Physical Layer and Media II

Data Communication

Digital-to-Digital Conversion 1/2

Agenda

Data Communication
- Data Communication Definitions
- Transmission Modes
- Switching Methods

Digital-to-Digital Conversion 1/2
- Line Coding Scheme Parameters
- Line Coding Schemes

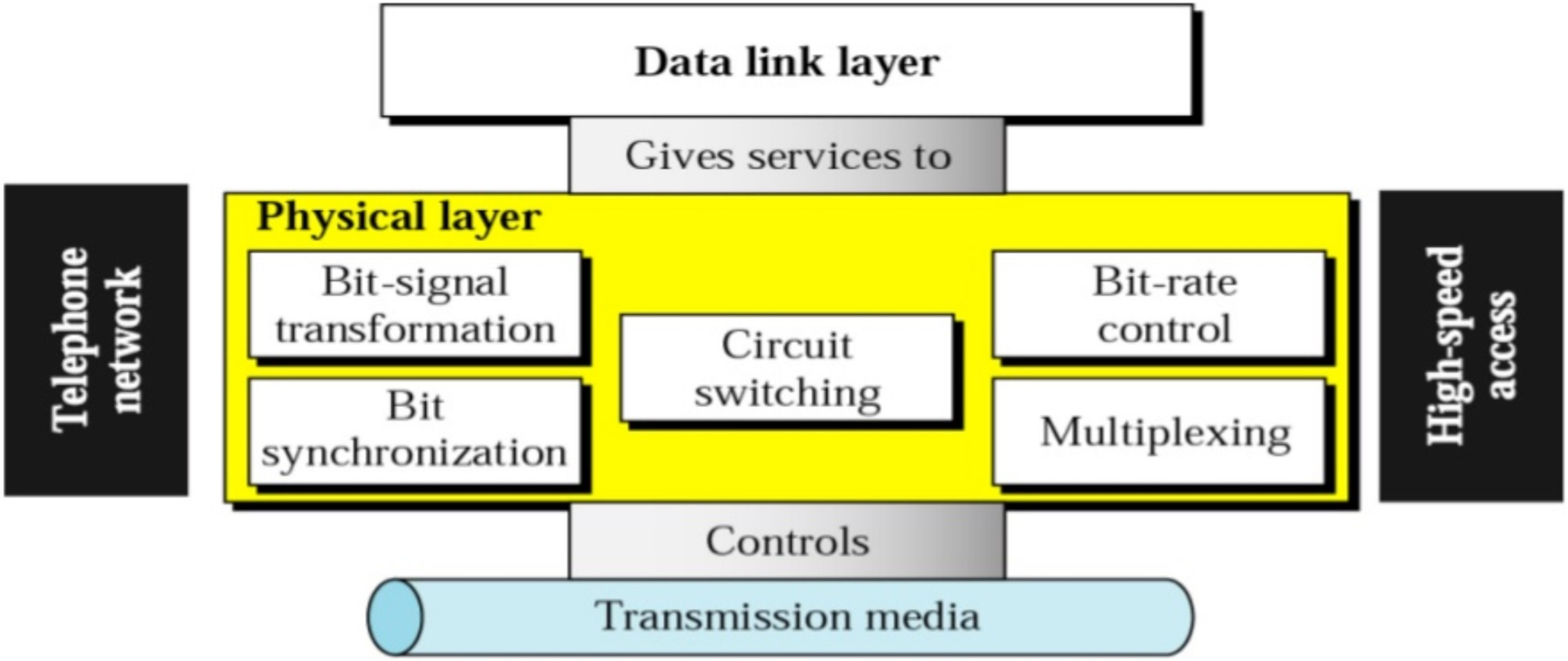
Data Communications

Data Communication Definitions

Data – Information presented in whatever form is agreed upon by the parties creating and using the data.
Data communication – Exchange of data between two devices via some form of transmission medium.
Telecommunication – communication at a distance (‘tele’ in Greek=‘far”).

Data Communications

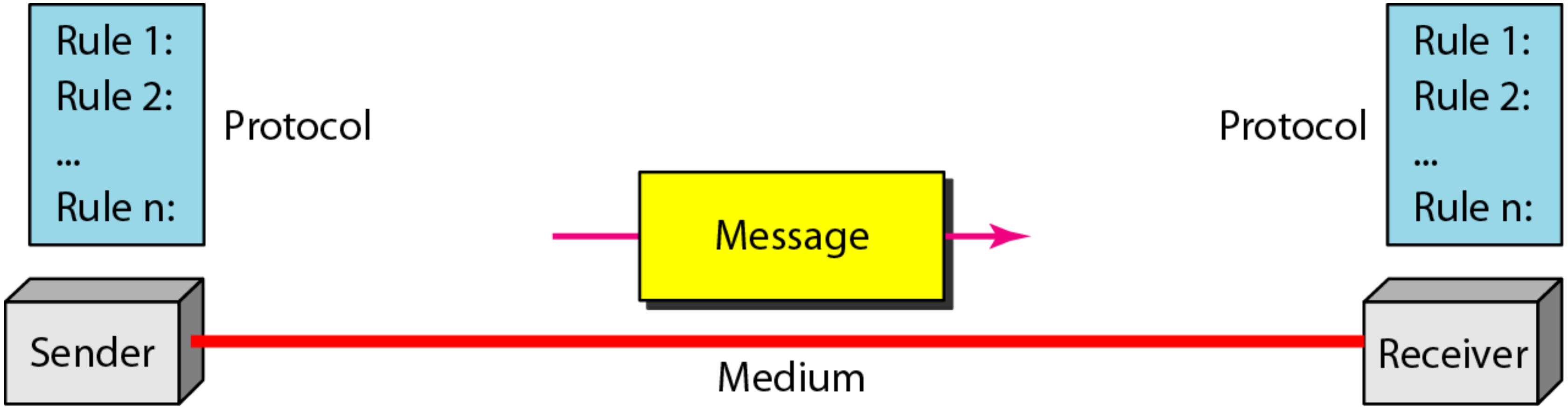
Physical Layer Position in OSI/RM



Data Communications

Five Components of Data Communication System

1. Protocol: a set of rules that govern data communication
2. Message: Information (data) to be communicated
3. Sender
4. Receiver
5. Transmission medium: physical path by which a message travels



Elements of a Protocol

A protocol is synonymous with rule. It consists of a set of rules that govern data communications.
It determines what is communicated, how it is communicated and when it is communicated.
The key elements of a protocol are:

Syntax - Structure or format of the data. Indicates how to read the bits - field delineation.

Semantics - Interprets the meaning of the data. Knows which fields define what action.

Timing - When data should be sent and what. Speed at which data should be sent or speed at which it is being received.

Communications Architecture

The complexity of the communication task is reduced by using multiple protocol layers:
- Each protocol is implemented independently;
- Each protocol is responsible for a specific subtask;
- Protocols are grouped in a hierarchy.

A structured set of protocols is called a **communications architecture or protocol suite**

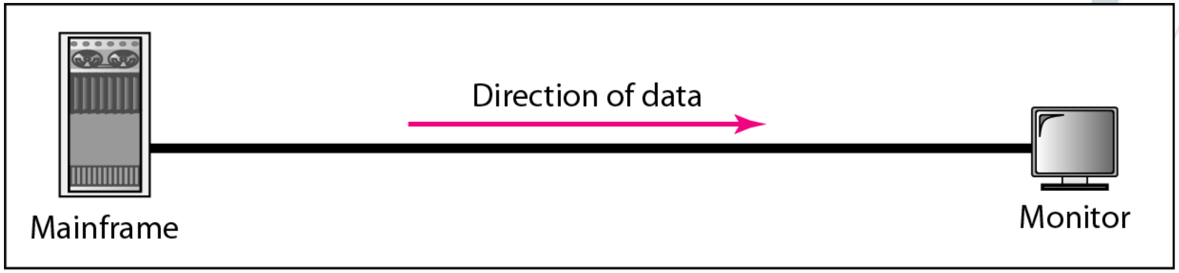
Data Communications

Direction of Data Flow

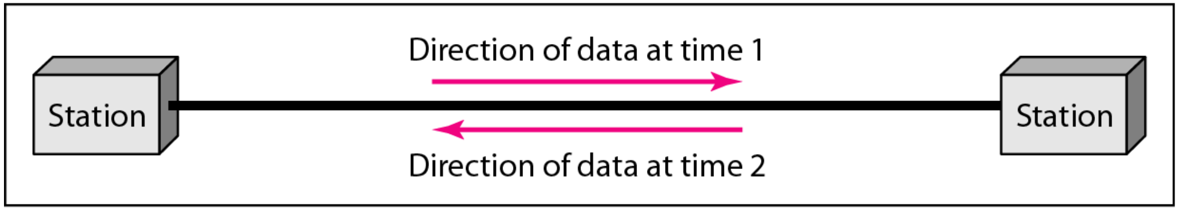
Simplex
– Unidirectional
– As on a one-way street

Half-duplex
– Both transmit and receive possible, but not at the same time
– Like a one-lane road with two-directional traffic

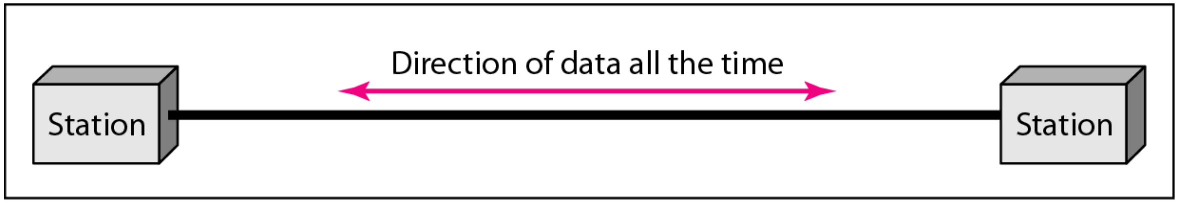
Full-duplex
– Transmit and receive simultaneously
– Like a two-way street, telephone network
– Channel capacity must be divided between two directions



a. Simplex



b. Half-duplex



c. Full-duplex

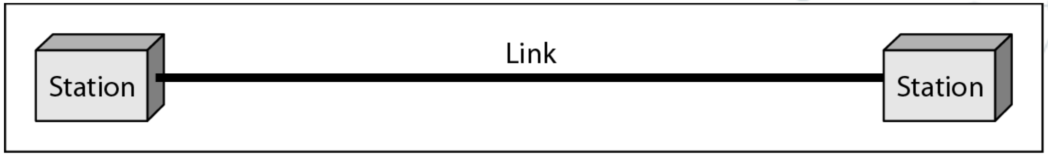
Data Communications

Type of Connection

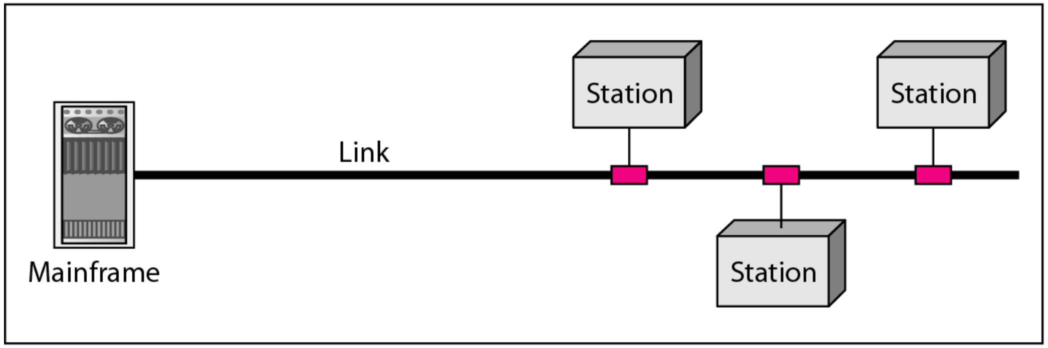
Direct link - no intermediate devices.

Point-to-Point - direct link, single transmitter and receiver.

Multi-point - direct link, more than two devices share the link, ex. multiple recipients of single transmission.



a. Point-to-point

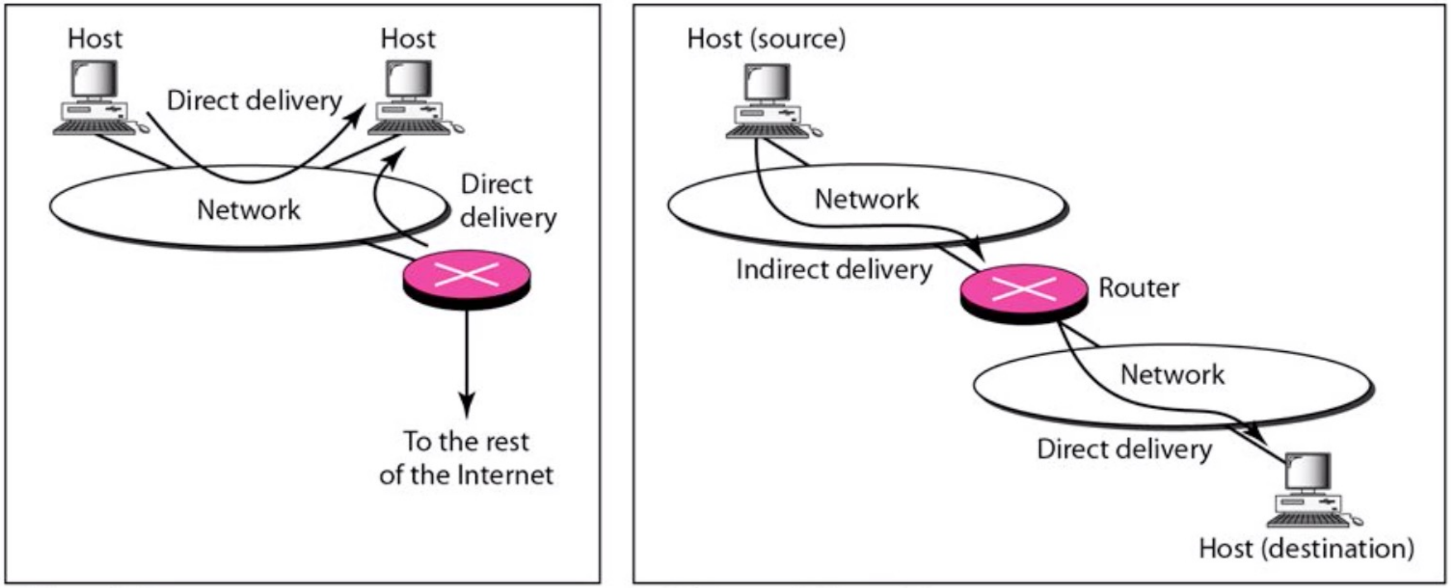


b. Multipoint

Type of transmission - unicast, multicast, broadcast, anycast.

Data Communications

Type of Delivery



a. Direct delivery   b. Indirect and direct delivery

Type of Delivery Modes

- unicast,
- multicast,
- broadcast,
- anycast,
- geocast.

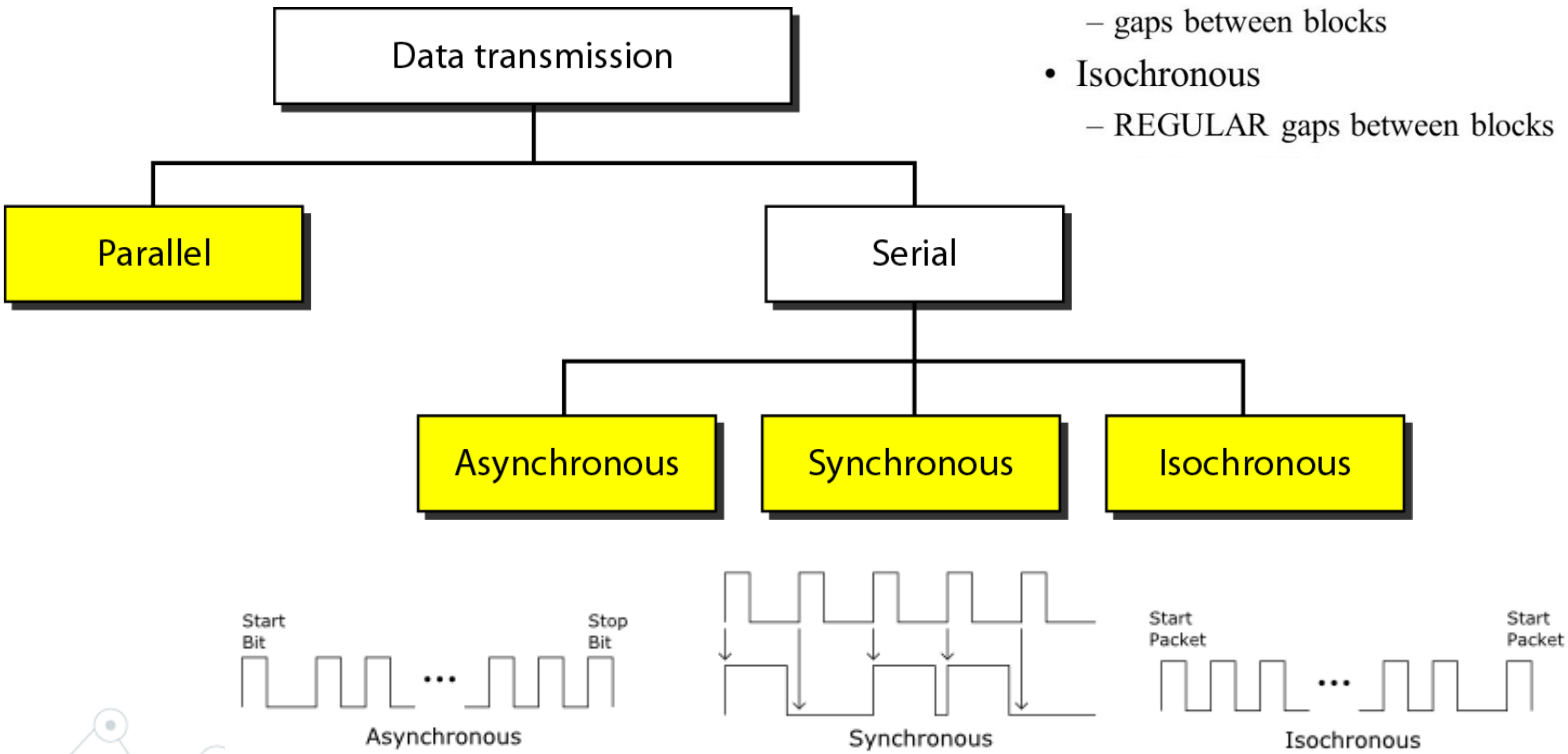
Data Communications

Transmission Modes

Data Communications

Transmission Modes

- Asynchronous
  - irregular gaps between bytes
- Synchronous
  - no gaps between bytes
  - gaps between blocks
- Isochronous
  - REGULAR gaps between blocks

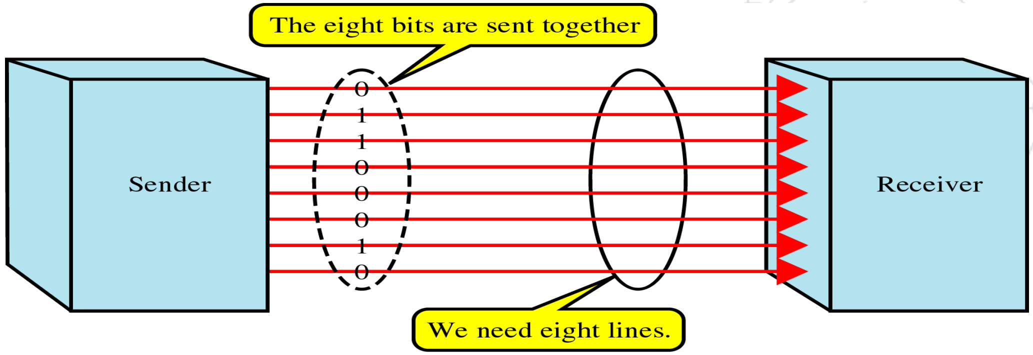


Data Communications

Transmission Modes: Parallel & Serial

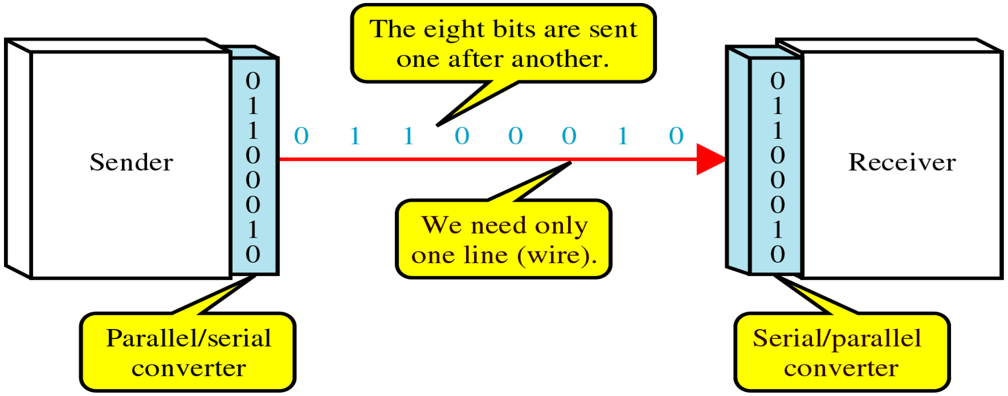
Parallel Transmission use n wires to send n bits at one time synchronously.

Advantage: very speed.
Disadvantage: more expensive, limited to short distances.



Serial Transmission use one communication channel.

Advantage: less expensive, more distance.
Disadvantage: less speed.

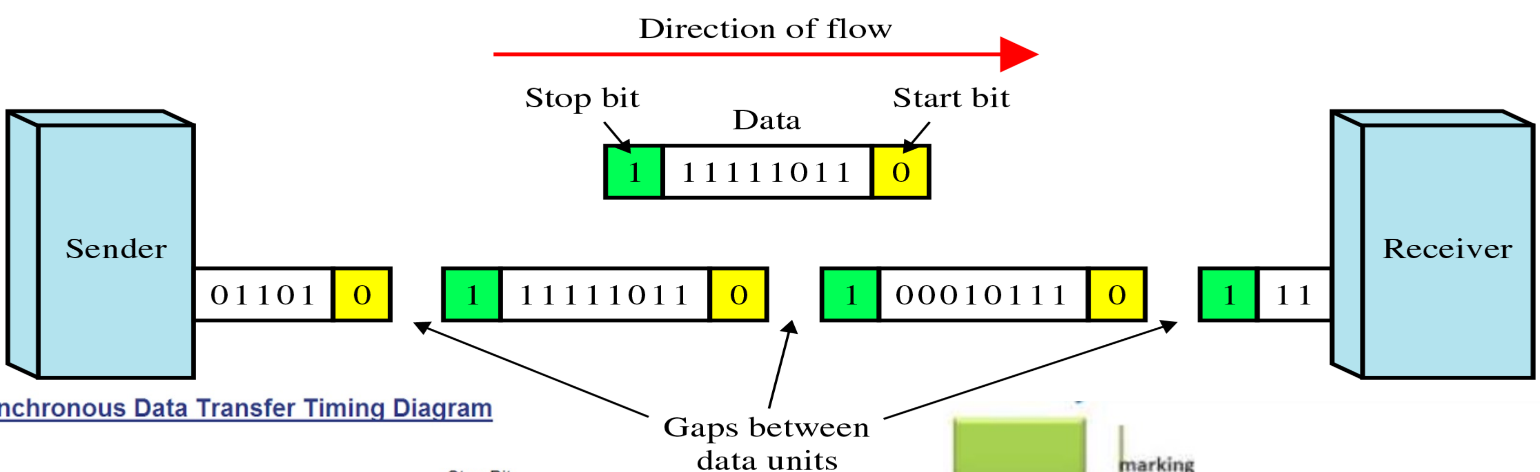


Categories of Serial Transmission (depending on how transmissions are spaced in time):
- Asynchronous transmission can occur at any time;
- Synchronous transmission occurs continuously;
- Isochronous transmission occurs at regular intervals.

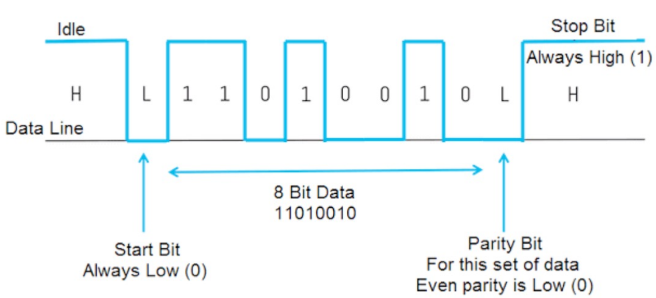
Data Communications

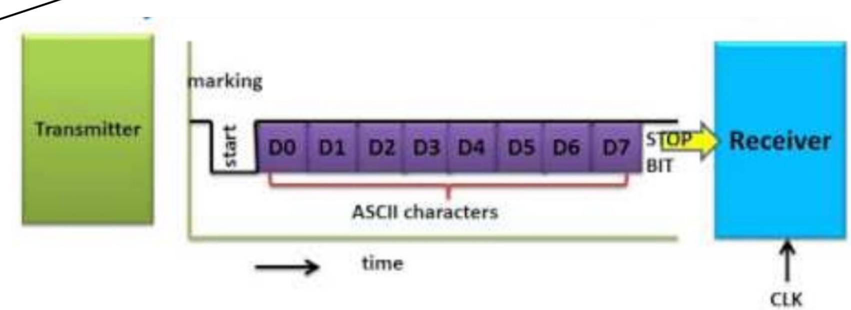
Transmission Modes: Serial - Asynchronous Transmission

Asynchronous Transmission use start bit (0) and stop bits (1s)
A gap between two bytes: idle state or stop bits
It means asynchronous at byte level.
Must still be synchronized at bit level
Good for low-speed communications generate data at random time intervals (keyboard, modem, terminal). **Example RS-232 interface.**



Asynchronous Data Transfer Timing Diagram

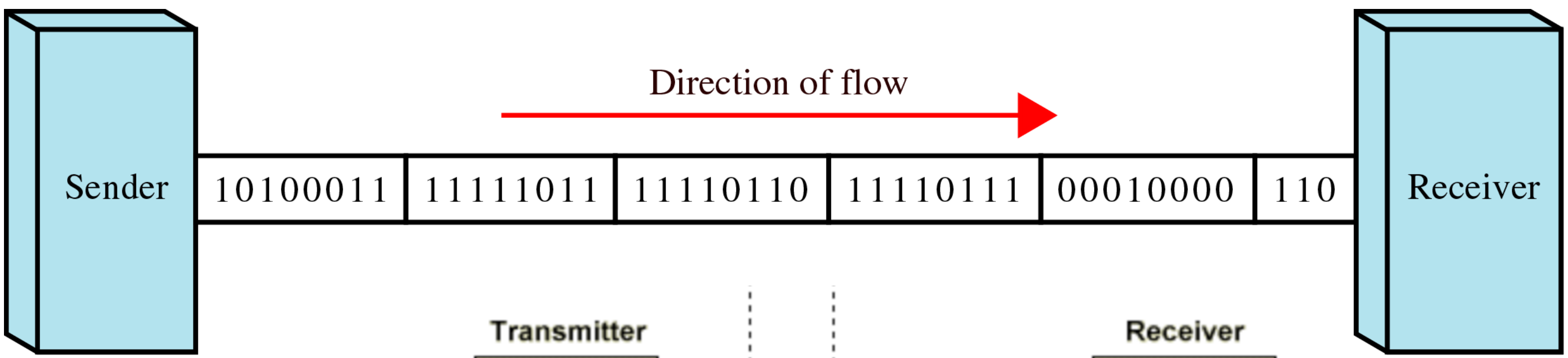


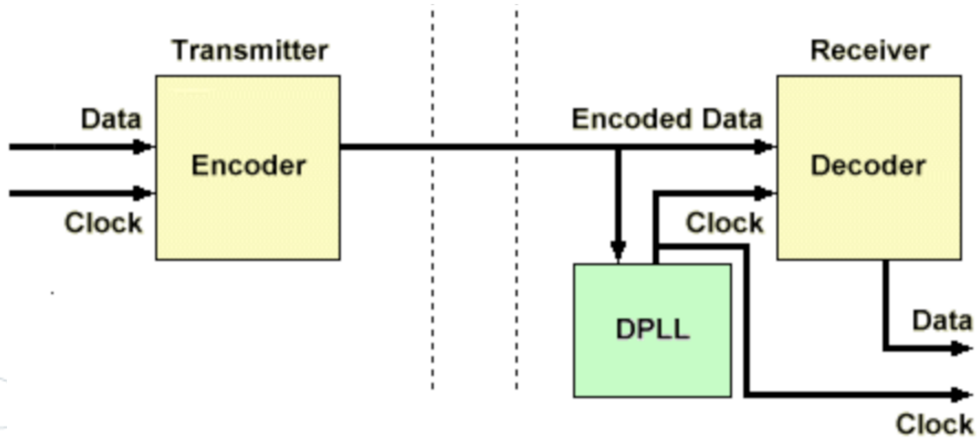


Data Communications

Transmission Modes: Serial - Synchronous Transmission

Synchronous Transmission use bit stream is combined into “frames”.
Special sequence of 1/0 between frames: No gap.
Timing is important in midstream.
Byte synchronization in the data link layer.
Advantage: speed ⇒ high-speed transmission.





DPLL - Digital Phase Lock Loop – regenerate a Clock

Transmission Modes: Serial - Isochronous Transmission

Isochronous Transmission
Use in a data network where the information channel rate is higher than the input data signaling rate.
The Isochronous transmission guarantees that the data arrive at a fixed rate.

Use in real time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails.

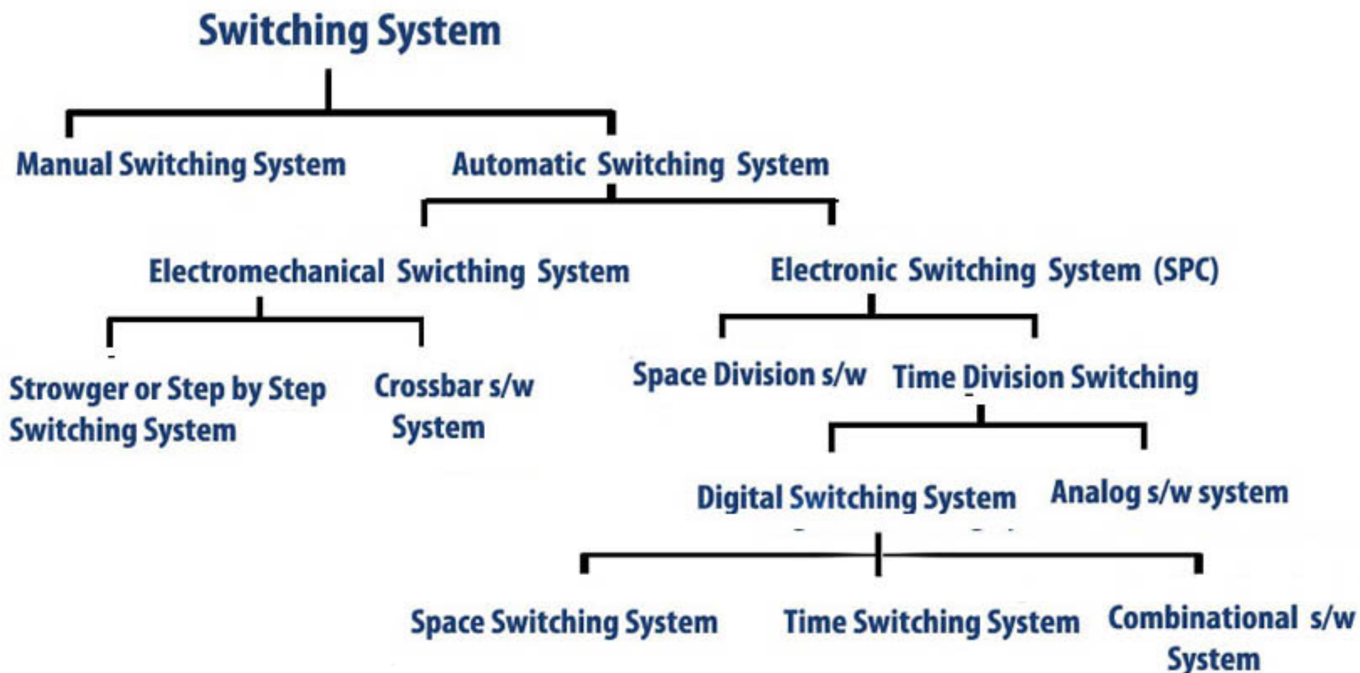
Example: TV image are broadcast at the rate of 30 images per sec, they must be viewed at the same rate if each images is sent by using one or more frames, there should be no delays between frames.

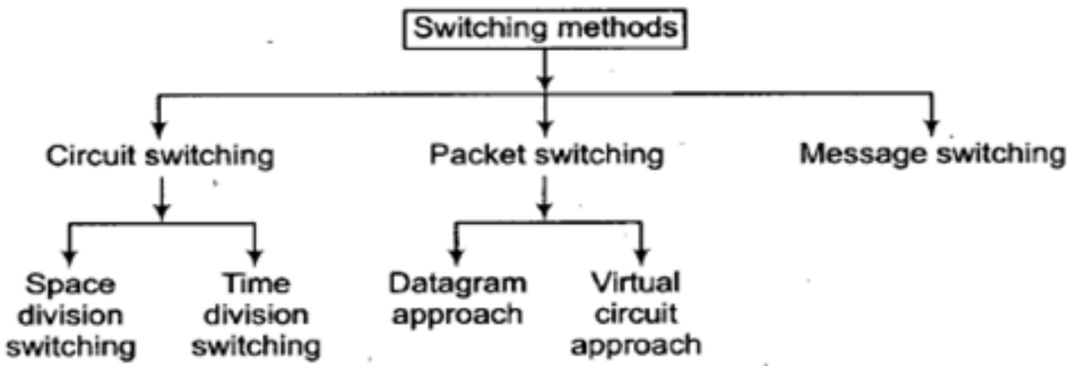
Data Communications

Switching Methods

Data Communications

Switching Systems: Genealogy & Methods





Type of Switching

Leased Line (not switching) – fixed end2end line, very big cost.

Message Switching (asynchronous) – store-and-forward systems (Telegraph, teletype).

Circuit Switching (isochronous) – establish fixed end2end connection, ideal for real-time applications, guaranteed quality of service (Telephone, modem).

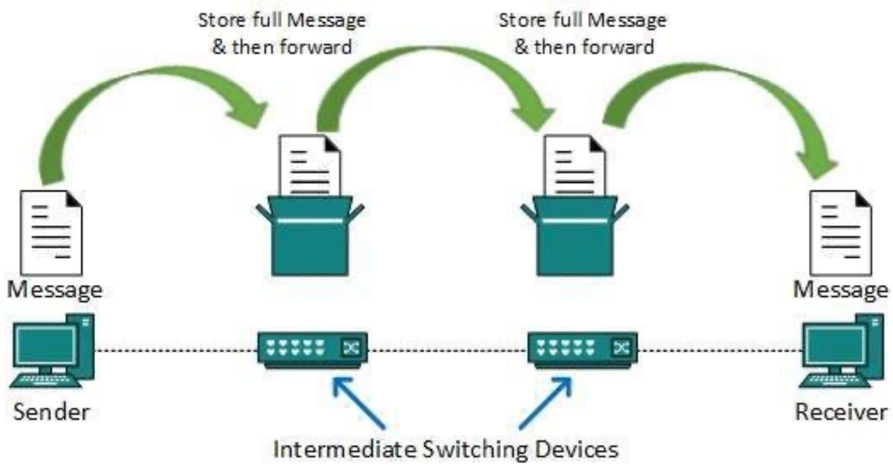
Communication via circuit switching involves **three phases**:

1. Circuit Establishment,
2. Data Transfer,
3. Circuit Disconnect.

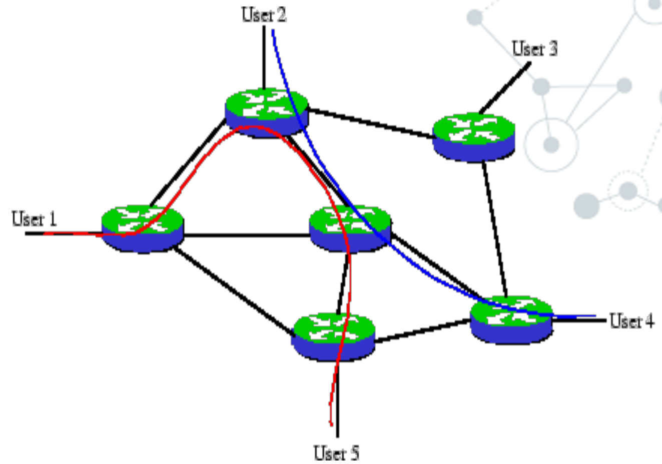
Packet Switching – shared facilities, used for data communication (Computer).

- Datagrams
- Virtual Circuit

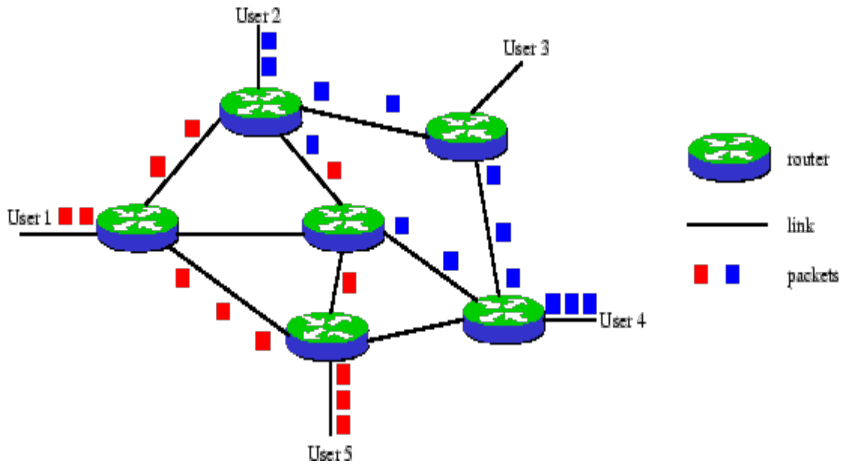
Data Communications



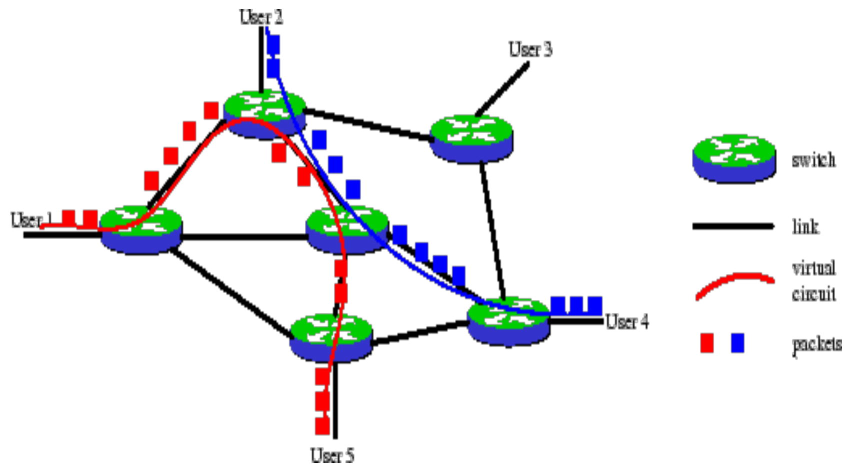
Message Switching



Circuit Switching



Packet (Datagram) Switching



Virtual Circuit Switching

Virtual circuit packet switching (VC-switching) is a packet switching technique which merges datagram packet switching and circuit switching to **extract both of their advantages**.

Data Communications

Switching: Packet switching versus Circuit switching

Blocking or Non-blocking Network

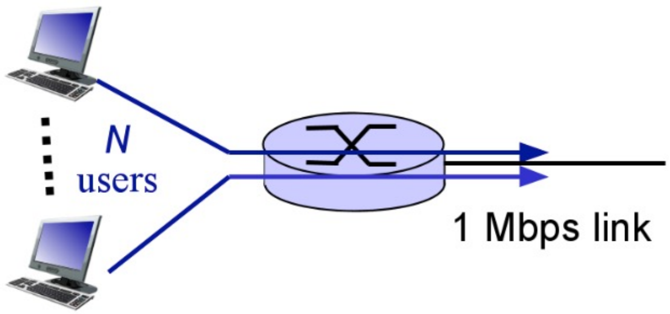
Blocking network

- may be unable to connect stations because all paths are in use
- used on voice systems

Non-blocking network

- permits all stations to connect at once
- used for some data connections

Example 1. What user count?
Network: with 1 Mb/s link channel,
link each user:100 kb/s when “active”,
active 10% of time.

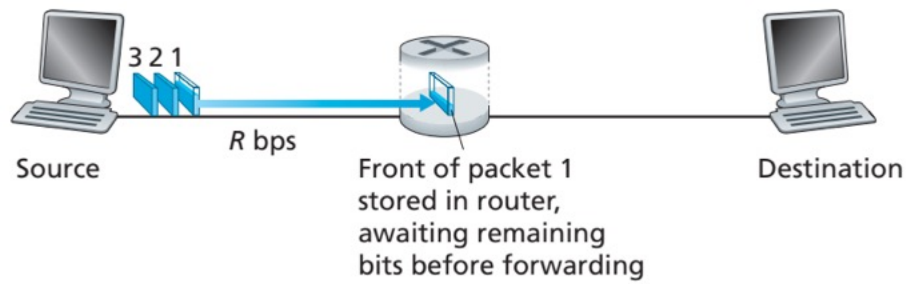


Circuit switching: 10 users at same time
Packet switching: allows more users to use network at same time,
because with 35 users, probability >10 active at same time is less than P(10 active from 35)<0.0004

Data Communications

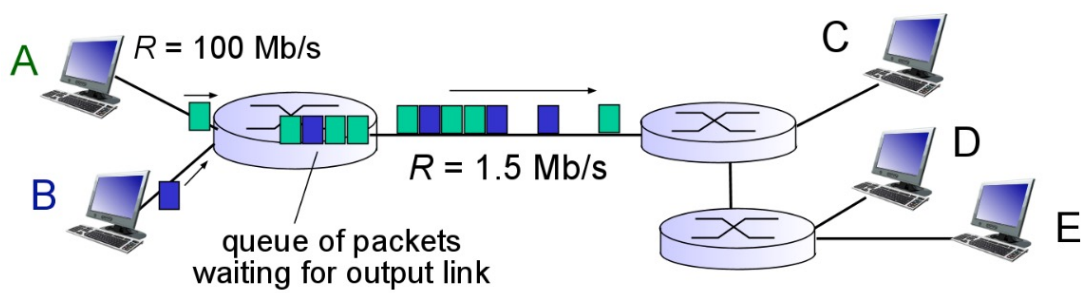
Switching: Packet switching versus Circuit switching

Example 2. Store and forward:
Source sending a packet of L bits over a link with transmission rate R bits/sec, then the Time to transmit the packet is L/R seconds.
Entire packet must arrive at router before it can be transmitted on next link.
End2end transmission delay:
$Dt = N*L/R$
N- links count between source and destination.



Example 3. Queuing and loss:
If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
packets will queue, wait to be transmitted on link -
packets can be dropped (lost) if memory (buffer) fills up -

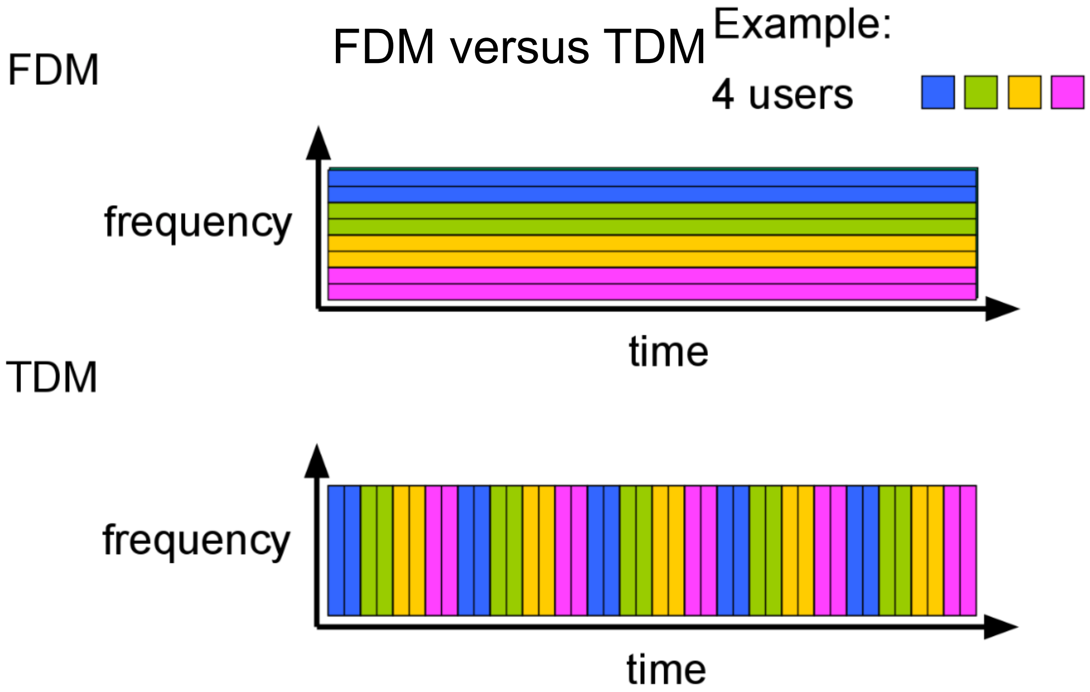
Circuit switching allows less delay and no loss!



Data Communications

Switching: Circuit switching - Implementation

Implementation of Circuit-Switching
– Spice Division without Multiplexing (WiFi, CelPhone)
– Frequency Division Multiplexing (FDM)
– Time Division Multiplexing (TDM)
– Wavelength Division Multiplexing (WDM)
– Code Division Multiplexing (CDM)

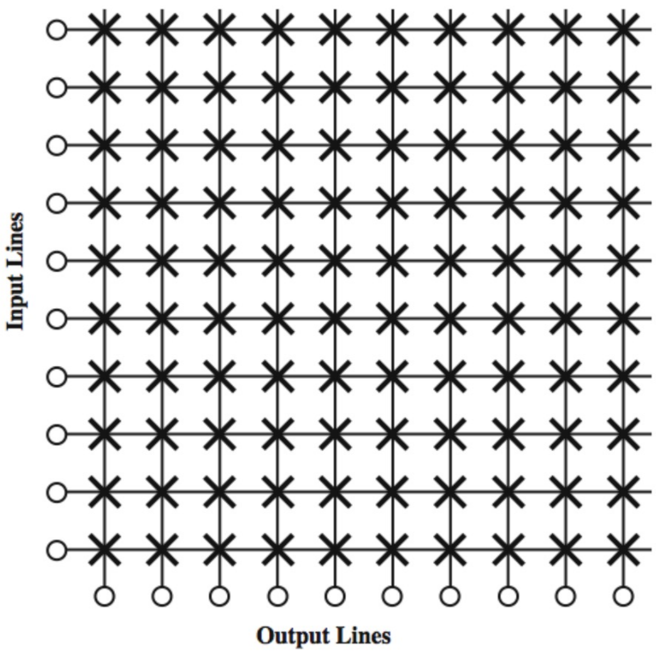


Data Communications

Switching: Structure Of Circuit Spice Division Switches

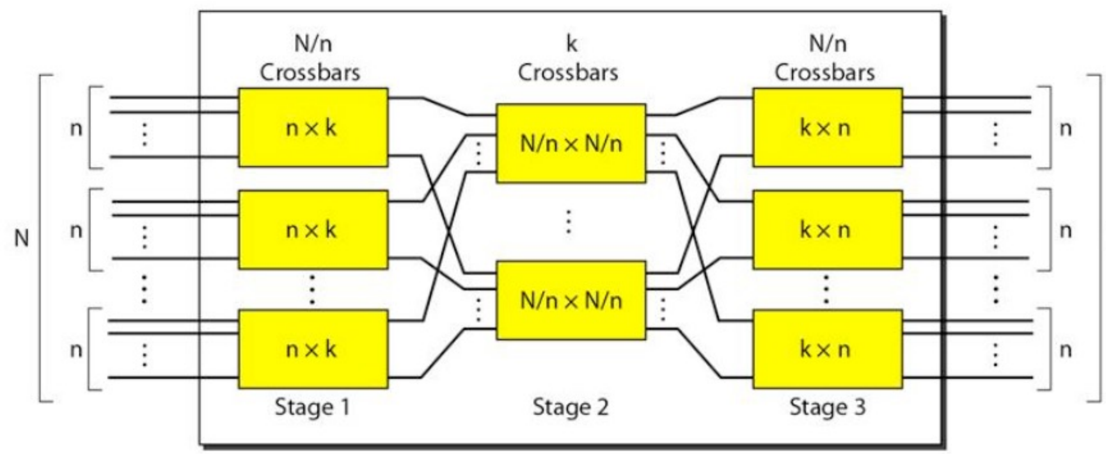
Problems of Crossbar Space Division Switches:
- many Crosspoints O(n^2) one-stage device,
- < 25% Crosspoint are in use at a given time.

Solution: Multistage Stage Space Division Switch.



Crossbar Switch

N=48, n^2=48^2=2304



Multi (Three) Stage Switch

Example:

Numbers of Crosspoints for 3-stage switch :

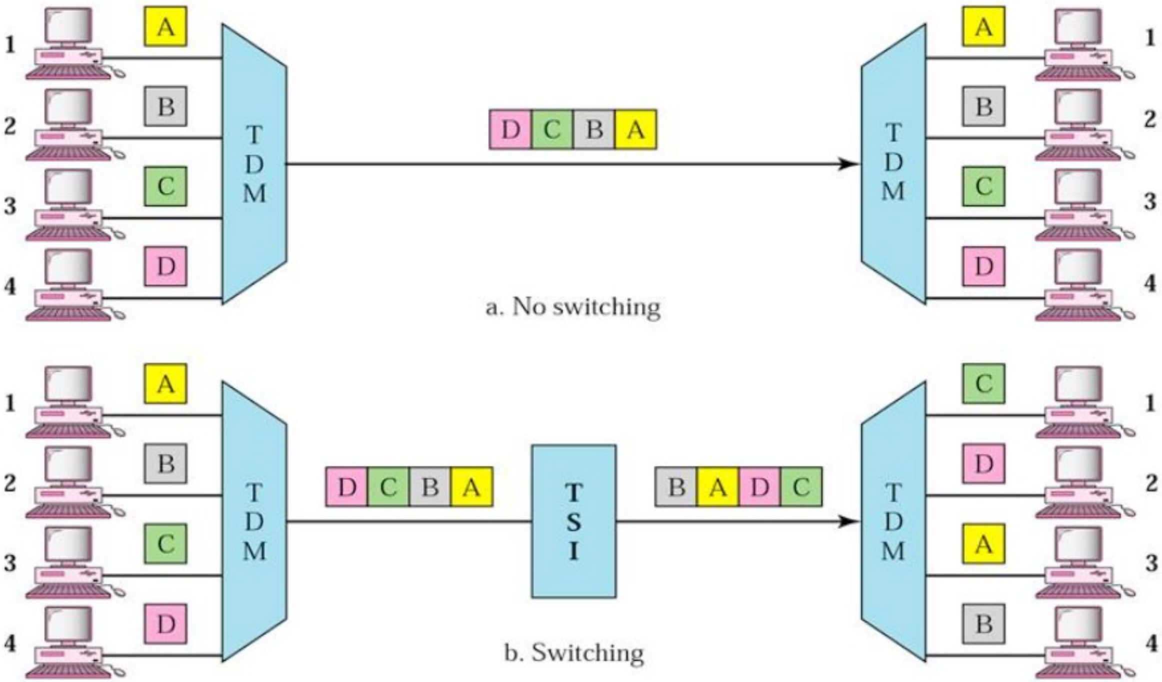
N/n*(n*k)+k*(N/n*N/n)+N/n*(k*n)=2kN+k(N/n)^2

48/8*(8*3)+3*(48/8*48/8)48/8*(3*8)=2*3*48+3*(48/8)^2=

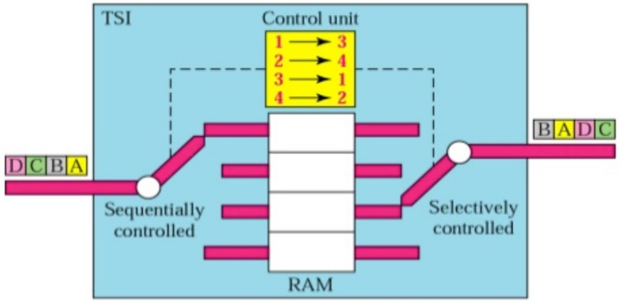
=6*48+3*6^2=288+108=396

Data Communications

Switching: TDM & Time Division Switching



TDM – Time Division Multiplexing
TSI - Time Slot Interchange



Digital-to-Digital Conversion

The Dig2Dig Parameters

The Dig2Dig Conversion involves three techniques:

- Line coding,
- Block coding,
- Scrambling.

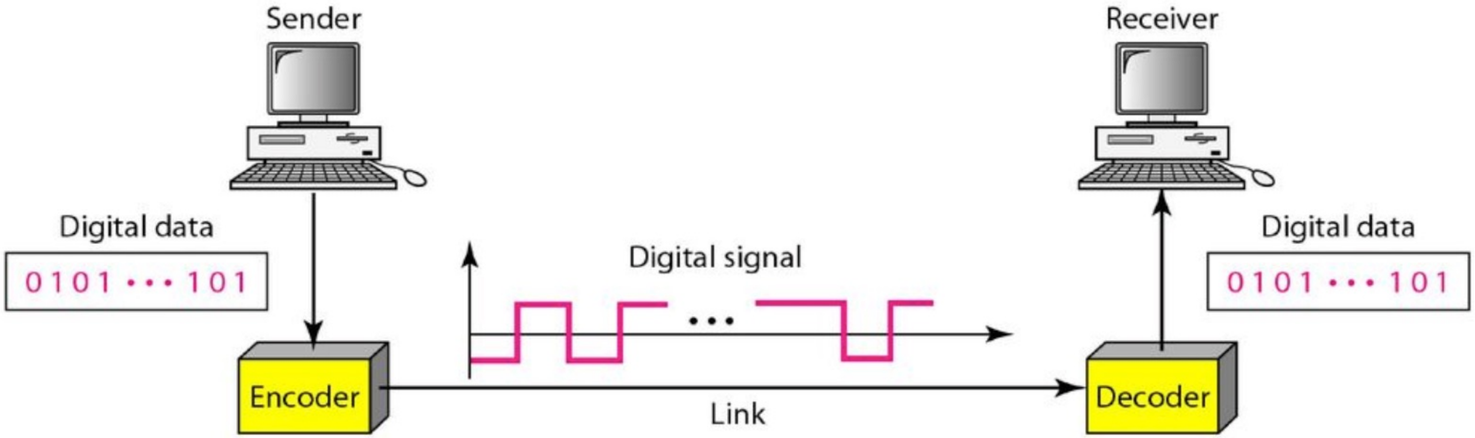
In this section, we see how we can represent digital data by using digital signals.
Line Coding Schemes

Digital-to-Digital Conversion

Signal Element versus Data Element

Data element - the smallest entity that can represent a piece of information: this is bit.
Signal element - the shortest unit (timewise) of a digital signal: this is boud.

In other words
— Data element are what we need to send.
— Signal elements are what we can send.



Digital-to-Digital Conversion

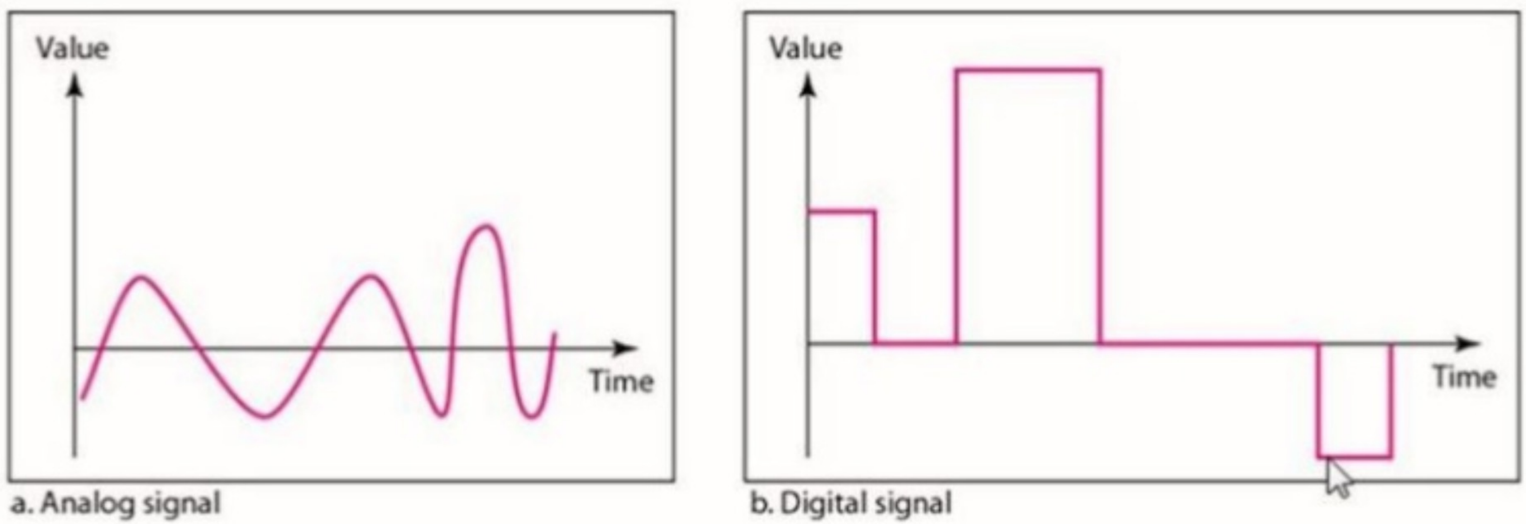
Analog vs Digital Signal & Data

DATA

- Analog: Continuous value data (sound, light, temperature)
- Digital: Discrete value (text, integers, Symbols)

SIGNAL

- Analog: Continuously varying electromagnetic wave
- Digital: Series of voltage pulses (square wave)



Digital-to-Digital Conversion

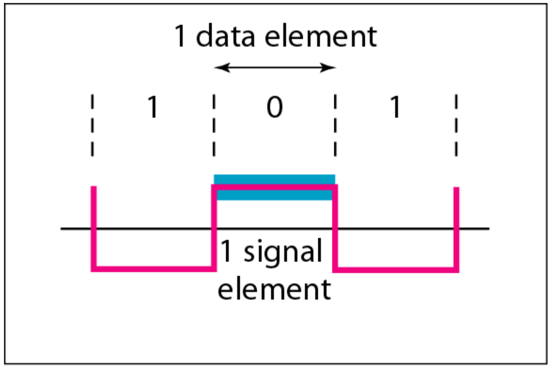
Mapping Data symbols onto Signal levels

- A data symbol (or element) can consist of a number of data bits:
  - 1 , 0
  - 00, 01, 10, 11
  - 000, 001, 010, .. 111
- A data symbol(s) can be coded into a single signal element or multiple signal elements
  - 1 → +V, 0 → -V
  - 1 → +V and -V, 0 → 0V
  - 1 → 0V, 0 → -V and +V
- The mapping ratio ‘r’ is the number of data elements ‘d’ carried by a signal element ‘s’ r=d/s.

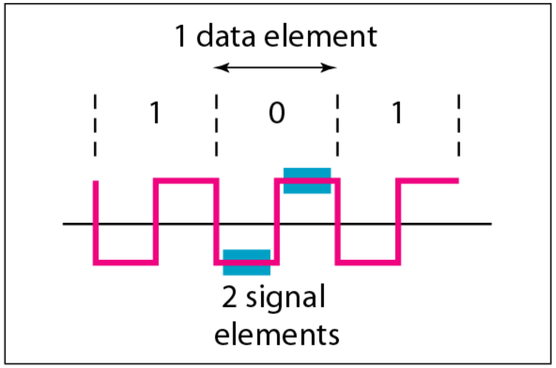
Digital-to-Digital Conversion

Signal Element and Data Element Rate

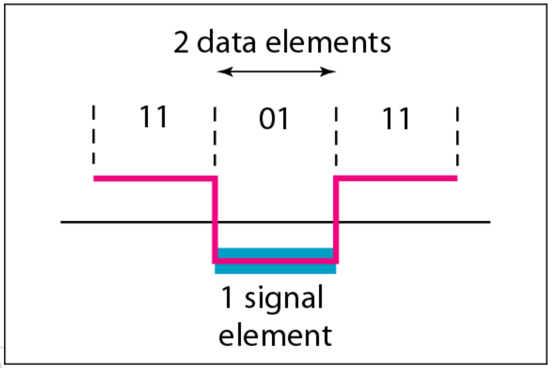
Data elements are what we need to send; signal elements are what we can send



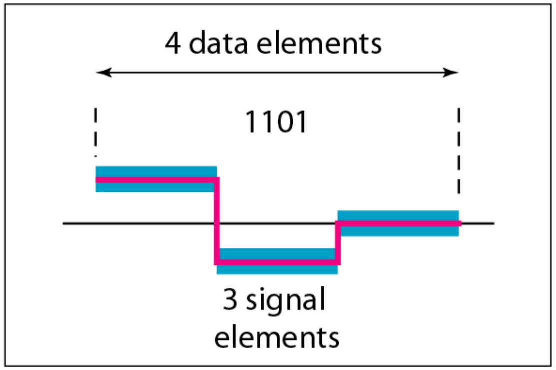
a. One data element per one signal element (r = 1)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element (r = 2)



d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

Digital-to-Digital Conversion

Data Rate Versus Signal Rate

- Signal rate S is the number of signal elements sent in 1s: baud.

Signal rate = pulse rate, modulation rate, baud rate.

- Data rate N defines the number of data elements (bits) sent in 1s: bps.

Data rate = bit rate.

- $S = c * N * 1/r$, where
  - S is the number of signal elements;
  - N is the date rate;
  - c is the case factor (worst, best, average);
  - r mapping ratio ‘r’ is the number of data elements ‘d’ carried by a signal element ‘s’ $r=d/s$.
- The actual bandwidth of a digital signal is infinite, bet effective bandwidth is finite
- The bandwidth is proportional to the signal rate (baud rate)
- The minimum bandwidth: $B_{min} = c * N * 1/r$
- The maximum data rate: $N_{max} = 1/c * B * r$
- Goal is to increase the data rate N whilst reducing the baud rate S.

Digital-to-Digital Conversion

Example of Data and Baud Rates for RS-232

<u>Defn</u>: The **baud rate** of transmission hardware is the number of changes in the signal per second that the hardware generates. Typical baud rates: 9.6 kbaud, 14.4 kbaud and 28.8 kbaud.

For RS-232 (it is a very simple transmission scheme), the baud rate is exactly equal to the number of bits per second. Example: 28.8 kbaud= 28.8 kbits per second.

The duration of a bit in RS-232 is determined by the baud rate: bit duration = 1/(baud rate).

Typical RS232 Ports found on Scales

Type	Port Image	Connector Image
25-Pin Female		
25-Pin Male		
9-Pin Female		
9-Pin Male		

To make RS-232 more general, manufacturers design each piece of hardware to operate at a variety of baud rates.

- Sender and receiver must agree on the baud rate
- Receiver samples the signal to verify agreement
- Disagreement results in a framing error

Digital-to-Digital Conversion

Example 1. Data Rate vs Baud Rate

Task

A signal is carrying data in which one data element is encoded as one signal element (r = d/s = 1).

If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

Solution

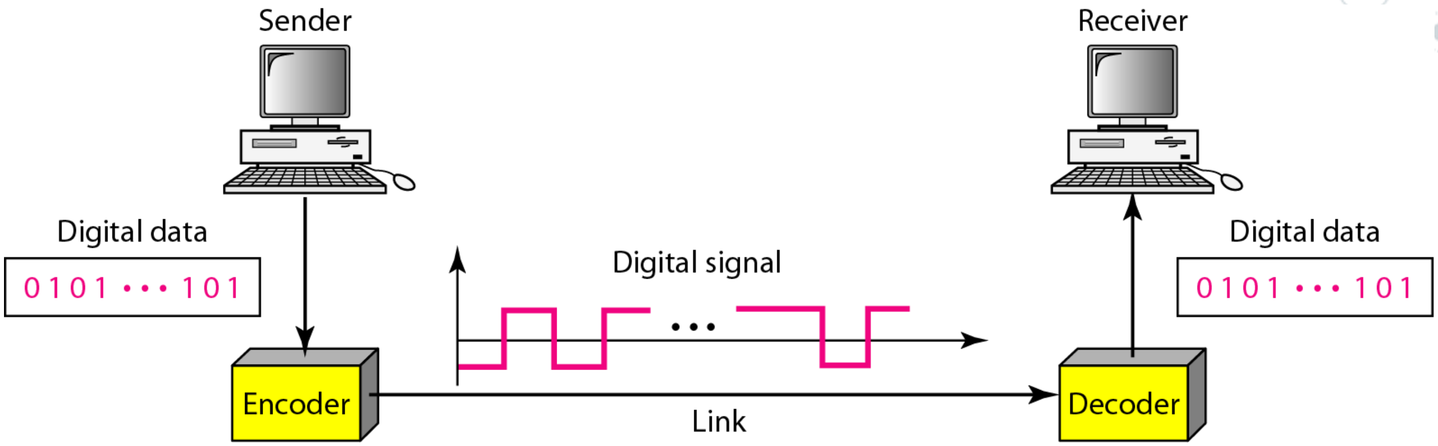
We assume that the average value of c is 1/2 .

The baud rate is then 50 kbaud.

$$S = c \times N \times \frac{1}{r} = \frac{1}{2} \times 100{,}000 \times \frac{1}{1} = 50{,}000 = 50 \text{ kbaud}$$

Digital-to-Digital Conversion

Scheme of Digital Transmission



- Involves three techniques:
  - line coding (always needed),
  - block coding,
  - scrambling.
- Line coding: the process of converting digital data to digital signals.

Digital-to-Digital Conversion

The Line Code Problems

Use many line coding schemes, each has advantages and disadvantages.

The particular line code scheme used is chosen to solution one or more of the following Problem:

1. Minimize transmission hardware;
2. Eliminate a DC component;
3. Facilitate synchronization;
4. Minimize spectral content (bandwidth).
5. Ease error detection and correction;

Solutions:
Multimedia access, Self-synchronization, Rate bit/signal, Paired disparity, Scrambling, Redundancy

For solution of error detection/correction use special code scheme width built-in error detection/correction and protocol solution.

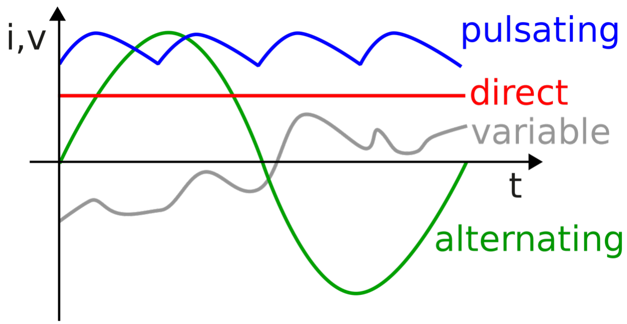
For solution of minimize bandwidth use special code scheme.
Bandwidth:

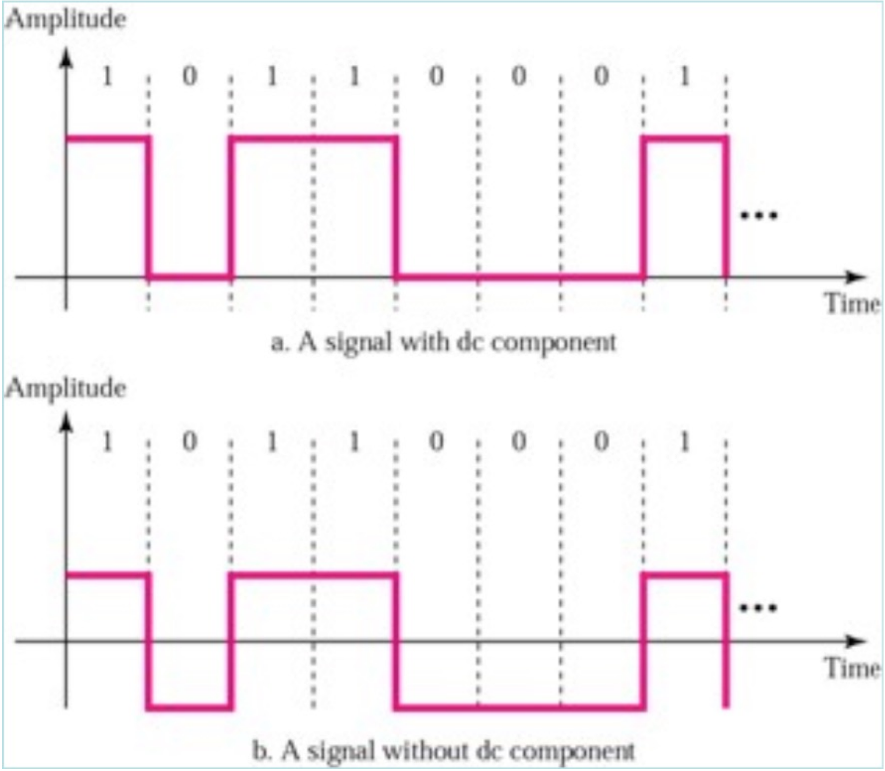
a. The range of frequencies that a medium can pass is called bandwidth.
b. It is the difference between the highest and lowest frequencies.

Digital-to-Digital Conversion

DC components Problem

- Baseline drifting. Long string of 0s or 1s can cause a drift in the baseline, and this create DC component.
- DC components (Direct Current) or low frequencies component (below 200 Hz)
  - cannot pass a transformer or telephone line,
  - DC component is extra energy and is ineffective.





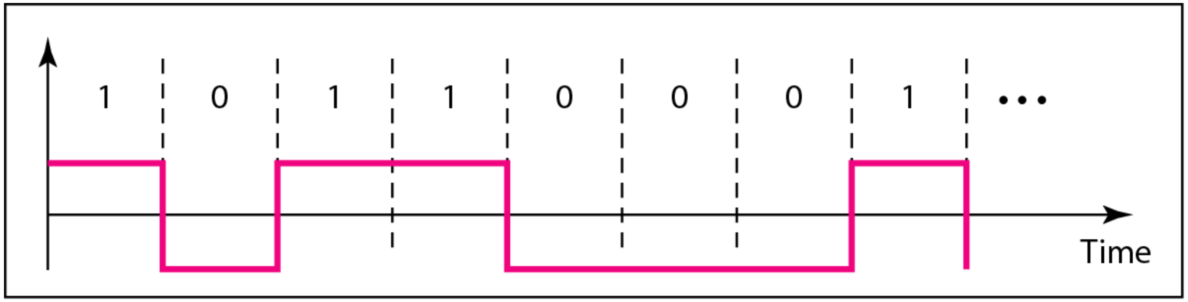
a. A signal with dc component

b. A signal without dc component

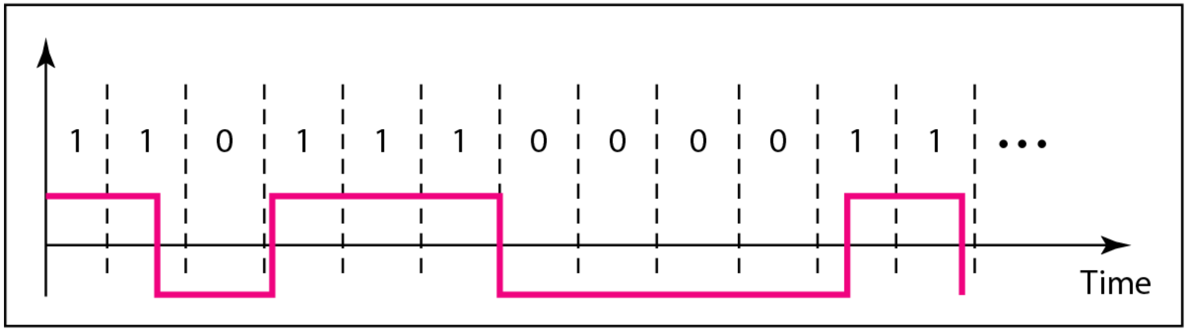
For DC component problem solution use special code schemes or codes with paired disparity technic.

Digital-to-Digital Conversion

Effect of Lack Synchronization



a. Sent



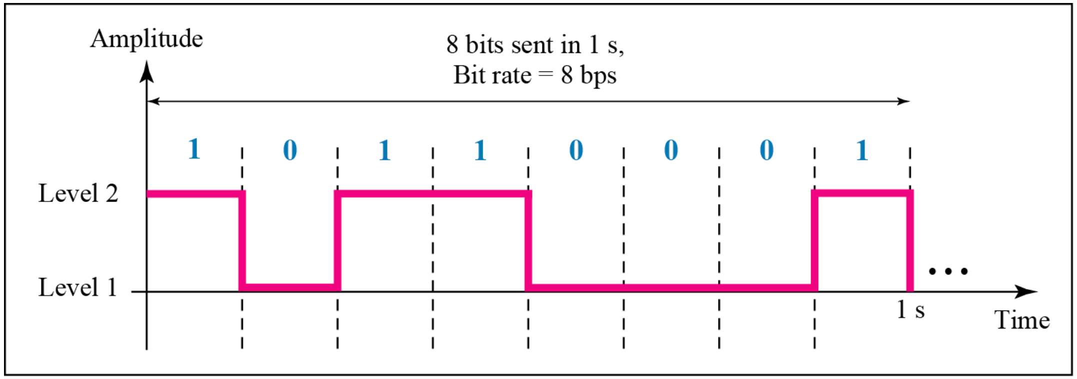
b. Received

For synchro-problem solution use:

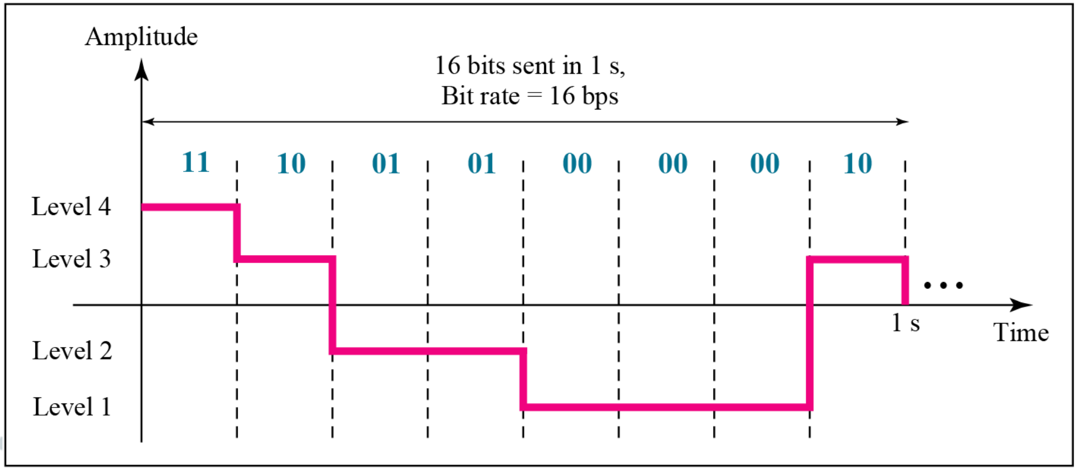
- one generator on sender and receiver (for short distance);
- self-synchronization codes (for long distance) with clock recovery.

Digital-to-Digital Conversion

Effect of Bit Rate



a. A digital signal with two levels



b. A digital signal with four levels

Different bitrate → different bandwidth.

Number N of bits per level L

$N = \log_2(L)$

(or L = 2^N)

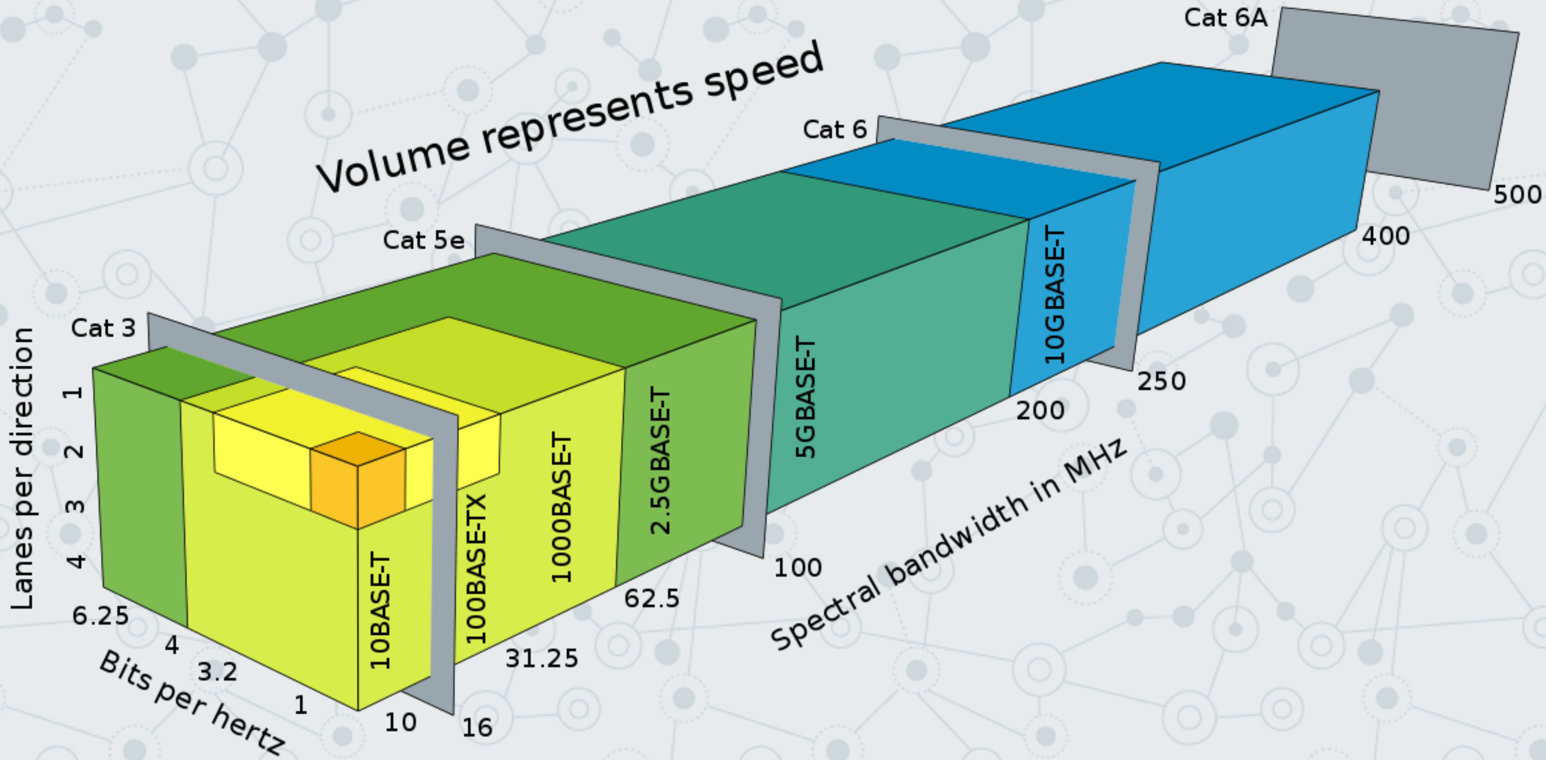
$N = \log_2(2)=1$

$N = \log_2(4)=2$

$N = \log_2(8)=3$

Digital-to-Digital Conversion

Line Coding Schemes

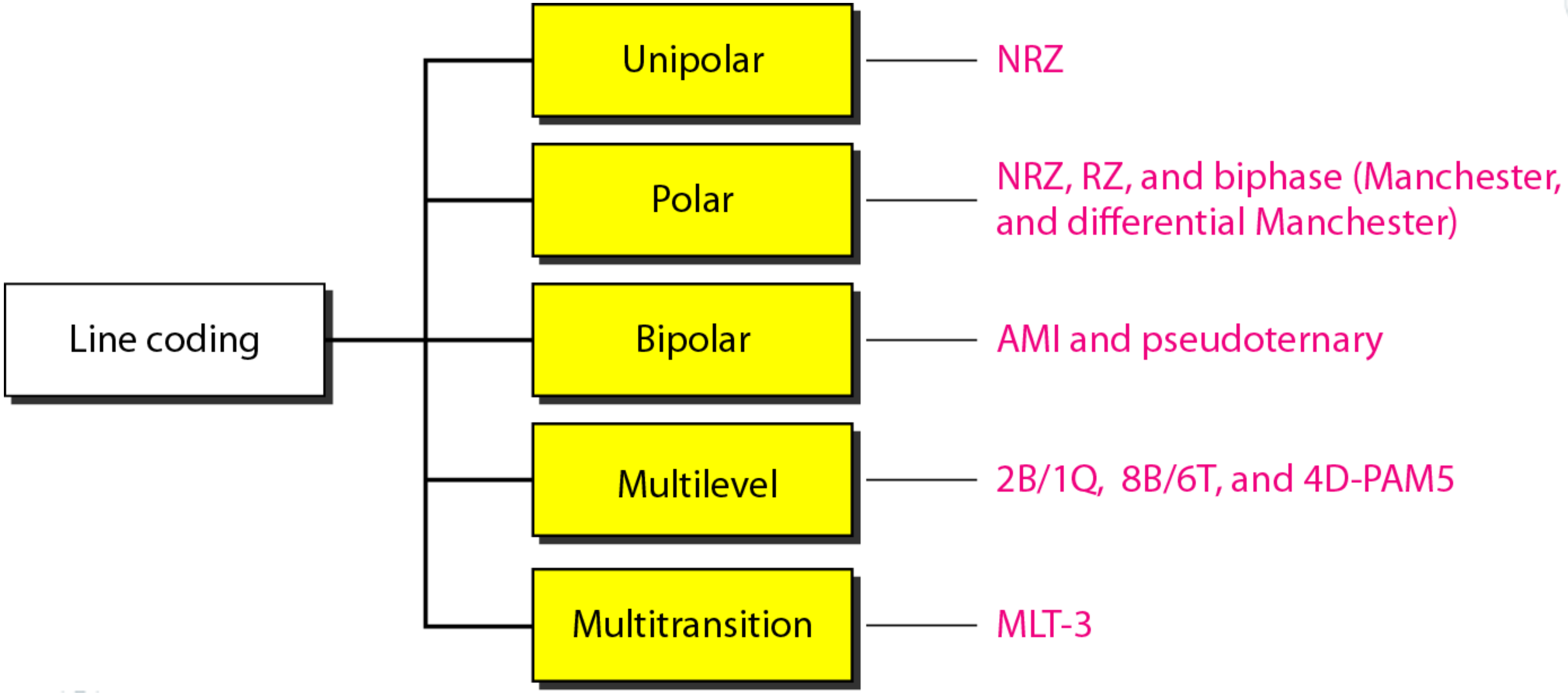


Line Coding Goal is to increase the data rate N whilst reducing the baud rate S for optimal transmit over media.

Digital-to-Digital Conversion

Line Coding Schemes: Genealogy

Line coding is always needed!



Digital-to-Digital Conversion

Applications of Line and Block Coding

- NRZ encoding: RS232 based protocols
- Manchester encoding: Ethernet networks (10 Mbit/s)
- Differential Manchester encoding: Token-Ring networks
- NRZ-Inverted encoding: FDDI (Fiber Distributed Data Interface)
- MLT-3: 100BASE-[TF]X (Fiber Optic)
- 4D-PAM5: 1000Base-T (Gigabit Ethernet)

Codes mBnB – maps block of m bits into n bits, n>m; mBnB line code provides increased number of transitions (signals) for improved synchronization:

- 1B/2B: is Manchester Code Ethernet
- 2B1Q: ISDN and HDSL
- 4B/5B: FDDI LAN
- 4B3T: Prior ISDN
- 8B6T: combination of 4B/5B and MLT-3 Fast Ethernet (100 Mbit/s)
- 8B10B: Gigabit Ethernet
- 64B66B: 10GEthernet

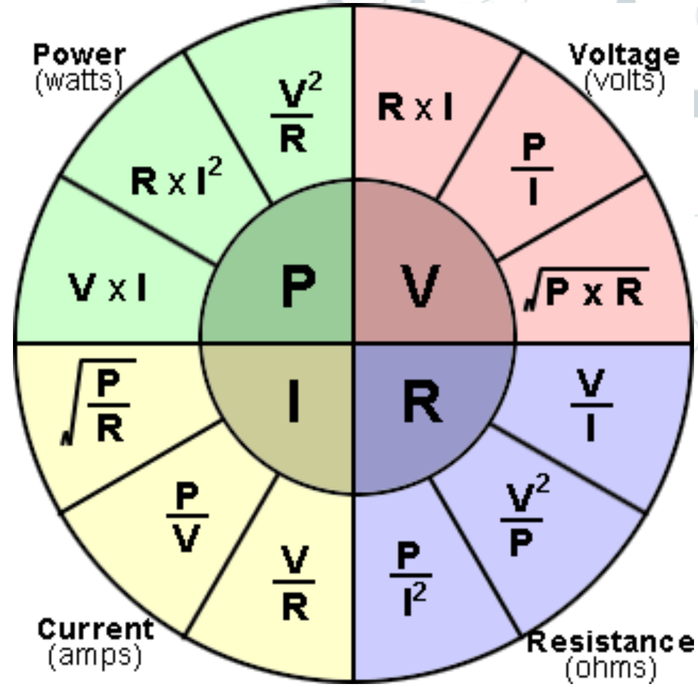
Digital-to-Digital Conversion

Unipolar Scheme: NRZ

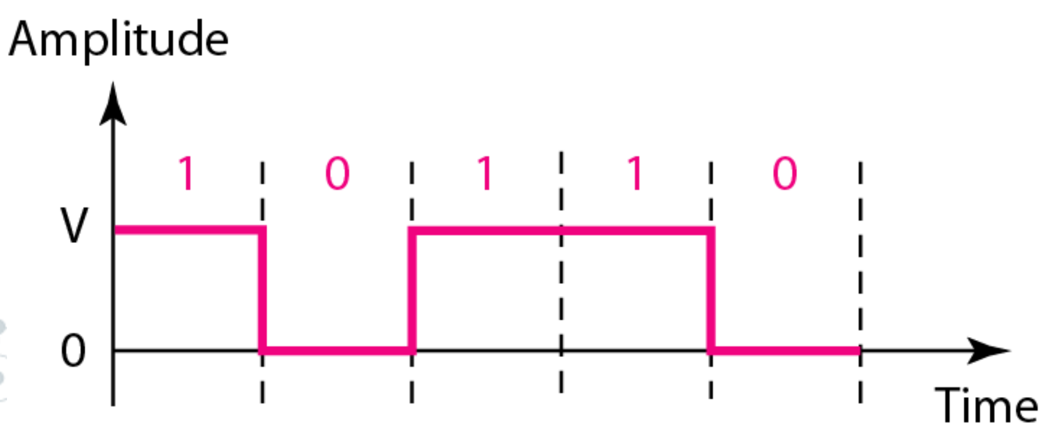
+One polarity: one level of signal voltage
+Unipolar NRZ (None-Return-to-Zero) is simple, but have a problems with:

-DC component: Cannot travel through microwave or transformer
-Synchronization: Consecutive 0's and 1's are hard to be synchronized → Separate line for a clock pulse

Normalized power is double that for polar NRZ



Ohm's Law



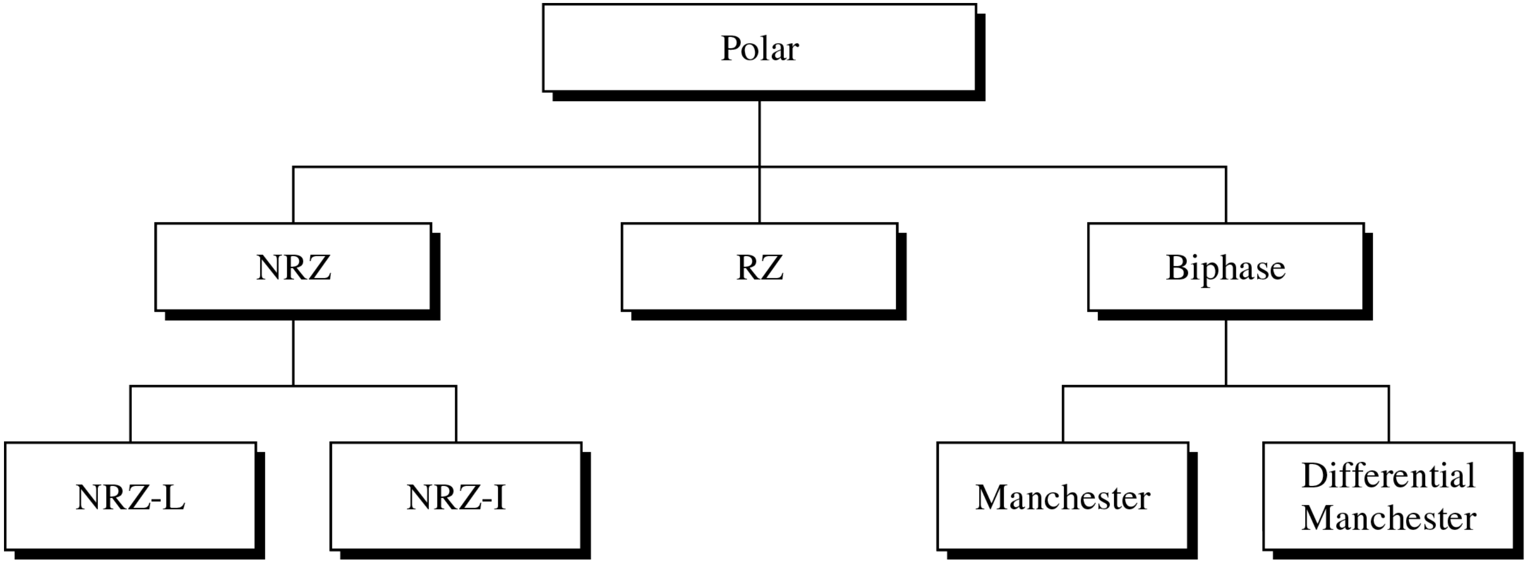
$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

Digital-to-Digital Conversion

Polar Schemes Genealogy

Two polarity: two levels of voltage
Problem of DC component is alleviated (NRZ, RZ) or eliminated (Biphase)



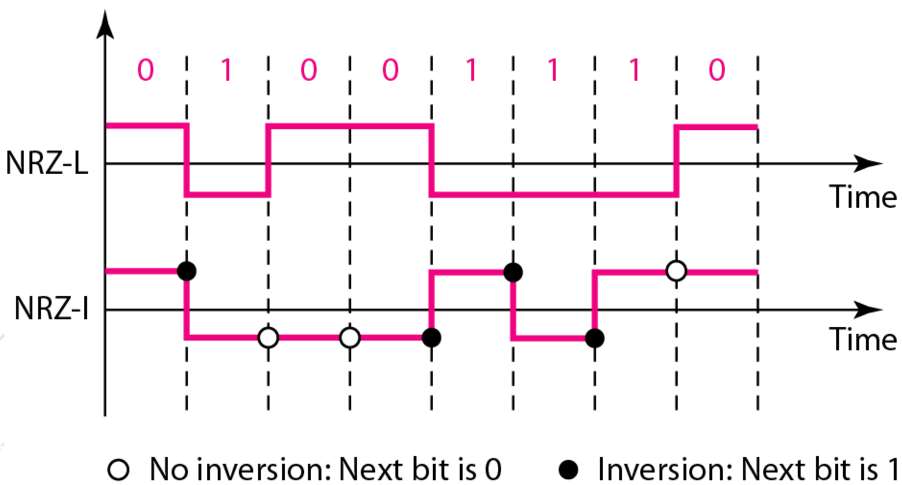
Digital-to-Digital Conversion

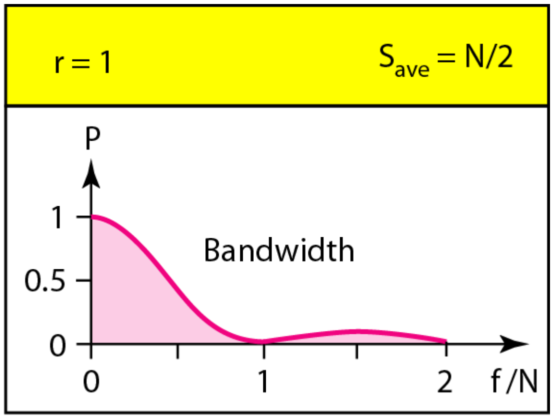
Polar NRZ Schemes: NRZ-L and NRZ-I

NRZ-L (Non Return to Zero-Level) - level of the voltage determines the value of the bit (0→+V, 1→-V)

NRZ-I (Non Return to Zero-Invert) - inversion or the lack of inversion determines the value of the bit (Inverse → next bit 1)

+ Both simple to implement
- Both have a DC component problem
- Both have an average signal rate (Save) of N/2 bauds
- Both no error detection
-- Baseline wandering problem, both, but NRZ-L is twice severe
-- Synchronization problem, both, but NRZ-L is more serious





Digital-to-Digital Conversion

Polar NRZ-I, what Signal Rate & Bandwidth?

Task.

A system is using NRZ-I to transfer 1-Mbps data.
What are the average signal rate and minimum bandwidth?

Solution.
The average signal rate is S= c x N x r = 1/2 x N x 1 = 500 kbaud.
The minimum bandwidth for this average baud rate is Bmin = c * N * 1/r = S = 500 kHz.
Note.
N = 1 Mbps = 1000 kbps
r = 1
c = 1/2 for the avg. case as worst case is 1 (for sequence 00000…) and best case is 0 (for sequence 111111…)

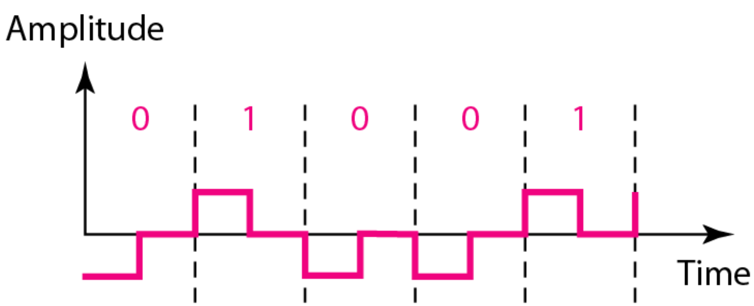
S = c * N * 1/r, where
- S is the number of signal elements;
- N is the date rate;
- c is the case factor (worst, best, average);
- r mapping ratio is the number of data elements 'd' carried by a signal element 's' r=d/s.

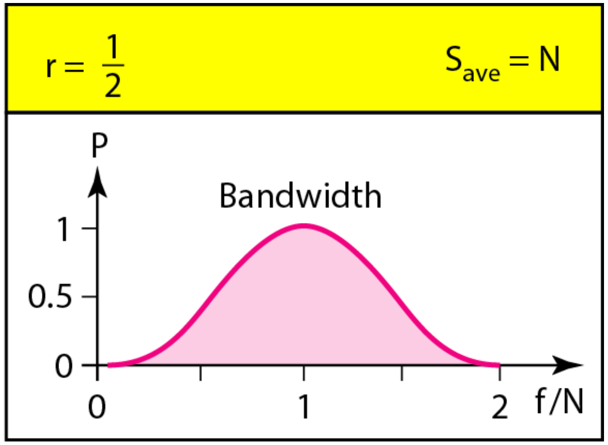
Digital-to-Digital Conversion

Polar RZ Scheme

Provides synchronization for consecutive 0s/1s

Signal changes during each bit. Three values (+, -, 0) are used
Bit 1: positive-to-zero transition,
Bit 0: negative-to-zero transition





+ No DC components and baseline wandering.
+ Self synchronization - transition indicates symbol value.
- Scheme has 2 signal transitions per bit and therefore requires a wider bandwidth.
- No error detection capability.
- More complex as it uses three voltage level.

Digital-to-Digital Conversion

Polar Biphase Schemes: Manchester & Dif. Manchester

Signal transition at the middle of the bit is used for synchronization

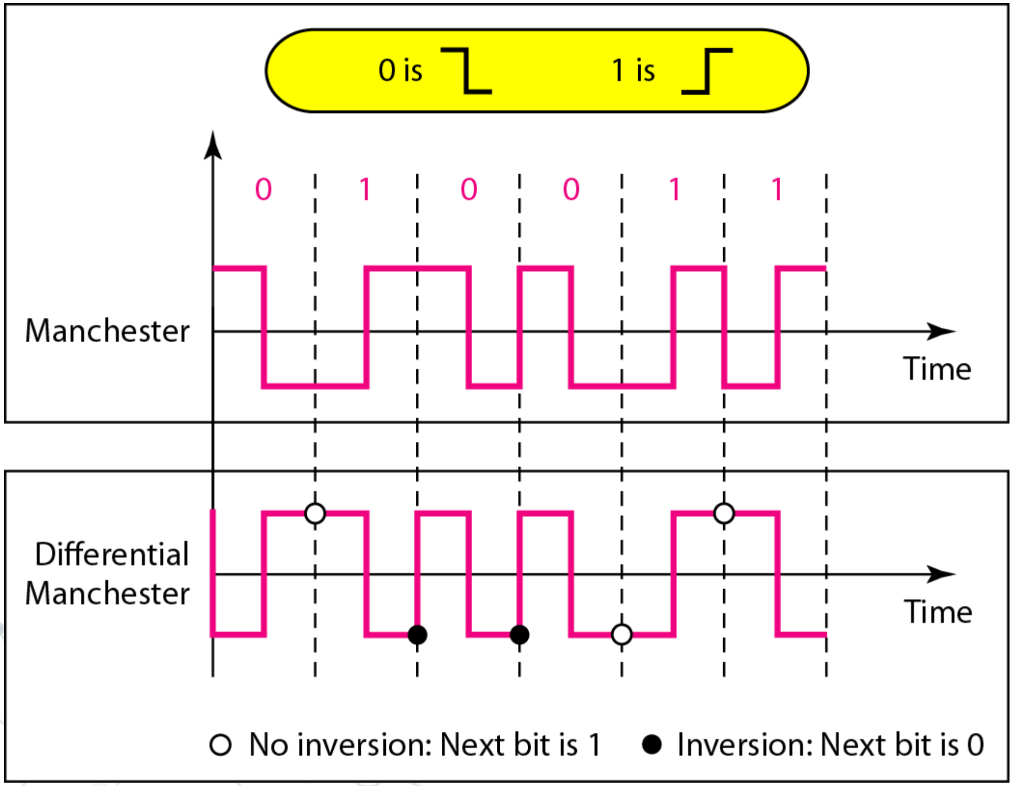
Manchester
Used for Token-bus, Ethernet 10BASE5 LAN (standards IEEE 802.3, IEEE 802.4)
Combination of NRZ-L and RZ schemes
Every symbol has a level transition in the middle: from high to low or low to high.
Uses only two voltage levels.
Bit 1: negative-to-positive transition
Bit 0: positive-to-negative transition

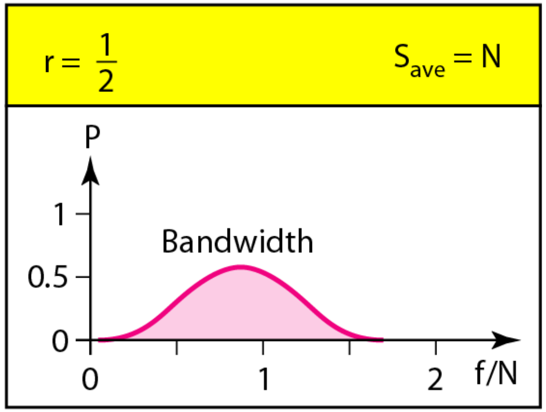
Differential Manchester
Used for Token-ring LAN (standard IEEE 802.5)
Combination of NRZ-I and RZ schemes
Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value.
One symbol causes a level change the other does not.
Bit 1: no transition at the beginning of a bit
Bit 0: transition at the beginning of a bit

Digital-to-Digital Conversion

Polar Biphase Schemes: Manchester & Dif. Manchester

+ No DC component and no baseline wandering.
+ Self synchronization.
- Minimum bandwidth both, is 2 times that of NRZ.
- No error detection.





Digital-to-Digital Conversion

Bipolar Schemes

AMI (Alternate Mark Inversion) (Pseudoternary is the reverse of AMI)
- Three levels of voltage, called “multilevel binary”

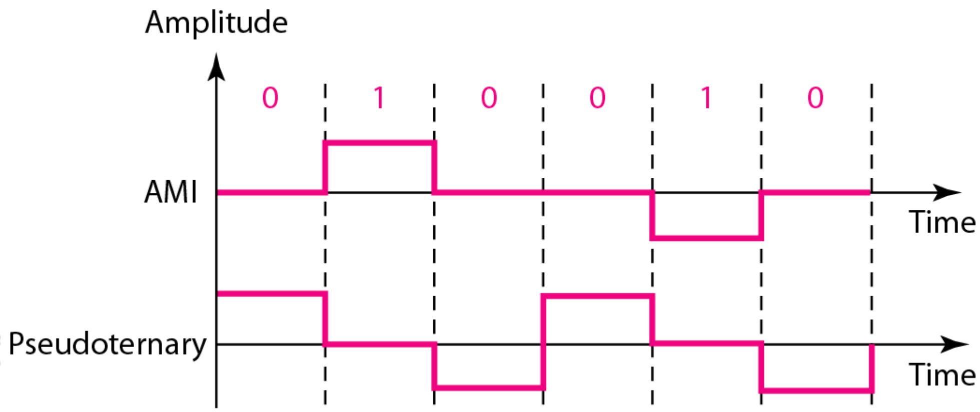
Bit 0: zero voltage,

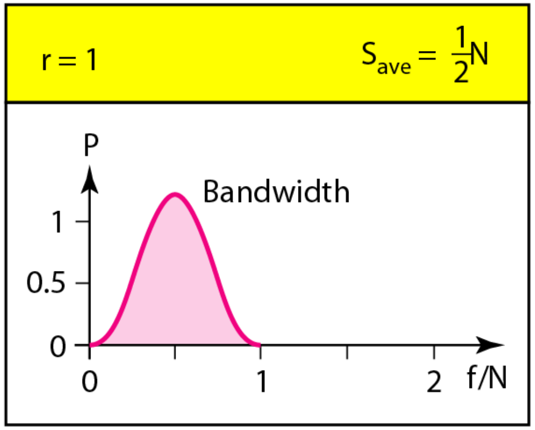
Bit 1: alternating +1/-1

Bath codes better alternative to NRZ.

+ no DC component problem
- no Self synchronization because long runs of “0”s results in no signal transitions.

+ small bandwidth (signal rate=1)
- no error detection.





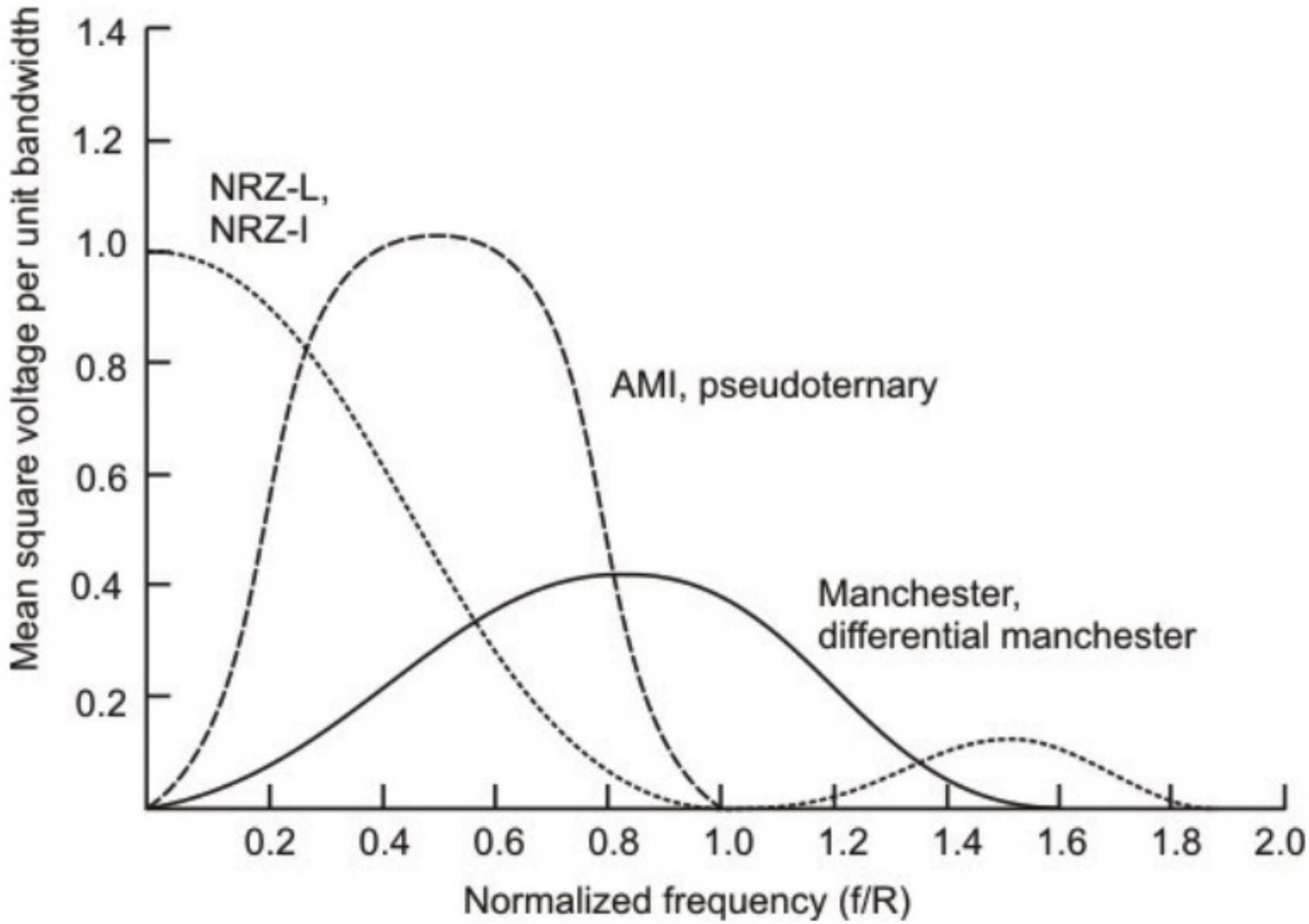
Digital-to-Digital Conversion

Summary of Line Coding Schemes

Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Polar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multitransition	MLT-3	$B = N/3$	No self-synchronization for long 0s

Digital-to-Digital Conversion

Frequency spectrum (bandwidth) of Line Coding Schemes



Digital-to-Digital Conversion

To be continue: Line Coding, Block Coding, Scrambling