Chapter Two
Fundamental of Data Communication

Main content

- Theoretical basis of data communication
- Basic model of data communication system
- Several basic concepts about channel
- The limit capacity and transmission rate of channel
- Channel Multiplexing and Compression technology
- Digital transmission system
- Broadband access technology
- The development of mobile phone system

2.1 Theoretical basis of data communication

- We can transmit information online through some changes of physical characteristics (such as voltage or current).
- If using time t as the independent variable of single-valued function f(t), which represent the value of the voltage or current, then we can model the behavior of the signal and analyze the signal with mathematical methods.

< Mathematical analysis of the signal >

2.1 Theoretical basis of data communication

Fourier Analysis

- **In the early 19th century, the French mathematician Fourier proved that any normal function f (t) which cycle is T, can be expanded into a multiple** (possibly infinite) **sum of sine and cosine functions:**

$$f(t)=\frac{1}{2}C+\sum_{n=1}^{\infty}a_n\sin(2\pi nft)+\sum_{n=1}^{\infty}b_n\cos(2\pi nft) < 2-1 >$$

- **Among them： f =1/T is fundamental frequency， and a_n and b_n are amplitudes of Nth-degree harmonic Sine and cosine. This decomposition is called Fourier Series.**
- **A function can be reconstructed with the above series, that is, if T is known, and the amplitude is given too, then the original function f (t) signal can be received through <2-1> formula.**

2.1 Theoretical basis of data communication

Fourier Analysis

- **Multiplied by sin(2∏kft) on both sides of <2-1> type, and calculate the integral from zero to T and the amplitude of a_n can be obtained, then b_n item disappear.**
- **Multiplied by cos(2∏kft) on both sides of <2-1> type, and calculate the integral from zero to T and the amplitude of bn can be obtained, then an items disappear.**
- **Calculate the integral of <2-1> type from zero to T can get the constant C.**

Obtained by the above method:

$$a_n = \frac{2}{T}\int_0^T f(t)\sin(2\pi nft)\,dt,$$

$$b_n = \frac{2}{T}\int_0^T f(t)\cos(2\pi nft)\,dt,$$

$$C = \frac{2}{T}\int_0^T f(t)\,dt,$$

2.1 Theoretical basis of data communication

Fourier Analysis

$$f(t) = \mathcal{F}^{-1}[F(\omega)] = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)e^{i\omega t}\,d\omega.$$

$$f(t) = \frac{1}{2}c + \sum_{n=1}^{\infty}\left[a_n \sin(2\pi nft) + b_n \cos(2\pi nft)\right]$$

Among them

$$c = \tfrac{2}{T}\int_0^{\infty} f(t)dt$$

$$a_n = \frac{2}{T}\int_0^T f(t)\sin(2\pi nft)dt$$

$$b_n = \frac{2}{T}\int_0^T f(t)\cos(2\pi nft)dt$$

In this formula: C is a dc component, f=1/T is the fundamental frequency， t is time, T is the time required for digital signal transmission, a_n and b_n are n times harmonic amplitude respectively. It can be seen that, this is the linear superposition by an infinite number of sine and cosine function.

The properties of Fourier transform

Properties Name	F(t)	$F(j\omega)$
1. Linear	$A1f1(t)+a2f2(t)$	$a1F1(j\varpi)=a2F2(j\varpi)$
2. Symmetry	$F(jt)$	$2\pi f(-\varpi)$
3.Foldability	$f(-t)$	$F(-j\varpi)$
4. Scale transformation	$F(at)$ ($a\neq 0$ real number)	$\frac{1}{\lvert a\rvert}F(j\frac{\omega}{a})$
5. Time shift sex	$f(t-t_0)$	$F(jw)e^{-j\omega\tau_0}$
6. Frequency shift sex	$f(t)e^{\pm j\omega_0\tau}$	$F[j(\omega\mu\omega_0)]$
7. The time domain differential	$\int_{-\infty}^{\infty} f^{(n-1)}(t)dt<\infty$ $\frac{d^n f(\tau)}{d^{\tau n}}$	$j(\varpi)nF(j\varpi)$
8.Frequency Domain Differential	$t^n f(t)$	$(j)^n F^{(n)}(j\omega)$
9. Time Domain Integral	$\int_{-\infty}^{t} f(\tau)d\tau$	$\pi F(0)\delta(\omega)+\frac{F(j\omega)}{jw}$
10. Frequency domain integral	$\pi f(0)\delta(t)+\frac{f(t)}{-jt}$	$\int_{-\infty}^{\omega} F(j\eta)d\eta$
11. Time-domain convolution	$f1(t)*f2(t)$	$F1(j\varpi)F2(j\varpi)$
12. Frequency domain convolution	$f1(t).f2(t)$	$[F1(j\varpi)*F2(j\varpi)]$
13. Parseval theorem	$\int_{-\infty}^{\infty} f^2(t)dt$	$\frac{1}{2\pi}\int_{-\infty}^{\infty}\lvert F(j\omega)\rvert^2 d\omega$

Calculation example of Fourier transform and inverse transform (Sinax/x function)

Solve the $\frac{\sin ax}{x}, a > 0$ **, Fourier transform:**

$$F\left[\frac{\sin ax}{x}\right] = \int_{-\infty}^{\infty} \frac{\sin ax}{x} e^{i\omega x} dx = \int_{-\infty}^{\infty} \frac{\sin ax}{x} (\cos \omega x + i \sin \omega x) dx$$

$$= 2\int_0^{\infty} \frac{\sin ax \cos ax}{x} dx = \int_0^{\infty} \frac{\sin(a+\omega)x}{x} dx + \int_0^{\infty} \frac{\sin(a-\omega)x}{x} dx$$

$$= \frac{\pi}{2}\left[\operatorname{sgn}(a+\omega) + \operatorname{sgn}(a-\omega)\right] = \begin{cases} \pi, |\omega| < a \\ \frac{\pi}{2}, |\omega| = a \\ 0, |\omega| > a \end{cases}$$

Among them with the

$$\int_0^{\infty} \frac{\sin ax}{x} dx = \begin{cases} \frac{\pi}{2}, a > 0 \\ 0, a = 0 \\ -\frac{\pi}{2}, a < 0 \end{cases}$$

Prove that $I(t) = \int_0^{\infty} \frac{\sin tax}{x} dx, a \neq 0$

Take Laplace transform

$$L[I(t)] = \int_0^{\infty} \frac{1}{x} \frac{ax}{s^2 + a^2 x^2} dx = \left(\frac{1}{s} \arctan \frac{ax}{s}\right)_0^{\infty} = \begin{cases} \frac{\pi}{2} \cdot \frac{1}{s}, a > 0 \\ -\frac{\pi}{2} \cdot \frac{1}{s}, a < 0 \end{cases}, s > 0$$

Calculation example of Fourier transform and inverse transform (Sinax/x function)

Take Inverse Laplace transformation

$$I(t) = L^{-1}\left[I(t)\right] = \begin{cases} \frac{\pi}{2}, a > 0, \\ -\frac{\pi}{2}, a < 0 \end{cases},$$

Hence

$$I(1) = \int_0^{\infty} \frac{\sin ax}{x} dx = \begin{cases} \frac{\pi}{2}, a > 0 \\ 0, a = 0 \\ -\frac{\pi}{2}, a < 0 \end{cases}$$

2.1 Theoretical basis of data communication

- The maximum transmission rate of channel
  - Nyquist Theorem (in noiseless channel case)
    - Nyquist proved that if any signal has passed a low-pass filter with H (Hz) bandwidth, the filtered signal can be reconstructed completely as long as 2H per second sampling. And if the signal contains V discrete series, then:
    - The maximum data transfer rate = $2H\log_2 V$

2.1 Theoretical basis of data communication

- The maximum transmission rate of channel
  - **Shannon Theorem (in noisy channel case)**
    - **On the basis of Nyquist Theorem, Shannon get the maximum data transfer rate of a noisy channel which bandwidth is H (Hz), signal to noise ratio is S / N**
    - **The maximum data transfer rate**

      $= H\log_2(1+S/N)$

      PS: S is the signal power, N is the noise power

      and dB=10lg(S/N)

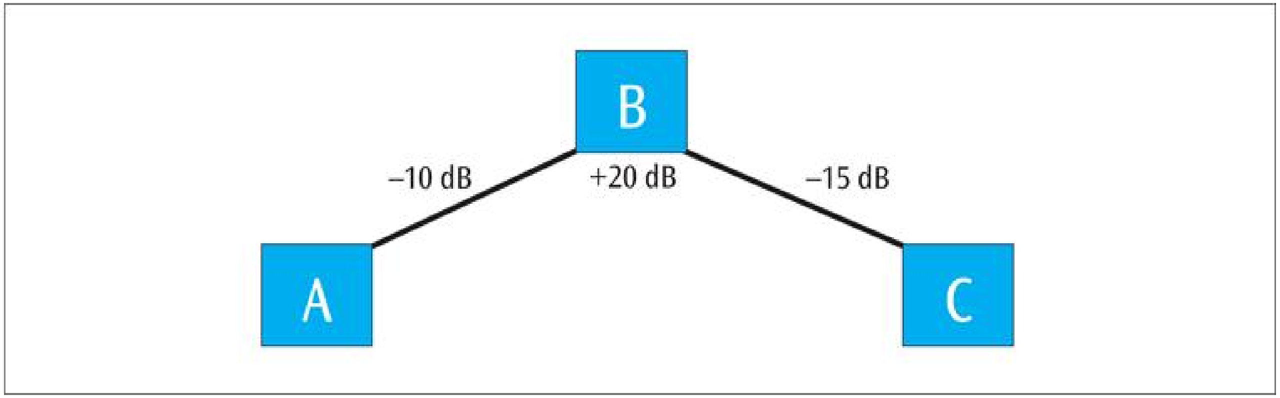
Sample of Shannon Theorem

- **For example, what is the data rate of a 3400 Hz signal with 0.2 watts of power and 0.0002 watts of noise?**
  - **$S(f) = 3400 \times \log_2 (1 + 0.2/0.0002)$**
    $= 3400 \times \log_2 (1001)$
    $= 3400 \times 9.97$
    $= 33898$ bps

Loss of Signal Strength

- All signals experience loss (attenuation)
- Attenuation is denoted as a decibel (dB) loss
- Decibel losses (and gains) are additive

Figure 2-10
Example demonstrating decibel loss and gain



Loss of Signal Strength

- So if a signal loses 3 dB, is that a lot?
- What if a signal starts at 100 watts and ends at 50 watts? What is dB loss?

  $dB = 10 \times \log_{10} (P_2 / P_1)$

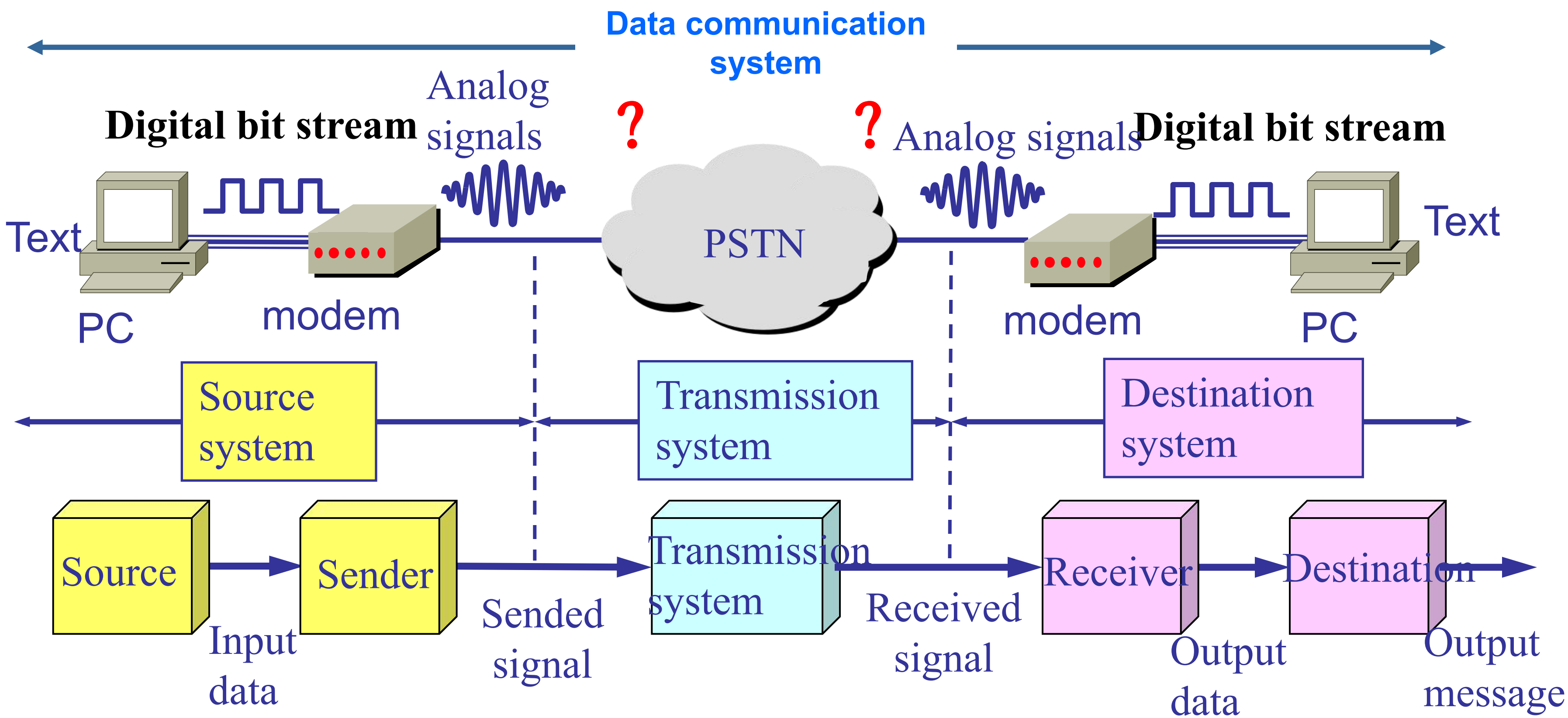
  $dB = 10 \times \log_{10} (50 / 100)$

  $dB = 10 \times \log_{10} (0.5)$

  $dB = 10 \times -0.3$

  $dB = -3.0$
- So a 3.0 decibel loss losses half of its power

2.2 Basic model of data communication system



2.2 Basic model of data communication system

Function of model

- **Source**: Source device generates the data that to be transmitted
- **Sender**: Format conversion, encoded into a signal suitable for transmission (typical transmitter is modulator)
- **Transmission system**: The transmission line (which may be a line , or may be a network system)
- **Receiver**: Receive signal and convert it to the data format which can be recognized by the destination device (the typical receiver is demodulator)
- **Destination**: Accept and deal with data as required

2.2 Basic model of data communication system

Several Terms

- **Data**: Data are entities that convey meaning within a computer or computer system, divided into analog data and digital data.
- **Signal**: Signals are the electric or electromagnetic impulses used to encode and transmit data– three components: Amplitude, Frequency, and Phase.
- **Information**: Collection of facts grouped together in a specific way, which contains entities, attributes, and values represented by data. Information is the higher level of abstract conception.
- **Code:** Express the digital signal in using time domain waveform, which represents the basic waveform of different discrete values.

2.2 Basic model of data communication system

- **Several Terms**
  - **Analog:** is a **continuous waveform**, with examples such as (naturally occurring) music and voice
  - **Digital:** is a **discrete or non-continuous waveform**
  - **Modulation：** The process of **converting digital signals into analog signals**
  - **Demodulation：** The process of **converting analog signals into digital signals**
  - **Channel：** **A path can transmit signals** which contains the line and ancillary equipment; it is usually used to represent the media that transmit information to a certain direction
  - **Baud**: It is the unit of **code transmission rate**, and 1 baud represents transmit 1 code per second.
  - **A communication circuit often contains a sending channel and a receiving channel**

Four combinations of data and signals

Data and signals can be either analog or digital

Table 2-1 Four combinations of data and signals

Data	Signal	Encoding or Conversion Technique	Common Devices	Common Systems
Analog	Analog	Amplitude modulation Frequency modulation	Radio tuner TV tuner	Telephone AM and FM radio Broadcast TV Cable TV
Digital	(Square-wave) Digital	NRZ-L NRZI Manchester Differential Manchester Bipolar-AMI 4B/5B	Digital encoder	Local area networks Telephone systems
Digital	(Discrete) Analog	Amplitude shift keying Frequency shift keying Phase shift keying	Modem	Dial-up Internet access DSL Cable modems Digital Broadcast TV
Analog	Digital	Pulse code modulation Delta modulation	Codec	Telephone systems Music systems

Converting Data into Signals

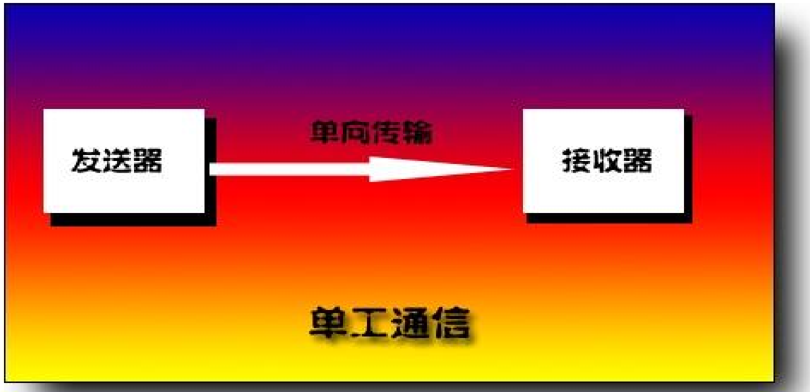
- There are four main combinations of data and signals:
  - Analog data transmitted using analog signals
  - Digital data transmitted using digital signals
  - Digital data transmitted using discrete analog signals
  - Analog data transmitted using digital signals
- More details seen in English Book Chapter 2 page 40-51

2.3 Several Concepts of Channel

- **From the way of information interaction between the two sides of communication, there are three basic ways:**
  - **One-way communication (simplex communication): It can only communicate in one direction but can't interaction in the opposite direction.**
  - **Two-way alternate communication (half duplex communication): Both sides can send information, but both sides can't send information at the same time (of course can't receive information simultaneously).**
  - **Simultaneous two-way communication (full-duplex communication) :Both sides can send and receive information at the same time.**

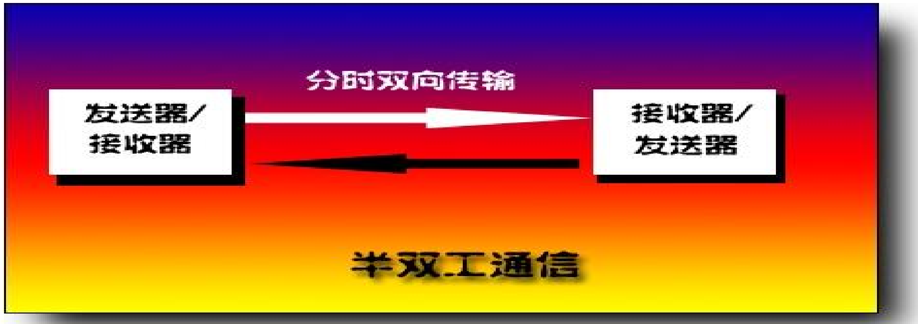
2.3 Several Concepts of Channel

- **One-way communication (simplex communication): It can only communicate in one direction but can't interaction in the opposite direction. It can only be sent from the transmitter to the receiver. For example, radios, televisions, computer output devices (printer or monitor) and other equipments that using simplex operation mode.**



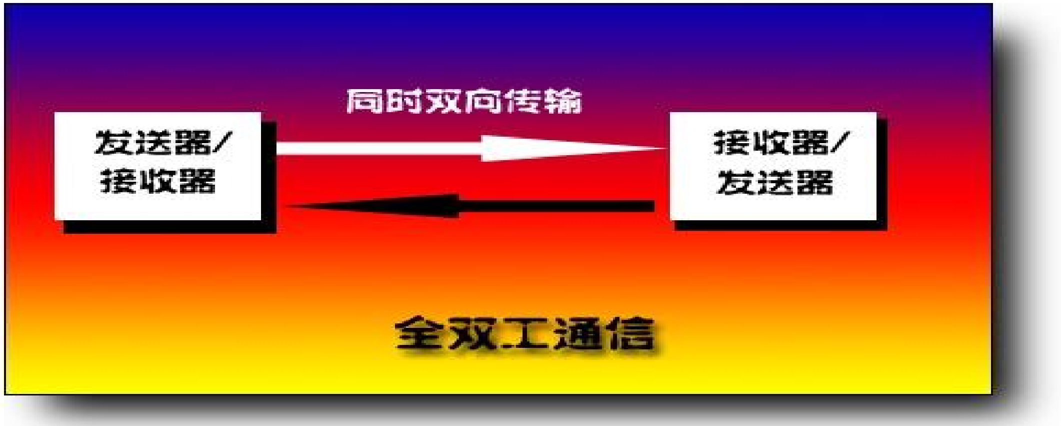
2.3 Several Concepts of Channel

- **Two-way alternate communication (half duplex communication): Both sides can send information, but both sides can not send information at the same time(of course can not receive simultaneously). Half-duplex operation mode is commonly used in communication equipment or occasions that transmission channel does not have enough bandwidth to support the bidirectional communication occasions, or a communication sequence between the two sides of communication requires alternating occasions. For example, radio, shared LAN and other equipment uses half-duplex mode of operation.**



2.3 Several Concepts of Channel

- **Simultaneous two-way communication (full-duplex communication)** Both sides can send and receive information at the same time. This communication operation mode has the advantage of large throughput, but it requires the transmission channel to provide enough bandwidth support. For example, switch based network and so on that use the full-duplex operation mode.



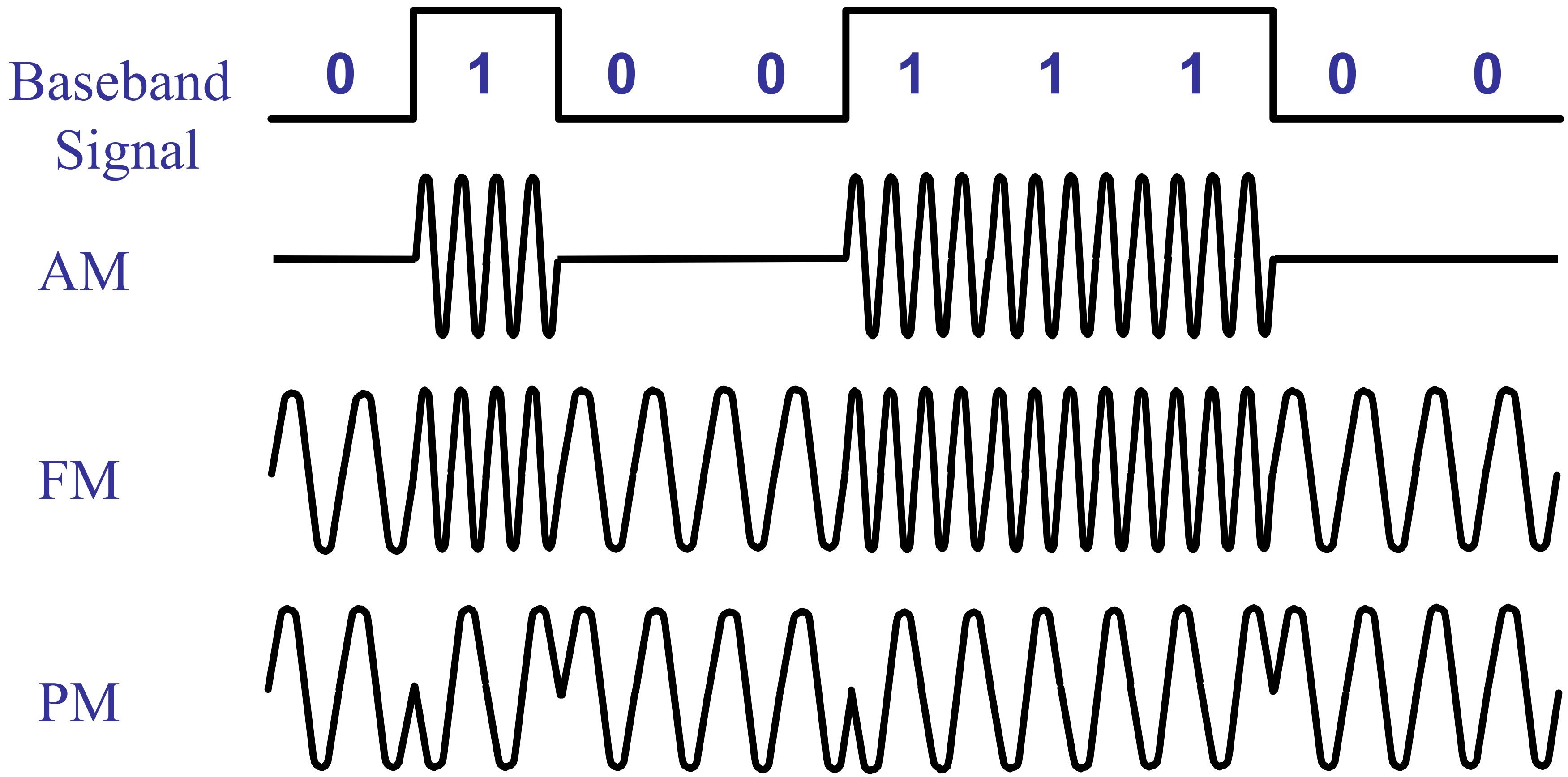
2.3 Several Concepts of Channel

- **Base-band Signal（that is** the basic frequency band signal）—— **From source of the signal. The data signal of a variety of texts or image files that output from the computer all belong to baseband signal.**
- **The baseband signal often contains more low frequency components, even DC components. However, many channels can not transmit such a low frequency component or DC component . Therefore, it is necessary to modulate the base-band signal .**

2.3 Several Concepts of Channel

- **Band-pass Signal**——**After the carrier modulation of the baseband signal, the frequency range of the signal is moved to a higher frequency in order to transmit in the channel** （**only through channel in a range of frequencies**）**.**
- **The basic binary system modulation methods：**
  - **Amplitude Modulation (AM)：** **The amplitude of the carrier varies with the baseband digital signal .**
  - **Frequency Modulation (FM)：** **The frequency of the carrier varies with the baseband digital signal .**
  - **Phase Modulation (PM) ：** **The initial phase of the carrier varies with the baseband digital signal .**

Basic binary system modulation methods

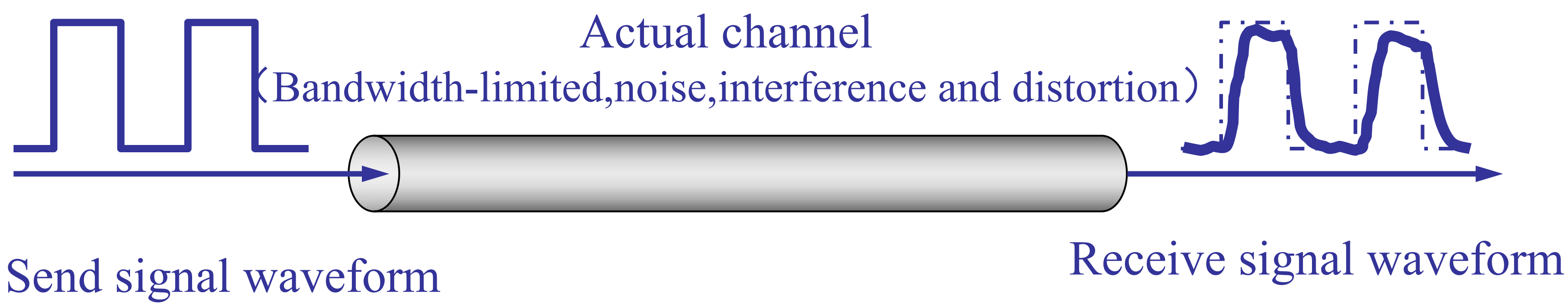


2.4 The Limit Capacity and Limit Transmission Rate of Channel

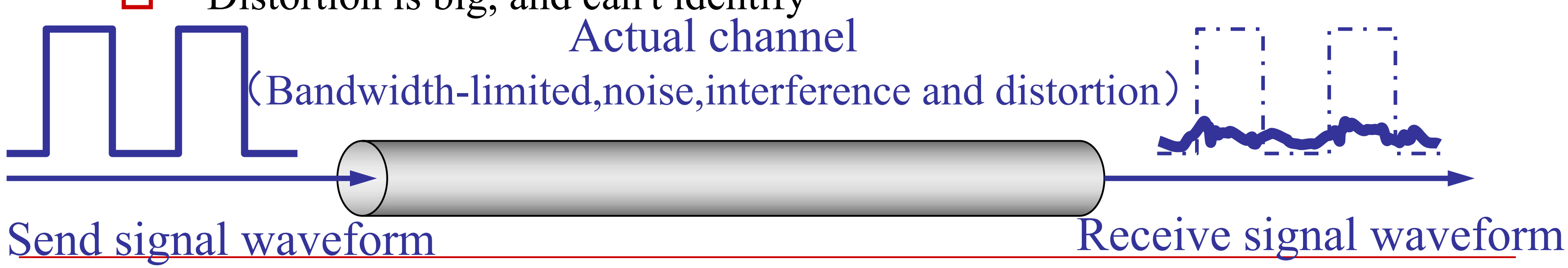
- **In fact, any actual channel is not ideal, a variety of interference and signal distortion will occur when transmitting signals.**
- **The higher the symbol transmission rate, or the longer the transmission distance of signal, the more serious the waveform distortion in the output of the channel.**

2.4 The Limit Capacity and Limit Transmission Rate of Channel

- **Digital signal goes through the actual channel**
  - The distortion is existing, but waveform still can be identified.



  - Distortion is big, and can't identify



2.4 The Limit Capacity and Limit Transmission Rate of Channel

- The frequency range of channel can be through
  - Nyquist deduced the famous Nyquist Criteria in 1924. He proposed the maximum value of symbol transmission rate under the assumed ideal conditions in order to avoid the inter-code interference.
  - $C^{*} = 2H^{*}\log_2 V$ (2-1) (Nyquist Criteria)
  - In any channel, the code transmission rate must have a maximum value, otherwise there will be inter-code interference and the receiver can not recognize the code.
  - The wider the broadband of channel, that is the more signal high-frequency component can pass through, the higher code transmission rate can be obtained and inter-code interference will not occur.

2.4 The Limit Capacity and Limit Transmission Rate of Channel

- SNR (Signal to Noise Ratio)
  - 1948, Shannon deduced the limited bandwidth and there is a Gaussian white noise disturbed channel limit, error-free information transfer rate derives with information theory.
  - Limit channel information transmission rate C can be expressed as
  - $C = W \log_2(1+S/N)$ <2-2> （Shannon Formula）
    - W is Bandwidth of the channel（Hz）；
    - S is the average power of the signal transfer in the channel;
    - N is Gaussian noise internal power in the channel.

2.4 The Limit Capacity and Limit Transmission Rate of Channel

- **Shannon Formula illustrates that:**
  - **The larger channel bandwidth or channel noise ratio is, the higher the limit of the information transmission rate is.**
  - **As long as the information transmission rate is lower than the limit transmission rate of channel, it could find some ways to achieve error-free transmission.**
  - **If the channel bandwidth W or signal-to-noise ratio S/N have no upper limit (of course it won't happen in actual condition), then the limit information transmission rate C have no upper limit too.**
  - **The information transmission rate of actual channel is much lower than Shannon's limit transmission rate (The meaning of limit capacity).**

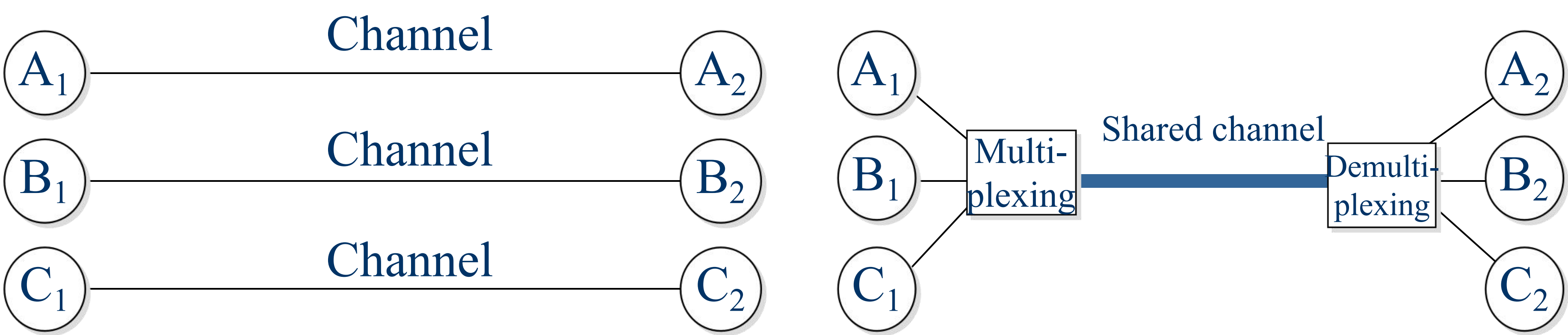
2.5 Channel Multiplexing and Compression Technology

Multiplexing Technology

- In a network system, line capacity or media bandwidth is very valuable resource, so we must improve the utilization of media as much as possible. Generally, the media bandwidth of network system is larger than the bandwidth of single signal transmission. In order to utilize the transmission system more effective, we can adopt multiplexing technology to resolve the problem of multiple signals multiplex signal media at the same time.

2.5 Channel Multiplexing and Compression Technology

- **Multiplexing is the transmission of multiple signals on one medium**
- **Under simplest conditions, medium can carry only one signal at any moment in time**
- **For multiple signals to share a medium, medium must somehow be divided, giving each signal a portion of the total bandwidth**



(a) Not use multiplexing

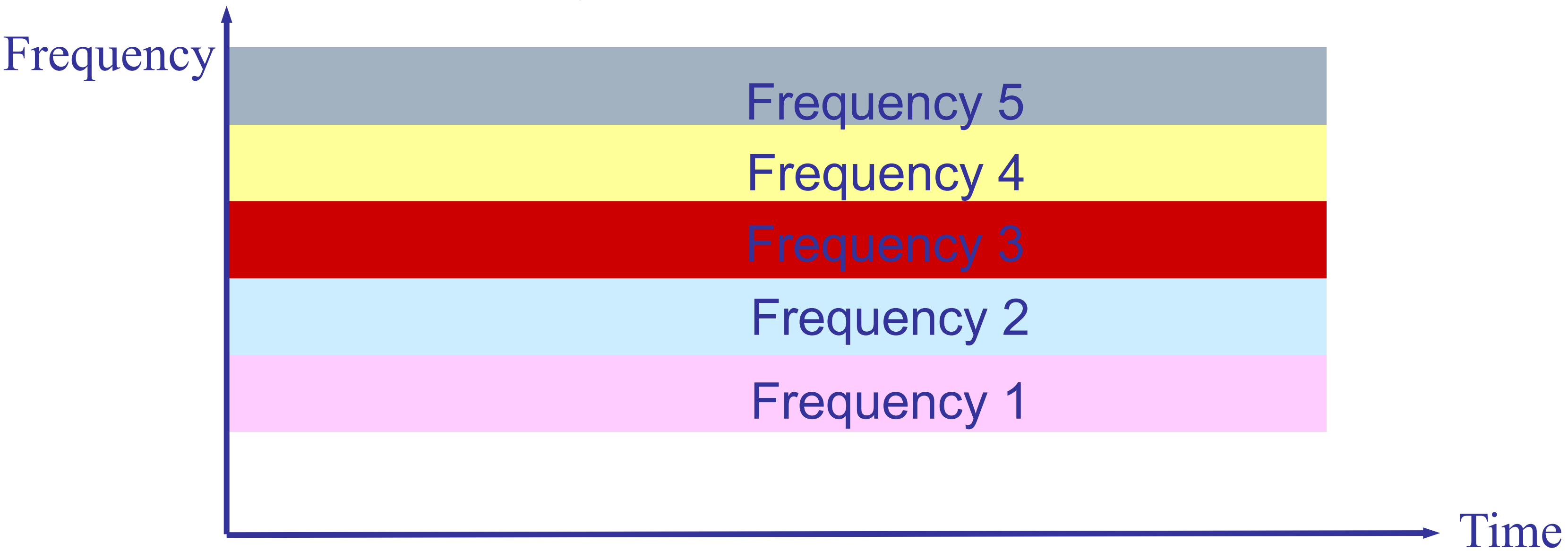
(b) Use multiplexing

2.5 Channel Multiplexing and Compression Technology

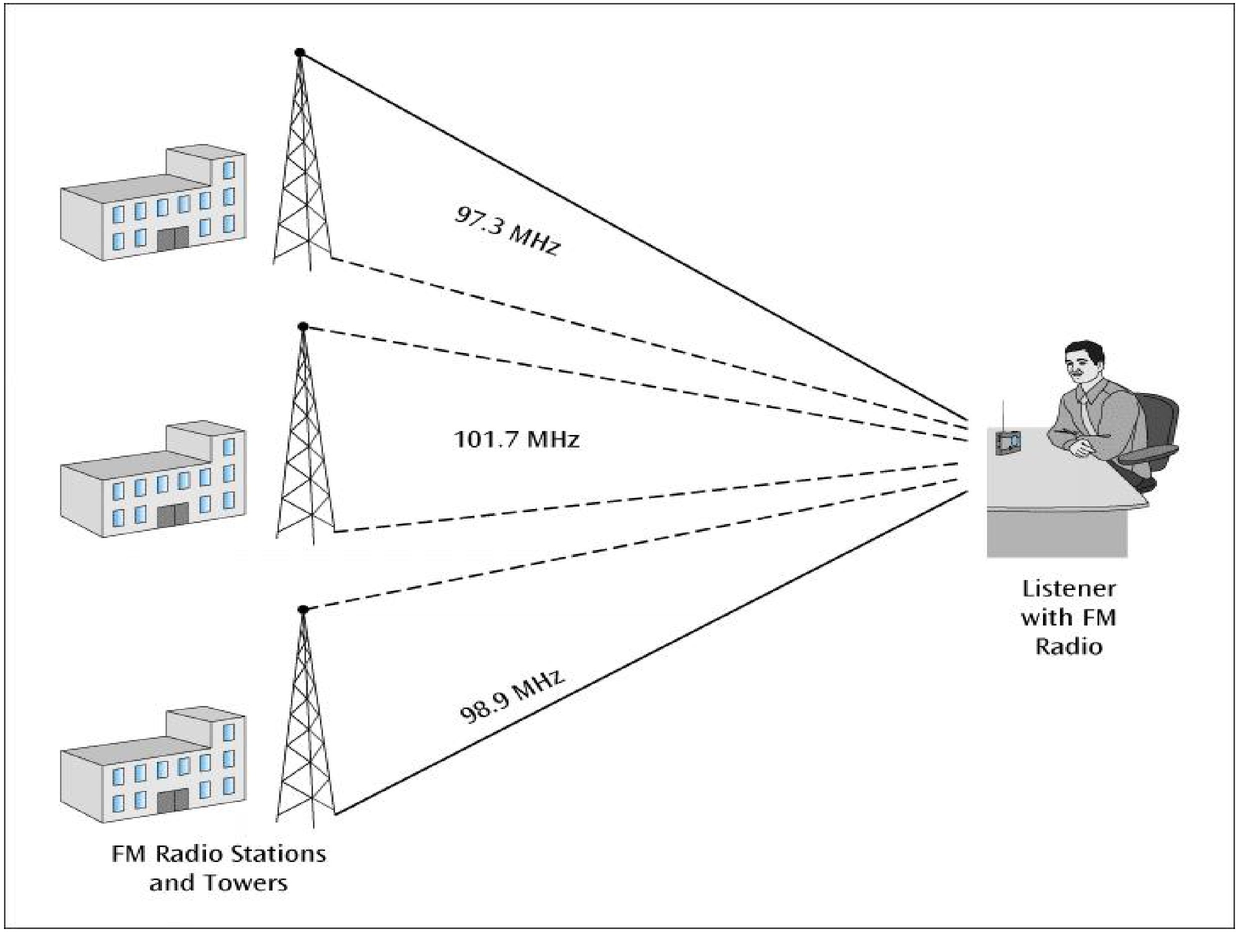
- **Multiplexing technology can be divided into four types:**
  - **FDM (Frequency Division Multiplexing)** **<in space>**
  - **TDM/STDM (Time Division Multiplexing)** **<in time>**
  - **WDM（Wavelength Division Multiplexing ）**
  - **CDM（Code Division Multiplexing）** **<by code>**
- **The above two methods of channel multiplexing is relative mature but not flexible. FDM is more conducive for analog signal transmission, but TDM is more conducive for digital signal transmission.**

FDM (Frequency Division Multiplexing)

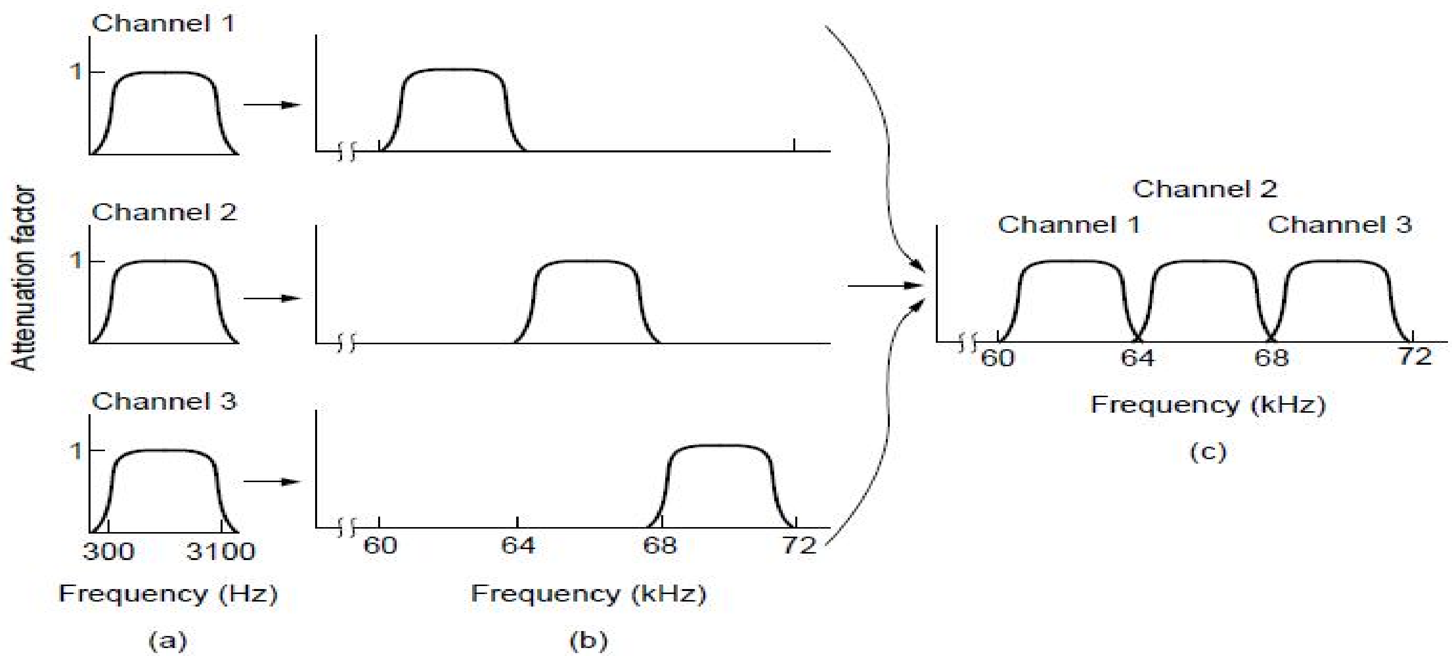
- Since a user is assigned to a certain frequency band, the user occupy this frequency band throughout the communication process.
- **All users of FDM occupy different bandwidth resources at the same time.** (Attention please: the "bandwidth" here is not the transmit rate but the frequency bandwidth.)



FDM (Frequency Division Multiplexing)



FDM (Frequency Division Multiplexing)



Frequency division multiplexing:

(a) The original bandwidths.
(b) The bandwidths raised in frequency.
(c) The multiplexed channel.

FDM (Frequency Division Multiplexing)

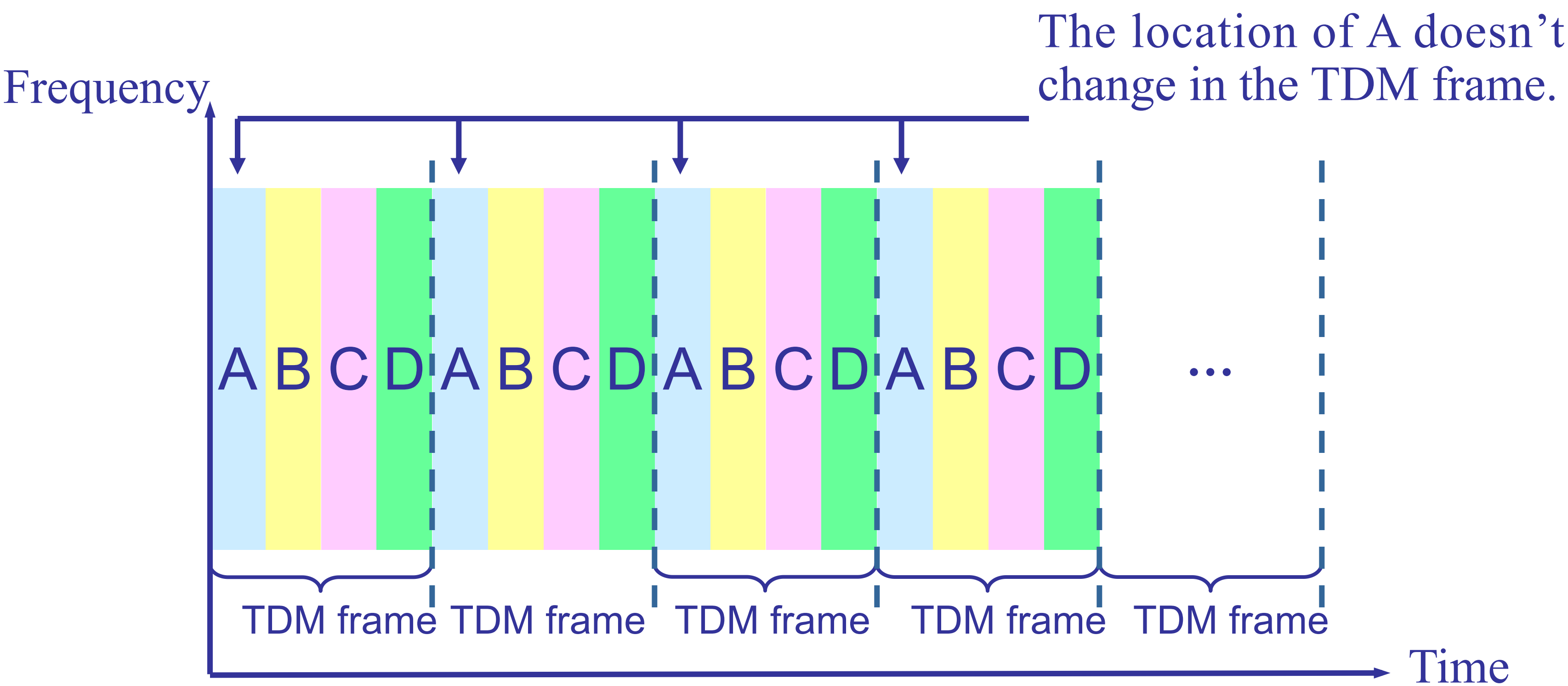
- In using FDM, if each user take up bandwidth unchanged, when the multiplexing users increase, the multiplexed channel bandwidth will expand.

- For example: if the bandwidth of telephone line is 4 kHz, the total bandwidth will be 4 MHz when 1000 users multiplexing the channel.

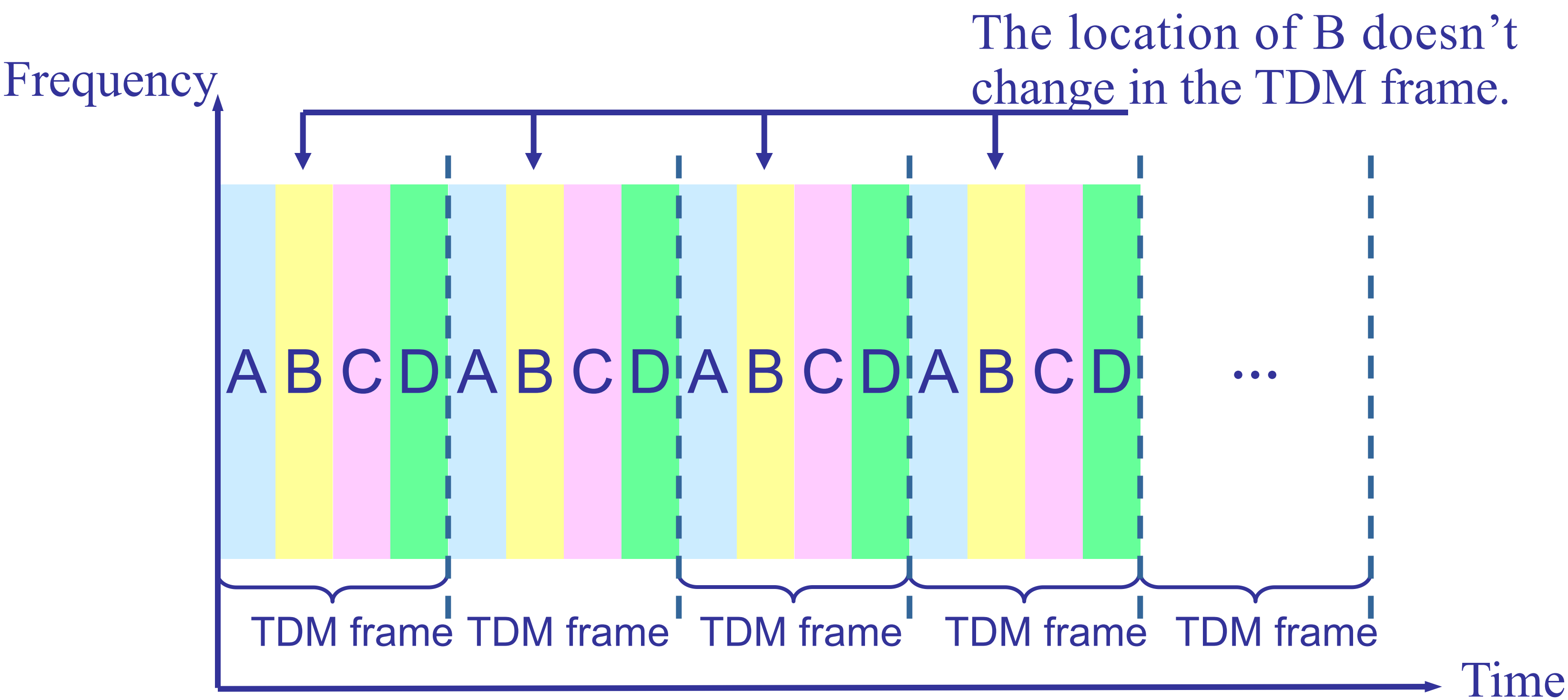
TDM (Time Division Multiplexing)

- TDM is divide time into some TDM frames which have the same length. Each users of TDM occupy a fixed number of time slots in TDM frame. Every time slot the user occupy appears periodically. The period is the length of TDM frame. And TDM signal is also called isochronous signal. All the users of TDM occupy the same bandwidth at different time.
- Time division multiplexing comes in two basic forms:
  - Synchronous time division multiplexing (original TDM)
    - Sample: T-1 and SONET telephone systems
  - Statistical time division multiplexing

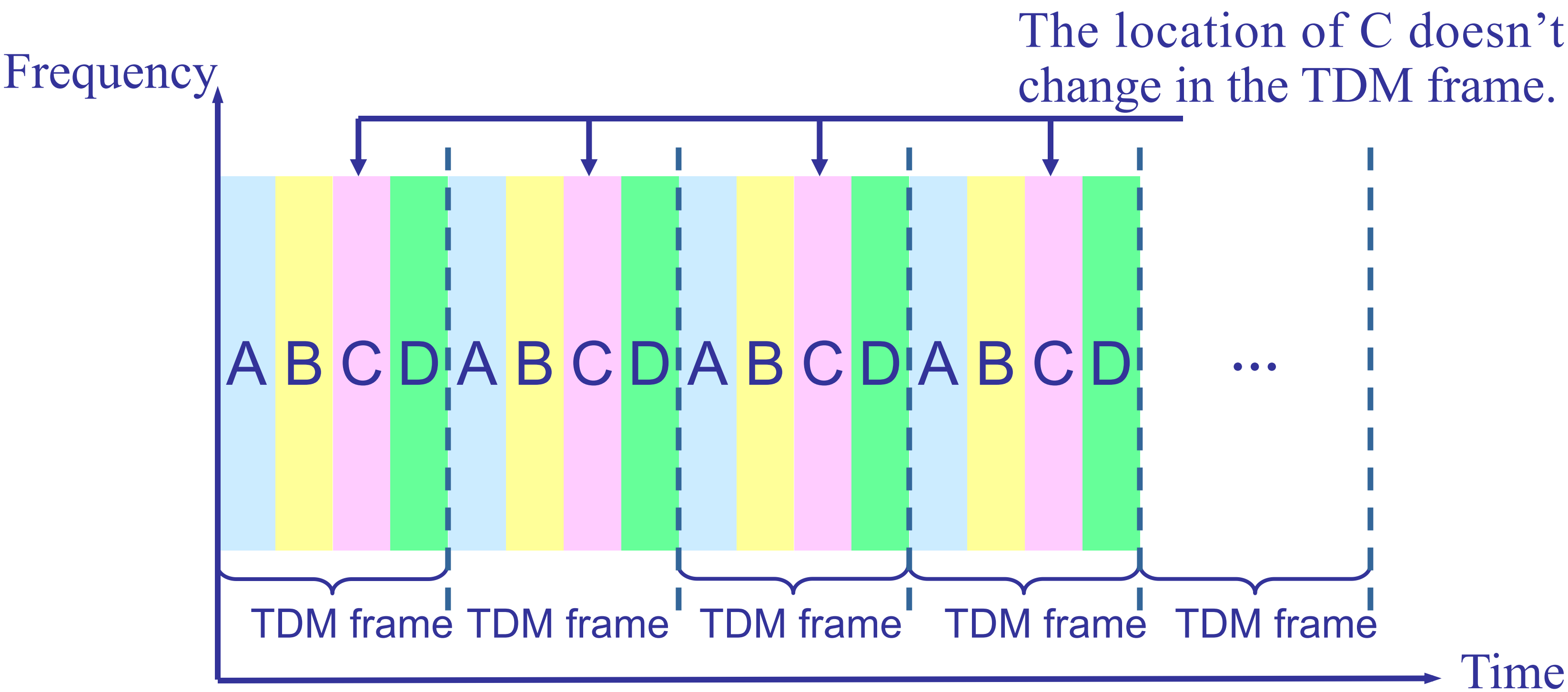
TDM (Time Division Multiplexing)



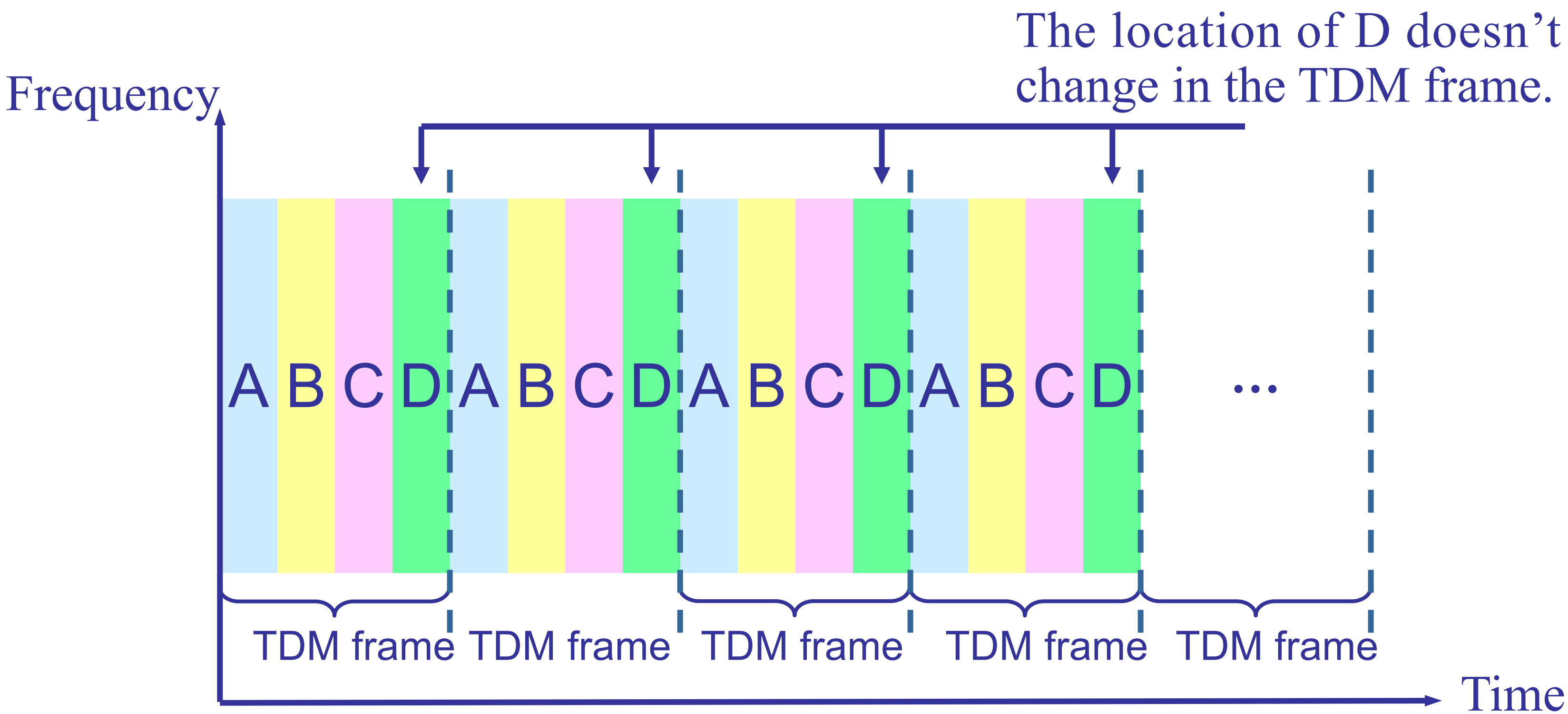
TDM (Time Division Multiplexing)



TDM (Time Division Multiplexing)

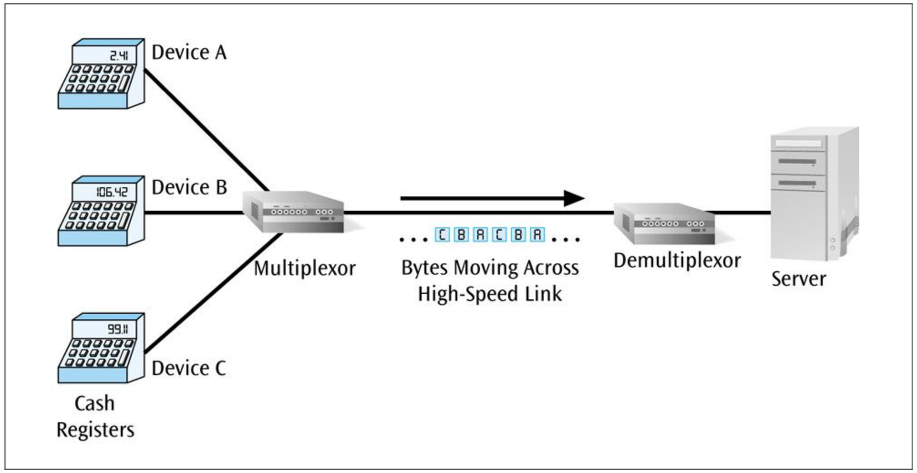


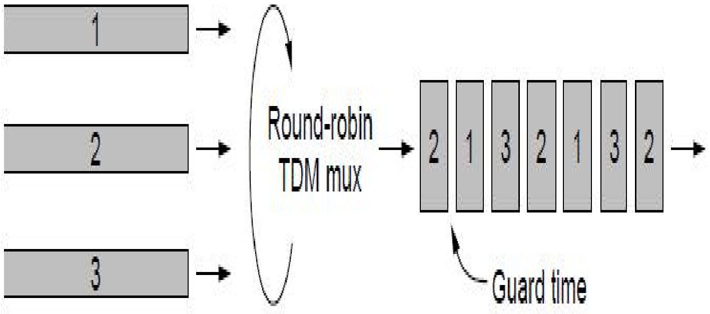
TDM (Time Division Multiplexing)



TDM (Synchronous Time Division Multiplexing)

Figure 5-2 Several cash registers and their multiplexed stream of transactions





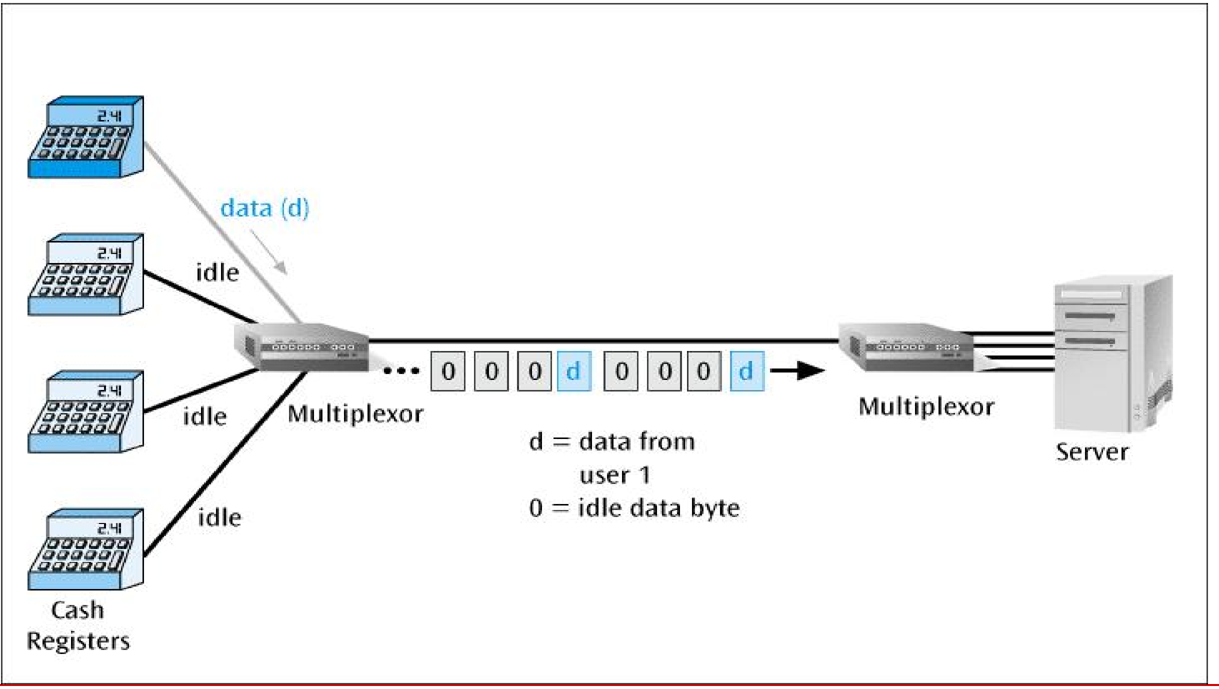
Time Division Multiplexing (TDM).

TDM (Time Division Multiplexing)

- For example, if the length of TDM frame is 125us, when the number of TDM user is 1000, each user will assigned a very narrow time slot width (0.125us).

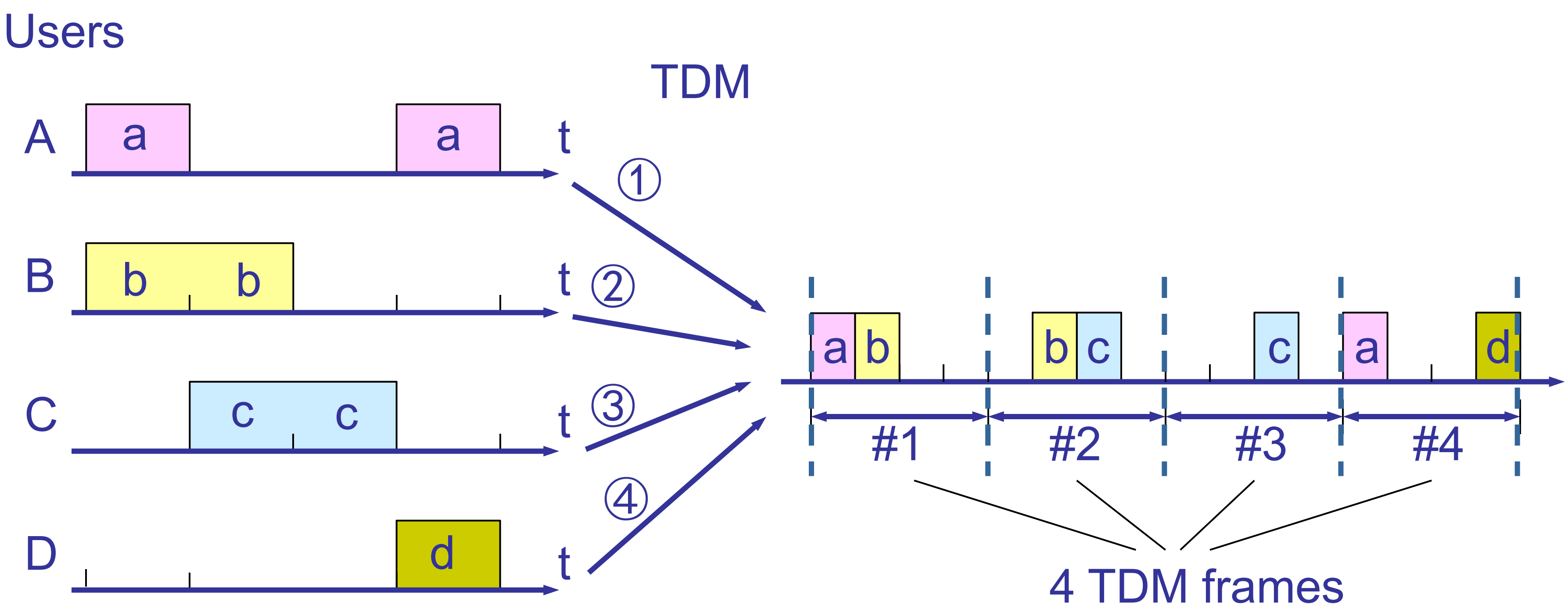
Figure 5-3

Multiplexor transmission stream with only one input device transmitting data



Problems of TDM－may be a waste of line resources

- When transmitting data by TDM system, due to the sudden nature of computer data, the utilization of channels which assigned to users is not high.

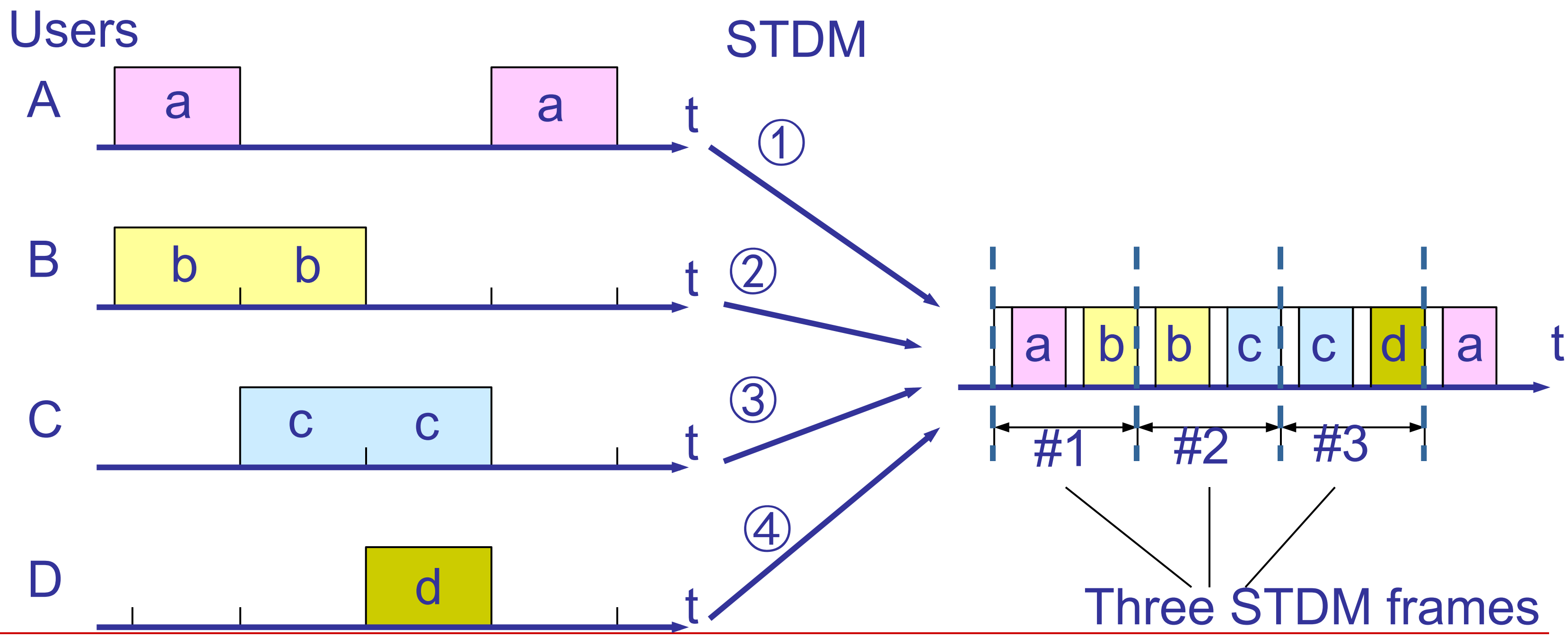


STDM (Statistic TDM)

- STDM is also called asynchronous time division multiplexing, it uses STDM frame to transmit multiplexed data, but the time slots of each STDM frame are less than the users connecting to the concentrator. Each user with data input buffer to concentrator at any moment, then concentrator will scan the input buffer in order and put the data into STDM frame. If the buffer doesn't have data, concentrator will ignore it. When a frame is full of data, concentrator will send the frame out.
- Hence STDM frame doesn't assign time slot fixedly but dynamic allocation on demand. So can improve the utilization of lines.

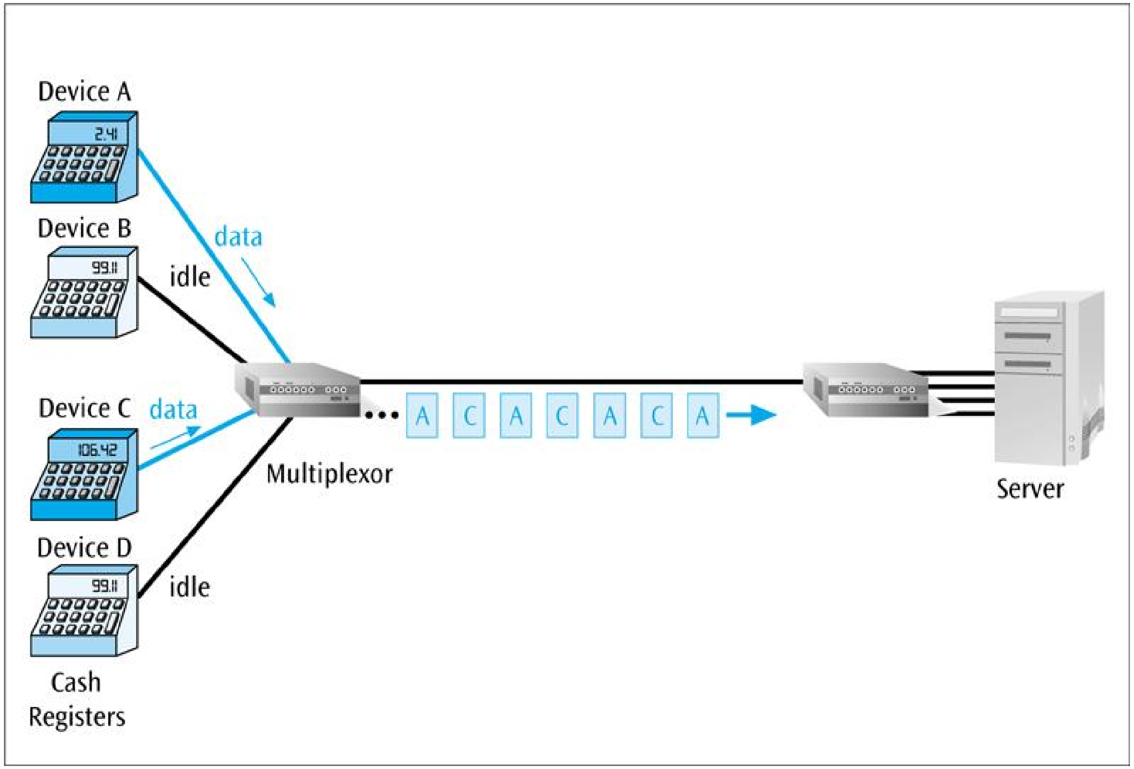
STDM (Statistic TDM)

- STDM is a kind of improved TDM, it can improve the utilization of channel significantly and is generally used in concentrator.



STDM (Statistic TDM)

Figure 5-7 Two stations out of four transmitting via a statistical multiplexor

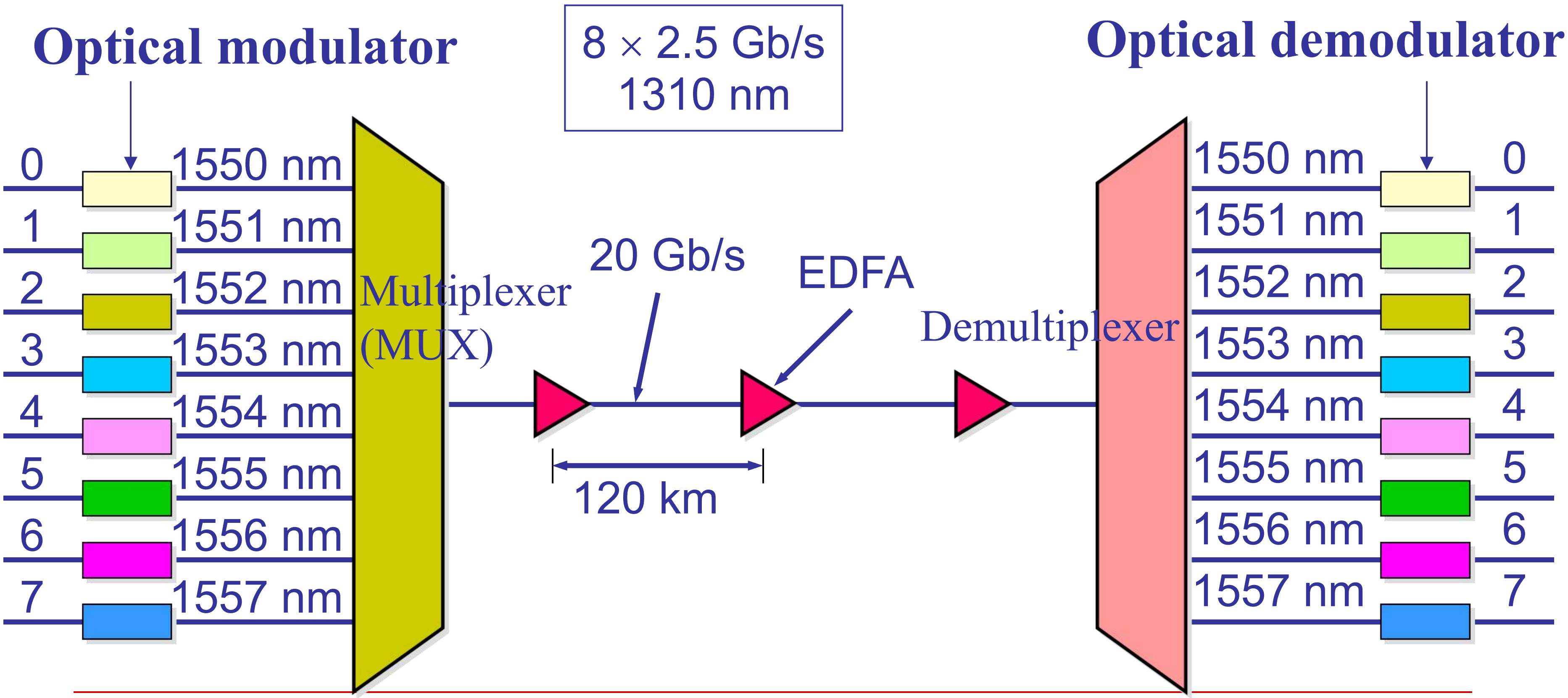


WDM（Wavelength Division Multiplexing)

- People can use the concept of traditional telephone carrier frequency division multiplexing , a single optical fiber could transmit multiple optical carrier signal which frequencies are very close, so the transmission capacity of optical fiber can be doubled. （WDM）
- Here use wavelength rather than frequency to represent the optical carrier here.
- Today Dense Wavelength Division Multiplexing (DWDM) could multiplex more than 80 roads optical carrier signal on a single fiber.
- Erbium Doped Fiber Amplifier (EDFA):Erbium-doped fiber amplifier.

WDM（Wavelength Division Multiplexing)

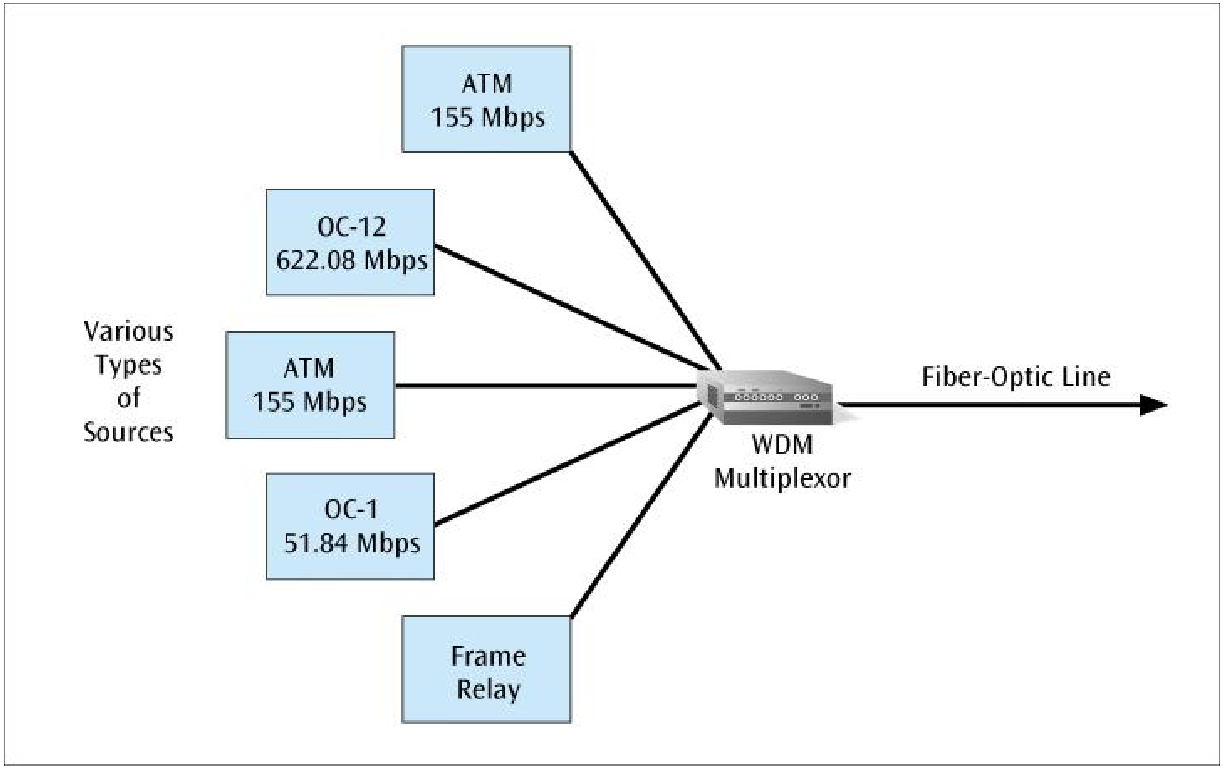
- WDM is the optical frequency division multiplexing.



WDM（Wavelength Division Multiplexing)

Figure 5-11

Fiber optic line using wavelength division multiplexing and supporting multiple- speed transmissions



CDM (Code Division Multiplexing)

- **CDM is also a way of shared channel, the** commonly-used noun **is CDMA (Code Division Multiple Access).**
- **Different users can communicate using the same frequency band at the same time. Since each user uses different code form selected specially, it will not interface with each other.**
- **This system was used in military communication at the earliest, the transmitted signal has a strong anti-interference capability, its frequency is similar to white noise and difficult to be found by enemies.**
- **In CDMA, each bit time is divided into *m* short intervals and each interval is called chip.**

CDM (Code Division Multiplexing)

- Each station is assigned a unique *m* bit chip sequence.
  - If send bit 1, then send your *m* bit code sequence.
  - If send bit 0, then the anti binary code of this chip sequence will be sent.
- For example, the chip sequence of 8bits in S station is 00011011:
  - If bit 1 is to be sent, the station will send 00011011.
  - If bit 0 is to be sent, the station will send 11100100.
- Chip sequence of S station: (–1 –1 –1 +1 +1 –1 +1 +1)
- -1 is used to represent 0 here.

CDM (Code Division Multiplexing)

- **Important features of CDMA:**
  - **The chip sequence assigned to each station must not only be different, but also be orthogonal to each other.**
  - **A pseudo random code sequence is used in a practical system.**

CDM (Code Division Multiplexing)

- **Orthogonal relationship of chip sequence:**
  - **Let vector S represent the vector of station S, and vector T represent the vector of any other station.**
  - **The chip sequences of two different stations are orthogonal means the normalized inner product of vector S and T is 0:**

$$\mathbf{S} \bullet \mathbf{T} \equiv \frac{1}{m}\sum_{i=1}^{m} S_i T_i = 0 \qquad (2\text{-}3)$$

Examples of the Orthogonal Relationship of Chip Sequence

- Assume: S = (–1 –1 –1 +1 +1 –1 +1 +1), T = (–1 –1 +1 –1 +1 +1 +1 –1)。.
- Complete the computing as (2-3) with the vector component values of S and T, can find that S and T are orthogonal.

CDM (Code Division Multiplexing)

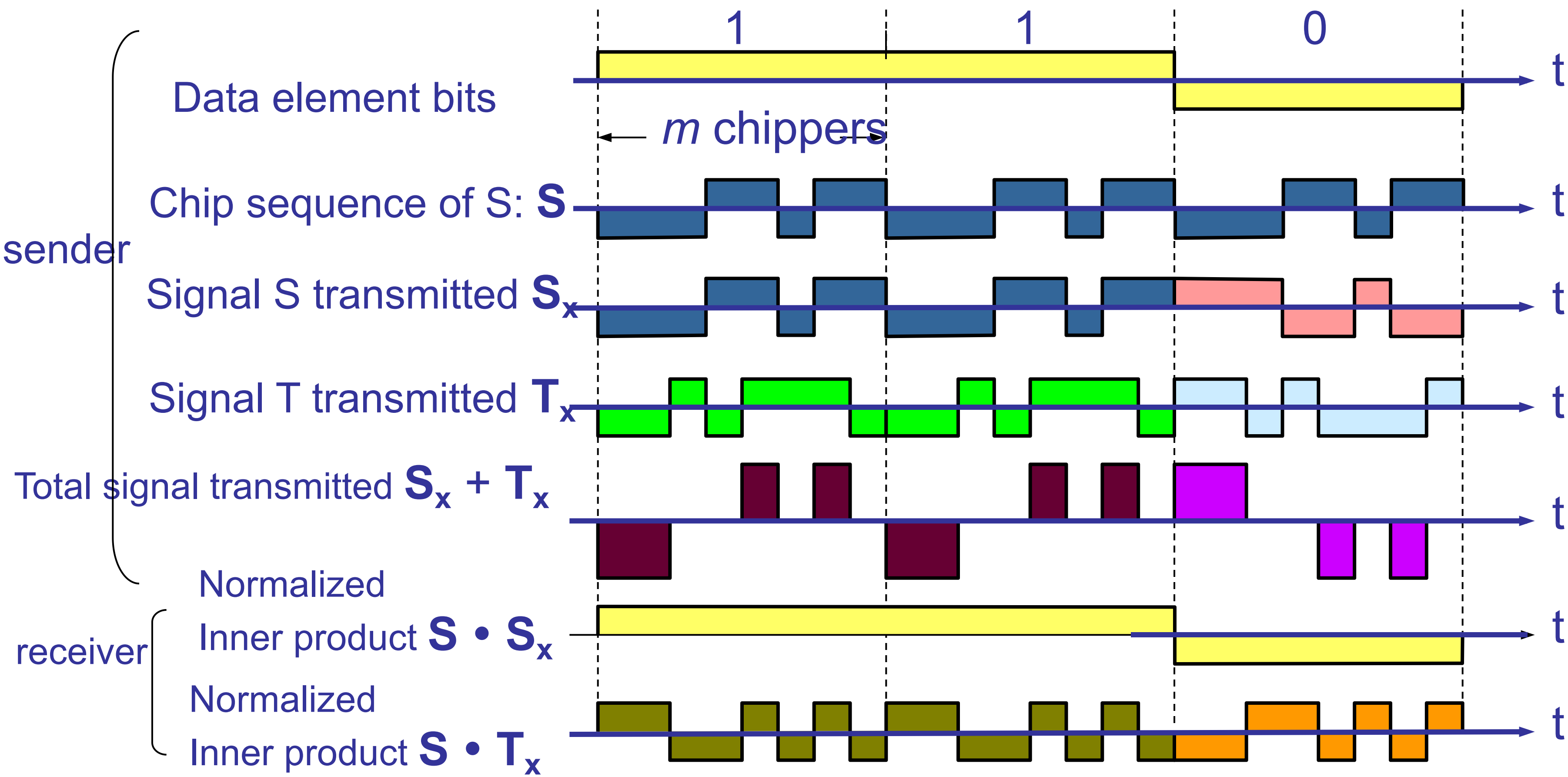
- An important features of the orthogonal relationship of chip sequence:
  - The normalized inner product of any chip vector and itself is 1.

$$\mathbf{S} \bullet \mathbf{S} = \frac{1}{m}\sum_{i=1}^{m} S_i S_i = \frac{1}{m}\sum_{i=1}^{m} S_i^2 = \frac{1}{m}\sum_{i=1}^{m} (\pm 1)^2 = 1 \quad (2\text{-}4)$$

  - Similarly, the normalized inner product of any chip vector and its chip vector's component is -1.（Thinking the proved process）

$$\mathbf{S} \bullet \overline{\mathbf{S}} = -1 \quad (2\text{-}5)$$

Principle of CDMA



Principle of CDMA

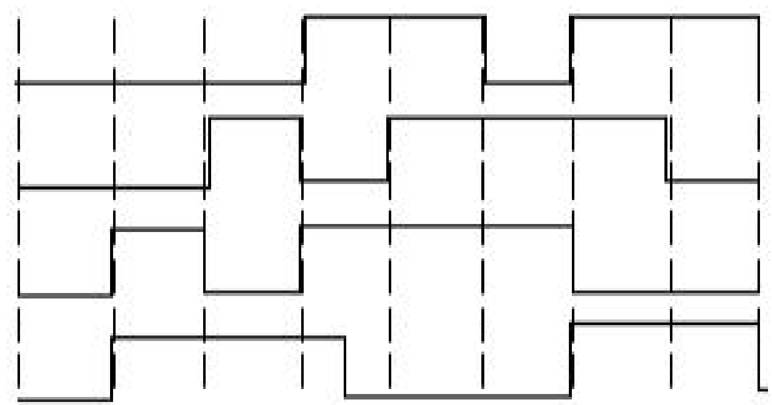
A = (−1 −1 −1 +1 +1 −1 +1 +1)

B = (−1 −1 +1 −1 +1 +1 +1 −1)

C = (−1 +1 −1 +1 +1 +1 −1 −1)

D = (−1 +1 −1 −1 −1 −1 +1 −1)

(a)



(b)

(a) Chip sequences for four stations. (b) Signals the sequences represent

Principle of CDMA

$$
\begin{array}{llll}
S_1 = C & = (-1\ {+1}\ {-1}\ {+1}\ {+1}\ {+1}\ {-1}\ {-1}) & \quad S_1 \bullet C = [1+1-1+1+1+1-1-1]/8 = 1 \\
S_2 = B+C & = (-2\ \ 0\ \ 0\ \ 0\ {+2}\ {+2}\ \ 0\ {-2}) & \quad S_2 \bullet C = [2+0+0+0+2+2+0+2]/8 = 1 \\
S_3 = A+\overline{B} & = (\ 0\ \ 0\ {-2}\ {+2}\ \ 0\ {-2}\ \ 0\ {+2}) & \quad S_3 \bullet C = [0+0+2+2+0-2+0-2]/8 = 0 \\
S_4 = A+\overline{B}+C & = (-1\ {+1}\ {-3}\ {+3}\ {+1}\ {-1}\ {-1}\ {+1}) & \quad S_4 \bullet C = [1+1+3+3+1-1+1-1]/8 = 1 \\
S_5 = A+B+C+D & = (-4\ \ 0\ {-2}\ \ 0\ {+2}\ \ 0\ {+2}\ {-2}) & \quad S_5 \bullet C = [4+0+2+0+2+0-2+2]/8 = 1 \\
S_6 = A+B+\overline{C}+D & = (-2\ {-2}\ \ 0\ {-2}\ \ 0\ {-2}\ {+4}\ \ 0) & \quad S_6 \bullet C = [2-2+0-2+0-2-4+0]/8 = -1
\end{array}
$$

(c) (d)

(c) Six examples of transmissions. (d) Recovery of station C's

Comparison of Multiplexing Techniques

Table 5-3
Advantages and disadvantages of multiplexing techniques

Multiplexing Technique	Advantages	Disadvantages
Frequency Division Multiplexing	Simple Popular with radio, TV, cable TV All the receivers, such as cellular telephones, do not need to be at the same location	Noise problems due to analog signals Wastes bandwidth Limited by frequency ranges
Synchronous Time Division Multiplexing	Digital signals Relatively simple Commonly used with T-1, SONET	Wastes bandwidth
Statistical Time Division Multiplexing	More efficient use of bandwidth Frame can contain control and error information Packets can be of varying size	More complex than synchronous time division multiplexing
Wavelength Division Multiplexing	Very high capacities over fiber Signals can have varying speeds Scalable	Cost Complexity
Discrete Multitone	Capable of high transmission speeds	Complexity, noise problems
Code Division Multiplexing	Large capacities Scalable	Complexity Primarily a wireless technology

2.5 Channel Multiplexing and Compression Technology

- **Compression Technology**
  - **Compression is another technique that can maximize the amount of data sent over a medium.**
  - **Compression is another technique used to squeeze more data over a communications line or into a storage space**
    - **If you can compress a data file down to one half of its original size, the file will obviously transfer in less time**
  - **Two basic groups of compression:**
    - **Lossless – when data is uncompressed, original data returns**
    - **Lossy – when data is uncompressed, you do not have the original data**

Compression–Lossless versus Lossy

- Compress a financial file?
  - You want lossless
- Compress a video image, movie, or audio file?
  - Lossy is OK
- Examples of lossless compression include:
  - Huffman codes, run-length compression, Lempel-Ziv compression, and FLAC
- Examples of lossy compression include:
  - MPEG, JPEG, and MP3

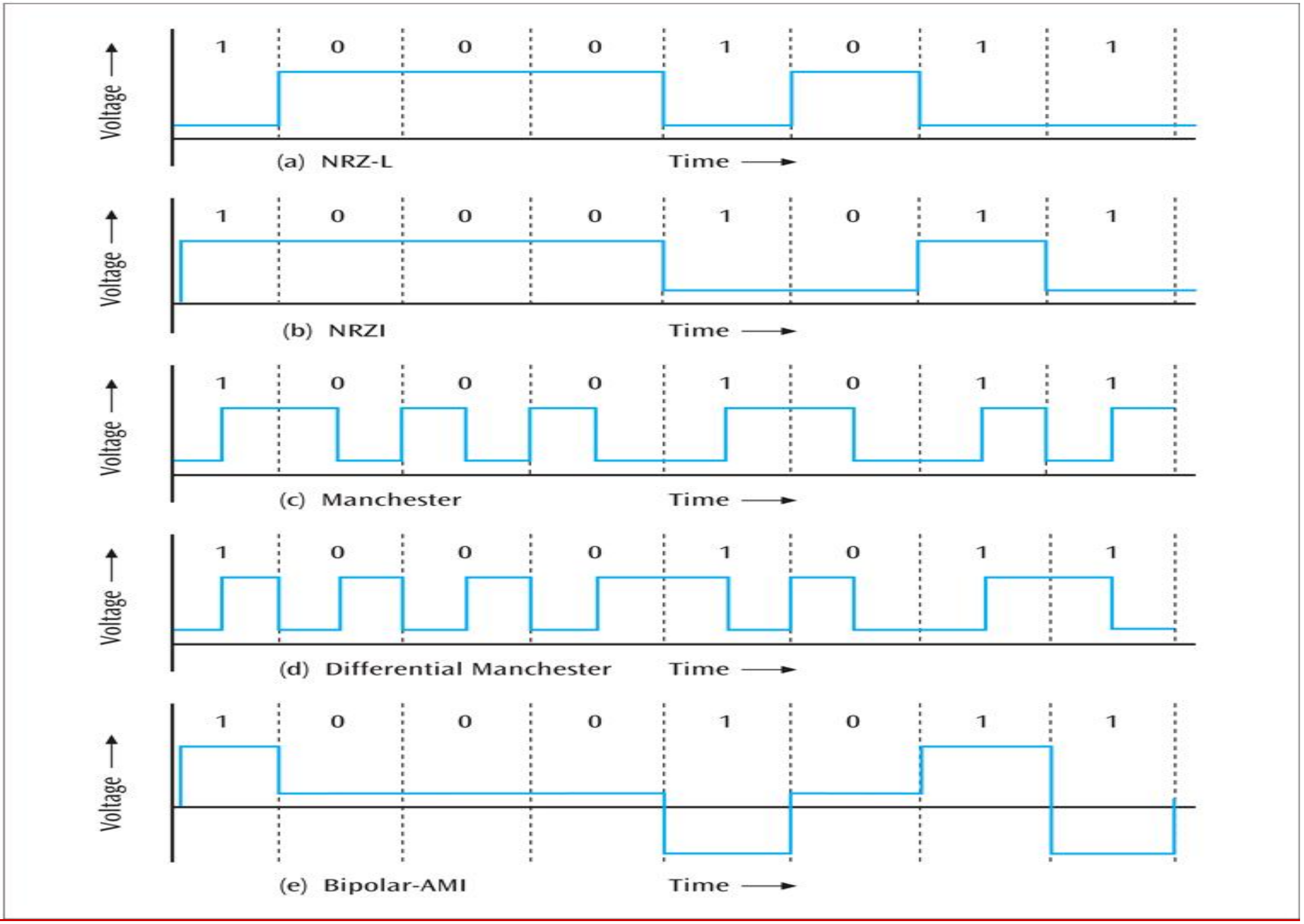
(More detail seen in English book page 138-144)

2.6 Digital Transmission System

- If we **transmit digital data with digital signals** in a digital transmission system, there are numerous techniques available to convert digital data into digital signals. Let's examine following:
  - NRZ-L (Nonreturn to zero-level)
  - NRZI (Nonreturn to zero inverted)
  - Manchester
  - Differential Manchester
  - Bipolar AMI
  - 4B/5B Digital Encoding Schemes
- These are used in LANs and some telephone systems

Examples of five digital encoding schemes

Figure 2-12
Examples of five digital encoding schemes



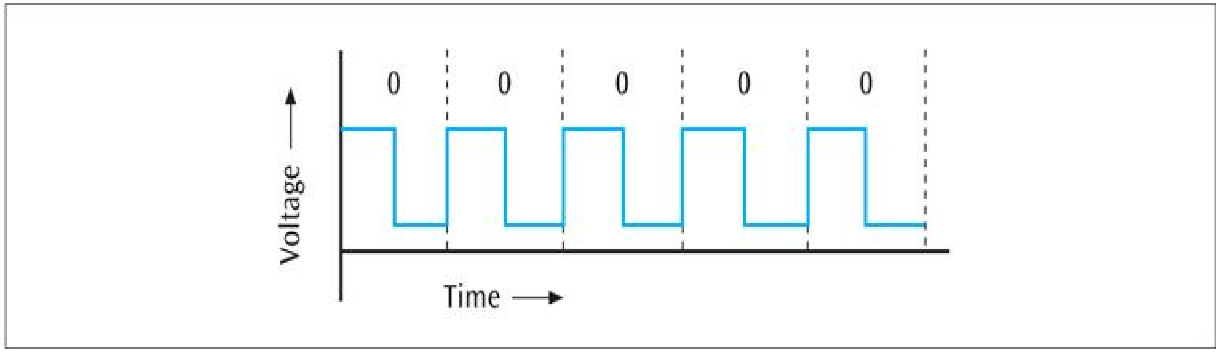
Nonreturn to Zero Digital Encoding Schemes

- **Nonreturn to zero-level (NRZ-L) transmits 1s as zero voltages and 0s as positive voltages**
- **Nonreturn to zero inverted (NRZI) has a voltage change at the beginning of a 1 and no voltage change at the beginning of a 0**
- **Fundamental difference exists between NRZ-L and NRZI**
  - **With NRZ-L, the receiver has to check the voltage *level* for each bit to determine whether the bit is a 0 or a 1,**
  - **With NRZI, the receiver has to check whether there is a *change at the beginning* of the bit to determine if it is a 0 or a 1**

Manchester Digital Encoding Schemes

- In a **Manchester code**, every bit has a significant change
- Note how with a **Differential Manchester code**, every bit has at least one significant change. Some bits have two signal changes per bit (baud rate = twice bps)

Figure 2-13
Transmitting five binary 0s using differential Manchester encoding



Bipolar-AMI Encoding Scheme

- The **bipolar-AMI encoding scheme** is unique among all the encoding schemes because it uses **three voltage levels**
  - When a device transmits a binary 0, a zero voltage is transmitted
  - When the device transmits a binary 1, either a positive voltage or a negative voltage is transmitted
  - Which of these is transmitted depends on the binary 1 value that was last transmitted

4B/5B Digital Encoding Scheme

- Yet another encoding technique; this one **converts four bits of data into five-bit quantities**
- The five-bit quantities are **unique** in that no five-bit code has more than 2 consecutive zeroes
- The five-bit code is **then transmitted using an NRZI encoded signal**

4B/5B Digital Encoding Scheme

Figure 2-14
The 4B/5B digital encoding scheme

Valid Data Symbols

Original 4-bit data	New 5-bit code
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

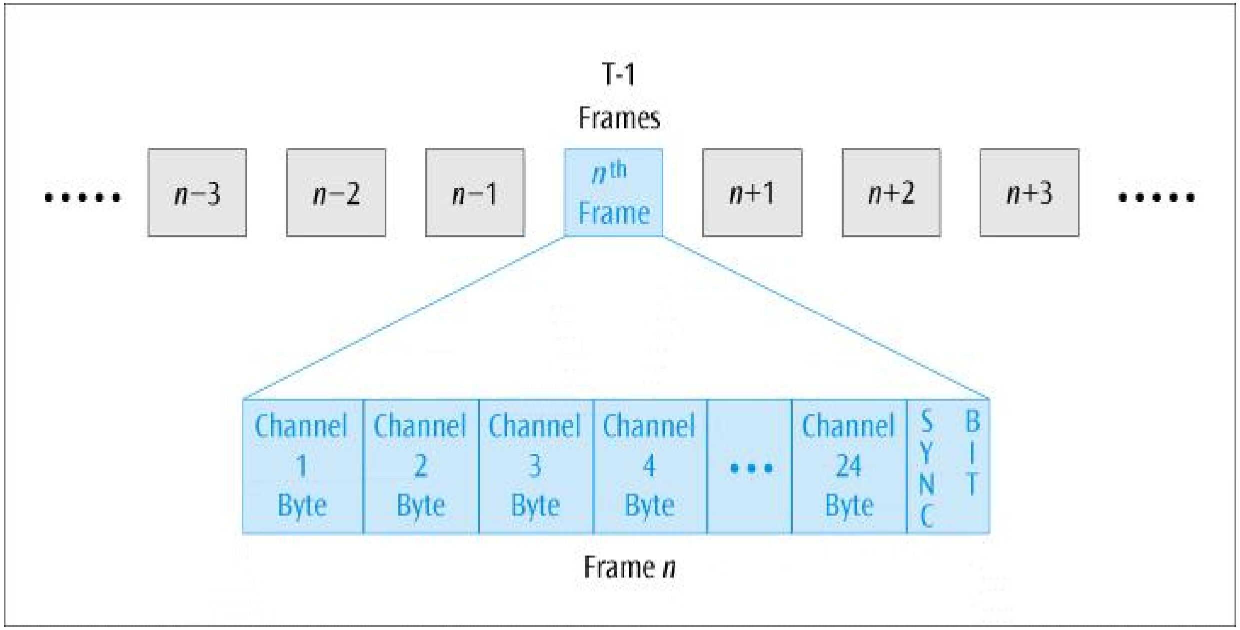
Invalid codes
00001
00010
00011
01000
10000

2.6 Digital Transmission System

- There is another digital transmission system, which convert analog data into a digital signal, there are two techniques:
  - Pulse code modulation (the more common)
  - Delta modulation
- PCM
  - PCM system was originally used to convey multiple calls on the trunk between the telephone offices.
  - Due to some history reasons, PCM has two incompatible international standards, they are 24-channel PCM of north America (T1) and 30-channel PCM of Europe (E1). China adopt the E1 standard of Europe.
  - The rate of E1 is 2.048 Mb/s (30-channel), and the rate of T1 is 1.544 Mb/s (24-channel).
  - If we need to obtain a higher data rate, we can adopt the method of multiplexing.

T-1 Multiplexing

- The T-1 multiplexor stream is a continuous series of frames
- Note how each frame contains the data (one byte) for potentially 24 voice-grade telephone lines, plus one sync bit
- It is possible to combine all 24 channels into one channel for a total of 1.544 Mbps



Pulse code modulation

- The analog waveform is sampled at specific intervals and the “snapshots” are converted to binary values
- When the binary values are later converted to an analog signal, a waveform similar to the original results
- The more snapshots taken in the same amount of time, or the more quantization levels, the better the resolution
- How fast do you have to sample an input source to get a fairly accurate representation?
- Nyquist tell us it need 2 times the highest frequency
- Thus, if you want to digitize voice (4000 Hz), you need to sample at 8000 samples per second

Figure 2-21
Example of taking “snapshots” of an analog waveform for conversion to a digital signal

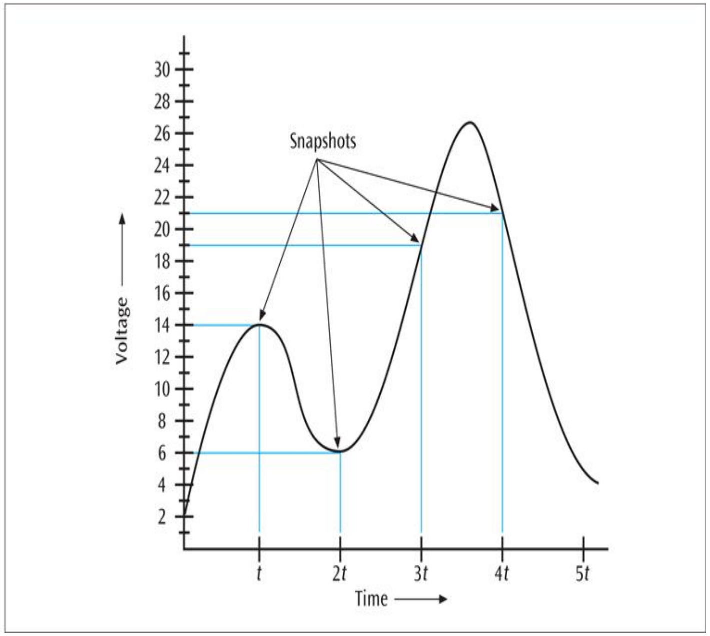
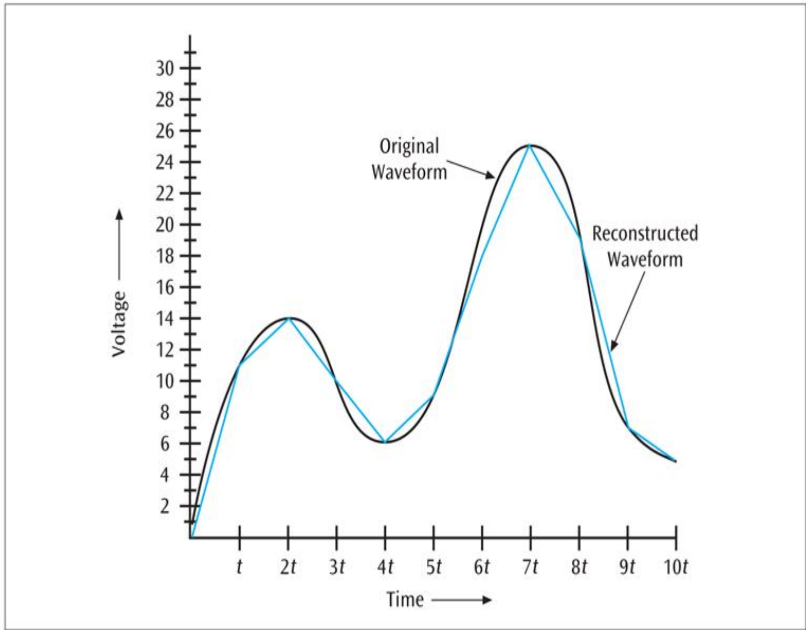


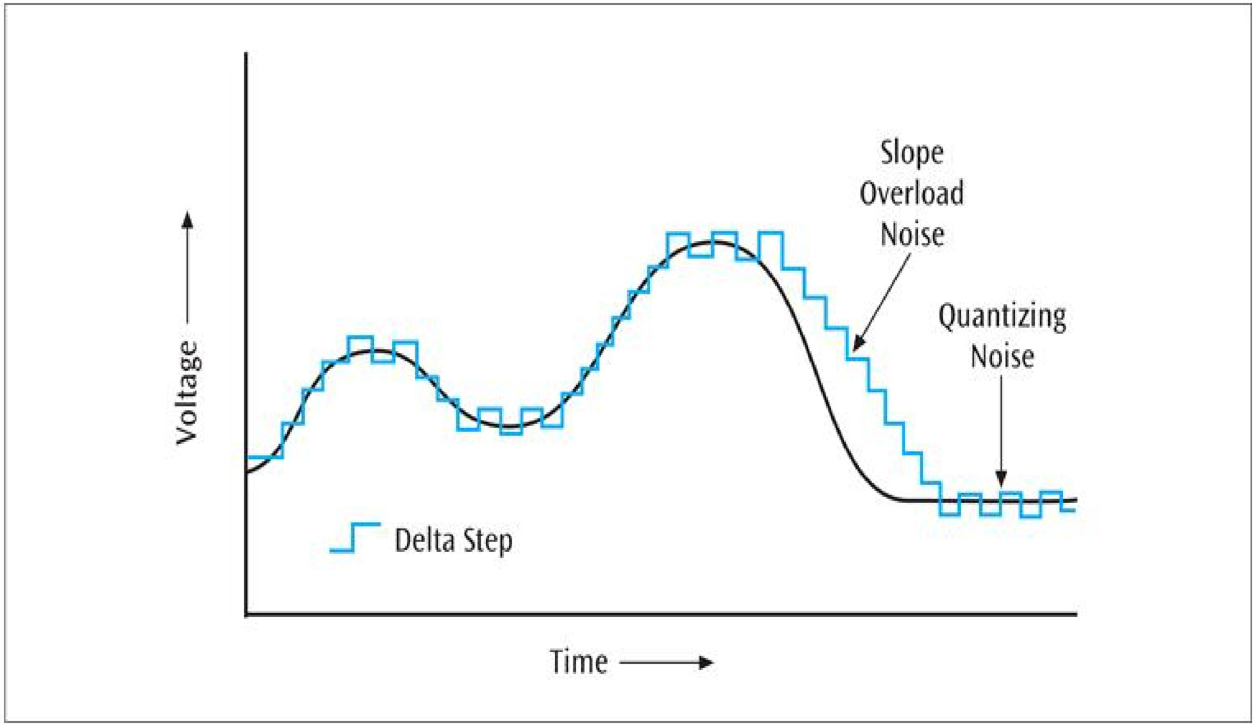
Figure 2-23
A more accurate reconstruction of the original waveform, using a higher sampling rate



Delta Modulation

- An analog waveform is tracked, using a binary 1 to represent a rise in voltage, and a 0 to represent a drop

Figure 2-24
Example of delta modulation that is experiencing slope overload noise and quantizing noise



2.6 Digital Transmission System

Data Codes

- The set of all textual characters or symbols and their corresponding binary patterns is called a data code
- There are three common data code sets:
  - EBCDIC
  - ASCII
  - Unicode

EBCDIC

Figure 2-27
The EBCDIC character code set

Bits			4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
			3	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
			2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
			1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
8	7	6	5																
0	0	0	0	NUL	SOH	STX	EXT	PF	HT	LC	DEL			SMM	VT	FF	CR	SO	SI
0	0	0	1	DLE	DC_1	DC_2	DC_3	RES	NL	BS	IL	CAN	EM	CC		IFS	IGS	IHS	IUS
0	0	1	0	DS	SOS	FS		BYP	LF	EOB	PRE			SM			ENQ	ACK	BEL
0	0	1	1			SYN		PN	RS	UC	EOT					DC_4	NAK		SUB
0	1	0	0	SP												<	(	+	|
0	1	0	1	&										!	$	.	)	:	¬
0	1	1	0	—												%	-	>	?
0	1	1	1													@		=	"
1	0	0	0		a	b	c	d	e	f	g	h	i						
1	0	0	1		j	k	l	m	n	o	p	q	r						
1	0	1	0			s	t	u	v	w	x	y	z						
1	0	1	1																
1	1	0	0		A	B	C	D	E	F	G	H	I						
1	1	0	1		J	K	L	M	N	O	P	Q	R						
1	1	1	0			S	T	U	V	W	X	Y	Z						
1	1	1	1	0	1	2	3	4	5	6	7	8	9						

ASCII

Figure 2-28
The ASCII character set

High-Order Bits (7, 6, 5) / Low-Order Bits (4, 3, 2, 1)

	000	001	010	011	100	101	110	111
0000	NUL	DLE	SPACE	0	@	P	`	p
0001	SOH	DC1	!	1	A	Q	a	q
0010	STX	DC2	“	2	B	R	b	r
0011	ETX	DC3	#	3	C	S	c	s
0100	EOT	DC4	$	4	D	T	d	t
0101	ENQ	NAK	%	5	E	U	e	u
0110	ACK	SYN	&	6	F	V	f	v
0111	BEL	ETB	‘	7	G	W	g	w
1000	BS	CAN	(	8	H	X	h	x
1001	HT	EM	)	9	I	Y	i	y
1010	LF	SUB	*	:	J	Z	j	z
1011	VT	ESC	+	;	K	[	k	{
1100	FF	FS	’	<	L	\	l	|
1101	CR	GS	-	=	M	]	m	}
1110	SO	RS	.	>	N	^	n	~
1111	SI	US	/	?	O	—	o	DEL

Unicode

- Each character is 16 bits
- A large number of languages / character sets
- For example:
  - T equals 0000 0000 0101 0100
  - r equals 0000 0000 0111 0010
  - a equals 0000 0000 0110 0001

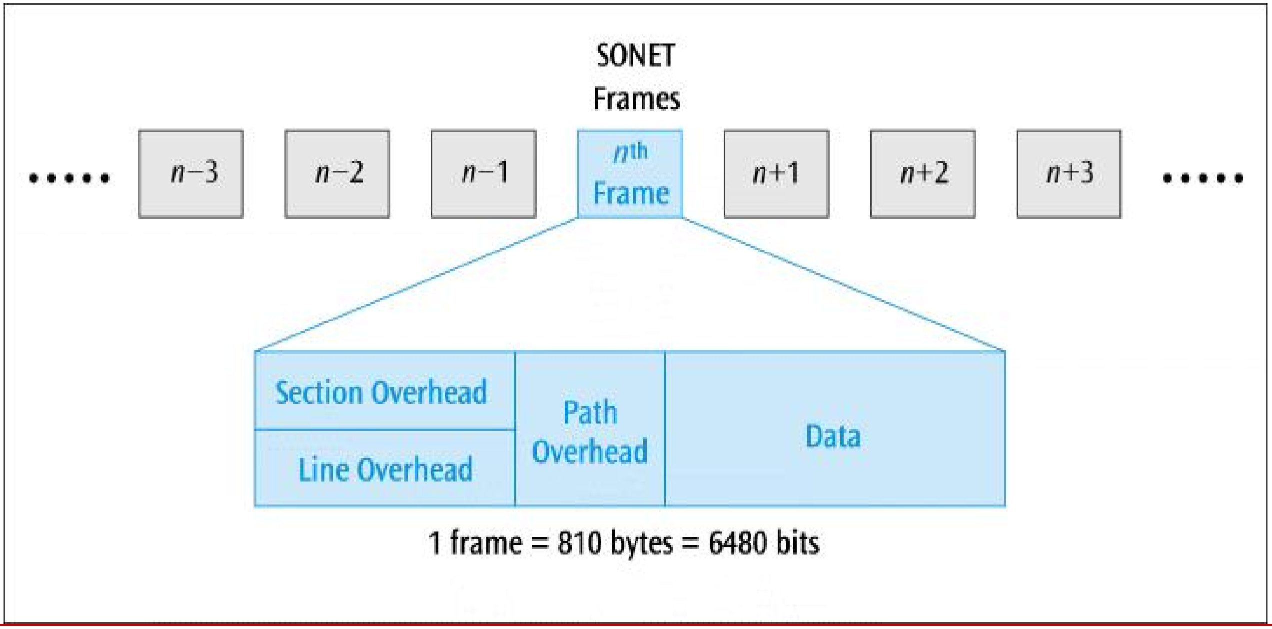
(more detail seen in p55 in English textbook)

2.6 Digital Transmission System

- **Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH)**
  - **The old digital transmission system has many shortcomings especially the two aspects as follows:**
    - **Rate standards are not unified.**
      - **If the high group of digital transmission rate is not to be standardized, it is different to realize the high-speed data transmission in international rang.**
    - **Not synchronous transmission**
      - **For a long time in the past, in order to save cost, the digital network of many countries mainly adopt quasi-synchronous mode.**

SONET/SDH Multiplexing

- Similar to T-1, SONET incorporates a continuous series of frames
- SONET is used for high-speed data transmission
- Telephone companies have traditionally used a lot of SONET but this may be giving way to other high-speed transmission services
- SDH is the European equivalent to SONET



Synchronous Optical Network (SONET)

- SONET (Synchronous Optical Network) : all levels of clock are from a very precise master clock.
- STS-1 (Synchronous Transport Signal Level 1): transmission rate is 51.84 Mb/s.
- Optical signal is called Level 1 optical carrier OC-1 (OC represent Optical Carrier).

Synchronous Digital Hierarchy (SDH)

- ITU-T set the international standard SDH (Synchronous Digital Hierarchy) based on SONET.
- SDH and SONET are generally considered to be synonymous.
- The basic rate of SDH is 155.52 Mb/s, it is called STM-1 (Synchronous Transfer Module)， and amount to OC-3 of SONET.
- SDH/SONET define the standard optical signal at the same time, which laser source wavelength of 310nm and 1550nm respectively.

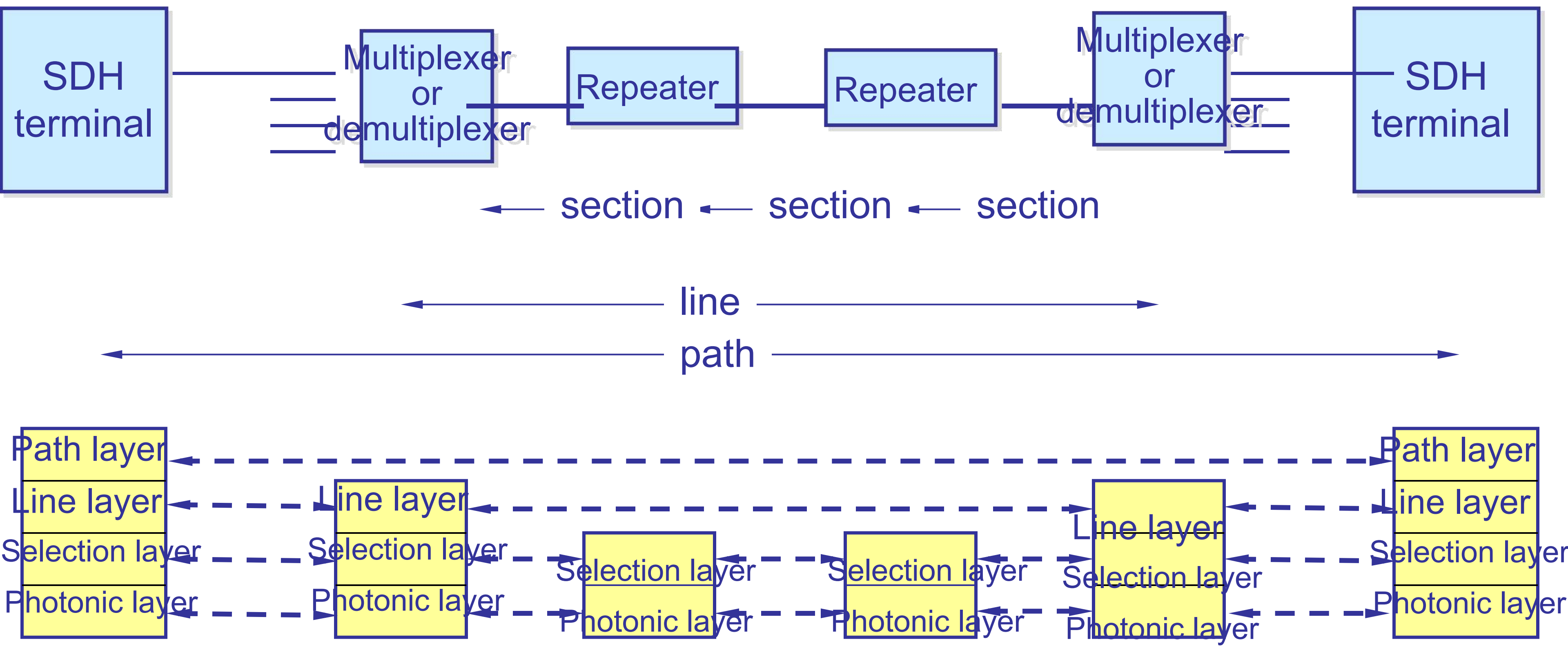
Correspondence between OC/STS level of SONET and STM Level of SONET

Line rate (Mb/s)	SONET symbols	ITU-T symbols	Common approximation of line rate
51.840	OC-1/STS-1	—	
155.520	OC-3/STS-3	STM-1	155 Mb/s
466.560	OC-9/STS-9	STM-3	
622.080	OC-12/STS-12	STM-4	622 Mb/s
933.120	OC-18/STS-18	STM-6	
1244.160	OC-24/STS-24	STM-8	
2488.320	OC-48/STS-48	STM-16	2.5 Gb/s
4976.640	OC-96/STS-96	STM-32	
9953.280	OC-192/STS-192	STM-64	10 Gb/s
39813.120	OC-768/STS-768	STM-256	40 Gb/s

SONET standard has defined 4 optical interface layers:

- **Photonic Layer**
  - **Processing bits transmission over optical cables.**
- **Section Layer**
  - **STS-N frame transmission on optical cable.**
- **Line Layer**
  - **Synchronization and multiplexing in path layer.**
- **Path Layer**
  - **Handle the business transmission among PTE (Path Terminating Element).**

System Structure of SONET



2.7 Broadband Access Technology

xDSL technology

- xDSL technology is to modify the existing analog telephone subscriber lines and make that can carry broadband service.
- Although the frequency band of standard analog telephone signal is limited to a range of 300~3400 kHz, the signal frequency through the subscriber line still more than the 1 MHz actually.
- xDSL technology leaves the low-band spectrum to traditional telephone service, but leaves the high-band spectrum which was not used in the past to users for internet service.
- Digital Subscriber Line is called DSL for short. And the prefix x of DSL stands for different broadband solutions achieved on the digital subscriber lines.

2.7 Broadband Access Technology

Types of xDSL

- ADSL - Asymmetric Digital Subscriber Line
- HDSL - High speed DSL
- SDSL - Single-line DSL
- VDSL - Very high speed DSL
- DSL - Digital Subscriber Line< Symmetric Digital Subscriber Line>
- RADSL: Rate-Adaptive DSL is a subset of DSL and can adjust the line rate automatically.

2.7 Broadband Access Technology

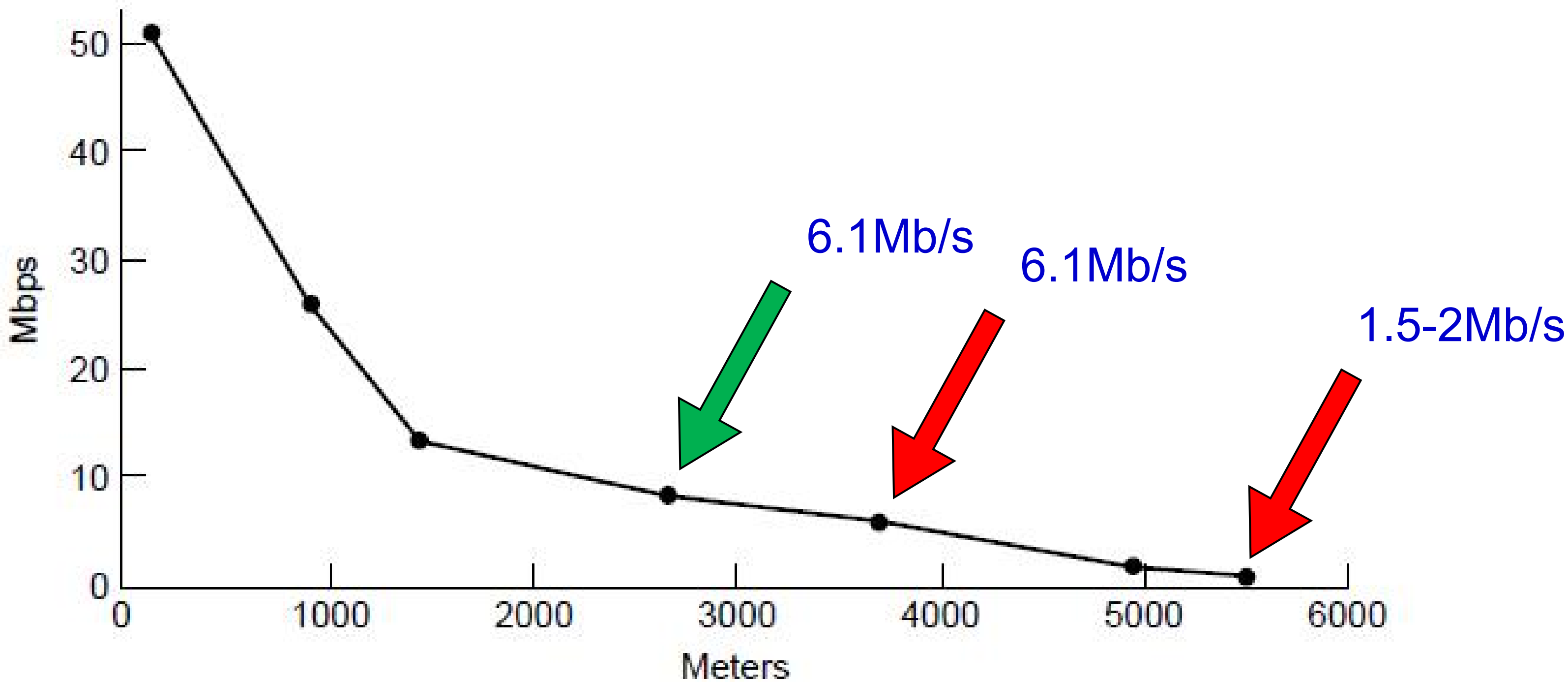
- **The limit transmission distance of ADSL**
  - **The limit transmission distance and data rate of ADSL has a great connection to the wire diameter of user line, the smaller the wire diameter is, the greater the signal transmission attenuation will be.**
  - **The maximum data transfer rate is closely related to the SNR of the actual user lines. (According to the Shannon's theorem)**

2.7 Broadband Access Technology

The limit transmission distance of ADSL

- For example, if the user line's wire diameter is 0.5 mm, the limit transmission distance is 5.5 km when the transfer rate is 1.5 ~ 2.0 Mb/s. But when the transfer rate increase to 6.1 Mb/s, the transmission distance will decrease to 3.7 km.
- If the wire diameter of user line is decrease to 0.4 mm, the transmission distance will be only 2.7 km under the transfer rate of 6.1 Mb/s.

2.7 Broadband Access Technology



Bandwidth versus distance over Category 3（0.5mm/0.4mm）UTP for DSL.

2.7 Broadband Access Technology

Features of ADSL

- **The bandwidth of upstream and downstream are asymmetry.**
- **Upstream is from user to ISP, and downstream is from ISP to user.**
- **ADSL installs an ADSL modem at each end of subscriber line (copper).**
- **The ADSL solution adopt DMT (Discrete Multi-Tone) multiplexing technique in China. Here the "multi-tone" means "multi-carrier" or "multi sub-channel".**

DMT (Discrete Multi-Tone) multiplexing technique

- **Discrete Multi-tone (DMT) – a multiplexing technique commonly found in digital subscriber line (DSL) systems**
- **DMT combines hundreds of different signals, or sub-channels, into one stream**
- **Interestingly, all of these sub-channels belong to a single user, unlike the previous multiplexing techniques**

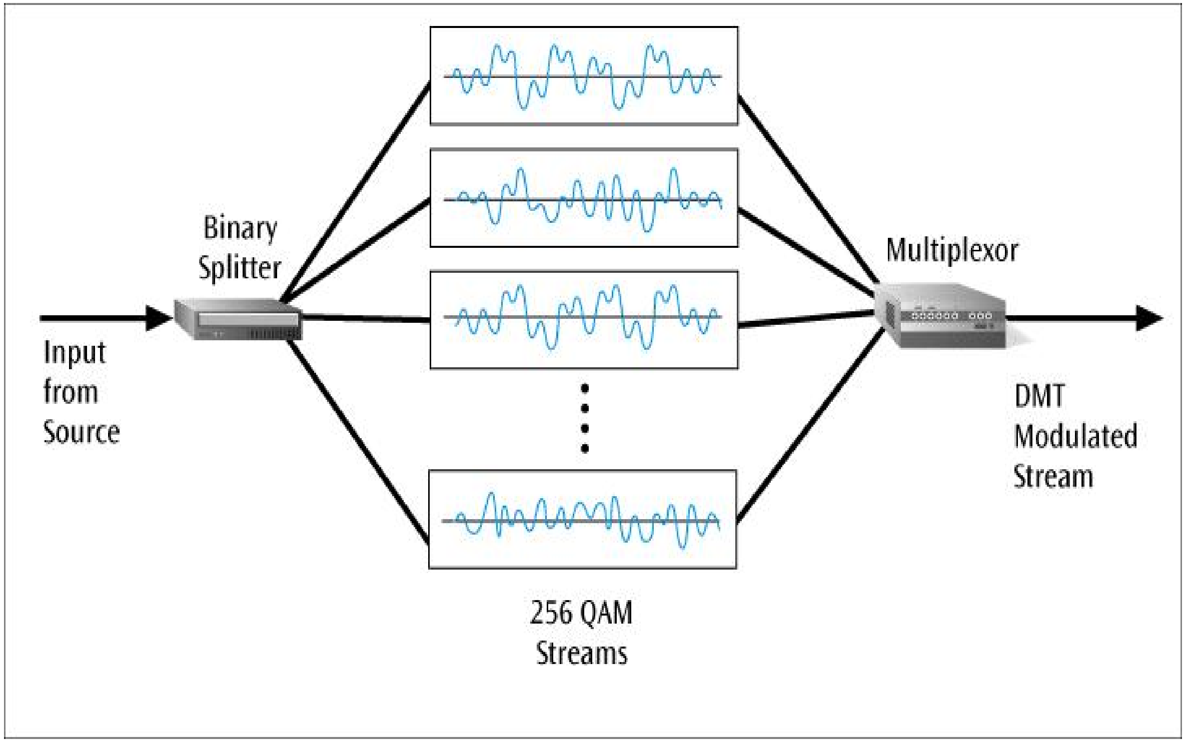
DMT (Discrete Multi-Tone) multiplexing technique

- Each sub-channel is quadrature amplitude modulated (recall eight phase angles, four with double amplitudes)
- Theoretically, 256 sub-channels, each transmitting 60 kbps, yields 15.36 Mbps
- Unfortunately, there is noise, so the sub-channels back down to slower speeds

DMT (Discrete Multi-Tone) multiplexing technique

Figure 5-12

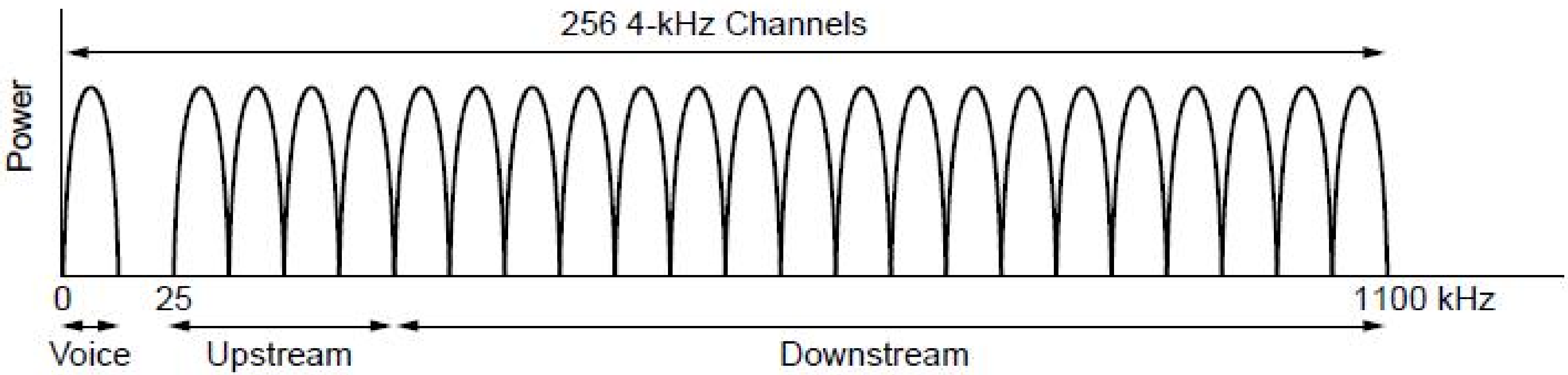
256 quadrature amplitude modulated streams combined into one DMT signal for DSL



2.7 Broadband Access Technology

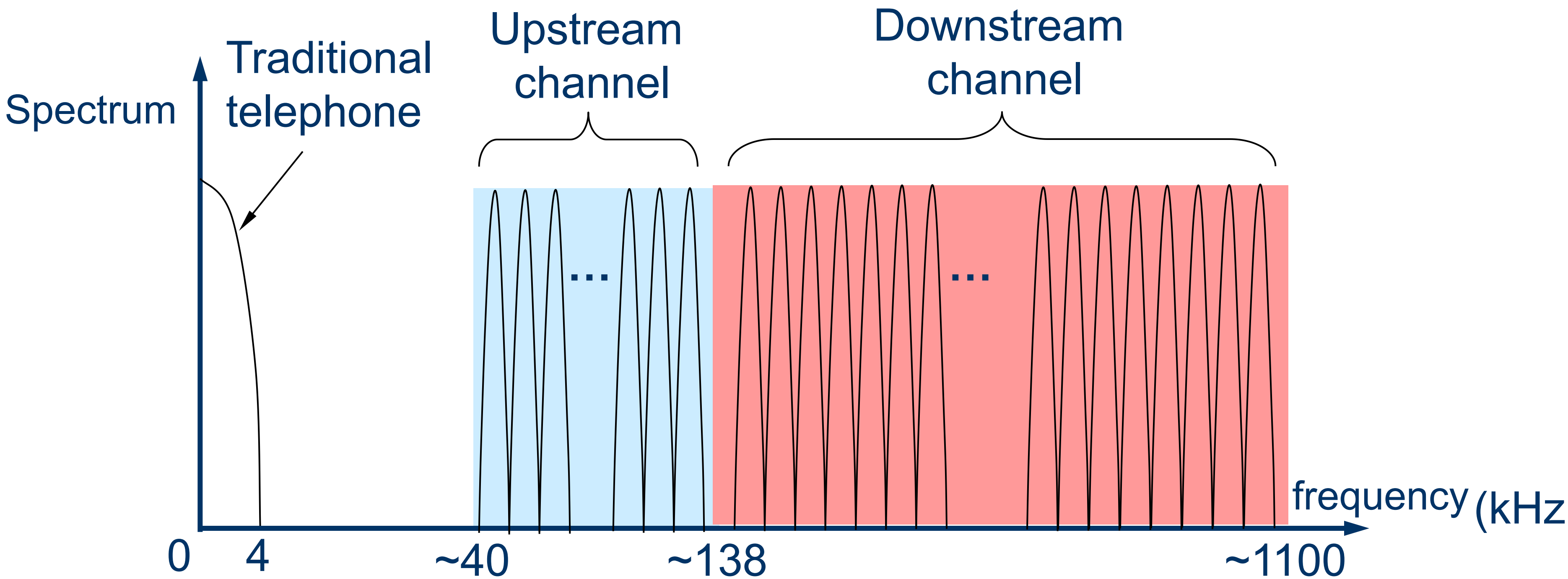
- **DMT (Discrete Multi-Tone)**
  - **DMT adopts the method of FDM. The high-band spectrum at the range of 40 kHz to 1.1 MHz is divided into so many sub-channels, 25 of them are used as upstream channel and 229 of them are used as downstream channel.**
  - **Each sub-channel takes up 4 kHz bandwidth (4.3125 kHz actually) and use different carriers (different tones) for digital modulation. This is equivalent to transmit data in a pair of subscriber lines paralleling by many small modem.**

DMT (Discrete Multi-Tone) multiplexing technique



Operation of ADSL using Discrete Multi-tone Multiplexing

Spectrum Distribution of DMT



2.7 Broadband Access Technology

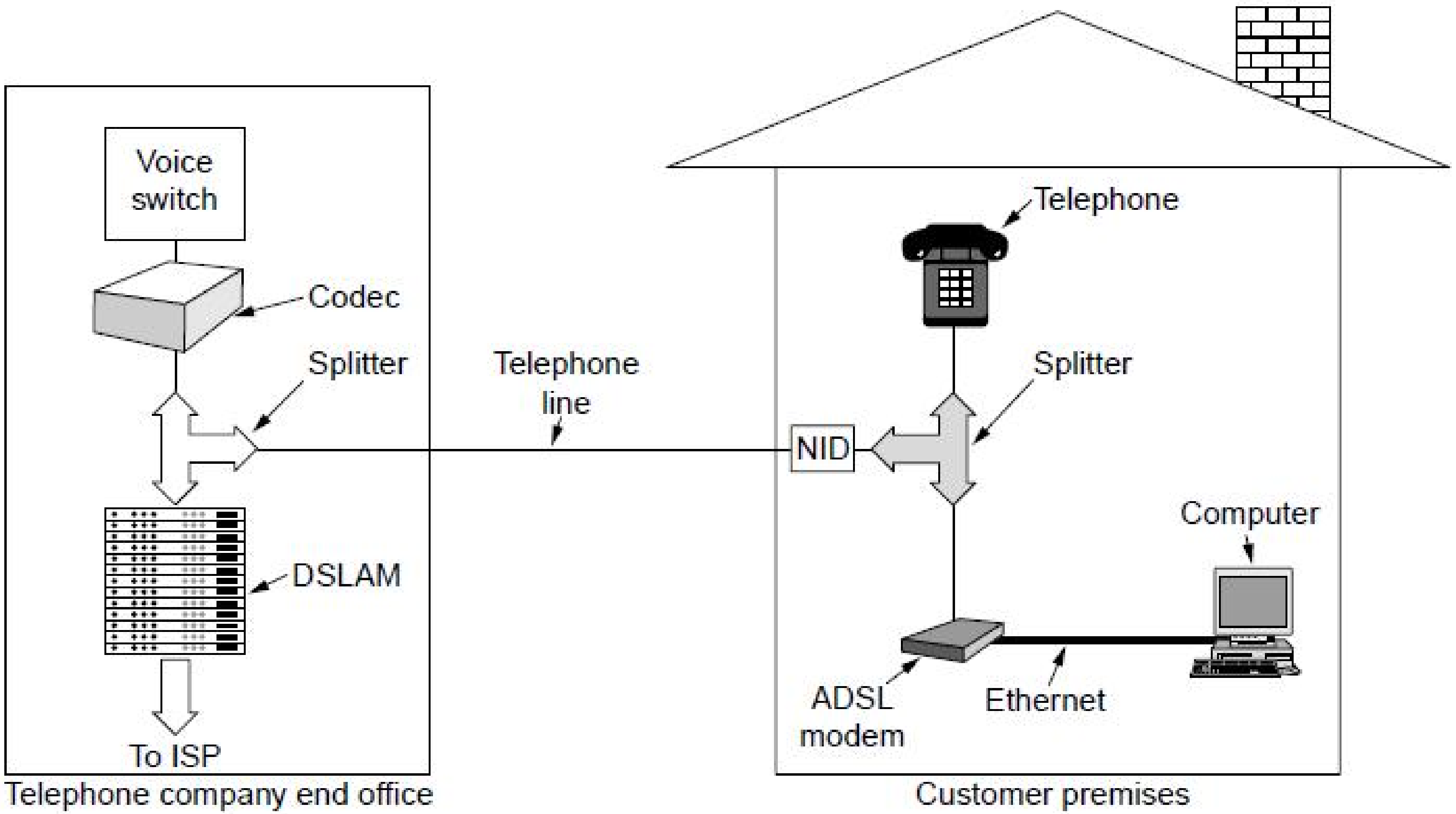
Data Rate of ADSL

- **Because there is a big difference in the specific condition of subscriber lines, such as the transmission distance, wire diameter and the degrees of interference adjacent subscriber lines and so on. Therefore ADSL adopts adaptive modulation technology that make the subscriber line get a transmission rate as high as possible.**
- **When ADSL starts to work, the ADSL modems at both ends of the subscriber line will test the available frequencies, the interference situation of each sub-channels and the transmission quality of test signal on each frequency.**

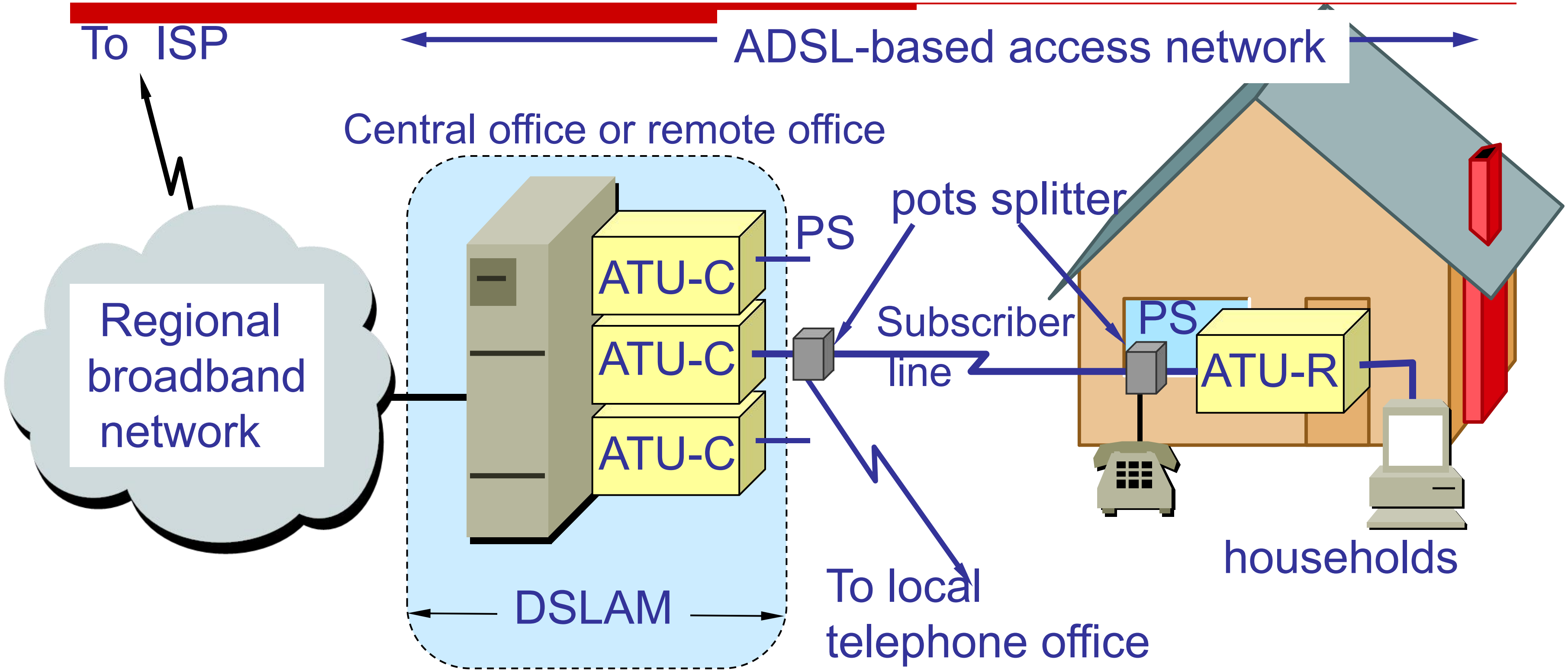
2.7 Broadband Access Technology

- **Data Rate of ADSL**
  - **ADSL can not guarantee a fixed data rate, and even can't work on the poor quality subscriber line.**
  - **Usually downstream rate is between 32 kb/s and 6.4 Mb/s, and upstream rate is between 32 kb/s and 640 kb/s.**

Composition of ADSL



Composition of ADSL



DSLAM (DSL Access Multiplexer)
Access Termination Unit
ATU-C（C represents Central Office）
ATU-R（R represent Remote）

PS (POTS Splitter)

2.7 Broadband Access Technology

- **The second generation of ADSL technology**
  - **Obtain a higher data rate by improving the modulation efficiency. For example, ADSL2 requires to support downlink 8 Mb/s and uplink 800 kb/s at least. ADSL2+ extends the spectral range from 1.1 MHz to 2.2 MHz and support downlink 16 Mb/s (maximum to 25 Mb/s) and uplink 800 kb/s.**
  - **Adopts SRA (Seamless Rate Adaptation), and could adaptively adjust the data rate without communication interruption and errors in the operation.**
  - **Improves line quality evaluation and fault location, and this has very important significance to improve network operation maintenance level.**

2.7 Broadband Access Technology

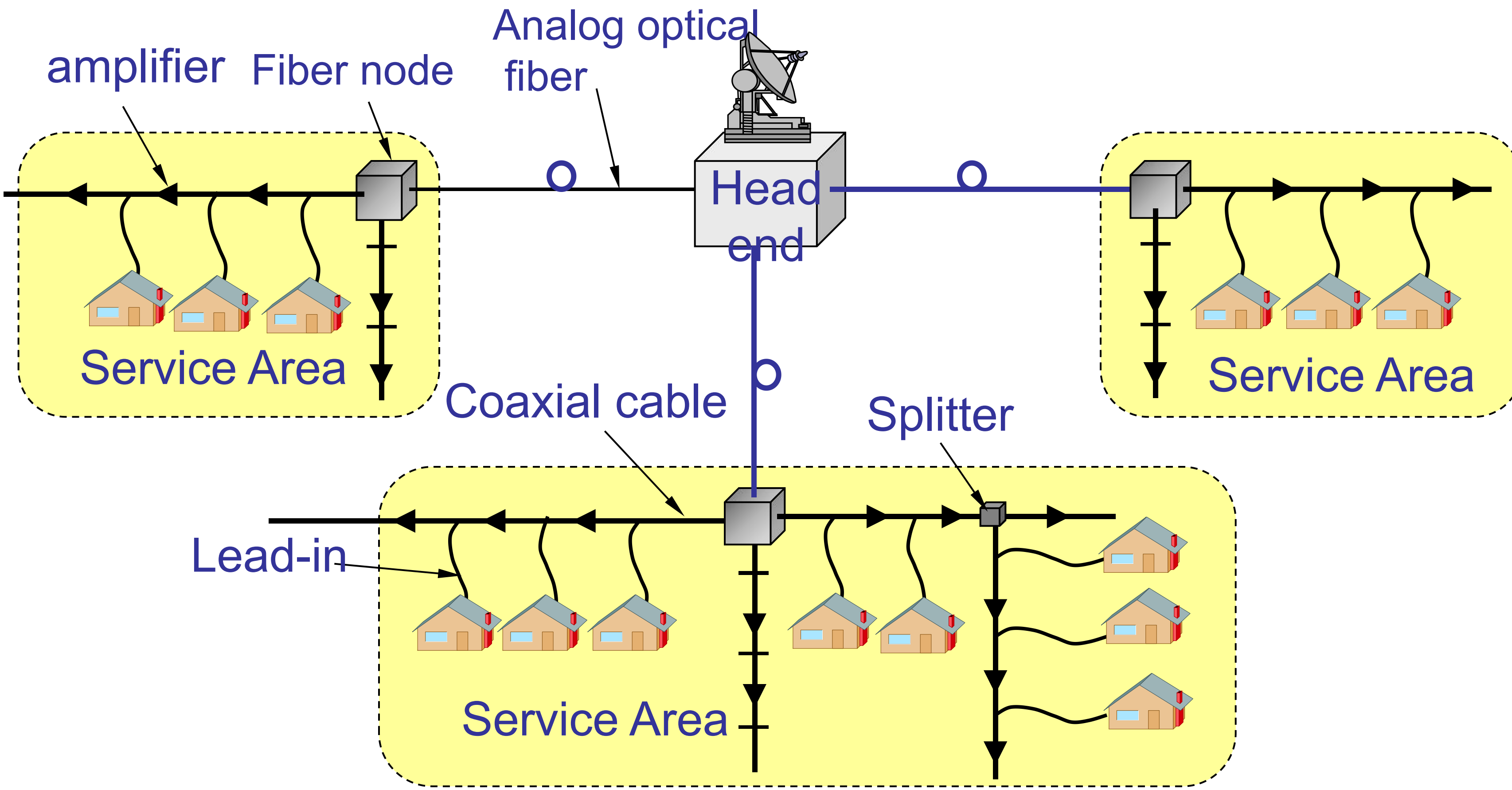
- **HFC (Hybrid Fiber Coax)**
  - **Currently HFC is widely used as cable television network, and HFC is a kind of residential broadband access network developed based on CATV.**
  - **In addition to transmitting CATV, HFC also provide telephone, data and other broadband interactive services.**
  - **The existing CATV network is tree topology coaxial cable network, it uses simulation technology of FDM to transmit TV programs one-way. It is necessary for HFC to transform CATV network.**

2.7 Broadband Access Technology

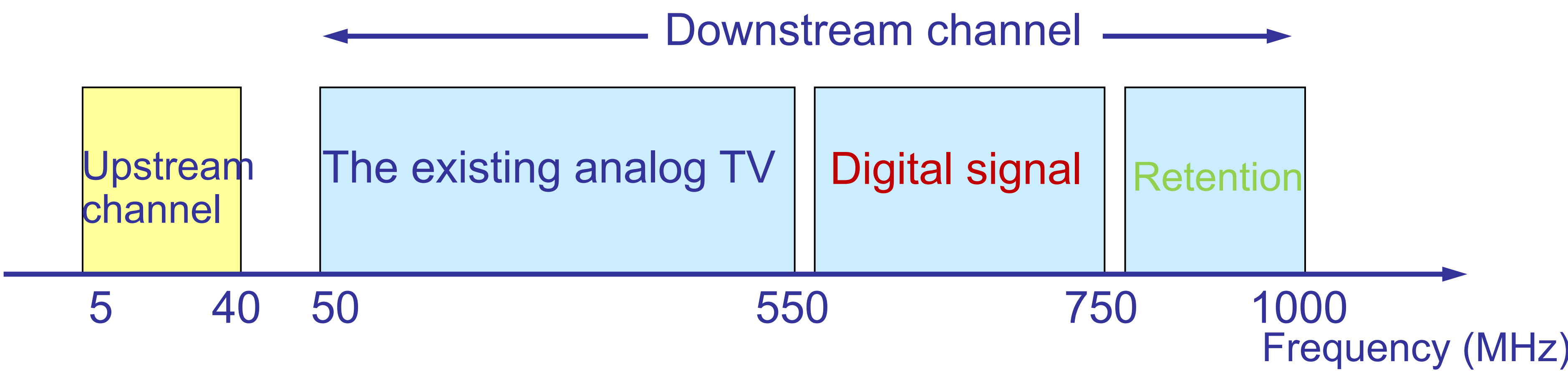
Main features of HFC

- The trunk line of HFC is optical cable
  - HFC network changes the trunk coaxial cable of CATV to optical cable and adopts analog optical fiber technology.
  - Amplitude modulation (AM) is adopted in analog optical fiber can save more cost than that in digital optical fiber.
  - Analog optical fiber connects from head to fiber node, it is called ODN (Optical Distribution Node). The optical signal is converted into electrical signal in fib. It is coaxial cable behind fiber node.
- HFC network adopts node architecture.
- HFC network has a wider spectrum than CATV and with function of bidirectional transmission.
- Every family needs to install a user interface box (STB).

HFC Adopts Node Architecture



HFC network has a wider spectrum than CATV and be able for two-way transmission



Every family needs to install a user interface box (STB)

- **UIB (User Interface Box) provides 3 types of connection:**
  - **Firstly connect coaxial cable to STB (set-top box), and then connect to TV.**
  - **Connect to telephone of user with twisted pair.**
  - **Connect to PC with cable modem.**

2.7 Broadband Access Technology

Cable Modem

- **Cable modem** is a kind of special modem used in HFC network.
- The most obvious feature of cable modem is the transmission rate is high. Usually the **downlink rate is 3 ~ 10 Mb/s and even up to 30 Mb/s, the uplink rate is 0.2 ~ 2 Mb/s and even to 10 Mb/s.**
- Cable modem is much more complex than the modem used on ordinary telephone line, and it is not used in pairs but only installed on the client.

Advantages and Disadvantage of HFC

- Has a very wide spectrum and be able to take advantage of the considerable coverage of cable networks.
- Ii is need to transform the existing **450 MHz one-way transmission cable network** into **750 MHz two-way transmission HFC network**, and connect all user service area instead of being isolated HFC network. These work require a lot of money and time.
- There are also some problems need to solve in telecommunications policy.

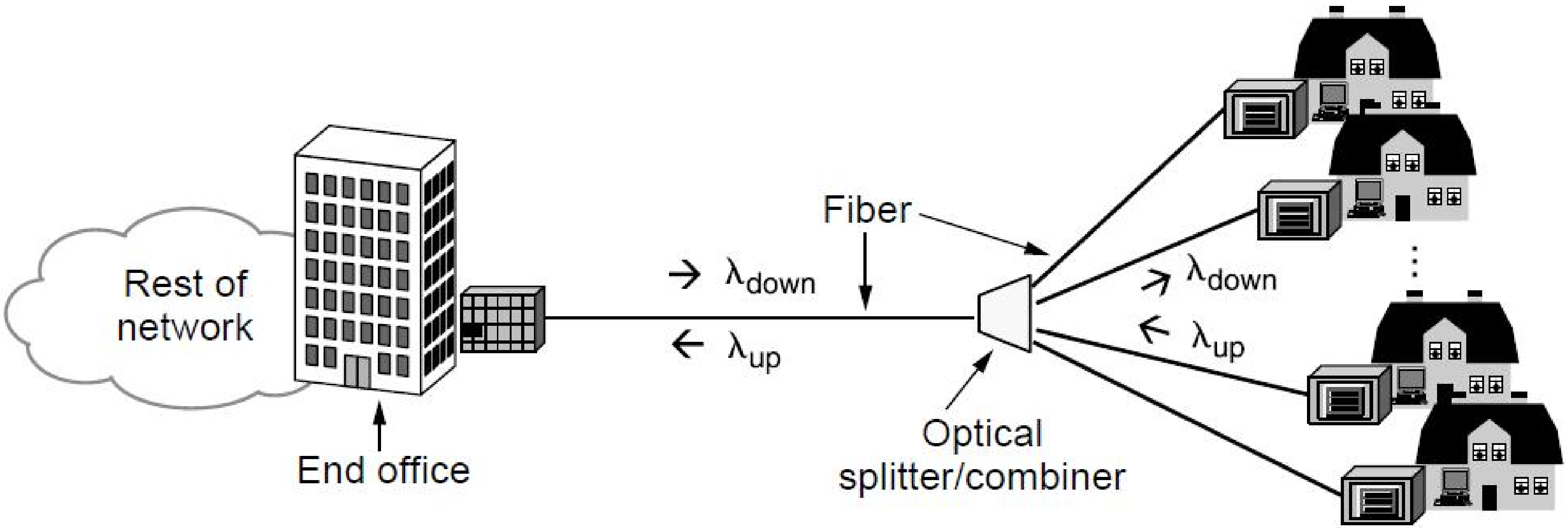
  (now it has been implemented in big cities)

2.7 Broadband Access Technology

FTTx Technology

- FTTx（Fiber to the ...）is also a solution of residential broadband access network. Here x could represent different approaches.
- FTTH (Fiber To The Home) - laying optical fiber to house may be the final solution of residential broadband access network.
- FTTB (Fiber To The Building) - optical signal will convert into electrical signal when the fiber laid into the building, and then the signal will be assigned to users through cable or twisted-pair.
- FTTC (Fiber To The Curb) - we can use the star structure twisted-pair as transmission media from curb to users.

FTTH (Fiber To The House)



Passive optical network for Fiber To The Home.

Comparison of xDSL/HFC/FTTx

- xDSL technology is to modify the existing analog telephone subscriber lines with digital technology, and make sure it can carry broadband services. Low cost, easy to implement, but it is hard to guarantee the bandwidth and quality.
- The best advantage of HFC is its wide spectrum, and it could take advantage of the current considerable coverage of cable networks. But it need a lot of money and time to transform the existing 450 MHz one-way transmission cable network into 750 MHz two-way transmission HFC network.
- FTTx (fiber to the ……) : the *x* has many different meanings. FTTx can provide the best bandwidth and quality, but the cost of line and engineering is very high nowadays.

2.8 Development of Mobile Communications System

- Analog voice（1 G）－ Cellular phone
- Digital voice（2 G）－ GSM/CDMA
- Digital voice（ 2.5G）－ GPRS
- Digital voice and data（3G）－ CDMA2000, WCDMA
- Digital voice and multimedia data（4G）－ TD-CDMA, TD-LTE/FDD-LTE
- High bandwidth and Multimedia data (5G) – 3GPP/WiMAX/ITU-R
- …

Summary

- Basic concepts (Fourier analysis, Nyquist theorem, and Shannon theorem)
- Basic model and function of data communications system (Components)
- Concept of Data and Signals (Four ways of converting data into signals)
- Some concepts about channel and channel communication styles (differences among simplex, half-duplex and full-duplex)
- Differences of base-band and band-pass signal, three basic components of modulation for analog signals (Frequency, Amplitude and Phase)
- The limit capacity and limit transmission rate computing of channel (Focus on Nyquist Criteria and Shannon Formula)
- Concept and category of Multiplexing and Compressing technology (Comparison of FDM, TDM/STDM, WDM and CDM)
- Basic principle and computing of CDMA
- Digital transmission system (Digital code schemes, PCM/SONET layers)
- Broadband access technology (Comparison of ADSL/HFC/FTTx technology)
- Development of mobile communication systems (Five generations, representative technologies)

Homework

- Exercises Two: P70 （8th Edition) in Chinese textbook
  - 2—03，04，06，07，08，09，11，12，13，15，16，17，18
- Read Chapter 2, Chapter 5 & Chapter 11 in English textbook
  - Case Study 1: Data and signal conversion in action: Two examples (page 56)
  - Case Study 2: Business multiplexing in action (page 144)
  - Case Study 3: Telecommunication systems in action: A Company makes a service choice (page 330)
  - According to Case Study 1 - 3, write a short reading report (in English ≥ 2000 characters or in Chinese >=1000 characters)