

FURTHER READING:

As a preview for further reading, the following reference has been provided from the pages of the book below:

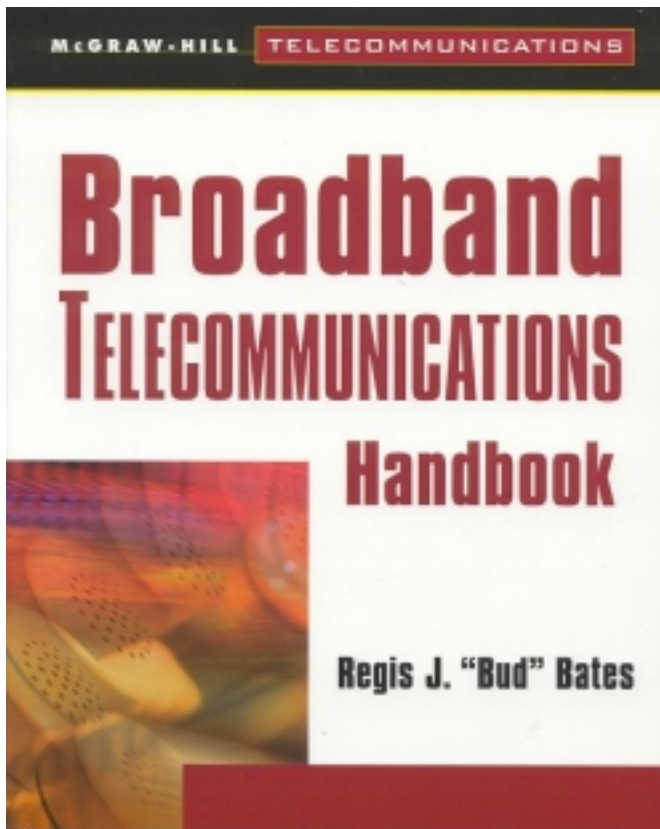
Title: Broadband Telecommunications Handbook

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Standards Organization (ISO) and the *International Telecommunications Union (ITU)*. These have a formal membership and a proposal submission and review procedure that is designed to form a consensus.

Internet Operation

We have seen that the Internet is really a collection of independently owned and operated networks. The concept of network was previously dominated by the telephone model. It had a central switching exchange and all information ran through this exchange. The telegraph network also used centralized switching. Like the telephone switching system, it, too, had telegraph lines that connected the switching centers. The telegraph-switching center was called a message switch. These message switching centers were originally manually operated copy and relay centers. Later, paper tape with automatic punches and finally computers replaced the manual switching centers. It became clear that some mechanism was needed to distinguish between the message content and the control characters that were used by the computer to recognize the beginning and end of the message.

Message switching with its telegraphy history was message integrity-oriented. Each message was carefully acknowledged. Losing messages was not acceptable. This formed the basis for reliable message transfer.

About the time the Internet was taking shape, the X.25 network protocol was being developed. One might say that the X.25 protocol is the successor to message switching. It was essentially designed with the Telco model in mind. It was intended to make money by charging for packets, just as the message switching system was designed to charge for each message. The goal was to provide end-to-end message integrity.

A further impetus to the development of X.25 was the deregulation of the telephone equipment market brought about by the Carterphone decision of 1968. Heretofore, modems were only available from the Telco, and the data rates were slow. At that time, the Telcos controlled telephone calls between countries and all data (telex) messages went through what were known as international record carriers. Because they were the only carriers permitted to transport such international traffic, the cost was high. Modems unfortunately fell into the hands of the travelling public who would make dial-up telephone calls across international boundaries and transmit data at a fraction of the cost of the “record traffic.” The Telcos tried to control this, but it was hopeless. Their next attempt was to offer a slightly lower cost *Public Data Network (PDN)*, which was the X.25 network. Although it worked well, it really was

still more costly (although more reliable) than using the *Public Switched Telephone Network* (PSTN). The X.25 network replaced the telex network to most parts of the world. When traveling, using the X.25 network to contact, for example, CompuServe is often the most cost-effective way to do it.

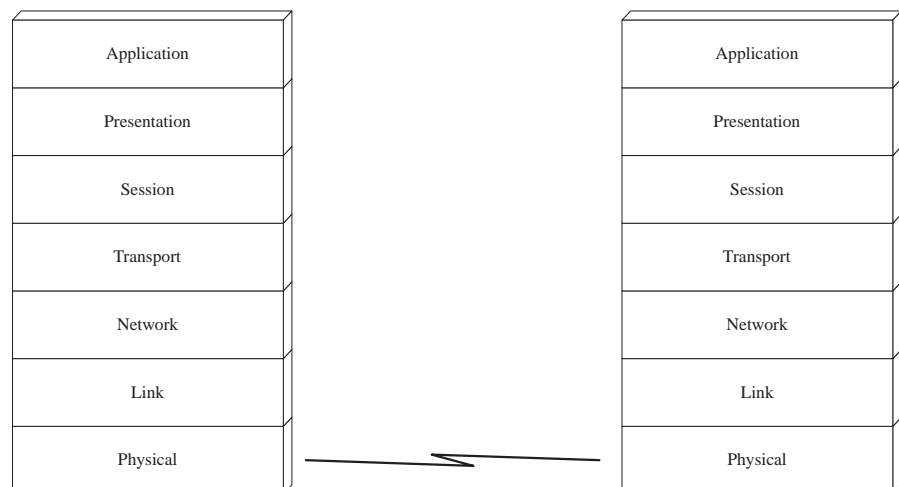
One of the large steps forward that X.25 provided was that it made the transport mechanism (packet switch) separate from the message content. The network was then optimized for packet transport, and was completely independent of the message or its content. The maintenance of end-to-end connectivity is a natural outgrowth of the Telco and message switching history.

The operation of X.25 is very different from the *Internet Protocol* (IP). It is important at some point to draw the distinction between the two protocols.

Without a full-blown discussion of the OSI Reference Model, let us start with the basic concepts of packet switching and the transport of packets across an X.25 network. Figure 29-1 is a picture of the Reference Model to be used as a reference as we discuss the operation of networking protocols. A few quick notes are in order:

1. The physical layer attaches to whatever network is at hand. There could be multiple physical connections in any given system.
2. The link layer handles communications across the physical link only between adjacent machines by putting data in frames.
3. The network layer must be consistent across the entire network, and it is where packet switching is handled.

Figure 29-1
The OSI model as the reference



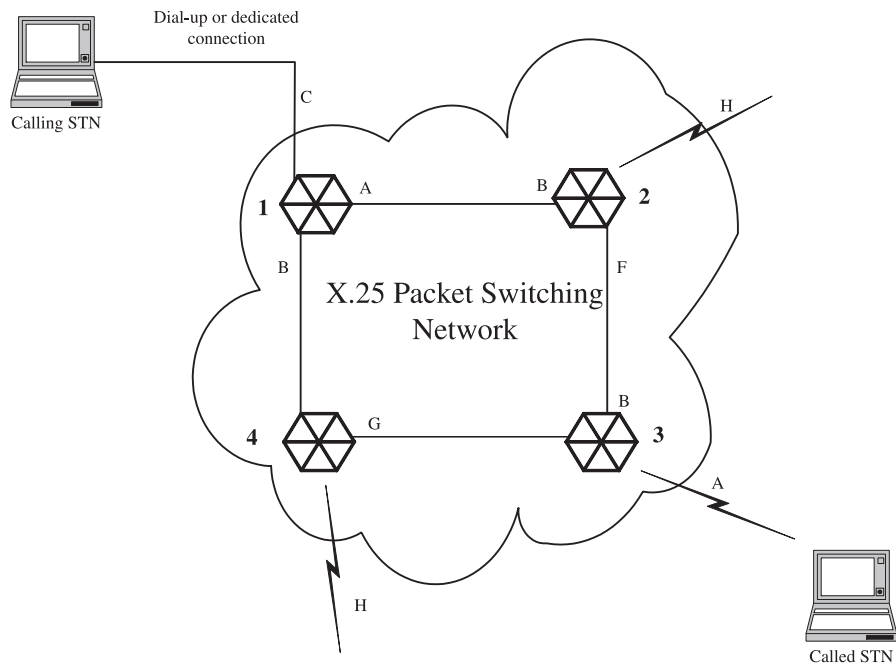
4. The Transport layer handles end-to-end transport and integrity of data. The communicating entities at transport layer have no idea (very theoretically) that the underlying layers exist or what their characteristics are.

X.25 is a *Connection Oriented Network Protocol* or service (CONS). The IP provides, by contrast, a *Connection-Less Network Service* (CLNS). This is the major difference, and as we shall see, it pervades the networking decisions made and the choices made for the functionality of the transport layer. The details of how the packets are handled within the packet switches are very similar in terms of how the queues are handled.

A connection is established by X.25 for the end user across the network. Although we said that transport is responsible for end-to-end connections, network layer can also choose to provide this capability. If our network layer is going to do this, then the transport layer need not be complex at all. You will note in the following discussion that the reference is to telephone terminology. The reasons for this are now clear.

An X.25 connection is established by the end system across the network. The calling party sends a setup packet containing the address of the source and destination systems. Figure 29-2 shows the basic network configuration. The packets travel on each leg of the journey in a link layer frame that

Figure 29-2
Basic configuration of
X.25 networks



primarily provides error detection and correction by using the FCS on a link by link basis. The packet containing the addresses permits each packet switch along the way to make a routing decision about the best way to send the packet toward its destination.

The frame itself consists of a *Flag* (F) character at the beginning and end, as delimiters of the frame. The *address field* (A) is rarely used, but logically contains the physical address of the device on the network. The control field tells what kind of frame it is (data bearing or control) and can be used to contain sequence and acknowledgement numbers. The *Frame Check Sequence* (FCS) is a very powerful, 16-bit checksum system that is able to detect 99.998% of all errors. Given the quality of the circuits of the day, such a powerful error detection scheme was necessary. The control field shown as C in Figure 29-3 carried the sequence and acknowledgement numbers.

Figure 29-3 shows the relationship of a packet being carried inside a frame. Note that the frame is terminated (FCS evaluated and acknowledgement sent on each hop). The packet is re-encapsulated in a new frame for its hop across the next link. Chapter 10 discusses Frame Relay, which is the successor to X.25.

In addition to the routing information, the first packet also contains the very important *Logical Channel Number* (LCN). You may think of it as a random number that is used by each packet switch instead of the address. There are several benefits to doing this. First, you don't need to put the complete address in each packet, and second, you achieve a relationship between packet switches that lasts for the duration of the call. (The importance of this will only become clear later). This relationship between packet switches is called a virtual circuit. You will find further discussions of virtual circuits in both Chapter 10 on Frame Relay and Chapter 11 on ATM.

Figure 29-4 shows the routing table (technically a switching table) in each packet switch shown earlier in Figure 29-2 that resulted from the call setup from caller to called system. This association of ports and LCN create the virtual circuit across the network. This has several major implications for overall network design.

1. All packets follow the same path between any source destination pair of end systems. (This makes maintaining sequencing of packets easy.)

Figure 29-3
The Frame carrying the X.25 packet

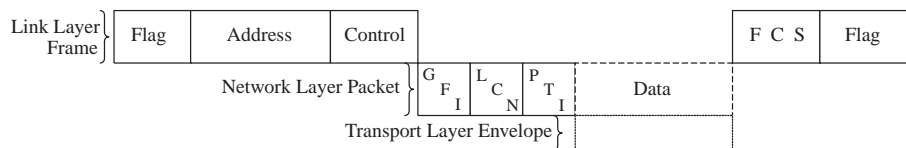


Figure 29-4
The routing table
example

Packet Switch #1				2				3			
Input		Output		Input		Output		Input		Output	
Port	LCN	Port	LCN	Port	LCN	Port	LCN	Port	LCN	Port	LCN
C	35	A	15	B	15	F	25	R	25	A	5

- Acknowledgements can be done link by link, using frame acknowledgements and end-to-end by using network layer sequence numbers.
- At setup time, we could determine the load on the packet switches and interconnecting links before choosing that path.

This would enable *Quality of Service (QoS)* and *Service Level Agreement (SLA)* adherence. It must be clearly stated here that X.25 doesn't provide these services. However the existence of a virtual circuit relationship between packet switches for the duration of the connection is a necessary condition to provide QoS and SLAs.

Connectionless Network Services

Now that we understand CONS, we can look at CLNS. The Internet Protocol is a CLNS. The apocryphal story as is oft repeated is that IP was designed during the height of the Cold War. The military (funded by ARPANET) wanted a bomb-proof network—one in which any of the lines or packet switches could be knocked out at any time and not seriously affect network operation. Therefore, the designers chose a dynamically routed CLNS. The philosophical differences between a CLNS and CONS are large, but each is a valid way to construct a network. The Internet has grown to become a high volume worldwide network. Even some of the original designers are amazed at its ability to continue to grow yet maintain its robustness. More than a few doubters have been predicting Internet meltdown. Congestion has occurred due to lack of bandwidth connecting routers. Adding more bandwidth has so far alleviated this condition. There was some discussion in the late 1990s that the demand for bandwidth would exceed the supply in the year 2001. The technology breakthrough of dense wave division multiplexing (discussed in Chapter 28) essentially solved the bandwidth problem. The solution isn't inexpensive per se, but it yields tremendous bandwidth for the price.