南方科技大學
SOUTH UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA

EE206 Communication Principles

Part B (Weeks 9-16)

Digital Communication Principles

Spring 2020

Outline

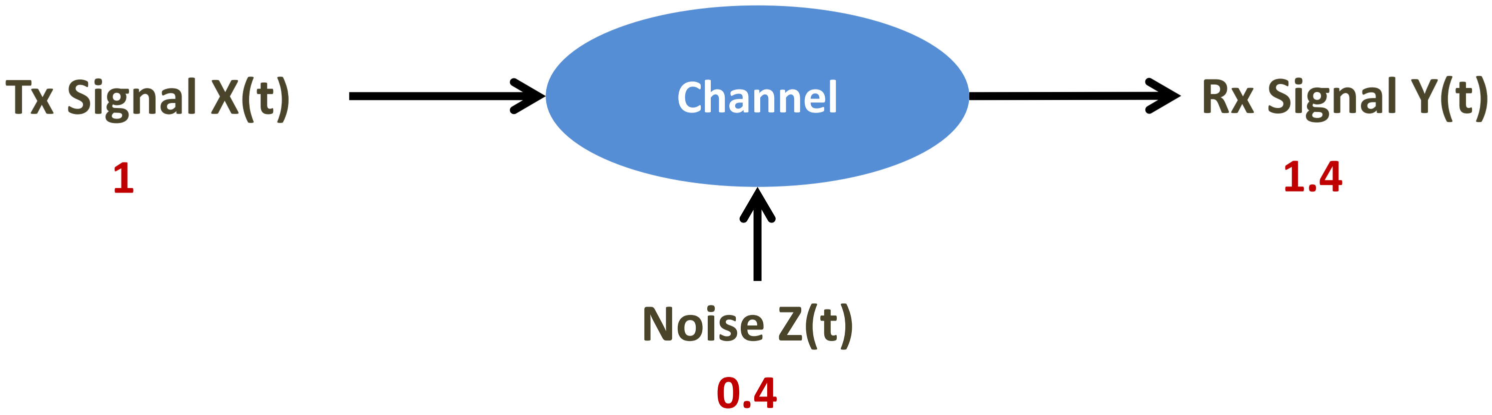
Analog signal: continuous in both time and signal scale

Digital signal: discrete in both time and signal scale

- Why do we need digital communications?
- Semi-digital representation of analog signals
  - Sampling: digitalization in time domain
  - Analog pulse modulation schemes: PAM, PDM, PPM
- Generation, detection and analysis of PPM
- Digital representation of analog signals
  - Quantization: digitalization in signal scale
  - Quantization noise
  - Digital modulation schemes: PCM, DM

Why Digital Communications?

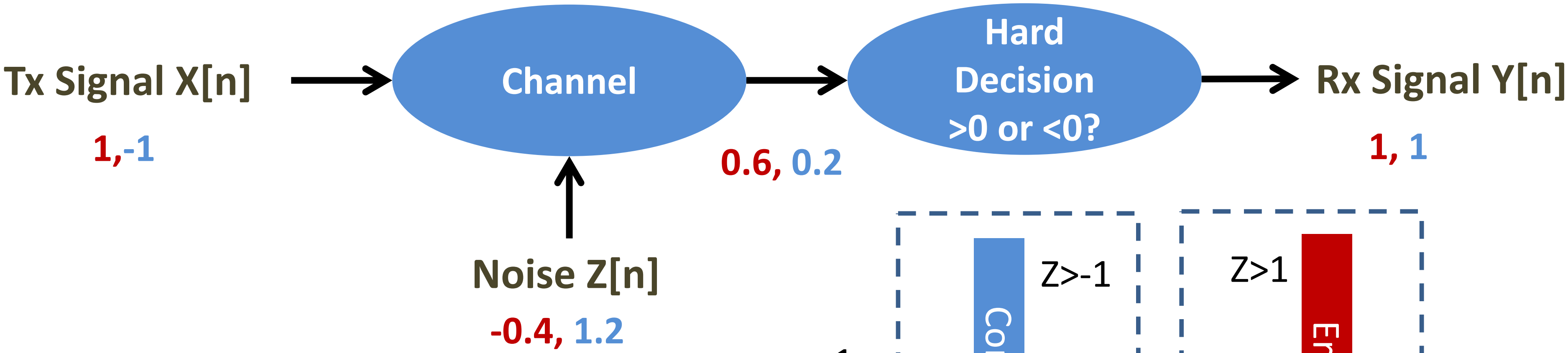
- Lots of benefits …
- Analog signal transmission example

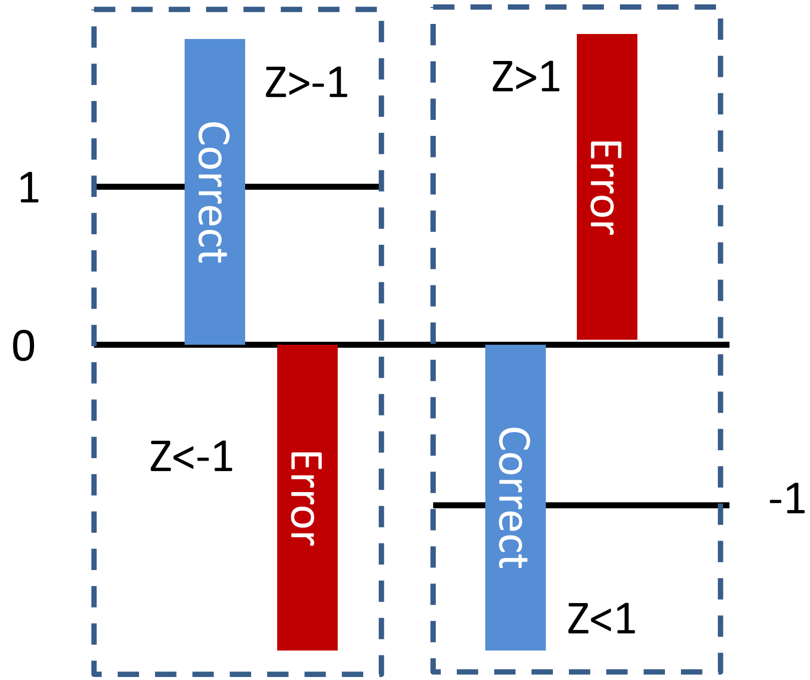


- Since noise Z(t) is unknown, it is impossible for the receiver to detect the exact value of X(t) given Y(t)=1.4
- How to improve the received signal's quality?

Why Digital Communications?--- Contd.

- Digital signal transmission example





- Error occurs when
  - Z<-1 for X=1
  - Z>1 for X=-1

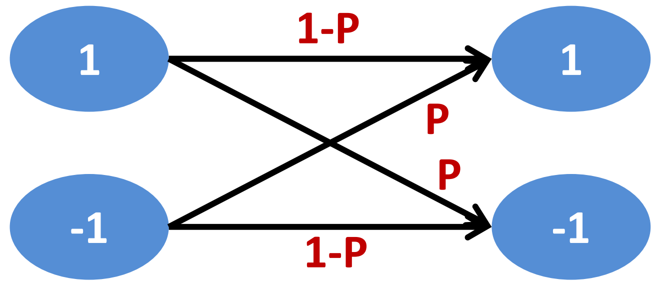
Why Digital Communications?--- Contd.

- Let

$$\Pr(Z < -1) = \Pr(Z > 1) = P$$

transmission model becomes

Binary Symmetric Channel:



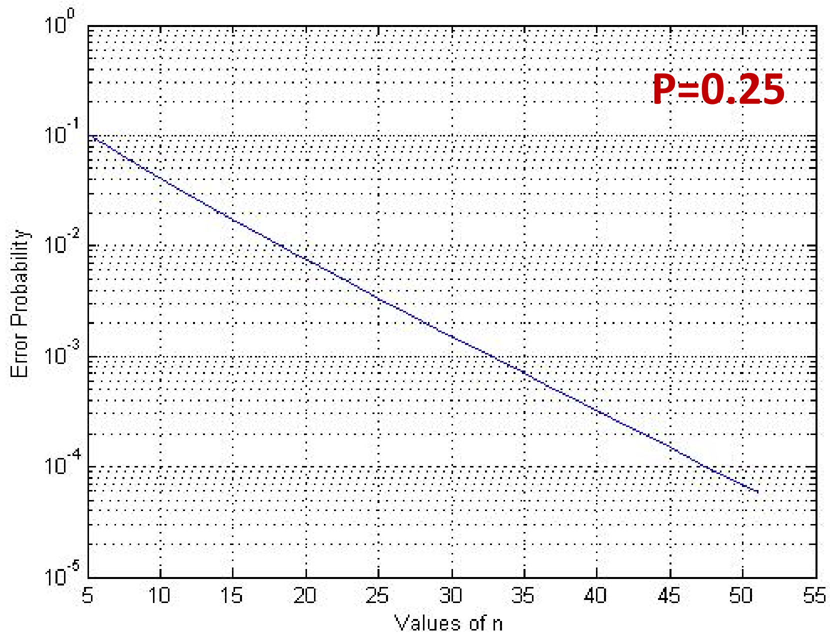
- Repetition code: reduce bit error probability by repeating each bit n times (n is odd) → 奇数
  - Code rate: 1/n
  - 1/n information bit per transmission

Repetition Code

- Example 1 (n=5)
  - Transmit bit: 1
  - After coding: 1 1 1 1 1
  - Received bits may be: 1 -1 1 1 -1
  - Majority voting: compare the # of 1 and -1
  - Receiver guesses the transmitted bit is 1
- Repetition code can cut down the error probability
- Example 2 (n=5)
  - Received bits may be: 1 -1 -1 1 -1
  - Receiver guesses the transmitted bit is -1
- Probability of 1-bit error $=\binom{n}{1} P(1-P)^{n-1}$
- Probability of 2-bit error $=\binom{n}{2} P^2(1-P)^{n-2}$
- …

Error Analysis

$$
\begin{aligned}
&\mathbf{Pr}(\boldsymbol{Error\ Occurs})\\
&= \mathbf{Pr}\left(\boldsymbol{More\ than\ \frac{n}{2}\ bits\ are\ wrong}\right)\\
&= \sum_{i=\lceil \frac{n}{2} \rceil}^{n} \boldsymbol{Pr(i\ bits\ are\ wrong)}\\
&= \sum_{i=\lceil \frac{n}{2} \rceil}^{n} \binom{n}{i} P^{i}(1-P)^{n-i}
\end{aligned}
$$



- Observation: Bit error rate (BER) can be arbitrarily small when increasing n (or decreasing code rate) → n↑, code rate ↓

Thomas M. Cover, and Joy A. Thomas, ***Elements of Information Theory***, Wiley-Interscience, 2006

若 n↑, code rate 不变, 则 BW↑

Channel Coding & Information Theory

- In digital communication, information bits are usually protected by channel coding, where redundant bits are added to correct potential transmission error.
- In repetition code, information is protected by repeating, whose protection efficiency is actually low.
- Channel coding schemes used in LTE: convolutional code, turbo code
  - These coding schemes could lead to higher data rate (given BER) or lower BER (given data rate)
- What's the maximum data rate for error-free transmission (Shannon Capacity)?
- The capacity of previous example is:

$$\boldsymbol{C = 1 + P\log_2 P + (1-P)\log_2(1-P)}$$

P=0, P=1 最好, P=0.5 性能最差

Summary

In analog communications,

- the only way to improve the signal receiving is to enhance the transmission power. However the transmission power of a communication system is usually limited.
- There is always distortion at the received signal.

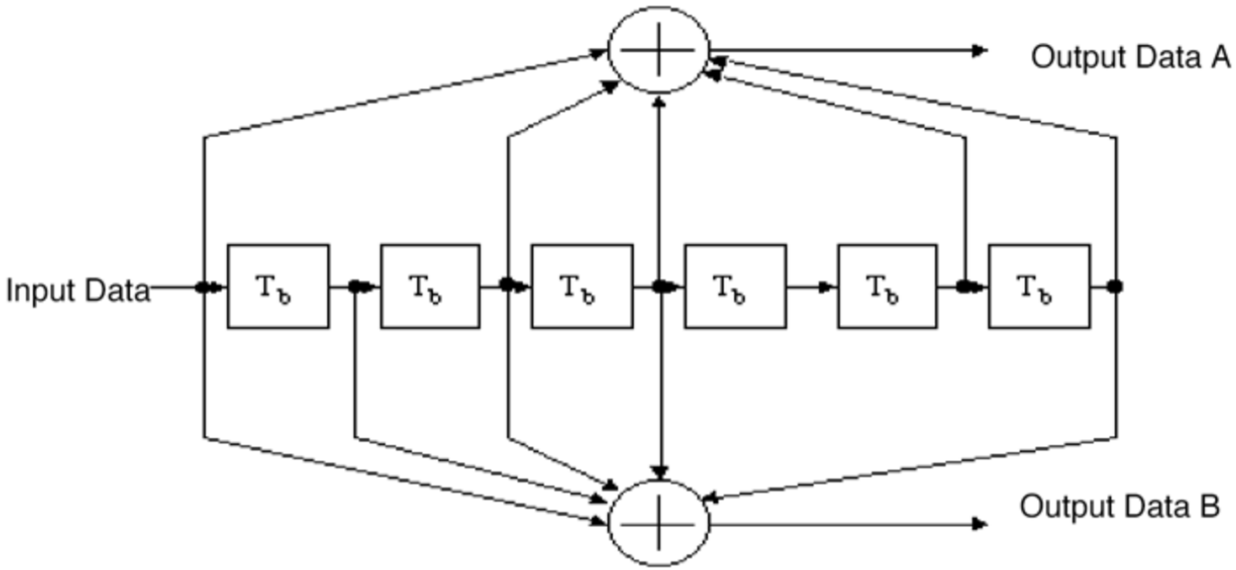
In digital communications,

- we are able to control the quality of received signal by both power and channel coding;
- the probability of transmission error can be arbitrarily small

Why digital communications have such advantages?

Advanced Knowledge – Convolutional Encoder

- One channel coding scheme in WiFi
- Convolutional encoder via shift register (Tb)



Wikipedia on convolutional code:
https://en.wikipedia.org/wiki/Convolutional_code
A story about the Viterbi decoder:
https://arxiv.org/pdf/cs/0504020v2.pdf

Homework #D1

- D1.1

Given the following communication channel, if each information bit is repeated 4 times (code rate = 1/5) at the transmitter and P=0.9, how to achieve a good bit error rate at the receiver? What will the bit error rate be?

Binary Symmetric Channel: