DIGITAL COMMUNICATION
Second Edition

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The two applications differ substantially in the types of problems which must be overcome. For the digital subscriber loop, the transmission medium is fairly ideal, consisting of wire pairs with a wide bandwidth capability. The biggest complication is the higher bit rate and the presence in some countries of bridged taps — open-circuited wire pairs bridged onto the main line. The voiceband data modem, while requiring a lower speed of transmission, encounters many more impairments. In addition to the severe bandlimiting when carrier facilities are used, there are problems with noise, nonlinearities, and sometimes even frequency offset. Another difference is that the subscriber loop can use baseband transmission, while the voiceband data set always uses passband transmission.

18.2. MULTIPLE ACCESS BY TIME DIVISION

By far the most common method of separating channels or users on a common digital communications medium is by ensuring that they transmit at different times. This is known as *multiple access by time-division*. This technique has many variations, the most common of which are described in this section. In all these variations, some method is used to avoid *collisions*, or two or more users transmitting simultaneously. Collision avoidance in link access is somewhat easier than in the other topologies, and therefore we discuss link access separately.

18.2.1. Point-to-Point Link Access

It is often desired to divide a high-speed bit stream over a point-to-point communications link into a set of lower-rate bit streams, each with a fixed and predefined bit rate. Where this is desired, it is appropriate to use a technique called *time-division multiplexing (TDM)*. The bit streams to be multiplexed are called *tributary streams*. Where these tributary bit-streams are provided directly to a user, that is they do not themselves consist of tributary streams, then they are called *circuits* or *connections*. We *interleave* these tributary streams to obtain a higher rate bit stream. The purpose of the multiplex, shown functionally in Figure 18-4, is to take advantage of the economies of scale of a high-speed transmission system.

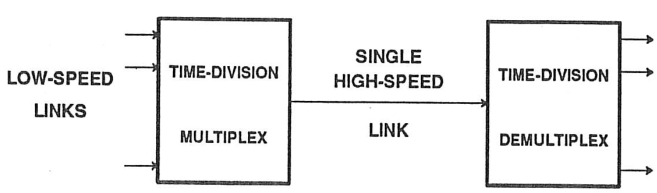

Figure 18-4. A time-division multiplex, which interleaves a number of lower-speed tributaries on a single higher-speed link.

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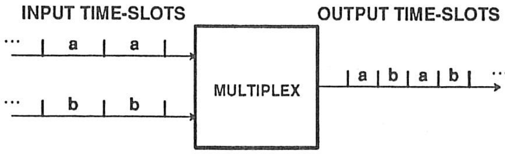
Example 18-3.

A simple multiplexing function for two tributary streams is shown below:



Each tributary stream is divided continuously into groups of bits, known as *time-slots*, and then these time-slots are interleaved to form the output bit stream. Each slot on the output bit stream occupies half the time of an input slot since the bit rate is twice as great. □

In practice any number of tributary streams can be multiplexed, and a defined time-slot can have any number of bits. However, two cases are particularly common: a time-slot equal to one bit, known as *bit-interleaving*, and a time-slot equal to eight bits, which is known as *octet-interleaving*. In multiplexing, an *octet* is a common term for eight bits. Organization around octets is common because voice PCM systems commonly use eight bits per sample quantization, and because data communications systems typically transfer eight-bit groupings of bits, known in the computer world as *bytes*. In both cases it is necessary to maintain *octet integrity* at the destination, meaning that the bit stream is delimited into the same eight-bit boundaries defined at the origin. This octet integrity is assured by using octet-interleaving, although this is not the only means.

On the high-speed output bit stream, the collection of bits corresponding to precisely one time-slot from each tributary stream is known as a *frame*. In Example 18-3 one frame corresponds to time-slots **a** and **b**. At the demultiplex, all we have is a bit-stream originating at the multiplex. In order to realize the demultiplexing function, the boundaries of the time-slots must be known. Furthermore, to ensure that the correspondence between input and output tributary streams is maintained, demultiplexing requires knowledge of the beginning of the frame. For this purpose, the multiplex typically inserts additional bits into the frame known as *framing bits*.

Example 18-4.

In a time-division multiplex, N tributary streams are multiplexed with M-bit time-slots into a single output bit stream. The number of bits in the output frame is $N \cdot M$ plus any added framing bits. □

The framing bits follow a deterministic pattern which can be recognized at the demultiplex as distinct from the information bits. Once the demultiplex has located these bits, through a process known as *framing recovery*, it has a reference point that enables it to locate the beginning of the frame.

Since a multiplex cannot store an unbounded number of bits, we must ensure that the minimum bit rate of the output high-speed stream is greater than or equal to the sum of the maximum bit rates rates of the tributary streams plus the rate required for framing and any other overhead bits.

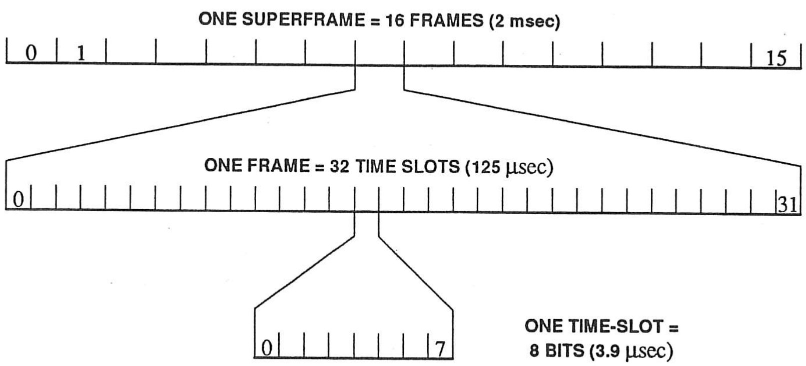


Figure 18-5. The frame structure for the CCITT G.732 30-channel PCM system.

Example 18-5.
The CCITT 30-channel system (recommendation G.732 [2]) is widely used in Europe and multiplexes 30 tributary streams, each at 64 kb/s, appropriate for a voiceband channel, into a single 2048 kb/s bit stream. Note that $30 \cdot 64 = 1920$, so that 128 kb/s is used for overhead functions such as framing. The organization of the frame is shown in Figure 18-5. Each frame is divided into 32 eight-bit time slots, 30 of them taken from the tributary streams, and the remaining two used for overhead. Thus, in this case as in the case of most lower-speed multiplexes, octet-interleaving is used. The time for one frame corresponds to an octet on each tributary stream, or 1.25 μsec. There is also defined a *superframe* or *multiframe* of 16 frames, which is used to transmit and frame *on-off hook information* for each of the 30 tributary voiceband channels. This on-off hook information, transmitted in frames 0 and 16, is used to communicate between switching machines during call setup and take-down. Time-slot 0 always contains the octet "x0011011" and "x10xxxxx" in alternate frames, indicating the beginning of the frame, and time-slot 16 contains "0000x0xx" in frame 0 of the superframe indicating the beginning of the superframe ("x" indicates bits not assigned, which can be used for other purposes). Time-slot 16 in the remaining frames of the superframe contains the aforementioned signaling information. □

Example 18-6.
The CCITT 24-channel system used in North America (CCITT G.733 [2]) has a frame consisting of 193 bits, including 24 eight-bit time-slots for the tributary 64 kb/s channels and one framing/superframing bit. In a superframe of 12 frames, the framing bit contains the pattern "101010", the framing pattern, interleaved with the pattern "001110", the superframe pattern. The bit rate is $193 \cdot 8 = 1544$ kb/s. □

Example 18-7.
The M12 multiplex used in the North American network multiplexes four tributary bit streams at 1544 kb/s (often the G.733 signal of Example 18-6) into a into a 1176-bit superframe shown in Table 18-1 using bit interleaving. Each line of the table represents one

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