

Data Communications and Networking Fourth Edition

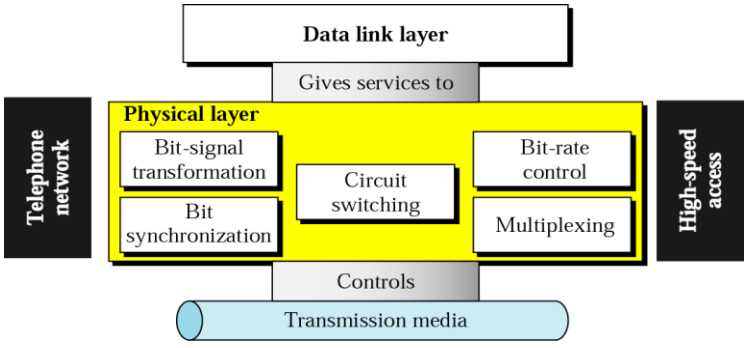
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Chapter 4

Digital Transmission

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Physical Layer



Physical Layer Topics to Cover

Signals

Digital Transmission

Analog Transmission

Multiplexing

Transmission Media

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Digital Transmission

- **digital-to-digital conversion (**convert digital data to digital signals**)**

Analog-to-digital conversion (ange an analog signal to a digital signal.**)**

- **transmission modes**

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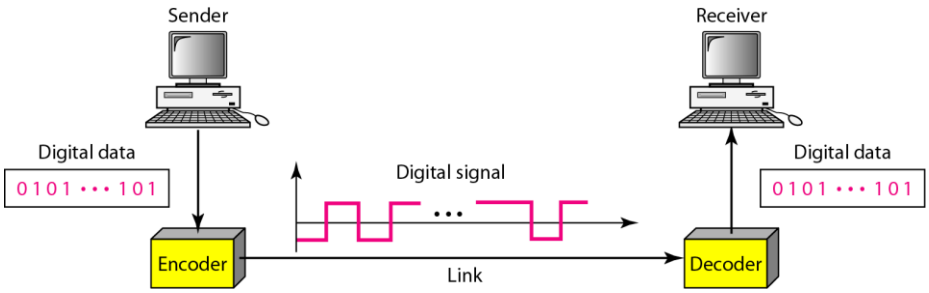
4-1 DIGITAL-TO-DIGITAL CONVERSION

- As explained in the last chapter data can be either digital or analog. In addition, signals that represent data can also be digital or analog.
- The conversion of digital data by using digital signals involves three techniques:
  - **Line Coding**
  - **Block Coding**
  - **Scrambling**

Line Coding

- **Line coding** is the process of converting digital data to digital signals
- Converting a string of 1's and 0's (digital data) into a sequence of signals that denote the 1's and 0's.
- For example a high voltage level (+V) could represent a "1" and a low voltage level (0 or -V) could represent a "0".

Figure 4.1 *Line coding and decoding*



- Line coding converts a sequence of bits to a digital signal.
- At the sender, digital data are encoded into a digital signal;
- At the receiver, the digital data are recreated by decoding the digital signal

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Mapping Data symbols onto Signal levels

- A data symbol (or element) can consist of a number of data bits:
  - 1 , 0 or
  - 11, 10, 01, ……
- A data symbol can be coded into a single signal element or multiple signal elements
  - 1 -> +V, 0 -> -V
  - 1 -> +V and -V, 0 -> -V and +V
- The ratio 'r' is the number of data elements carried by a signal element.

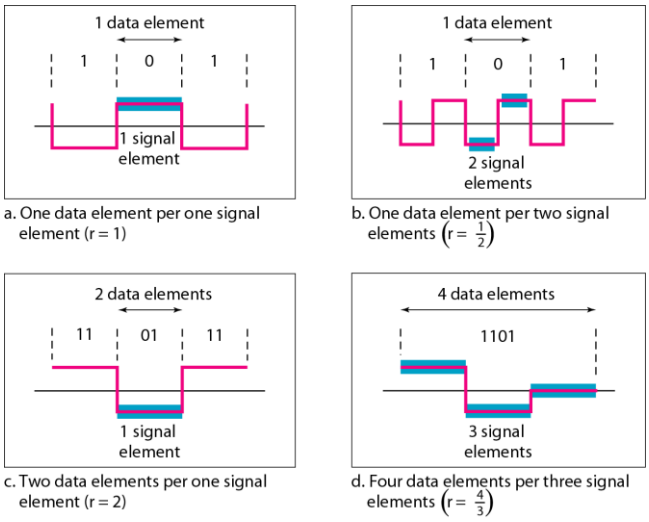
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Relationship between data rate and signal rate

- The data rate defines the number of bits sent per sec - bps. It is often referred to the bit rate.
- The signal (baud) rate is the number of signal elements sent in a second and is measured in bauds. It is also referred to as the modulation rate.
- Goal is to increase the data rate whilst reducing the baud rate.

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Figure 4.2 *Signal element versus data element*



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 $\left(r = \frac{4}{3}\right)$

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Data rate and Baud (signal) rate

- The baud or signal rate can be expressed as:

S = c x N x 1/r bauds

where N is data rate (bps)

c is the case factor (worst, best & avg.)

r is the ratio between data element & signal element

Example 4.1

A signal is carrying data in which one data element is encoded as one signal element (r = 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

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



Note

Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.

The bandwidth of a nonperiodic signal is continuous with an infinite range. So, the bandwidth is theoretically infinite. However, many of the components have such a small amplitude that they can be ignored. The effective bandwidth is finite.

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Line encoding C/Cs

- Self synchronization - the clocks at the sender and the receiver must have the same bit interval.
- If the receiver clock is faster or slower the bit intervals are not matched and the receiver might misinterpret the signals.

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Figure 4.3 *Effect of lack of synchronization*

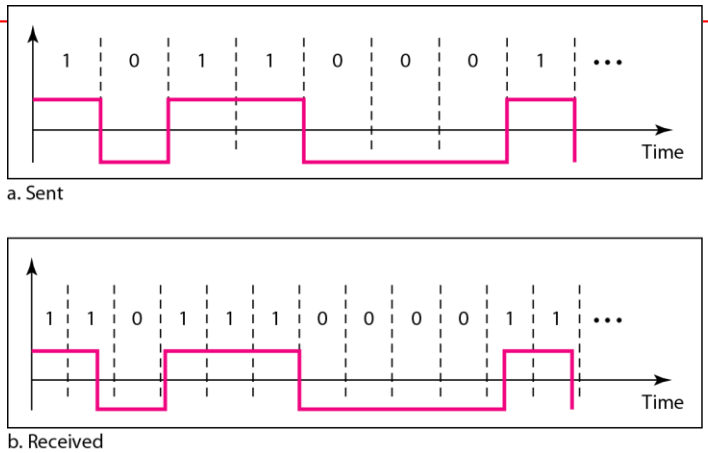


Figure 4.3 shows a situation in which the receiver has a shorter bit duration. The sender sends 10110001, while the receiver receives 110111000011.

Line encoding C/Cs

- Error detection - errors occur during transmission due to line impairments.
- Some codes are constructed such that when an error occurs it can be detected. For example: a particular signal transition is not part of the code. When it occurs, the receiver will know that a symbol error has occurred.

Line encoding C/Cs

- Noise and interference - there are line encoding techniques that make the transmitted signal "immune" to noise and interference.
- This means that the signal cannot be corrupted, it is stronger than error detection.

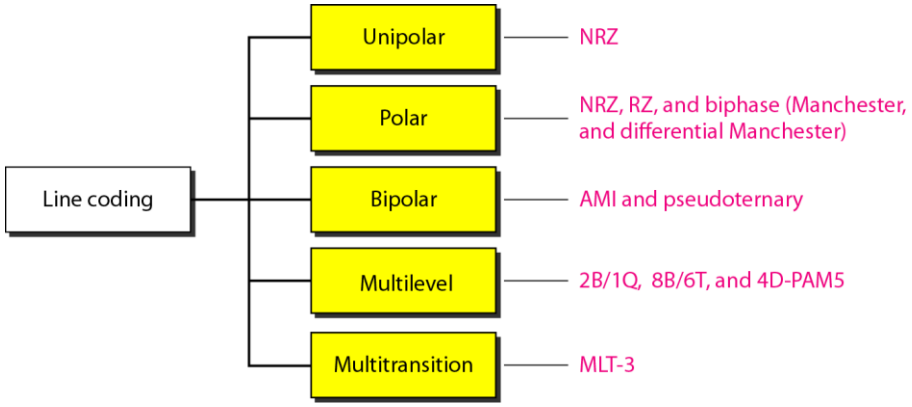
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Line encoding C/Cs

- Complexity - the more robust and resilient the code, the more complex it is to implement and the price is often paid in baud rate or required bandwidth.

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Line Coding Schemes



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Unipolar

- All signal levels are on one side of the time axis - either above or below.
- NRZ - Non Return to Zero scheme is an example of this code. The signal level does not return to zero during a symbol transmission.
- Scheme is prone to baseline wandering and DC components. It has no synchronization or any error detection. It is simple but costly in power consumption.

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Baseline Wandering

- In decoding a digital signal, the receiver calculates a running average of the received signal power. This average is called the ***baseline***
- A long string of 0s or 1s can cause a drift in the baseline (**baseline wandering**) and make it difficult for the receiver to decode correctly.

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DC Components

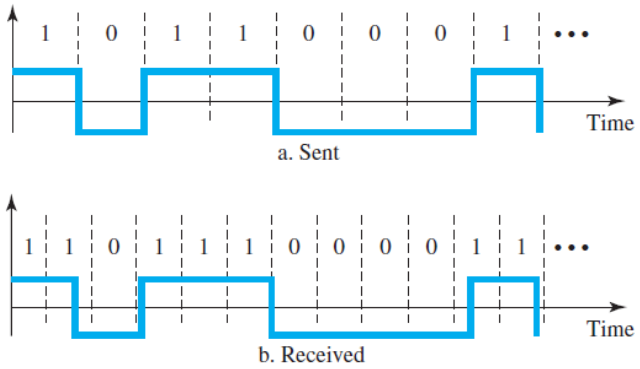
- When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies (results of Fourier analysis).
- These frequencies around zero, called DC (direct-current) *components,* present problems for a system that cannot pass low frequencies or a system that uses electrical coupling (via a transformer).
- For example, a telephone line cannot pass frequencies below 200 Hz.

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Self-synchronization

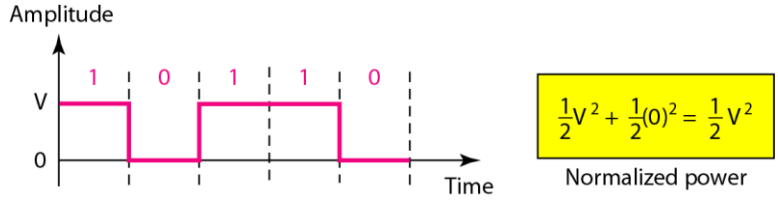
- If the receiver clock is faster or slower than the sender clock, the bit intervals are not matched and the receiver might misinterpret the signals.
- A **self-synchronizing** digital signal includes timing information in the data being transmitted.
- This can be achieved if there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.

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Figure 4.5 *Unipolar NRZ scheme*

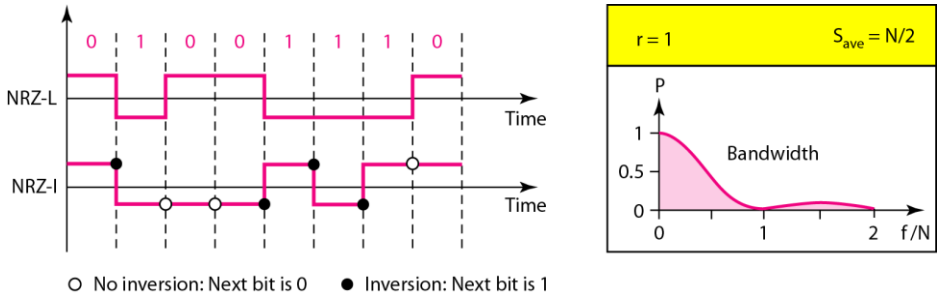


- The positive voltage defines bit 1 and the zero voltage defines bit 0.
- It is called NRZ because the signal does not return to zero at the middle of the bit.
- the normalized power (the power needed to send 1 bit per unit line resistance) is double that for polar NRZ

Polar - NRZ

- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.
- There are two versions:
  - NZR - Level (NRZ-L) - positive voltage for one symbol and negative for the other
  - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a "1" symbol inverts the polarity a "0" does not.

Figure 4.6 *Polar NRZ-L and NRZ-I schemes*





Note

In NRZ-L the level of the voltage determines the value of the bit. In NRZ-I the inversion or the lack of inversion determines the value of the bit.



Note

NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.

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Note

NRZ-L and NRZ-I both have a DC component problem and baseline wandering, it is worse for NRZ-L. Both have no self synchronization &no error detection. Both are relatively simple to implement.

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Example 4.4

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

Solution

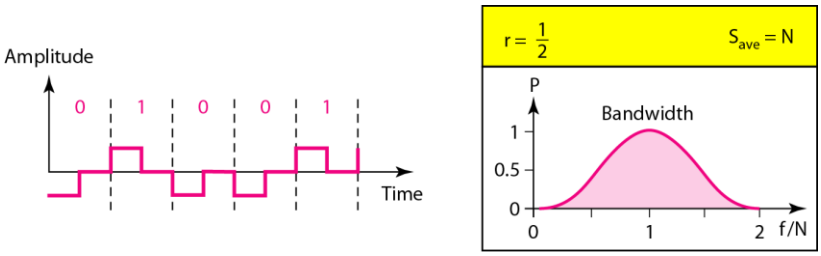
The average signal rate is S= c x N x R = 1/2 x N x 1 = 500 kbaud. The minimum bandwidth for this average baud rate is $B_{min} = S = 500$ kHz.

Note c = 1/2 for the avg. case as worst case is 1 and best case is 0

Polar - RZ

- The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized. The receiver does not know when one bit has ended and the next bit is starting.
- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- Each symbol has a transition in the middle. Either from high to zero or from low to zero.

Figure 4.7 *Polar RZ scheme*



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Figure 4.7 *Polar RZ scheme*

Advantages

- No DC components or baseline wandering.
- Self synchronization - transition indicates symbol value.
- More complex as it uses three voltage level. It has no error detection capability.

Disadvantages

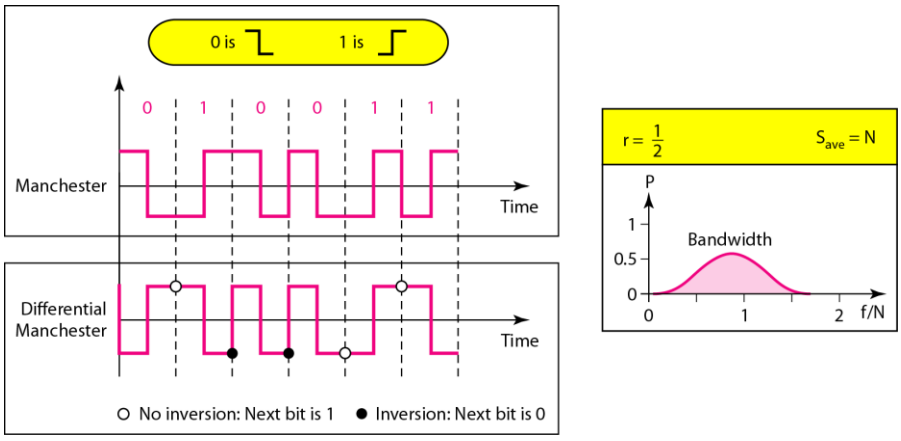
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth.
- RZ uses three levels of voltage, which is more complex to create

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Polar - Biphase: Manchester and Differential Manchester

- Manchester coding consists of combining the 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.
- Differential Manchester coding consists of combining the 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.

Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*





Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.



Note

The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ. The is no DC component and no baseline wandering. None of these codes has error detection.

Multilevel Schemes

- In these schemes we increase the number of data bits per symbol thereby increasing the bit rate.
- Since we are dealing with binary data we only have 2 types of data element a 1 or a 0.
- We can combine the 2 data elements into a pattern of "m" elements to create "2^m" symbols.
- If we have L signal levels, we can use "n" signal elements to create L^n signal elements.

Code C/Cs

- Now we have 2^m symbols and L^n signals.
- If $2^m > L^n$ then we cannot represent the data elements, we don't have enough signals.
- If $2^m = L^n$ then we have an exact mapping of one symbol on one signal.
- If $2^m < L^n$ then we have more signals than symbols and we can choose the signals that are more distinct to represent the symbols and therefore have better noise immunity and error detection as some signals are not valid.



Note

In *m*B*n*L schemes, a pattern of *m* data elements is encoded as a pattern of *n* signal elements in which $2^m \leq L^n$.

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Representing Multilevel Codes

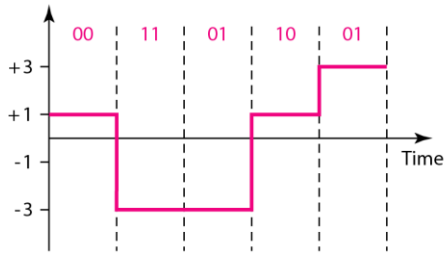
- We use the notation mBnL, where m is the length of the binary pattern, B represents binary data, n represents the length of the signal pattern and L the number of levels.
- L = B binary, L = T for 3 ternary, L = Q for 4 quaternary.

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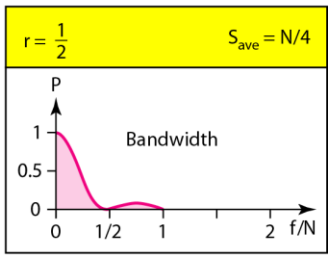
Figure 4.10 *Multilevel: 2B1Q scheme*

Next bits	Next level (Previous level: positive)	Next level (Previous level: negative)
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition table



Assuming positive original level



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