target applications include multimedia applications with voice, video, and data connections. ATM transport is a connection-oriented cell-based switching technology. Cells are short, fixed-sized packets. To establish a connection, routing tables in switches are configured so that cells on a particular connection are routed in order within their specified QoS.

There are special signaling considerations for B-ISDN. First, varying CPE types and applications will be supported on these networks, so negotiation procedures must be well defined. Control procedures, and hence protocol messages and information elements, must be defined to support QoS. In addition, the QoS requirements of a connection may change over time, so dynamic connection support must be built into signaling procedures. Key applications include multimedia conferencing and multimedia distribution, therefore requiring signaling support for multi-user connections and multicast connections. Applications may require asymmetric communication; that is, the bandwidth and QoS requirements may not be the same in both directions of a connection. Asymmetric connections must then be supported by B-ISDN signaling protocols. Standards for B-ISDN signaling are being addressed in two bodies: the ITU and the ATM Forum, a consortium of vendors.

ITU Signaling for B-ISDN

The signaling architecture for B-ISDN is similar to that of ISDN. Subscribers signal into the network using access signaling protocols, and network signal to each other using network signaling protocols. The UNI protocols are called the digital subscriber signaling system 2 (DSS2) (14). The NNI protocols are part of SS7 (15). The protocol stacks for DSS2 and the B-ISDN part of the NNI are shown in Fig. 8.

In B-ISDN users signal to establish a virtual connection (VC) with a certain QoS. The connection may be routed on a predefined virtual path (VP). Virtual connections are identified locally by a virtual channel identifier (VCI) and virtual path identifier (VPI). Two types of access signaling are defined. In VP-associated signaling, signaling messages are sent on a special signaling virtual connection and are used to establish, release, and modify user virtual connections on the same virtual path. In nonassociated signaling, a subscriber has a single virtual connection for signaling and uses it to control connections across virtual paths.

To establish signaling connections, meta-signaling procedures (16) are defined. These procedures are used to establish two types of signaling connections: point-to-point and broadcast. Point-to-point signaling links are used by subscribers to request typical communication services. Broadcast signaling links may be further classified into two categories: general broadcast and selective broadcast. The selective broadcast signaling links may be used by the network to offer calls to multiple subscribers. The default point-to-point signaling connection is carried on VCI 5 on all virtual paths, and is approximately 64 Kpbs. The default broadcast signaling link is on VCI 2.

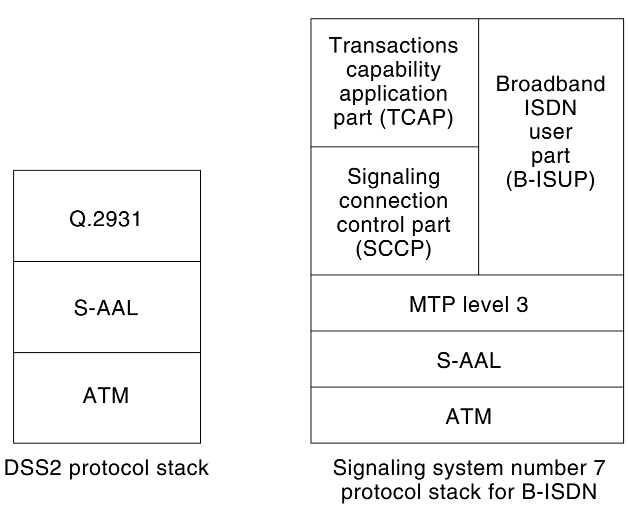

Figure 8. B-ISDN signaling protocol stacks.

Access Signaling. The access signaling protocols for B-ISDN are close in spirit to those used in ISDN. The D-channel in ISDN is replaced with a signaling virtual connection over ATM. LAPD is replaced with the signaling ATM adaptation layer protocol (S-AAL) (17). The Q.931 application layer protocol is replaced with its broadband counterpart, Q.2931 (14).

S-AAL is used both at the UNI and NNI. At the UNI it emulates LAPD. It provides point-to-point reliable data delivery for Q.2931. The S-AAL is broken into 2 main layers. The lower layer, called the common part convergence sublayer (CPCS), provides error detection and reporting and ensures ordered data delivery. The higher layer, called the service-specific convergence sublayer (SSCS), is further broken into two sublayers: the service-specific connection-oriented peer-to-peer protocol (SSCOP) and the service-specific coordination function (SSCF).

SSCOP provides reliable data delivery and flow control and monitors link status. Reliable data delivery is provided through periodic and on-demand status reports of received and transmitted messages. Retransmissions are performed on a selective repeat basis. Link status is monitored through the use of keep-alive messages. Status changes on the link, such as the link becoming congested or a signaling endpoint becoming unavailable, are reported to higher layer protocols.

SSCF provides an interface to the higher layer protocols. In this case it provides a set of primitives to Q.2931. Q.2931 is similar in many respects to Q.931. The message names and message flows are very similar. The major differences in the two protocols are the information elements. Q.2931 must provide support for B-ISDN services, such as QoS and varying traffic types. Key parameters to note are:

1. End-to-end transit delay specifies a maximum delay budget.
2. Broadband bearer capability specifies traffic type (variable/constant bit rate, etc.).
3. AAL parameters specify AAL type and parameters within a specific AAL.
4. Traffic descriptor specifies bandwidth requirements for a connection.

These information elements are processed in the network to route connections and allocate resources within the given subscriber requirements. Because connections may be asymmetrical, an indication is given if the parameter values apply to both directions of a connection, or if a connection is unidirectional.

Network Signaling. The NNI signaling in B-ISDN is also similar to its ISDN counterpart. The protocols used for service control, TCAP and SCCP, are reused directly. MTP L3 is reused for its routing and signaling network management capabilities. MTP L1 is replaced with ATM and MTP L2 is replaed with the S-AAL. The application layer protocol ISUP is replaced with B-ISUP (15).

At the NNI, S-AAL provides services similar to MTP L2. SSCOP provides reliable point-to-point data delivery. It also monitors the status of the signaling link and signaling endpoints throughout the use of keep-alive messages. If SSCOP detects any problems, such as a link becoming congested or a signaling code becoming unavailable, it reports the change in status to MTP L3. SCCF provides a set of primitives to MTP L3 for management and data transfer.

B-ISUP interworks with Q.2931 and provides support for B-ISDN functions such as QoS. It does this by passing parameters similar to those defined in the Q.2931 messages for required bandwidth, traffic types, and AAL types and parameters. In addition, B-ISUP passes cumulative delay estimates from node to node as a connection is being established. In this way, the terminating node can check the cumulative expected delay on a connection against the requested delay budget given in the Q.2931 connection establishment request. B-ISUP will also support supplementary services similar to those supported by ISUP.

ATM Forum Signaling

The ATM Forum is a consortium of vendors that is defining its own set of standards to support B-ISDN, including standards for UNI and NNI signaling.

ATM Forum UNI Signaling. The ATM Forum UNI (18) reuses the ITU S-AAL, and its UNI application layer message names, parameters, and procedures are all close in definition to Q.2931. The main contribution of the ATM Forum UNI version 3.1 is support for multicast connection establishment and control.

The ATM Forum defines a root node which controls the multicast connection. The root node establishes a unidirectional multicast connection to a set of leaf nodes. All branches on this tree have identical connections, i.e., cell transfer rate and broadband bearer capabilities. There is zero bandwidth allocated on the path from the leaf nodes to the root.

Two types of state are defined to support multicast communication. Link state is maintained on both sides of the UNI, the CPE, and network, and is similar to the normal call state. In addition, party state is maintained in all nodes. The root node establishes a point-to-point connection using procedures similar to Q.2931, and then adds other leaf nodes to the connection through the use of additional defined messages, such as ADD PARTY and ADD PARTY ACK. Procedures and messages are also defined for dropping parties from a multicast connection.

ATM Forum NNI Signaling. The ATM Forum NNI signaling protocol is called the private network–network interface (PNNI) (19). Its focus is on providing a scalable solution to routing in large ATM networks with a given QoS.

In the PNNI routing protocol, each node floods the network with advertisements of their connectivity and their QoS capabilities. Two types of QoS parameters are passed: additive parameters such as delay, and nonadditive parameters such as available bandwidth. To establish a connection, source routing is used. A node gathers information received from the advertisements of the other nodes, and determines a list of possible routes to its desired endpoint using the connectivity information. Once it forms this list, it determines on which routes the QoS requirements on the connection may be right. The node picks a route, and generates a message to the next hop node to request the connection. This message contains a list of designated transit links (DTLs) which denote the source route.

If along the path, the connection request cannot be fulfilled because of some event, such as a link or node outage, or sudden congestion, a crank-back mechanism is defined. The crank-back entails backtracking along the connection until a node that can find a path to the destination that meets the QoS requirements is reached. This node then determines a route to complete the connection using similar procedures as the source node.

To make this solution scalable, a hierarchy of nodes is created. A group of nodes at the same level in the hierarchy is called a peer group. Each peer group exchanges routing information with each other so that every member of a peer group can route within its group. Each peer group has a group leader which exchanges information with other peer group leaders. In this way, the amount of routing information that must be exchanged between peer groups in the wide area network is limited. There may be several levels of peer groups defined in a network.

SUMMARY

Signaling procedures are used for subscribers to request services from a network, and for a network to fulfill these service requests. They support procedures to establish connections, provide value-added services, and manage and monitor performance of signaling networks. The lower layers of the signaling protocols are designed to provide high performance and provide reliable service. The application layer protocols are designed to support specific services. ISDN signaling protocols support circuit-switched connections. B-ISDN protocols extend the ISDN protocols to support a richer set of connection services, including QoS-dependent connections and multiparty connections.

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THOMAS F. LA PORTA
Lucent Technologies, Bell Laboratories

SIGNALING, TELECOMMUNICATION. See TELECOMMUNICATION SIGNALING.

SIGNAL INTERFERENCE. See NOISE AND INTERFERENCE MODELING.

SIGNAL PROCESSING. See ACOUSTO-OPTICAL SIGNAL PROCESSING; MEDICAL SIGNAL PROCESSING.

SIGNAL PROCESSING AND CHAOS. See CHAOS TIME SERIES ANALYSIS.

SIGNAL PROCESSING BY SURFACE ACOUSTIC WAVE DEVICES. See SURFACE ACOUSTIC WAVE DEVICES.

SIGNAL PROCESSING IN SONAR. See SONAR SIGNAL PROCESSING.

SIGNAL PROCESSING, MULTIDIMENSIONAL. See MULTIDIMENSIONAL SIGNAL PROCESSING.

SIGNAL PROCESSING, NONLINEAR. See NONLINEAR FILTERS.

SIGNAL PROCESSING, RADAR. See RADAR SIGNAL DETECTION.

SIGNAL PROCESSING, SEISMIC. See SEISMIC SIGNAL PROCESSING.

SIGNAL PROCESSING, SONAR. See SONAR SIGNAL PROCESSING.

SIGNAL PROCESSING, VLSI. See VLSI SIGNAL PROCESSING.

SIGNAL REPRESENTATION. See DATA COMPRESSION FOR NETWORKING; HILBERT TRANSFORMS.

SILICON CONTROLLED RECTIFIER (SCR). See INVERTER THYRISTORS; THYRISTOR PHASE CONTROL.

SILICON-ELECTROLYTE JUNCTIONS. See SEMICONDUCTOR-ELECTROLYTE INTERFACES.