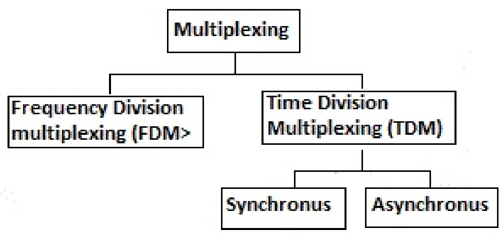
Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. Whenever the transmission capacity of a medium linking two devices is greater than the transmission needs of the devices, the link can be shared in order to maximize the utilization of the link, such as one cable can carry a hundred channels of TV.

Type of multiplexing

There are two basic techniques:

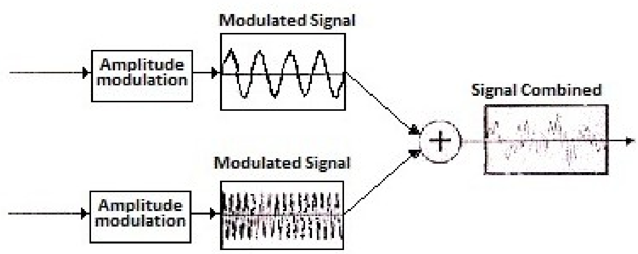
1. Frequency-Division Multiplexing (FDM)
2. Time-Division Multiplexing (TDM)
    1. Synchronous TDM
    2. A-Synchronous TDM

These types of multiplexing are shown in the figure.

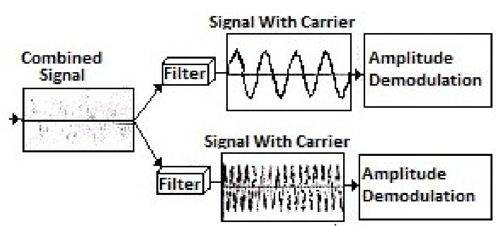


FREQUENCY-DIVISION MULTIPLEXING (FDM)

In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link. The carrier frequencies have to be different enough to accommodate the modulation and demodulation signals. The figure No.8.3 illustrates the FDM multiplexing process. The multiplexing process starts by applying amplitude modulation into each signal by using different carrier frequencies as/i and/j. Then both signals are combined



In demultiplexing process, we use filters to decompose the multiplexed signal into its constituent component signals. Then each signal is passed to an amplitude demodulation process to separate the carrier signal from the message signal. Then, the message signal is sent to the waiting receiver. The process of demultiplexing is shown in the figure.



Time-Division Multiplexing

Time division multiplexing is a technique used to transmit a signal over a single communication channel by dividing the time frame into slots – one slot for each message signal. Time-division multiplexing is primarily applied to digital signals as well as analog signals, wherein several low speed channels are multiplexed into high-speed channels for transmission. Based on the time, each low-speed channel is allocated to a specific position, where it works in synchronized mode. At both the ends, i.e., the multiplexer and demultiplexer are timely synchronized and simultaneously switched to the next channel.

Time-Division Multiplexing

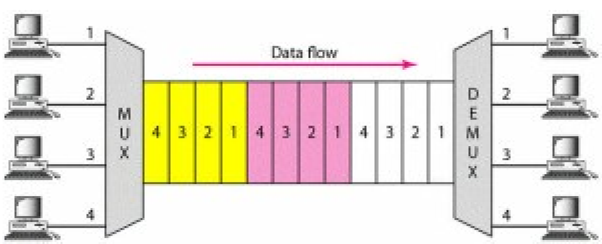
Types of TDM

Time division multiplexing is classifieds into four types:

- Synchronous time-division multiplexing
- Asynchronous time-division multiplexing
- Interleaving time-division multiplexing
- Statistical time-division multiplexing

Synchronous Time Division Multiplexing

Synchronous time division multiplexing can be used for both analog and digital signals. In synchronous TDM, the connection of input is connected to a frame. If there are ‘n’ connections, then a frame is divided into ‘n’ time slots – and, for each unit, one slot is allocated – one for each input line. In this synchronous TDM sampling, the rate is same for all the signals, and this sampling requires a common clock signal at both the sender and receiver end. In synchronous TDM, the multiplexer allocates the same slot to each device at all times.



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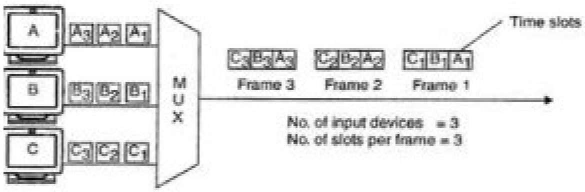
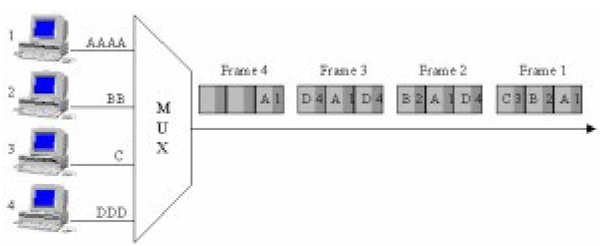


Asynchronous Time-Division Multiplexing

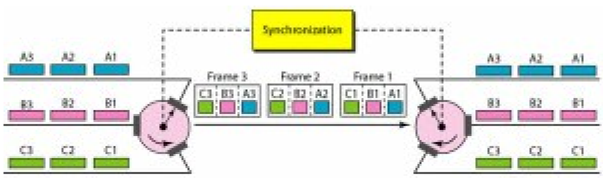
In asynchronous time-division multiplexing, the sampling rate is different for different signals, and it doesn't require a common clock. If the devices have nothing to transmit, then their time slot is allocated to another device. Designing of a commutator or de-commutator is difficult and the bandwidth is less for time-division multiplexing. This type of time-division multiplexing is used in asynchronous transfer mode networks.



Asynchronous Time-Division Multiplexing

Interleaving

Time-division multiplexing can be visualized as two fast rotating switches on the multiplexing and demultiplexing side. At the same speed these switches rotate and synchronize, but in opposite directions. When the switch opens at the multiplexer side in front of a connection, it has the opportunity to send a unit into the path. In the same way, when the switch opens on the demultiplexer side in front of a connection that has the opportunity to receive a unit from the path. This process is called interleaving.



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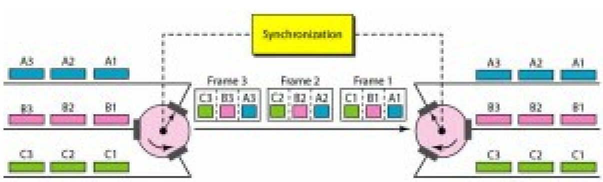
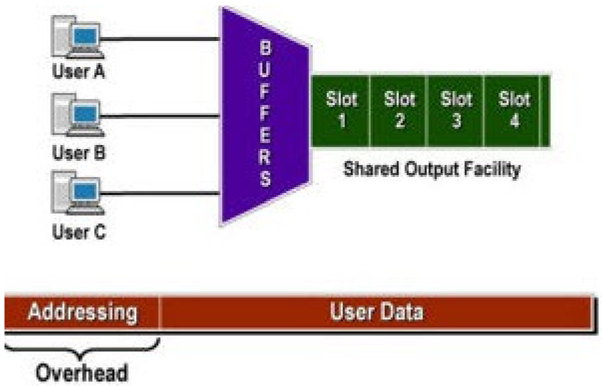


Statistical Time-Division Multiplexing

Statistical time-division multiplexing is used to transmit several types of data concurrently across a single transmission cable. This is often used for managing data being transmitted via LAN or WAN. The data is simultaneously transmitted from the input devices that are connected to the network including printers, fax machines, and computers. This type of multiplexing is also used in telephone switch board settings to manage the calls. Statistical TDM is similar to dynamic bandwidth allocation, an in this type of time-division multiplexing, a communication channel is divided into an arbitrary number of data streams.



Statistical Time-Division Multiplexing

These are the different types of multiplexing techniques used in communication system for efficient transferring and receiving of the data. Hope you have got a better idea of all these types of multiplexing, and therefore, you can share your views on this article in the comment section below. And, also mention any of the practical examples of these multiplexing types – if you are interested.

 11.1 **Introduction**

- Motivation for multiplexing
- Basic types of multiplexing
- Basis provided by modulated carriers

 11.2 **The Concept of Multiplexing**

- *Multiplex*: to combine information streams from multiple sources for the purpose of transmitting them over a shared medium.
- *Multiplexor*: a device that performs multiplexing
- *Demultiplex*: to separate information that has been multiplexed back into its constituent information streams.
- *Demultiplexor*: a device that performs demultiplexing

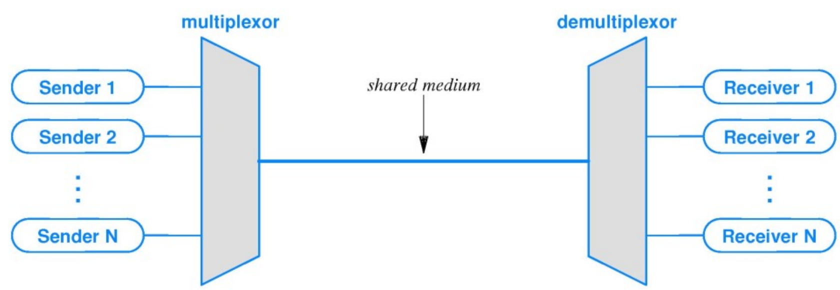


Figure 11.1 The concept of multiplexing in which independent pairs of senders and receivers share a transmission medium.

 11.3 **The Basic Types of Multiplexing**

- Frequency Division Multiplexing (FDM, widely used)
- Wavelength Division Multiplexing (form of FDM used with fiber)
- Time Division Multiplexing (TDM, widely used)
- Code Division Multiplexing (cell phone mechanisms)

 11.4 **Frequency Division Multiplexing**

- FDM is the familiar idea of "channels" in radio and television.
- The idea of FDM is to use multiple carriers of different frequencies simultaneously on a medium like a copper wire or optical fiber (or to broadcast through the air with RF as with radio and tv)
- Demultiplexors use filters to select a small range of frequencies near just one of the carrier frequencies, and suppress other frequencies.

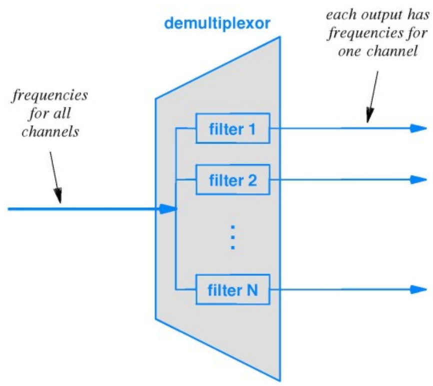


Figure 11.2 Illustration of basic FDM demultiplexing where a set of filters each selects the frequencies for one channel and suppresses other frequencies.

- Any modulation scheme can be used on each carrier.

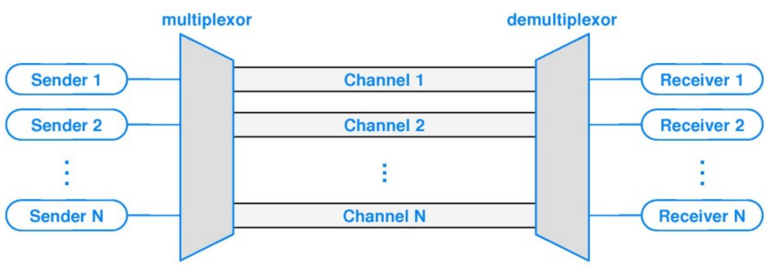


Figure 11.3 The conceptual view of Frequency Division Multiplexing (FDM) providing a set of independent channels.

- Carrier frequencies that are too close are difficult for a demultiplexor to separate, and they can interfere with each other. Therefore FDM schemes separate carriers with gaps called *guard bands*.

Channel	Frequencies Used
1	100 KHz - 300 KHz
2	320 KHz - 520 KHz
3	540 KHz - 740 KHz
4	760 KHz - 960 KHz
5	980 KHz - 1180 KHz
6	1200 KHz - 1400 KHz

Figure 11.4 An example assignment of frequencies to channels with a guard band between adjacent channels.

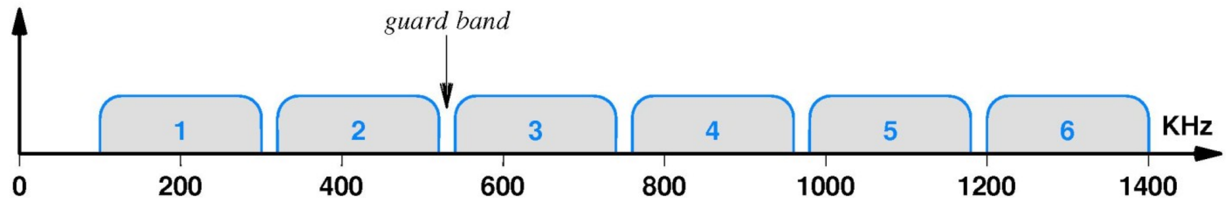


Figure 11.5 A frequency domain plot of the channel allocation from Figure 11.4 with a guard band visible between channels.

11.5 **Using a Range of Frequencies per Channel**

- Carrier 'channels' often contain a relatively wide range of frequencies.
- Users of the channel can divide it up into K 'sub-carriers' and, to achieve high data rates, send 1/K of the data over each carrier.
- To increase immunity from interference, a sender can transmit the same information over several 'sub-carriers' and give the receiver the option to use the ones that experience the least interference. This is the basic idea of *spread spectrum*.

11.6 **Hierarchical FDM**

- By using outputs of some multiplexors as inputs to other, it is possible to cause large numbers of individual communication streams to flow into a single shared medium supporting a very large number of data streams.
- This technique is used in telephone systems - e.g. 3600 telephone channels together on one 14,400 Hz signal band.

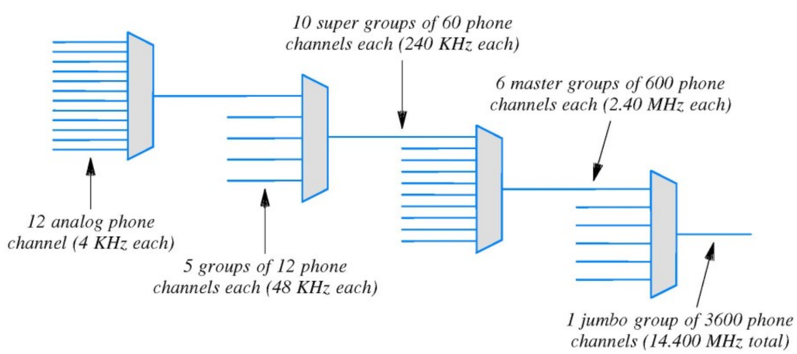


Figure 11.6 Illustration of the FDM hierarchy used in the telephone system.

□ 11.7 **Wavelength Division Multiplexing (WDM)**

- In the case of optical fibers, multiplexors and demultiplexors use prisms.
- This is the idea of wavelength division multiplexing (WDM)

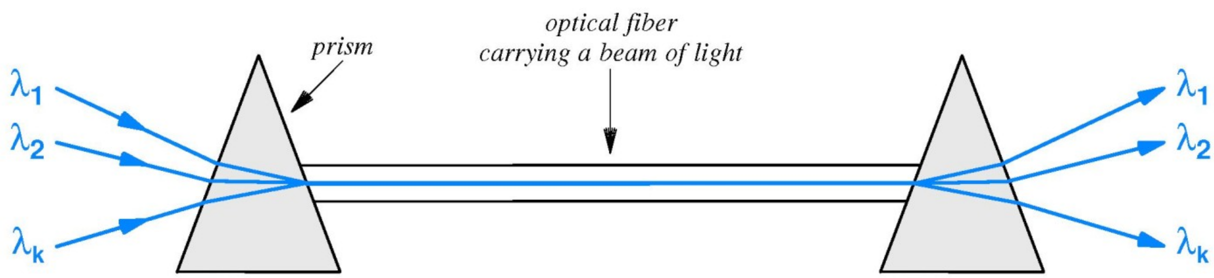


Figure 11.7 Illustration of prisms used to combine and separate wavelengths of light in wavelength division multiplexing technologies.

□ 11.8 **Time Division Multiplexing**

- TDM is the main alternative to FDM.
- Basically TDM is just 'taking turns' using the shared medium.

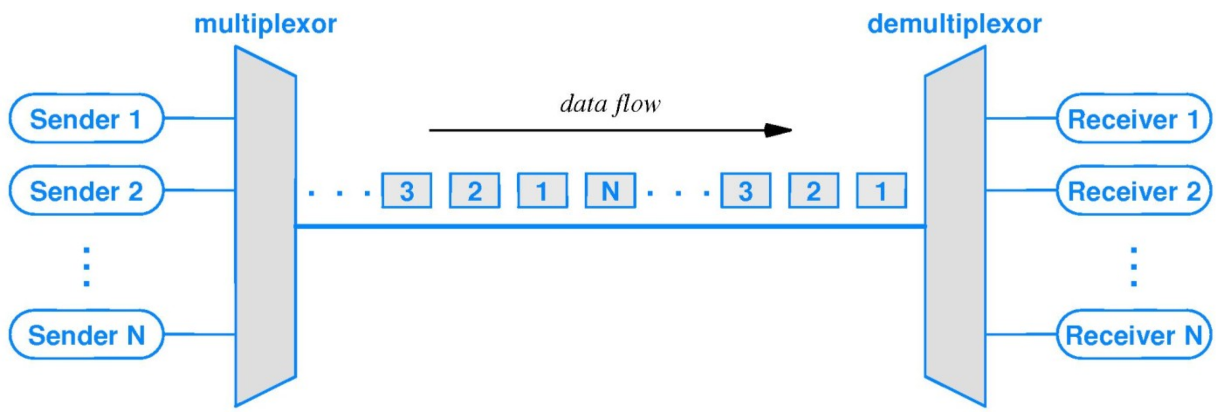


Figure 11.8 Illustration of the Time Division Multiplexing (TDM) concept with items from multiple sources sent over a shared medium.

 11.9 **Synchronous TDM**

- Round robin sharing may or may not be used with TDM
- On synchronous networks, TDM performs round robin sharing and there are no gaps between items sent.

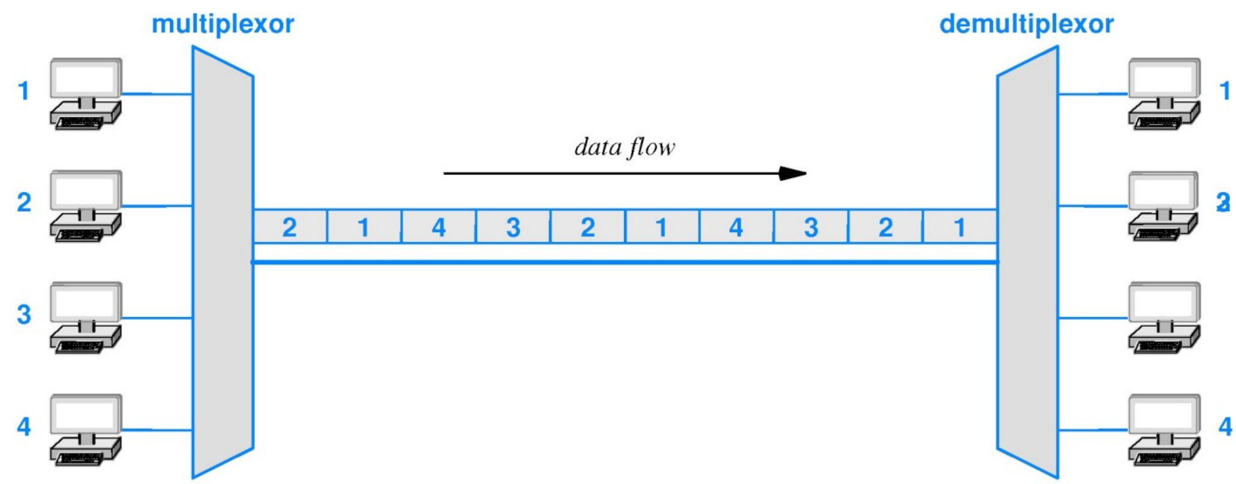


Figure 11.9 Illustration of a synchronous TDM system with four senders.

 11.10 **Framing Used in the Telephone System Version of TDM**

- The telephone company TDM scheme adds an extra framing channel and alternating framing bits to help the demultiplexor stay synchronized or (at least) detect errors.

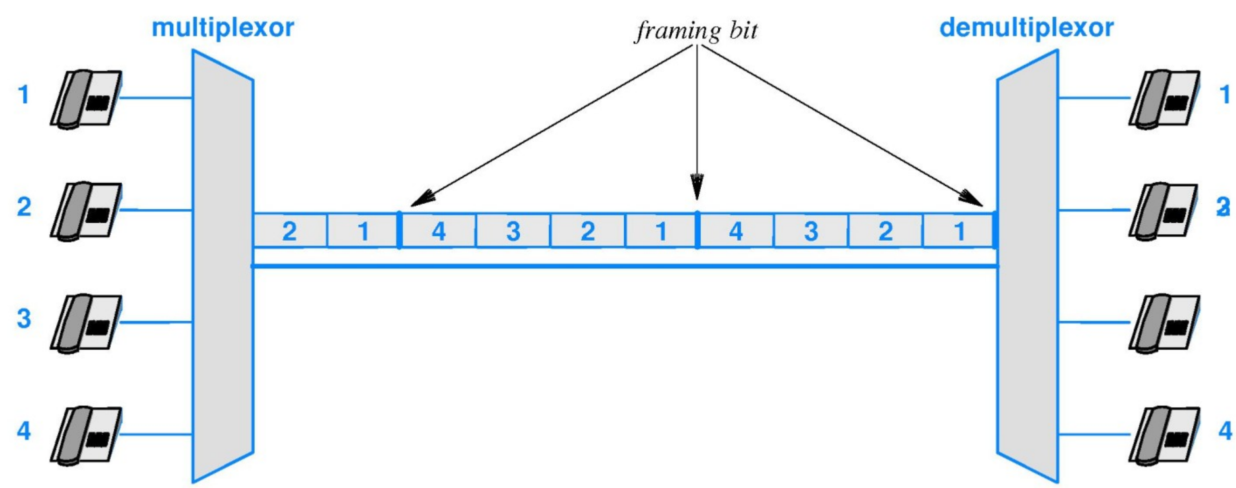


Figure 11.10 Illustration of the synchronous TDM system used by the telephone system in which a framing bit precedes each round of slots.

□ 11.11 **Hierarchical TDM**

- Hierarchical TDM works similarly to hierarchical FDM.
- At a stage where there are N inputs of bit rate R, one needs the output bit rate to be no less than NR.

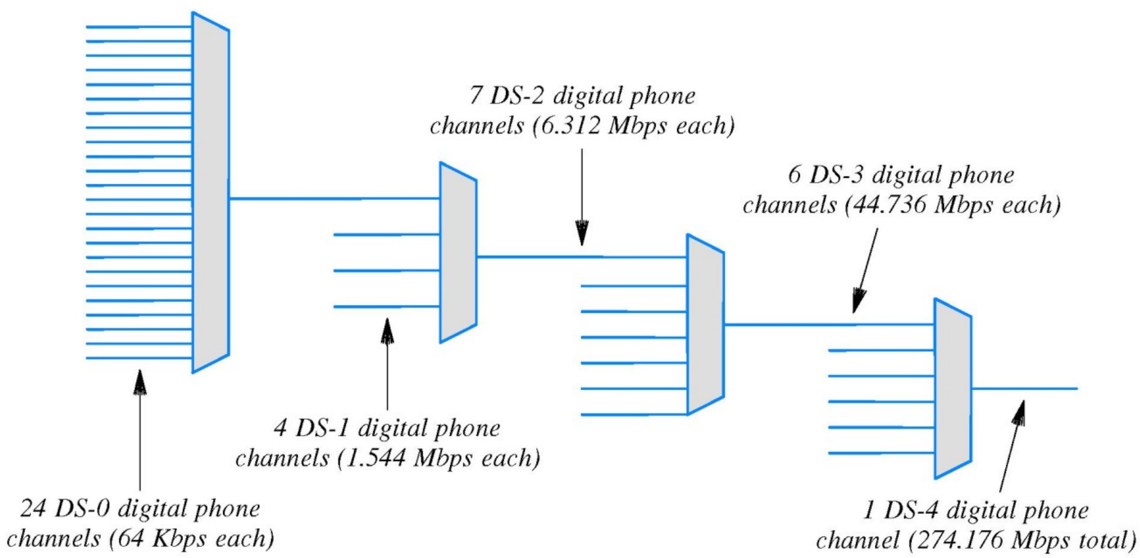


Figure 11.11 Illustration of the TDM hierarchy used in the telephone system.

□ 11.12 **The Problem with Synchronous TDM: Unfilled Slots**

- Under a 'vanilla' form of TDM, if a source has nothing to send when its time arrives, an "empty slot" is sent - probably a zero-filled block with some sort of invalid flag included.
- Thus capacity is wasted if sources don't always have data ready when it is their turn.

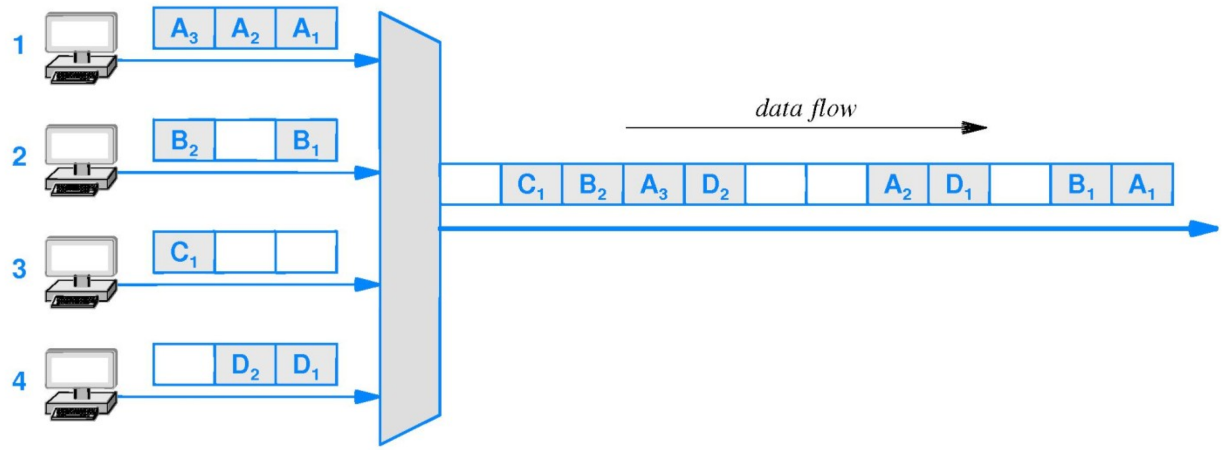


Figure 11.12 Illustration of a synchronous TDM system leaving slots unfilled when a source does not have a data item ready in time.

 11.13 **Statistical TDM**

- In a statistical TDM scheme, the multiplexor tries to skip over senders that don't have data ready until coming to one that has data.
- For this to work, the data blocks have to contain something that identifies the intended receiver, else there'd be no way for the demultiplexor to decide to which output stream to assign the data.

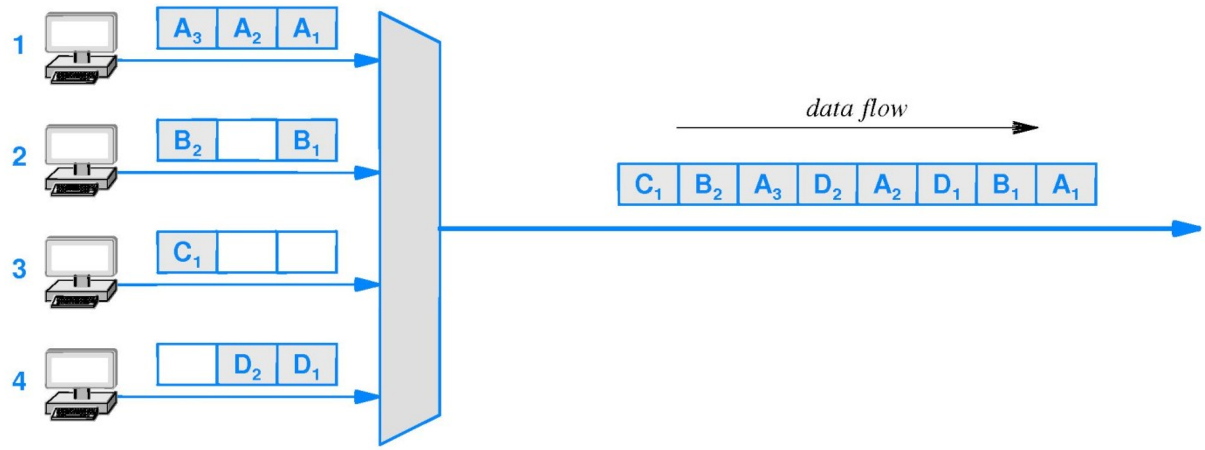


Figure 11.13 Illustration that shows how statistical multiplexing avoids unfilled slots and takes less time to send data.

 11.14 **Inverse Multiplexing**

- The idea is to distribute a single high-speed digital input over multiple lower-speed channels, transmit over the multiple channels, and reassemble the original digital signal at the receiving end.
- This is somewhat difficult to engineer.
- The scheme is used widely on the Internet.

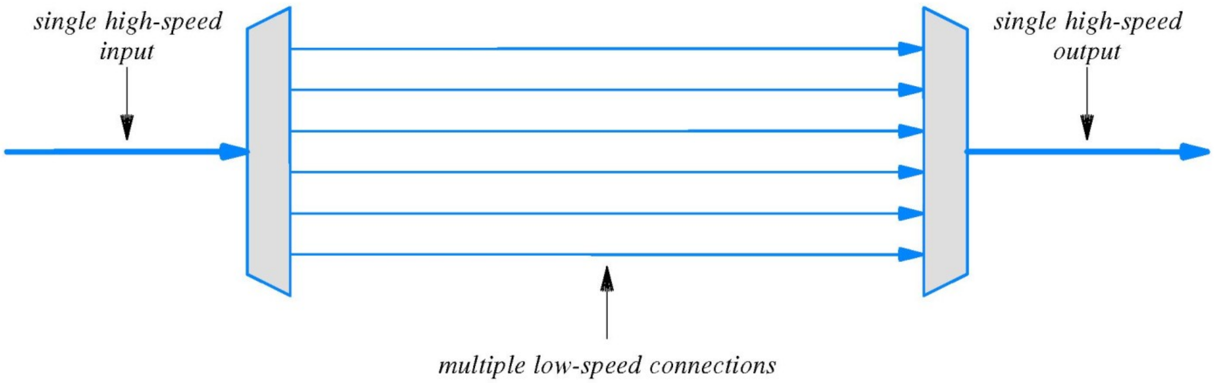


Figure 11.14 Illustration of inverse multiplexing in which a single high-capacity digital input is distributed over lower-capacity connections for transmission and then recombined to form a copy of the input.

11.15 **Code Division Multiplexing**

- CDM is the idea behind the CDMA used with cell phones.
- People who have studied vector spaces may understand the scheme more readily.
- The basic idea is actually a lot like doing TDM on a bit level.
- Each sender has a code called a chip sequence
- The chip sequence represents a vector.
- All the vectors determined by chip sequences are mutually orthogonal.
- In effect senders multiply their messages times their chip sequence and send the results to the multiplexor.
- The multiplexor adds the individual inputs from the senders and transmits the sum.
- The demultiplexor uses orthogonal projection - it projects the sum onto each chip sequence to recover one bit of the message from each phone.
- The scheme has some overhead that makes it less efficient than ordinary TDM if utilization is low.

- However, if utilization is high it has the advantage of lower delay. It is basically bit-at-a-time TDM, so phones are delayed only about as long as it takes all the other phones in use to send one bit - rather than the time it would take them to send large blocks of data.

Sender	Chip Sequence	Data Value
A	1 0	1 0 1 0
B	1 1	0 1 1 0

Figure 11.15 Example values for use with code division multiplexing.