

INTERNATIONAL  
EDITION



# Data and Computer Communications

TENTH EDITION

William Stallings



ALWAYS LEARNING

PEARSON

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*Tenth Edition*

**William Stallings**

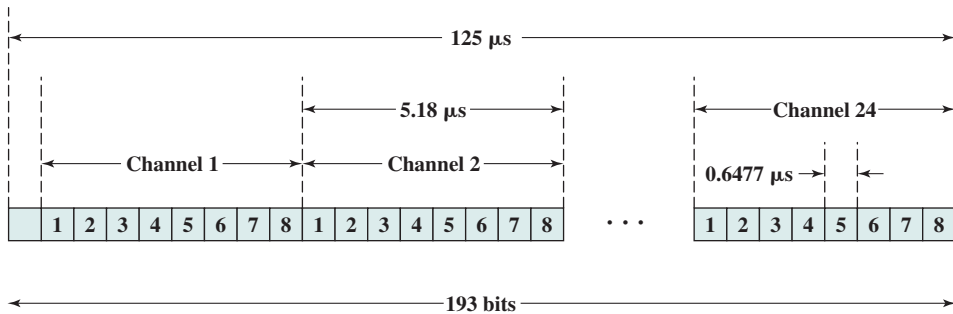
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Notes:

1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
  - 8-bit PCM used on five of six frames.
  - 7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
  - Channel 24 is used for signaling only in some schemes.
  - Bits 1–7 used for 56-kbps service.
  - Bits 2–7 used for 9.6-kbps, 4.8-kbps, and 2.4-kbps service.

**Figure 8.9** DS-1 Transmission Format

The basis of the TDM hierarchy (in North America and Japan) is the DS-1 transmission format (Figure 8.9), which multiplexes 24 channels. Each frame contains 8 bits per channel plus a framing bit for  $24 \times 8 + 1 = 193$  bits. For voice transmission, the following rules apply. Each channel contains one word of digitized voice data. The original analog voice signal is digitized using pulse code modulation at a rate of 8000 samples per second. Therefore, each channel slot and hence each frame must repeat 8000 times per second. With a frame length of 193 bits, we have a data rate of  $8000 \times 193 = 1.544$  Mbps. For five of every six frames, 8-bit PCM samples are used. For every sixth frame, each channel contains a 7-bit PCM word plus a *signaling bit*. The signaling bits form a stream for each voice channel that contains network control and routing information. For example, control signals are used to establish a connection or terminate a call.

The same DS-1 format is used to provide digital data service. For compatibility with voice, the same 1.544-Mbps data rate is used. In this case, 23 channels of data are provided. The twenty-fourth channel position is reserved for a special sync byte, which allows faster and more reliable reframing following a framing error. Within each channel, 7 bits per frame are used for data, with the eighth bit used to indicate whether the channel, for that frame, contains user data or system control data. With 7 bits per channel, and because each frame is repeated 8000 times per second, a data rate of 56 kbps can be provided per channel. Lower data rates are provided using a technique known as subrate multiplexing. For this technique, an additional bit is robbed from each channel to indicate which subrate multiplexing rate is being provided. This leaves a total capacity per channel of  $6 \times 8000 = 48$  kbps. This capacity is used to multiplex five 9.6-kbps channels, ten 4.8-kbps channels, or twenty 2.4-kbps channels. For example, if channel 2 is used to provide 9.6-kbps service, then up to five data subchannels share this channel. The data for each subchannel appear as six bits in channel 2 every fifth frame.

Finally, the DS-1 format can be used to carry a mixture of voice and data channels. In this case, all 24 channels are utilized; no sync byte is provided.

Above the DS-1 data rate of 1.544 Mbps, higher-level multiplexing is achieved by interleaving bits from DS-1 inputs. For example, the DS-2 transmission system combines four DS-1 inputs into a 6.312-Mbps stream. Data from the four sources are interleaved 12 bits at a time. Note that  $1.544 \times 4 = 6.176$  Mbps. The remaining capacity is used for framing and control bits.

## SONET/SDH

SONET (Synchronous Optical Network) is an optical transmission interface originally proposed by BellCore and standardized by ANSI. A compatible version, referred to as Synchronous Digital Hierarchy (SDH), has been published by ITU-T in Recommendation G.707.<sup>2</sup> SONET is intended to provide a specification for taking advantage of the high-speed digital transmission capability of optical fiber.

**SIGNAL HIERARCHY** The SONET specification defines a hierarchy of standardized digital data rates (Table 8.4). The lowest level, referred to as STS-1 (Synchronous Transport Signal level 1) or OC-1 (Optical Carrier level 1),<sup>3</sup> is 51.84 Mbps. This rate can be used to carry a single DS-3 signal or a group of lower-rate signals, such as DS1, DS1C, DS2, plus ITU-T rates (e.g., 2.048 Mbps).

Multiple STS-1 signals can be combined to form an STS- $N$  signal. The signal is created by interleaving bytes from  $N$  STS-1 signals that are mutually synchronized.

For the ITU-T Synchronous Digital Hierarchy, the lowest rate is 155.52 Mbps, which is designated STM-1. This corresponds to SONET STS-3.

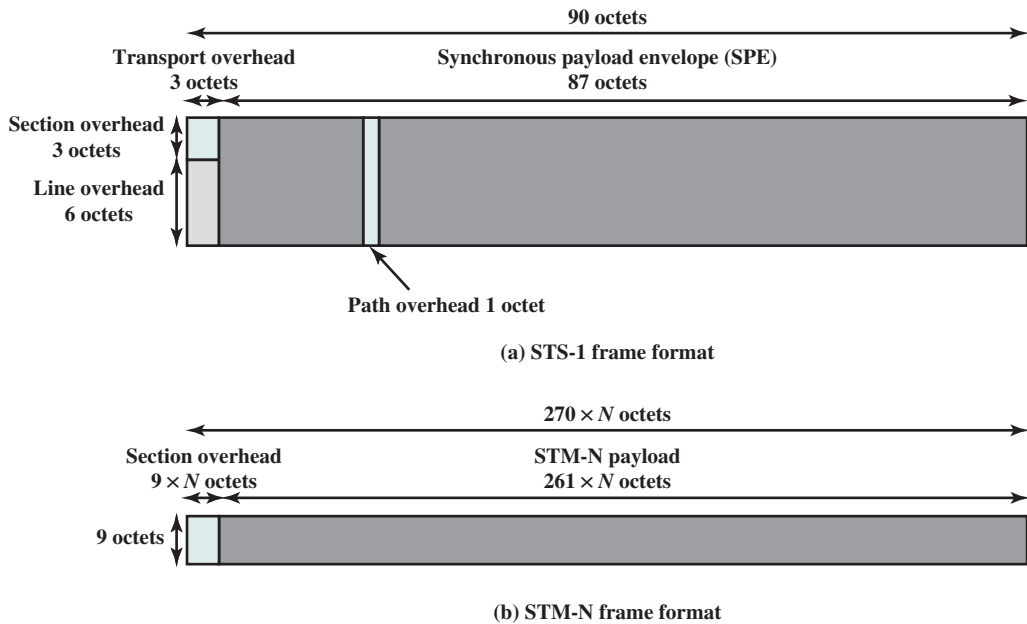
**FRAME FORMAT** The basic SONET building block is the STS-1 frame, which consists of 810 octets and is transmitted once every 125  $\mu$ s, for an overall data rate of 51.84 Mbps (Figure 8.10a). The frame can logically be viewed as a matrix of 9 rows of 90 octets each, with transmission being one row at a time, from left to right and top to bottom.

**Table 8.4** SONET/SDH Signal Hierarchy

SONET Designation	ITU-T Designation	Data Rate	Payload Rate (Mbps)
STS-1/OC-1		51.84 Mbps	50.112 Mbps
STS-3/OC-3	STM-1	155.52 Mbps	150.336 Mbps
STS-12/OC-12	STM-4	622.08 Mbps	601.344 Mbps
STS-48/OC-48	STM-16	2.48832 Gbps	2.405376 Gbps
STS-192/OC-192	STM-64	9.95328 Gbps	9.621504 Gbps
STS-768	STM-256	39.81312 Gbps	38.486016 Gbps
STS-3072		159.25248 Gbps	153.944064 Gbps

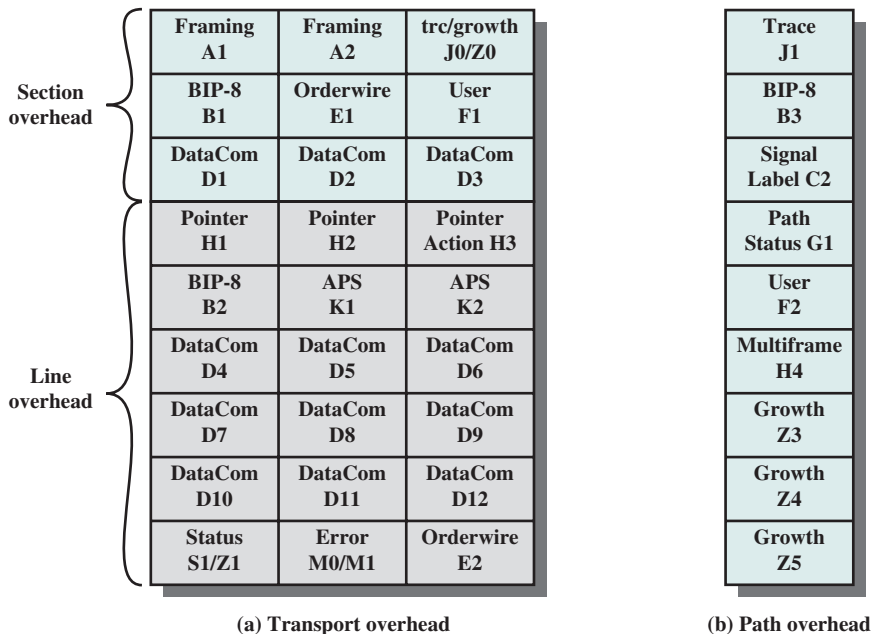
<sup>2</sup>In what follows, we will use the term *SONET* to refer to both specifications. Where differences exist, these will be addressed.

<sup>3</sup>An OC- $N$  rate is the optical equivalent of an STS- $N$  electrical signal. End-user devices transmit and receive electrical signals; these must be converted to and from optical signals for transmission over optical fiber.



**Figure 8.10** SONET/SDH Frame Formats

The first three columns ( $3 \text{ octets} \times 9 \text{ rows} = 27 \text{ octets}$ ) of the frame are devoted to overhead octets. Nine octets are devoted to section-related overhead and 18 octets are devoted to line overhead. Figure 8.11a shows the arrangement of overhead octets, and Table 8.5 defines the various fields.



**Figure 8.11** SONET STS-1 Overhead Octets

**Table 8.5** STS-1 Overhead Bits

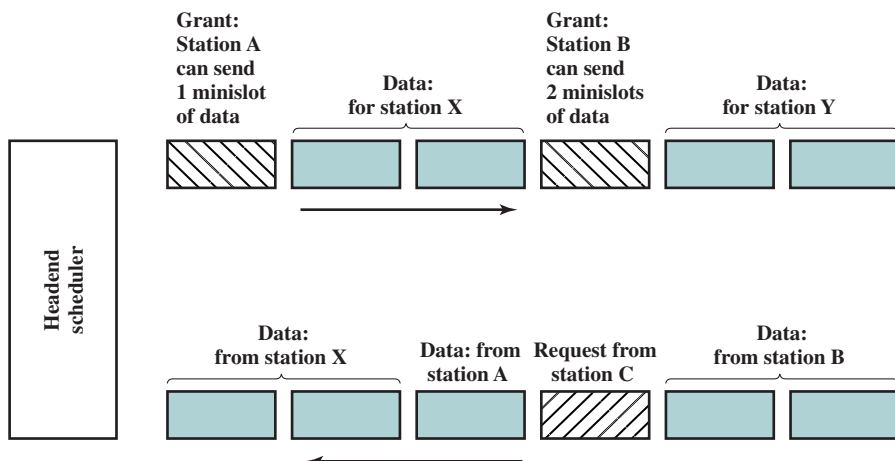
<b>Section Overhead</b>	
A1, A2:	Framing bytes = F6,28 hex; used to indicate the beginning of the frame.
J0/Z0:	Allows two connected sections to verify the connections between them by transmitting a 16-byte message. This message is transmitted in 16 consecutive frames with first byte (J0) carried in first frame, second byte in second frame, and so on (Z0).
B1:	Bit-interleaved parity byte providing even parity over previous STS- <i>N</i> frame after scrambling; the <i>i</i> th bit of this octet contains the even parity value calculated from the <i>i</i> th bit position of all octets in the previous frame.
E1:	Section level 64-kbps PCM orderwire; optional 64-kbps voice channel to be used between section terminating equipment, hubs, and remote terminals.
F1:	64-kbps channel set aside for user purposes.
D1-D3:	192-kbps data communications channel for alarms, maintenance, control, and administration between sections.
<b>Line Overhead</b>	
H1-H3:	Pointer bytes used in frame alignment and frequency adjustment of payload data.
B2:	Bit-interleaved parity for line level error monitoring.
K1, K2:	Two bytes allocated for signaling between line level automatic protection switching equipment; uses a bit-oriented protocol that provides for error protection and management of the SONET optical link.
D4-D12:	576-kbps data communications channel for alarms, maintenance, control, monitoring, and administration at the line level.
S1/Z1:	In the first STS-1 of an STS- <i>N</i> signal, used for transporting synchronization message (S1). Undefined in the second through <i>N</i> th STS-1 (Z1).
M0/M1:	Remote error indication in first STS-1 (M0) and third frames.
E2:	64-kbps PCM voice channel for line level orderwire.
<b>Path Overhead</b>	
J1:	64-kbps channel used to send repetitively a 64-octet fixed-length string so a receiving terminal can continuously verify the integrity of a path; the contents of the message are user programmable.
B3:	Bit-interleaved parity at the path level, calculated over all bits of the previous SPE.
C2:	STS path signal label to designate equipped versus unequipped STS signals. <i>Unequipped</i> means the line connection is complete but there is no path data to send. For equipped signals, the label can indicate the specific STS payload mapping that might be needed in receiving terminals to interpret the payloads.
G1:	Status byte sent from path terminating equipment back to path originating equipment to convey status of terminating equipment and path error performance.
F2:	64-kbps channel for path user.
H4:	Multiframe indicator for payloads needing frames that are longer than a single STS frame; multiframe indicators are used when packing lower rate channels (virtual tributaries) into the SPE.
Z3-Z5:	Reserved for future use.

The remainder of the frame is payload. The payload includes a column of path overhead, which is not necessarily in the first available column position; the line overhead contains a pointer that indicates where the path overhead starts. Figure 8.11b shows the arrangement of path overhead octets, and Table 8.5 defines these.

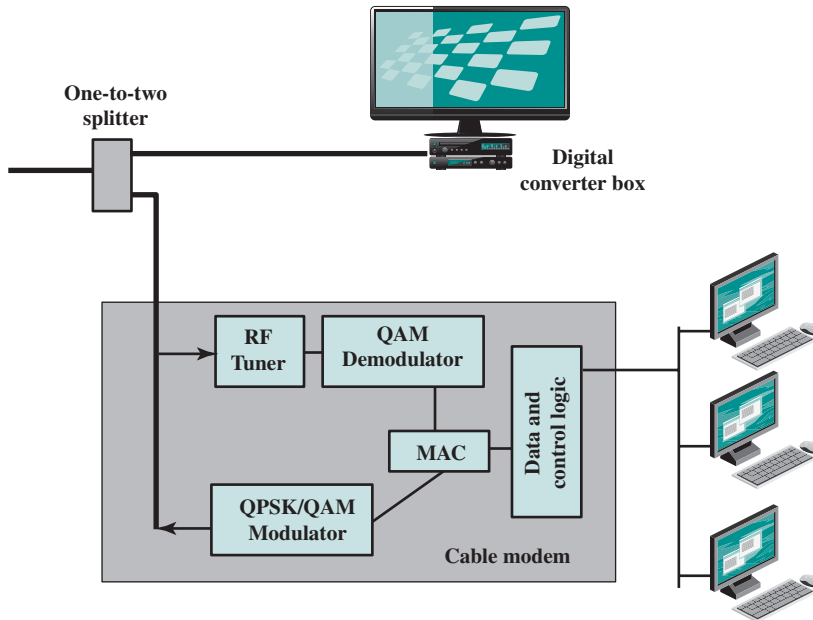
Figure 8.10b shows the general format for higher-rate frames, using the ITU-T designation.

### 8.3 CABLE MODEM

A **cable modem** is a device that allows a user to access the Internet and other online services through a cable TV network. To support data transfer to and from a cable modem, a cable TV provider dedicates two 6-MHz channels, one for transmission in each direction. Each channel is shared by a number of subscribers, and so some scheme is needed for allocating capacity on each channel for transmission. Typically, a form of statistical TDM is used, as illustrated in Figure 8.12. In the downstream direction, cable **headend** to subscriber, a cable scheduler delivers data in the form of small packets. Because the channel is shared by a number of subscribers, if more than one subscriber is active, each subscriber gets only a fraction of the downstream capacity. An individual cable modem subscriber may experience access speeds from 500 kbps to 1.5 Mbps or more, depending on the network architecture and traffic load. The downstream direction is also used to grant time slots to subscribers. When a subscriber has data to transmit, it must first request time slots on the shared upstream channel. Each subscriber is given dedicated time slots for this request purpose. The headend scheduler responds to a request packet by sending back an assignment of future time slots to be used by this subscriber. Thus, a number of subscribers can share the same upstream channel without conflict.



**Figure 8.12** Cable Modem Scheme



**Figure 8.13** Cable Modem Configuration

To support both cable television programming and data channels, the cable spectrum is divided into three ranges, each of which is further divided into 6-MHz channels. In North America, the spectrum division is as follows:

- User-to-network data (upstream): 5–40 MHz
- Television delivery (downstream): 50–550 MHz
- Network to user data (downstream): 550–750 MHz

Figure 8.13 shows a typical cable modem configuration at a residential or office location. At the interface to the external cable, a one-to-two splitter enables the subscriber to continue to receive cable television service through numerous FDM 6-MHz channels, while simultaneously supporting data channels to one or more computers in a local area network. The inbound channel first goes through a radio frequency (RF) tuner that selects and demodulates the data channel down to a spectrum of 0 to 6 MHz. This channel provides a data stream encoded using 64-QAM (quadrature amplitude modulation) or 256-QAM. The QAM demodulator extracts the encoded data stream and converts it to a digital signal that it passes to the media access control (MAC) module. In the outbound direction, a data stream is modulated using either QPSK or 16-QAM.

## 8.4 ASYMMETRIC DIGITAL SUBSCRIBER LINE

In the implementation and deployment of a high-speed wide area public digital network, the most challenging part is the link between subscriber and network: the digital subscriber line. With billions of potential endpoints worldwide, the prospect