Chapter 11

Multiplexing And Demultiplexing (Channelization)

Topics Covered

11.1 Introduction

- This chapter
  - continues the discussion of data communications by introducing multiplexing
  - defines basic types of multiplexing that are used throughout computer networks and the Internet
  - explains how modulated carriers provide the basis for many multiplexing mechanisms

11.2 The Concept Of Multiplexing

- Multiplexing to refer to the combination of information streams from multiple sources for transmission over a shared medium
  - A multiplexor implements the concept
- Demultiplexing to refer to the separation of a combination back into separate information streams
  - A demultiplexor implements the concept
- Figure 11.1 illustrates the concept
  - each sender communicates with a single receiver
  - all pairs share a single transmission medium
  - multiplexor combines information from the senders
  - demultiplexor can separate the information for receivers

11.2 The Concept Of Multiplexing

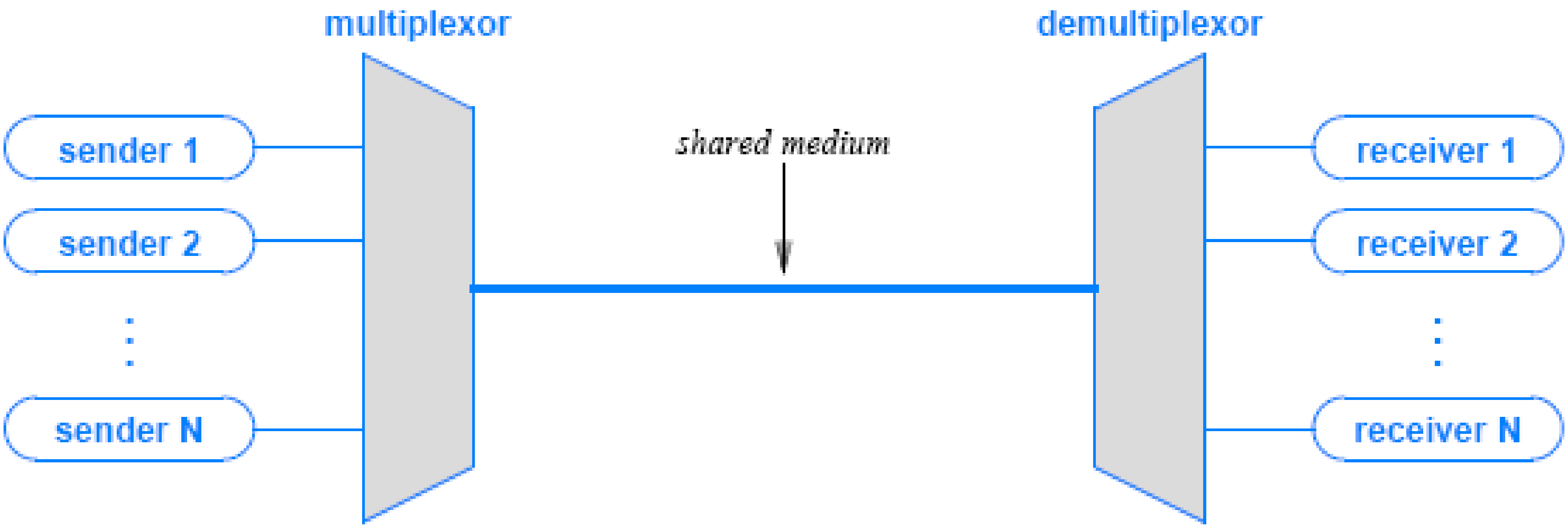


Figure 11.1 The concept of multiplexing in which independent pairs of senders and receivers share a transmission medium.

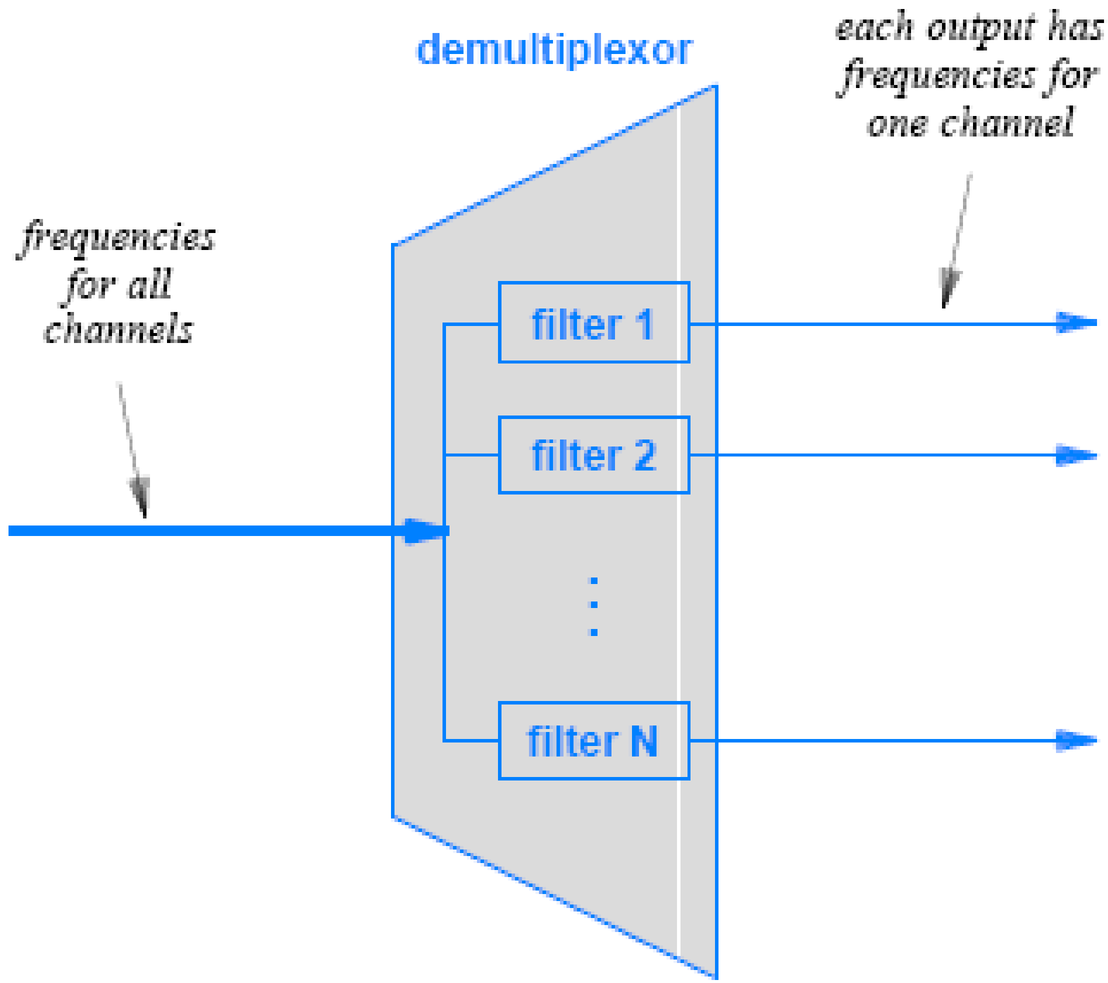
11.3 The Basic Types Of Multiplexing

- There are four basic approaches to multiplexing that each have a set of variations and implementations
  - Frequency Division Multiplexing (FDM)
  - Wavelength Division Multiplexing (WDM)
  - Time Division Multiplexing (TDM)
  - Code Division Multiplexing (CDM)
- TDM and FDM are widely used
- WDM is a form of FDM used for optical fiber
- CDM is a mathematical approach used in cell phones

11.4 Frequency Division Multiplexing

- A set of radio stations can transmit electromagnetic signals simultaneously
  - without interference provided they each use a separate channel (i.e., carrier frequency)
- A demultiplexor applies a set of filters that each extract a small range of frequencies near one of the carrier frequencies
- Figure 11.2 illustrates the concept
  - A key idea is that the filters used in FDM only examine frequencies
  - If a sender/receiver pair are assigned a particular carrier frequency FDM mechanism will separate the frequency from others

11.4 Frequency Division Multiplexing



11.4 Frequency Division Multiplexing

- Advantage of FDM is simultaneous use of a transmission medium by multiple pairs of entities
- FDM provides each pair with a private transmission path
  - as if the pair had a separate physical transmission medium
- Figure 11.3 illustrates the concept
- Practical FDM systems there are some limitations
  - If the frequencies of two channels are too close, interference can occur
  - Demultiplexing HW that receives a combined signal must be able to divide the signal into separate carriers
  - FCC (in USA) regulates adequate spacing occurs between the carriers
  - Choosing a set of carrier frequencies with a gap between them is known as a guard band
- Figures 11.4 & 11.5 show an example

11.4 Frequency Division Multiplexing

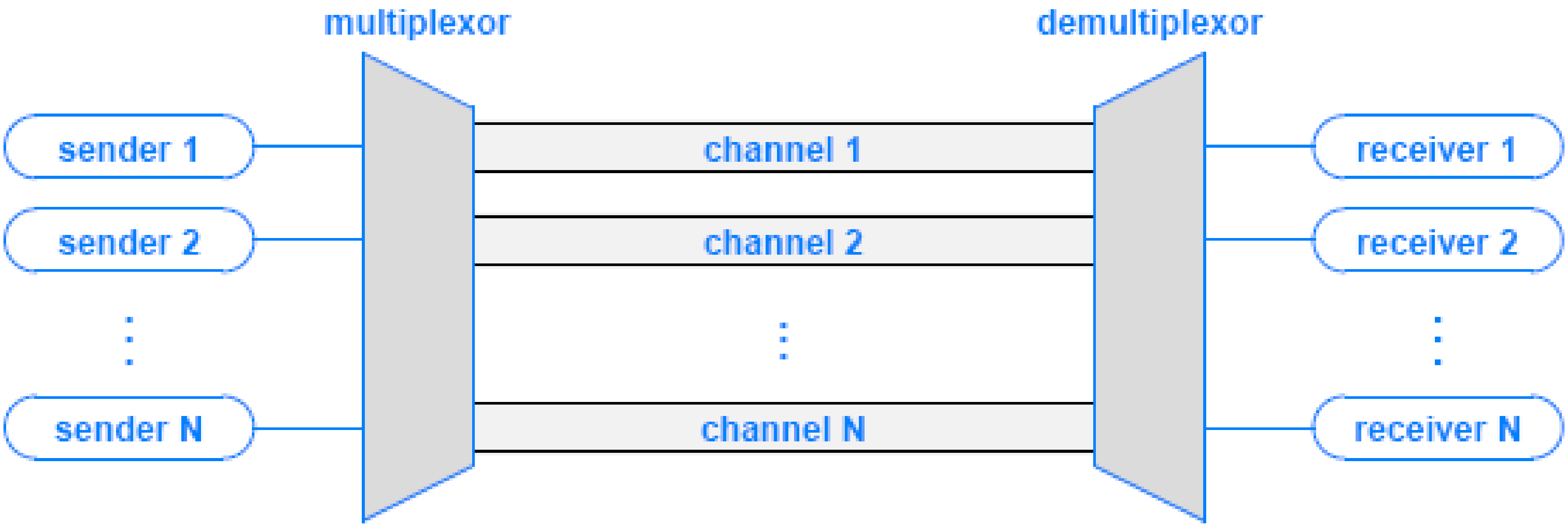
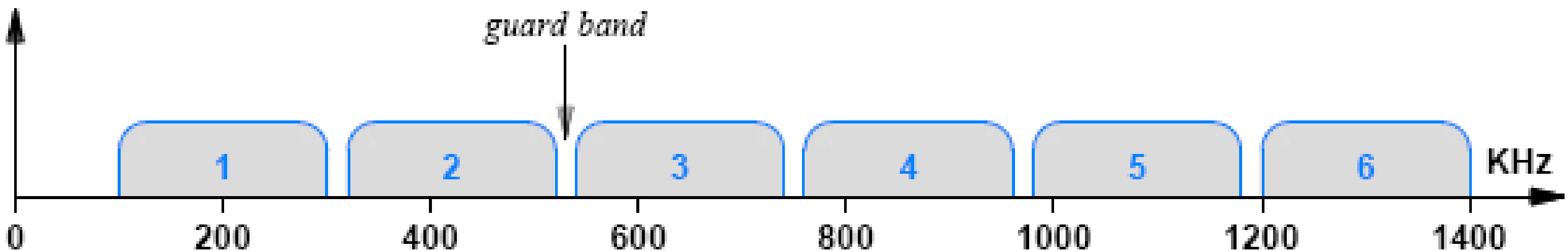


Figure 11.3 The conceptual view of Frequency Division Multiplexing (FDM) as providing a set of independent channels.

11.4 Frequency Division Multiplexing

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



11.5 Using a Range of Frequencies Per Channel

- Consider following points regarding FDM:
  - The idea of FDM arose in early experiments in radio
  - FDM is used in broadcast radio and television, cable television, and the AMPS cellular telephone
  - FDM multiplexing and demultiplexing hardware accepts and delivers analog signals
    - Even if a carrier has been modulated to contain digital information, FDM hardware treats the carrier as an analog wave
  - FDM is versatile, cecause it filters on ranges of frequency without examining other aspects of signals

11.5 Using A Range Of Frequencies Per Channel

- The analog characteristic has a disadvantage
  - FDM is susceptible noise and distortion
- Some FDM systems assign each sender/receiver pair a range of frequencies
  - FDM has the ability to choose how the frequencies can be used
- There are benefits of using a range of frequencies
  - Increase the data rate
  - Increase immunity to interference
- To increase the overall data rate
  - a sender divides the frequency range of the channel into K carriers
  - and sends 1/K of the data over each carrier

11.5 Using A Range Of Frequencies Per Channel

- A sender can perform FDM within an allocated channel
  - Sometimes, the term subchannel allocation to refer to the subdivision
- To increase immunity to interference, a sender can use spread spectrum (SS) techniques
  - various forms of SS are suggested, but basic idea is
    - divide the range of the channel into K carriers
    - transmit the same data over multiple channels
    - allow a receiver to use a copy of the data that arrives with fewest errors
  - SS works well in cases where noise is likely to interfere with some frequencies at a given time

11.6 Hierarchical FDM

- FDM HW has the ability to shift frequencies as needed
- For example, assume a set of incoming signals all use the frequency range between 0 and 4 KHz:
  - multiplexing hardware can leave the first stage as is
  - map the second onto the range 4 KHz to 8 KHz
  - map the third onto the range 8 KHz to 12 KHz, and so on
- Hierarchy in FDM multiplexors is that each map their inputs to a larger, continuous band of frequencies
- Figure 11.6 illustrates the concept of hierarchical FDM

11.6 Hierarchical FDM

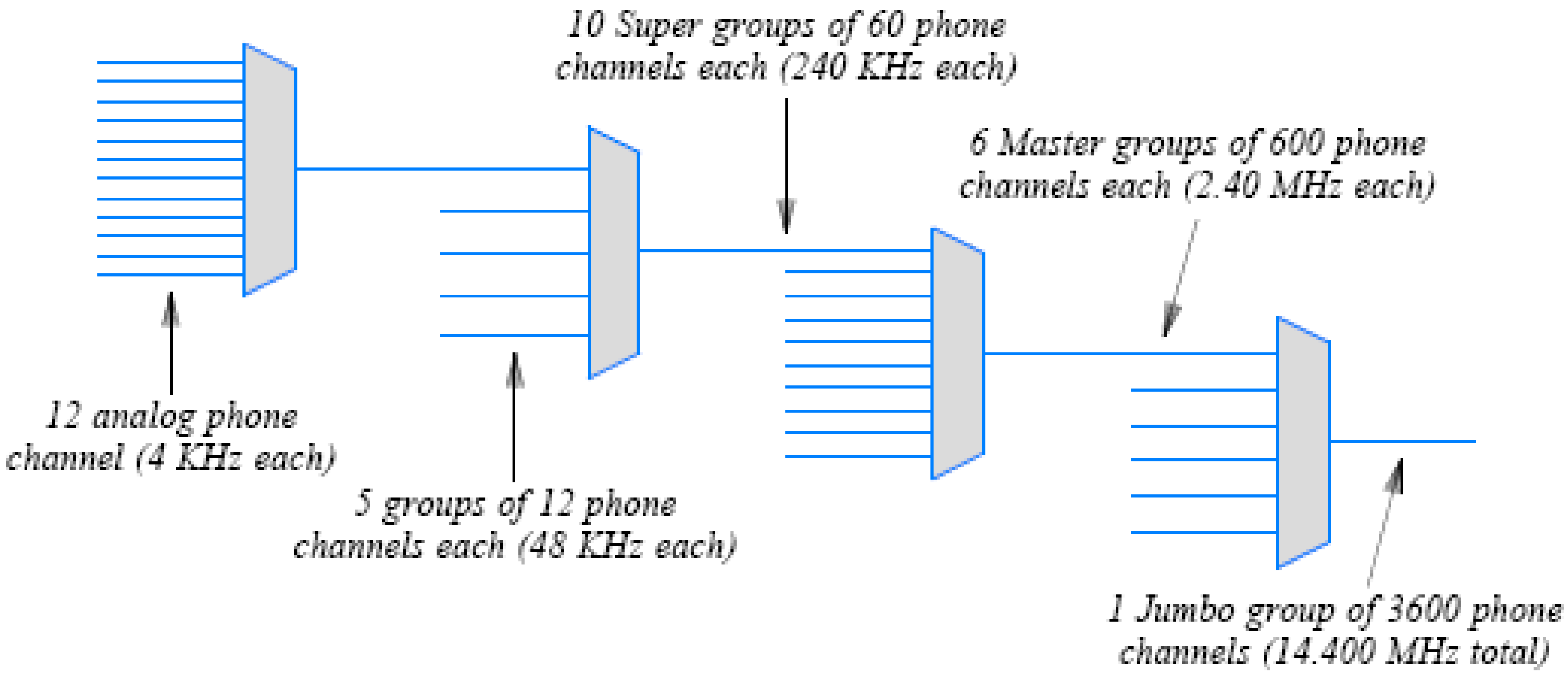


Figure 11.6 Illustration of the FDM hierarchy used in the telephone system.

11.7 Wavelength Division Multiplexing (WDM)

- WDM refers to the application of FDM to optical fiber
- The inputs and outputs of such multiplexing are wavelengths of light
  - denoted by the Greek letter λ, and informally called colors
- When white light passes through a prism colors of the spectrum are spread out
- If a set of colored light beams are each directed into a prism at the correct angle the prism will combine the beams to form a single beam of white light

11.7 Wavelength Division Multiplexing

- Prisms form the basis of optical multiplexing/demultiplexing
  - a multiplexor accepts beams of light (of various wavelengths) and uses a prism to combine them into a single beam
  - a demultiplexor uses a prism to separate the wavelengths.

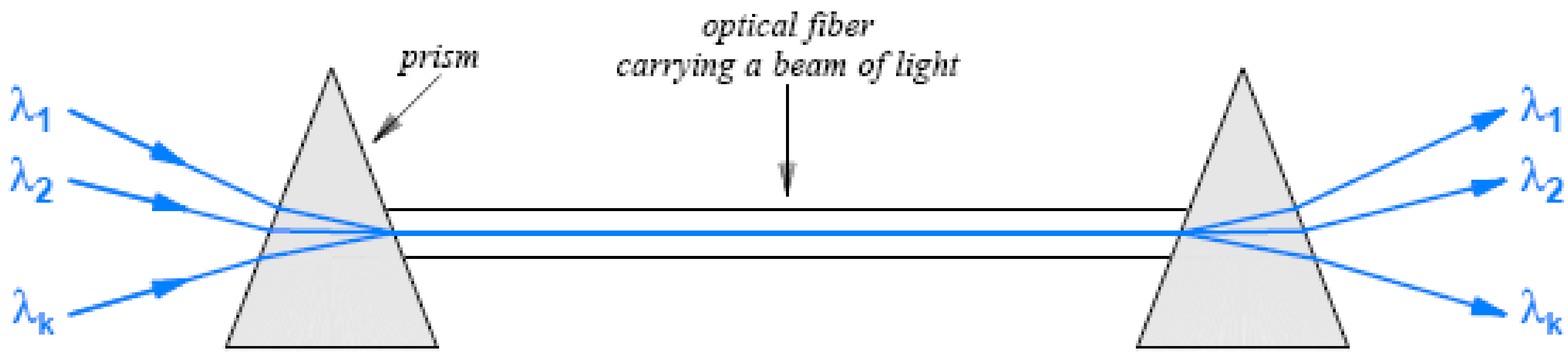
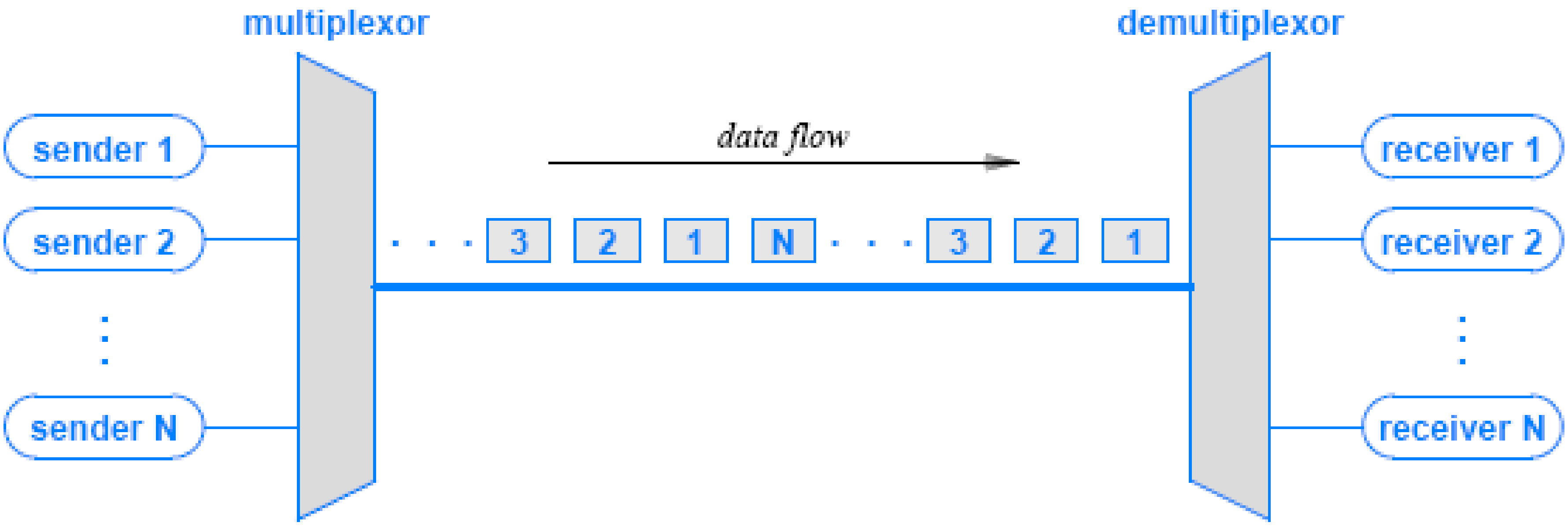


Figure 11.7 Illustration of prisms used to combine and separate wavelengths of light in wavelength division multiplexing technologies.

11.8 Time Division Multiplexing (TDM)

- Multiplexing in time simply means transmitting an item from one source, then transmitting an item from another source, and so on
- Figure 11.8 (below) illustrates the concept



11.9 Synchronous TDM

- TDM is a broad concept, and appears in many forms
- Figure 11.8 is a conceptual view, and the details may vary
  - Figure shows items being sent in a round-robin fashion
    - Most TDMs work this way
- Figure shows a slight gap between items
  - Recall from Chapter 9 that no gap occurs between bits if a communication system uses synchronous transmission
  - When TDM is applied to synchronous networks, no gap occurs between items, the result is known as Synchronous TDM
- Figure 11.9 illustrates how synchronous TDM

11.9 Synchronous TDM

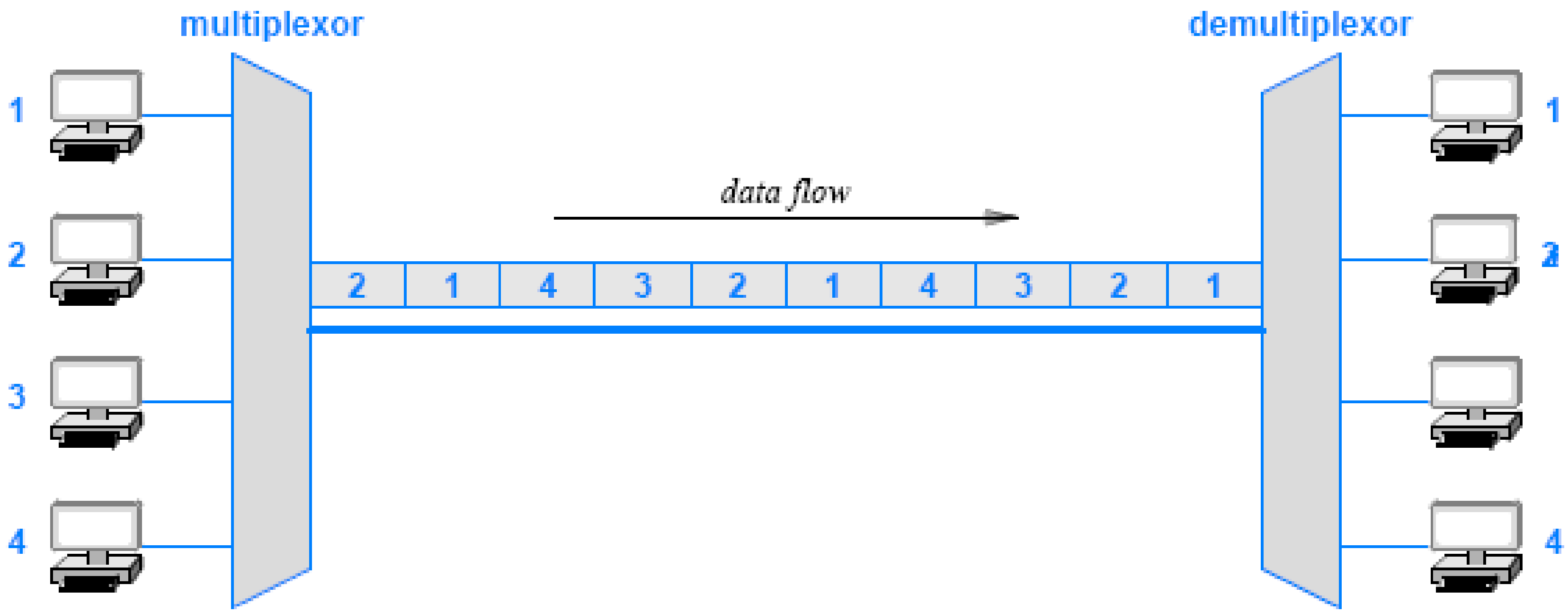


Figure 11.9 Illustration of a Synchronous Time Division Multiplexing system with four senders.

11.10 Framing Used In The Telephone System Version Of TDM

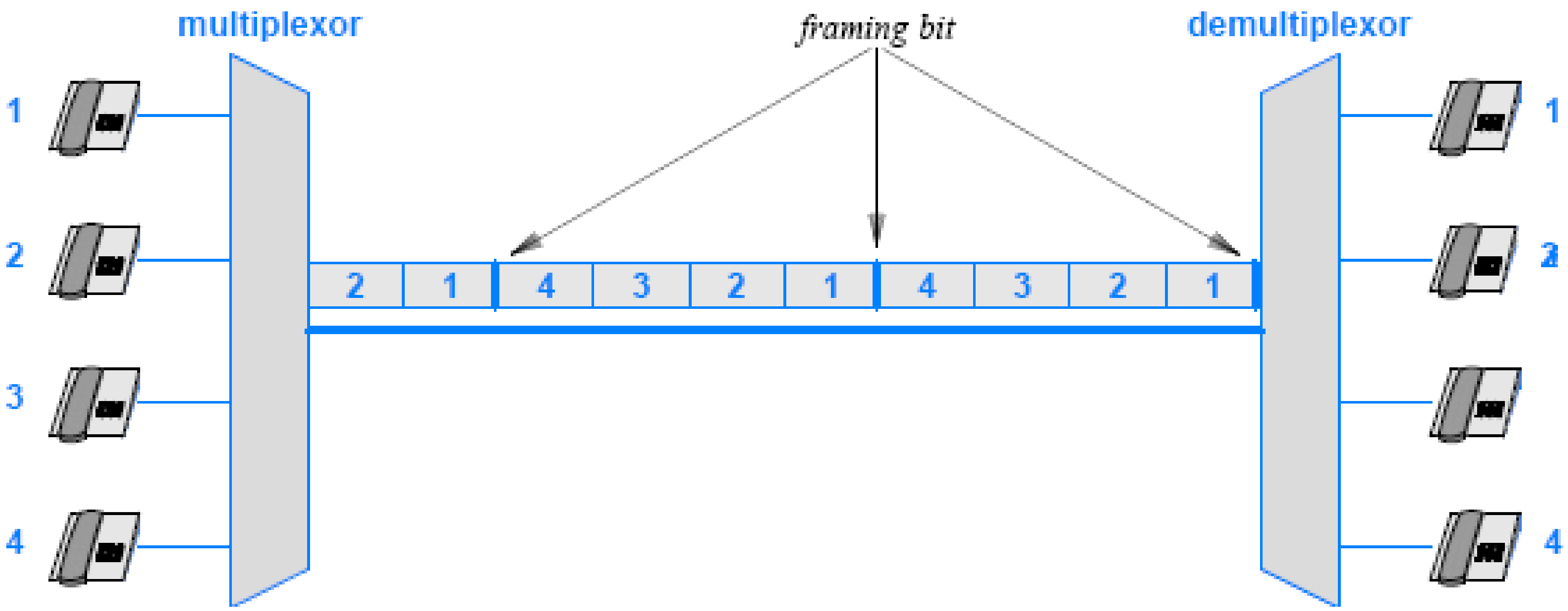
- Telephone systems use synchronous TDM
  - Acronym TDM refer to the specific form of TDM used to multiplex digital telephone calls
- TDM used in phone systems include an interesting technique to synchronize multiplexor/demultiplexor
- Why synchronization is needed?
  - observe that a synchronous TDM sends one slot after another without any indication of the output to which a given slot occurs
  - a demultiplexor cannot tell where a slot begins
  - a slight difference in the clocks used to time bits can cause a demultiplexor to misinterpret the bit stream

11.10 Framing Used in the Telephone System Version of TDM

- TDM used in the phone system includes an extra framing channel as input
- Instead of taking a complete slot, framing inserts a single bit in the stream on each round
- A demultiplexor extracts data from the framing channel and checks for alternating 0 and 1 bits
- If an error causes a demultiplexor to lose a bit, it is highly likely that the framing check will detect the error

- Figure 11.10 illustrates the use of framing bits

11.10 Framing Used in the Telephone System Version of TDM



11.11 Hierarchical TDM

- TDM can be arranged in a hierarchy
- Each successive stage of a TDM hierarchy uses N times the bit rate
- Additional framing bits are added to the data
  - this means that the bit rate of each successive layer of hierarchy is slightly greater than the aggregate voice traffic

11.11 Hierarchical TDM

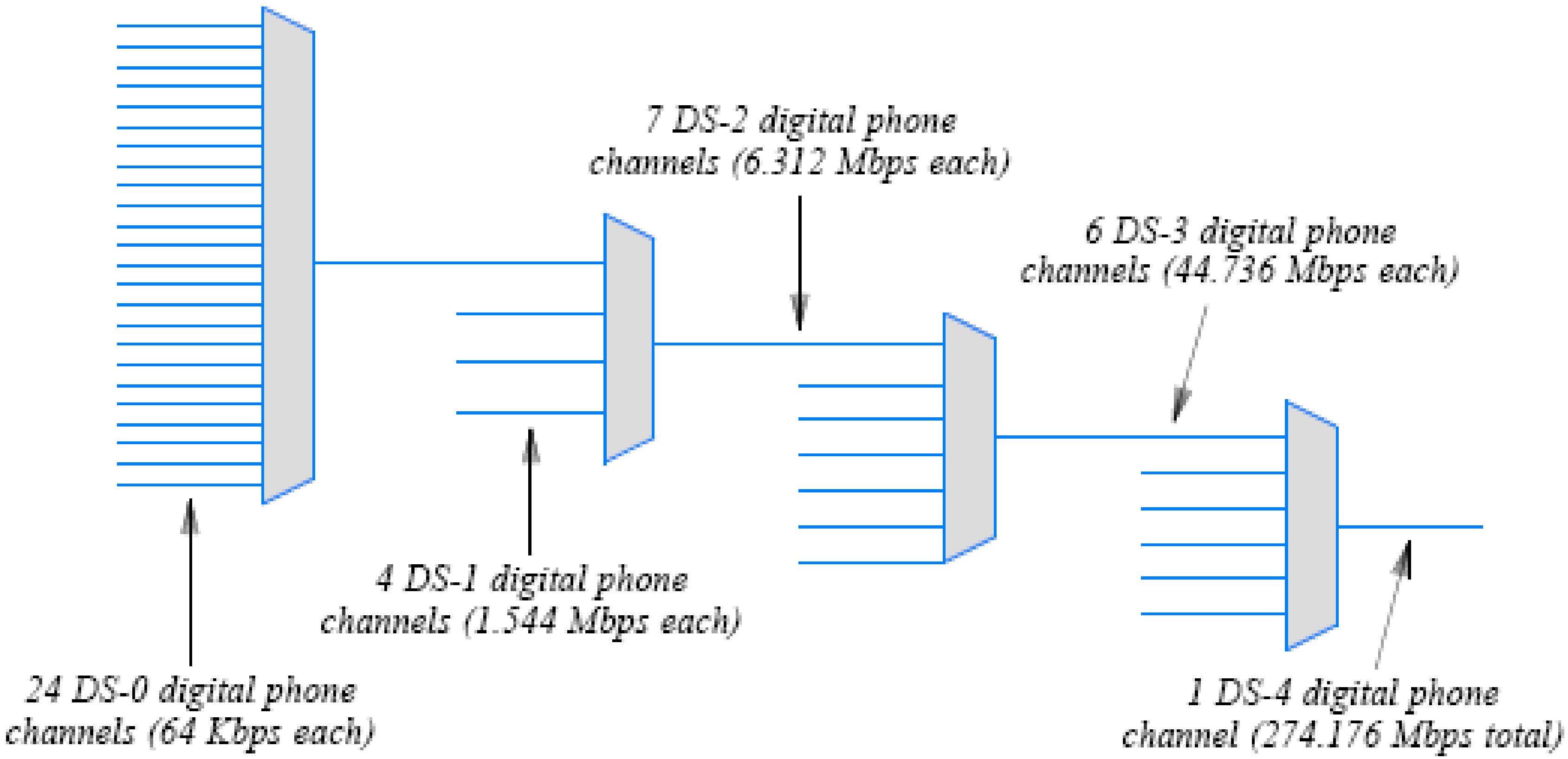


Figure 11.11 Illustration of the TDM hierarchy used in the telephone system.

11.12 The Problem with Synchronous TDM: Unfilled Slots

- Synchronous TDM works well if each source produces data at a uniform, fixed rate equal to 1/N of the capacity
- Many sources generate data in bursts
  - with idle time between bursts
- Consider the example in Figure 11.12
  - sources on the left produce data items at random
  - the synchronous multiplexor leaves a slot unfilled if the corresponding source has not produced an item for that slot
- In practice, a slot cannot be empty
  - because the underlying system must continue to transmit data
  - the unused slot is assigned a value (such as zero)
  - and an extra bit is set to indicate that the value is invalid

11.12 The Problem with Synchronous TDM: Unfilled Slots

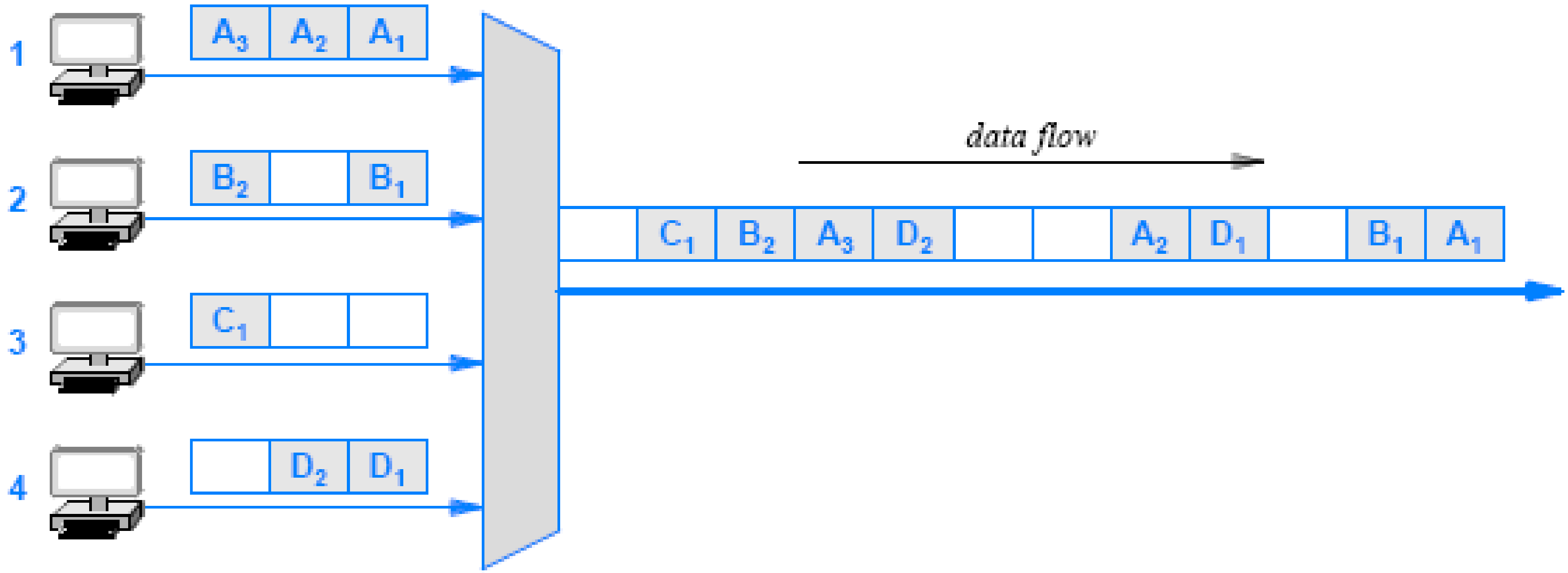


Figure 11.12 Illustration of a synchronous TDM system leaving slots unfilled when a source does not have a data item ready in time.

11.13 Statistical TDM

- How can a system make better use of a shared medium?
- One technique is known as statistical TDM or statistical multiplexing
  - Some literature uses the term asynchronous TDM
- The technique is straightforward:
  - select items for transmission in a round-robin fashion
  - instead of leaving a slot unfilled, skip any source that does not have data ready
- By eliminating unused slots statistical TDM takes less time to send the same amount of data
- Figure 11.13 illustrates how a statistical TDM system works

11.13 Statistical TDM

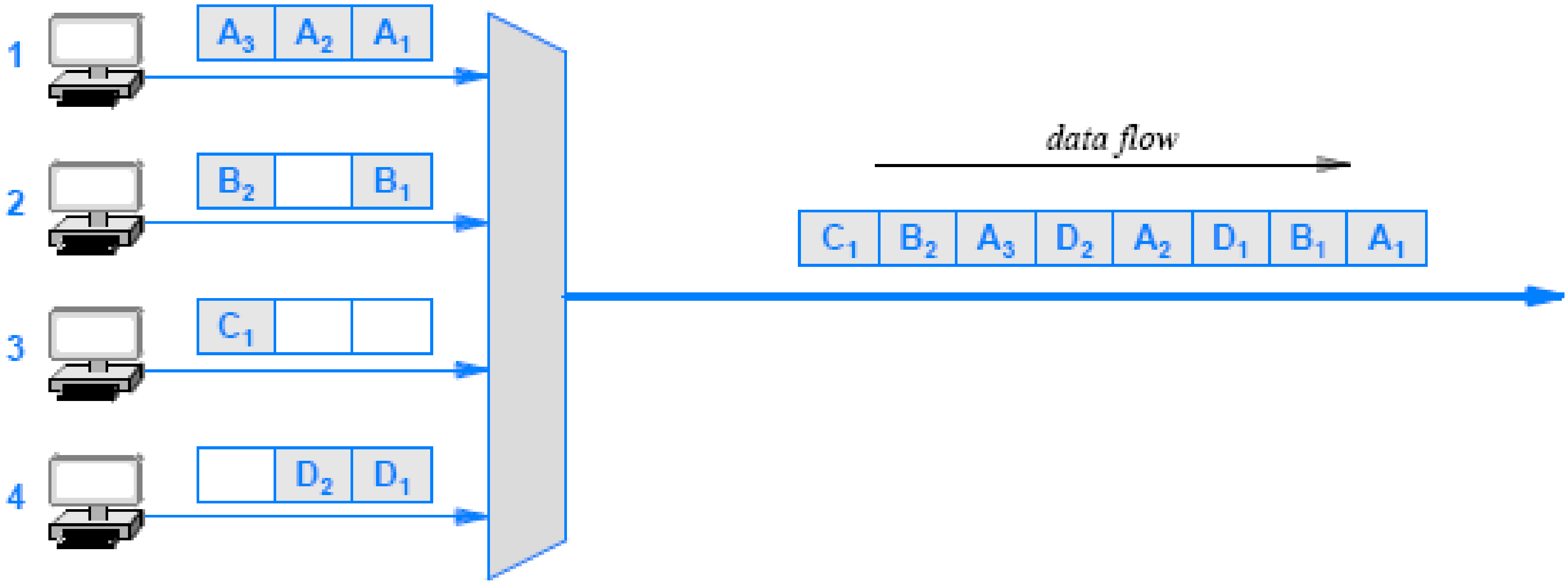


Figure 11.13 Illustration that shows how statistical multiplexing avoids unfilled slots and takes less time to send data.

11.13 Statistical TDM

- Statistical multiplexing generates extra overhead
- Consider demultiplexing:
  - In a synchronous TDM system a demultiplexor knows that every N slot corresponds to a given receiver
  - In a statistical multiplexing system, the data in a given slot can correspond to any receiver.
- Each slot must contain the identification of the receiver to which the data is being sent

11.14 Inverse Multiplexing

- Assume a case where a connection between two points consists of multiple transmission media but no single medium has sufficient bit rate
- Some service providers need higher bit rates than available
- ones
- To solve the problem, multiplexing is used in reverse:
  - spread a high-speed digital input over multiple lower-speed circuits for transmission and combine the results at the receiving end
- Figure 11.14 illustrates the concept

11.14 Inverse Multiplexing

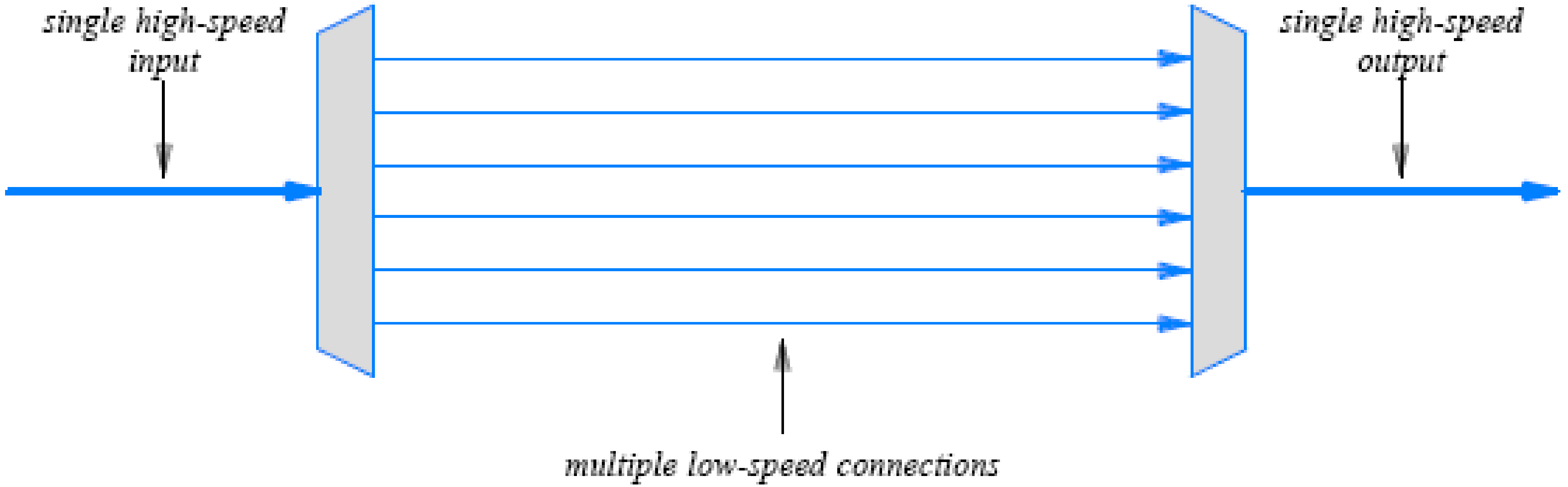


Figure 11.14 Illustration of inverse multiplexing in which a single high-speed digital input is distributed over lower-speed connections for transmission and then recombined to form a copy of the input.

11.15 Code Division Multiplexing (CDM)

- CDM used in the cellular telephone system and for some satellite communication
  - The specific version of CDM used in cell phones is known as Code Division Multi-Access (CDMA)
- CDM does not rely on physical properties
  - such as frequency or time
- CDM relies on an interesting mathematical idea:
  - values from orthogonal vector spaces can be combined and separated without interference
- Each sender is assigned a unique binary code C_i
  - that is known as a chip sequence
  - chip sequences are selected to be orthogonal vectors
  - (i.e., the dot product of any two chip sequences is zero)