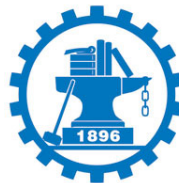# Elements of Information Theory

Lecture 1
Introduction to The Content

Instructor: Yichen Wang

Ph.D./Professor

School of Information and Communications Engineering
Division of Electronics and Information
Xi'an Jiaotong University

Outlines

> **Introduction to The Course**

> **History of Communications**

> **Introduction to Communications System**

> **Introduction to Information Theory**

> **Introduction to The Contents**

Introduction to The Course

- **Course Name**

  ---- Elements of Information Theory

- **Prerequisite Courses**

  ---- Probability Theory

  ---- Stochastic Process

- **Period**

  ---- 40 Class-hours/16 Weeks

- **Homework, Quiz and Exam**

  ---- 3 homework assignments + 1 quiz (30%)

  ---- Final exam (70%)

Introduction to The Course

- ## Office

  ---- *Room 448, West 1 Building, Xingqing Campus*

- ## Contact

  ---- *wangyichen0819@mail.xjtu.edu.cn*

- ## Webpage for The Course

  ---- *http://gr.xjtu.edu.cn/web/wangyichen/information-theory*

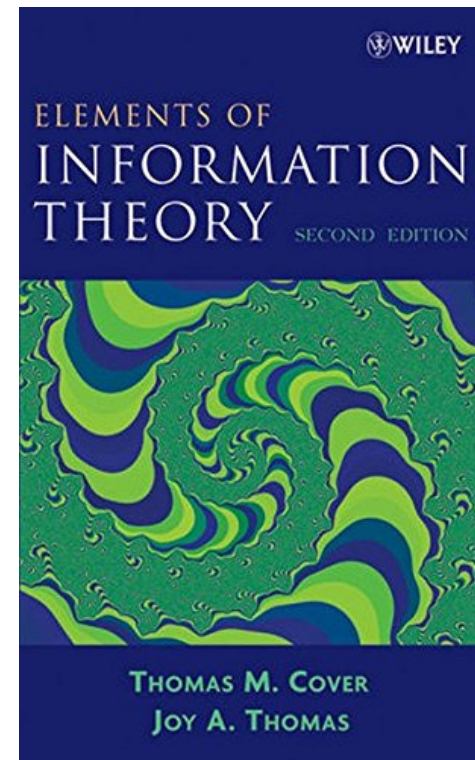# Introduction to The Course

● **Course Textbook**

---- Elements of Information Theory (2nd Edition)

(written by Thomas M. Cover and Joy A. Thomas)

Thomas M. Cover, PhD, was a Professor in the Depts. of Electrical Engineering and Statistics, Stanford University.

➢ **Past president of IEEE Information Theory Society**

➢ **Fellow of IEEE**

➢ **Member of National Academy of Engineering**

➢ **1990 Claude E. Shannon Award**

The Claude E. Shannon Award of the IEEE Information Theory Society was created to honor consistent and profound contributions to the field of Information Theory.
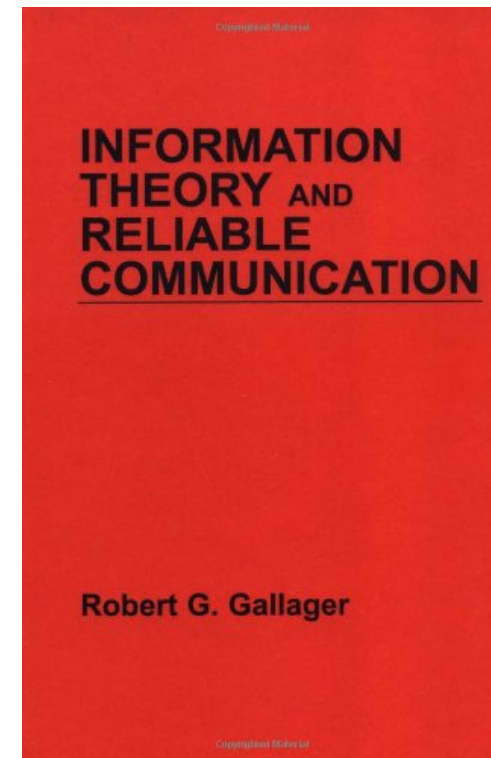
Introduction to The Course

● **Reference Books**

---- Information Theory and Reliable Communication

(written by Robert G. Gallager)

Robert G. Gallager, PhD, is Professor at MIT.

➢ *Past president of IEEE Information Theory Society*

➢ *1983 Claude E. Shannon Award*

➢ *Fellow of IEEE (1968)*

➢ *Member of National Academy of Engineering (1979) and Sciences (1992)*

➢ *Fellow of American Academy of Arts and Science (1999)*

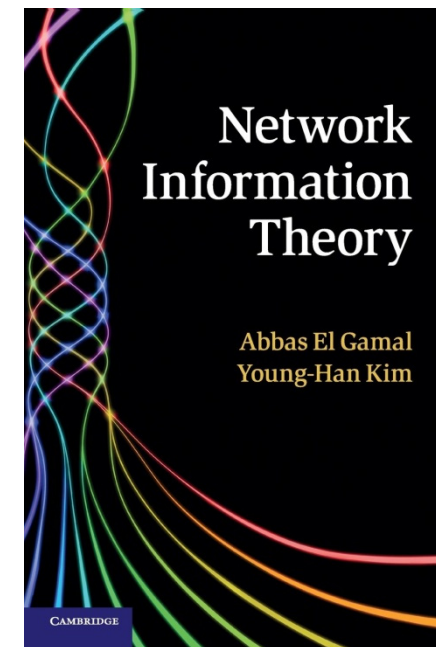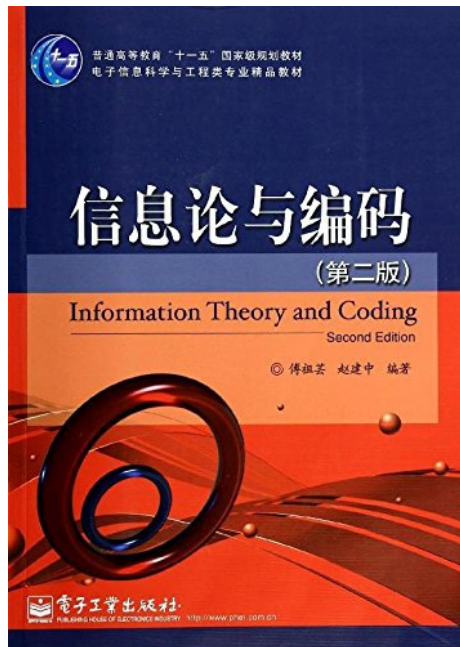➢ *Low Density Parity Check Codes (LDPC)*

Introduction to The Course

● **Reference Books**

---- 信息论—— 基础理论与应用（傅祖芸）

---- 信息论与编码理论（王育民，李晖，梁传甲）

---- *Network Information Theory (A. El Gamal and Y-H Kim)*

Outlines

➢ **Introduction to The Course**

➢ **History of Communications**

➢ **Introduction to Communications System**

➢ **Introduction to Information Theory**

➢ **Introduction to The Contents**

History of Communications

The purpose of communications:

---- *Deliver the information* **efficiently, reliably and securely**

● ***The earliest approach of communications:***
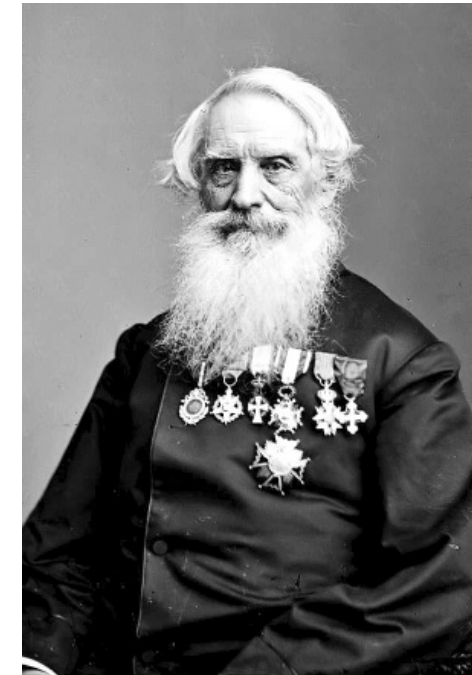

What can we learn from it?

1. **Prototype of Modern Wireless Communications**

2. **Multi-Hop Communications**

History of Communications

● *1830s: Birth of Modern Communications*

---- *Samuel F. B. Morse developed the*
electrical telegraph system.

---- *Morse Code*
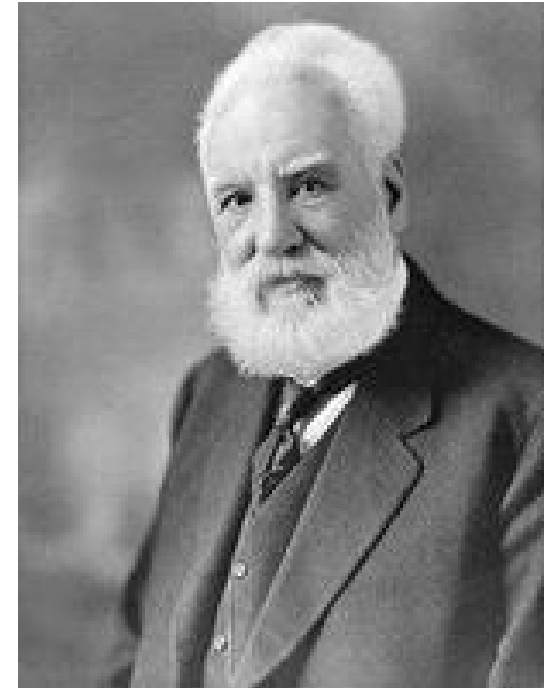
History of Communications

- *1876: Invention of Telephone*

  ---- *Alexander Graham Bell (1847 – 1922) was a Scottish-born scientist, inventor, engineer, and innovator.*

  ---- *In 1876, Alexander Graham Bell invented the telephone based on the electromagnetic induction principle.*

  ---- *The voice signal is delivered by the electric current.*

  ---- *Long-distance and wired communications.*

History of Communications

● *1901: Long-Distance Wireless Communications*

    ---- In 1876, James Clerk Maxwell predicted the existence of electromagnetic wave.

    ---- In 1887, Heinrich Rudolf Hertz proved the existence of electromagnetic wave.

    ---- In 1901, Guglielmo Marconi transmitted the first wireless signal from Cornwall, England to Newfoundland, Canada (3500km).

History of Communications

● *1906: Birth of Broadcast*

---- *In 1906, the first broadcast station (transmitter) in the world was set up near New York and transmitted the voice and music signals by amplitude modulation (AM) technique.*
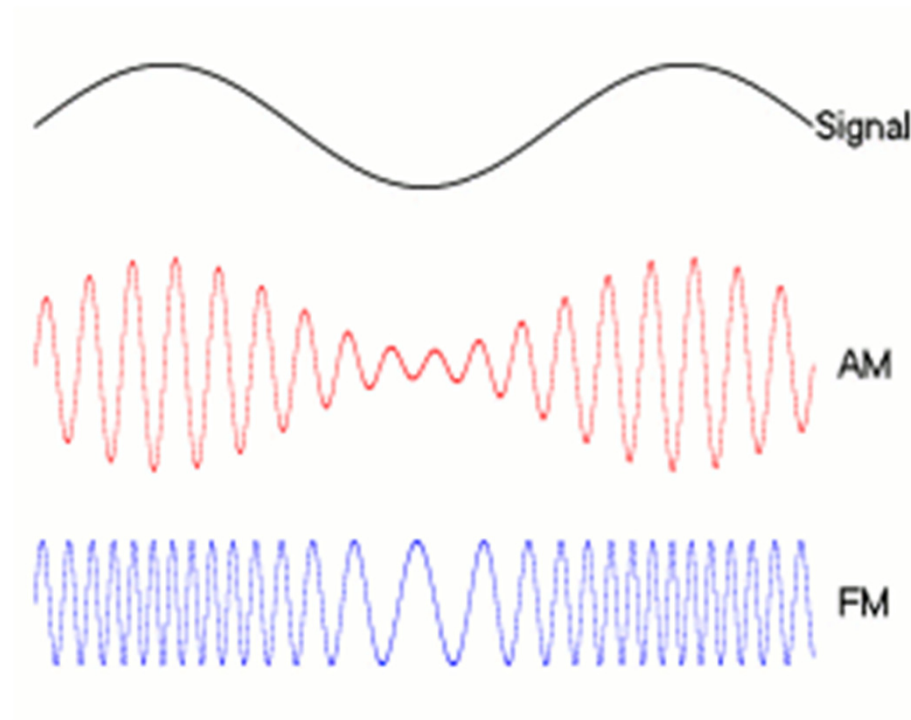
---- *From "point-to-point" to "point-to-many".*

---- *In 1918, frequency modulation (FM) technique was developed.*

---- *AM and FM: the era of analog communications.*

History of Communications

● *1906: Birth of Broadcast*



Is modulation important to wireless communications?

History of Communications

- *1928: Sampling Theorem*

    ---- The sampling theorem establishes a sufficient condition for a sample rate that permits a discrete sequence of samples to capture all the information from a continuous-time signal of finite bandwidth.

    ---- The sampling theorem is a fundamental bridge between continuous-time signals and discrete-time signals.

    ---- PCM technique was developed in 1937. However, the PCM-based digital communications system was implemented in 1950.
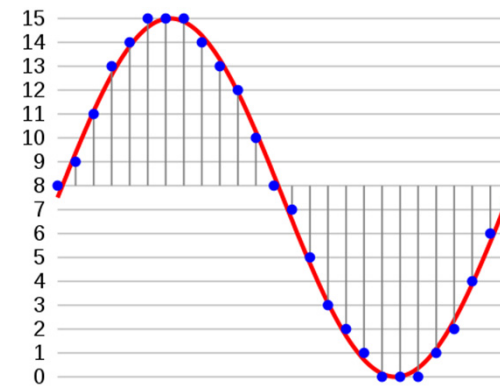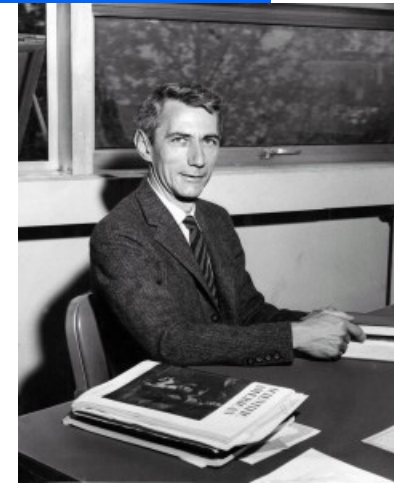
History of Communications

● *1948: Birth of Information Theory*

Claude E. Shannon (1916 - 2001)

➢ **Graduated in 1936 from University of Michigan with two bachelor's degrees, one in electrical engineering and one in mathematics**

➢ **Got his master's degree from MIT in 1937**

➢ **Got his PhD in mathematics from MIT in 1940**

➢ **Spent the rest of his life in Bell Labs and MIT**

➢ **Found Information Theory in 1948**

History of Communications

● *1948: Birth of Information Theory*

Claude Elwood Shannon: "A Mathematical Theory in Communications"

$$C = W \log \left(1 + \frac{P}{N_0 W} \right) \text{ bits/sec}$$

Review Comments:

The paper is poorly motivated and excessively abstract. It is unclear for what practical problem it might be relevant. ...... seems to indicate that his theory is suitable mostly for transmitting gibberish. Alas, people will not pay to have gibberish transmitted anywhere.

I don't understand the relevance of discrete sources: No matter what one does, in the end, the signal will have to be modulated using good old-fashioned vacuum tubes, so the signal on the "channel" will always be analogical.

A running example would have helped make the presentation clearer and less theoretical, but none is provided. Also, the author presents no implementation details or experiments taken from a practical application.

History of Communications

● *1948: Birth of Information Theory*
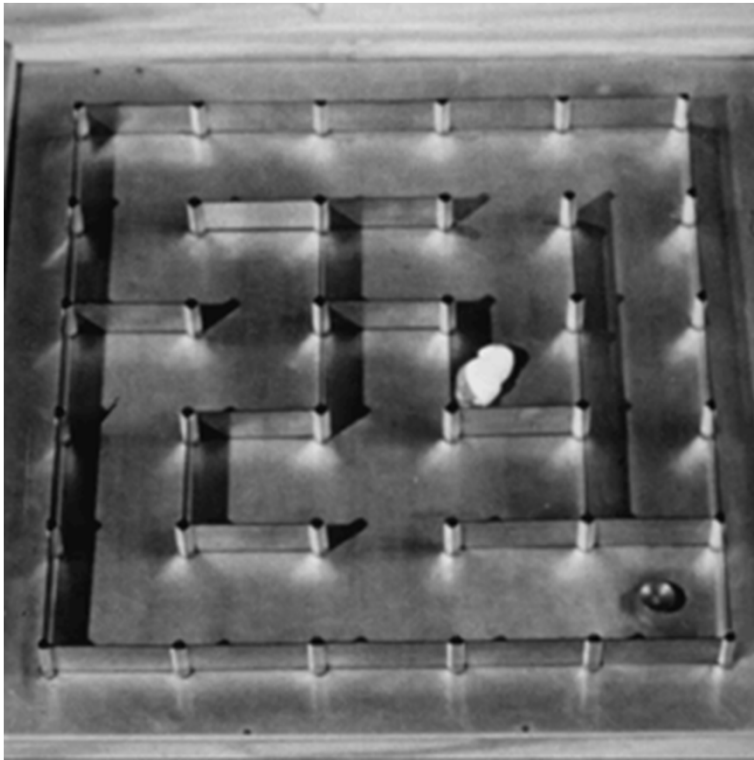
History of Communications
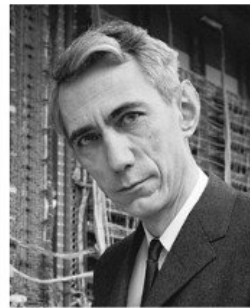
● *1948: Birth of Information Theory*

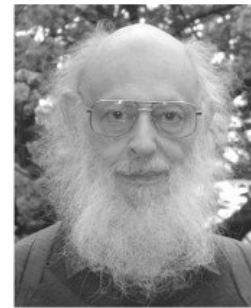## 1956 Dartmouth Conference: The Founding Fathers of AI

John MacCarthy
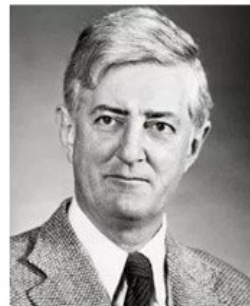
Marvin Minsky

Claude Shannon

Ray Solomonoff

Alan Newell
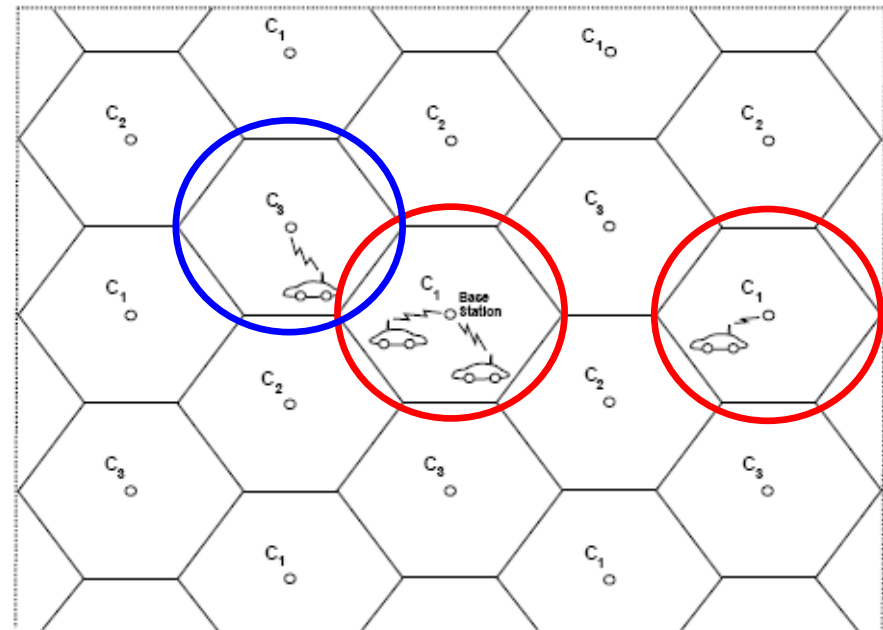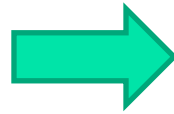
Herbert Simon

Arthur Samuel

Oliver Selfridge

Nathaniel Rochester

Trenchard More

History of Communications

● *1950s-1960s: Birth of Cellular Concept*

History of Communications

● *1967: Viterbi Algorithm*

---- *The algorithm was proposed by Andrew Viterbi, who is an Italian-born.*

---- *He is currently Presidential Chair Professor of Electrical Engineering at the University of Southern California's Viterbi School of Engineering, which was named in his honor in 2004 in recognition of his $52 million gift.*

---- *Andrew Viterbi: The father of CDMA and co-founded Qualcomm Inc.*

History of Communications

● *1983: Cellular Mobile Communications*

---- *In 1983, the first cellular mobile communications system in the world was operated in Chicago, U.S.*

---- *Over the past 40 years, the cellular mobile communications system was developed from 1G to 5G.*

---- *1G: Analog communications*

2G: Time division multiple access (TDMA)

3G: Code division multiple access (CDMA)

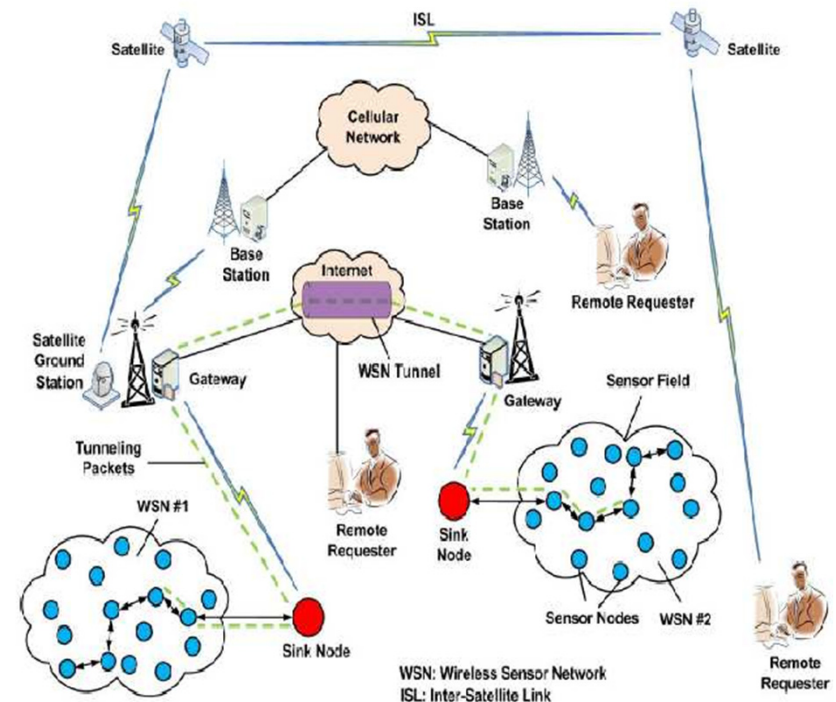*4G: Orthogonal frequency division multiple access (OFDMA) + Multiple-input multiple-output (MIMO)*

5G: Massive MIMO, mmWave……

History of Communications

● *2000s: New Technologies and New Scenarios*

  ➢ *Wireless sensor networks*
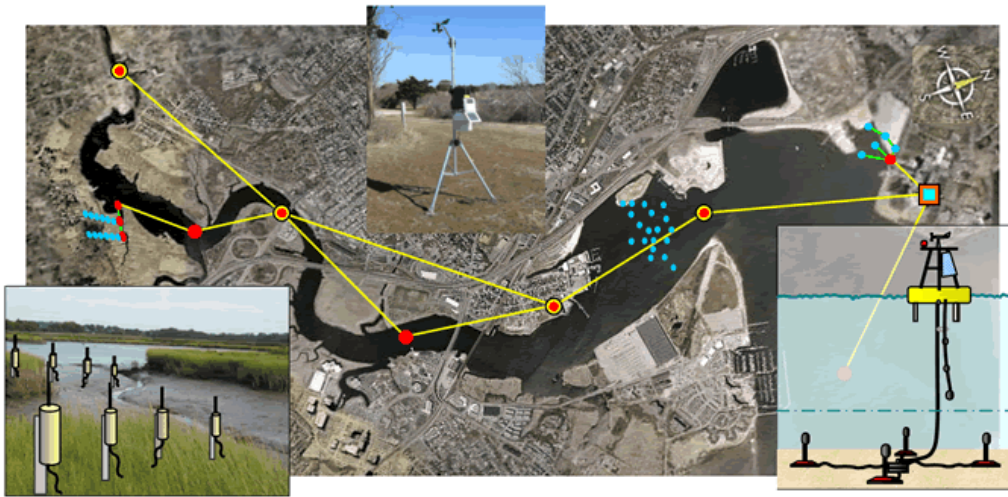
History of Communications

● *2000s: New Technologies and New Scenarios*

   ➢ *Ad hoc networks*

History of Communications

● *2000s: New Technologies and New Scenarios*

➢ *Internet of Things (IoT)*

Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021

History of Communications

● *2000s: New Technologies and New Scenarios*
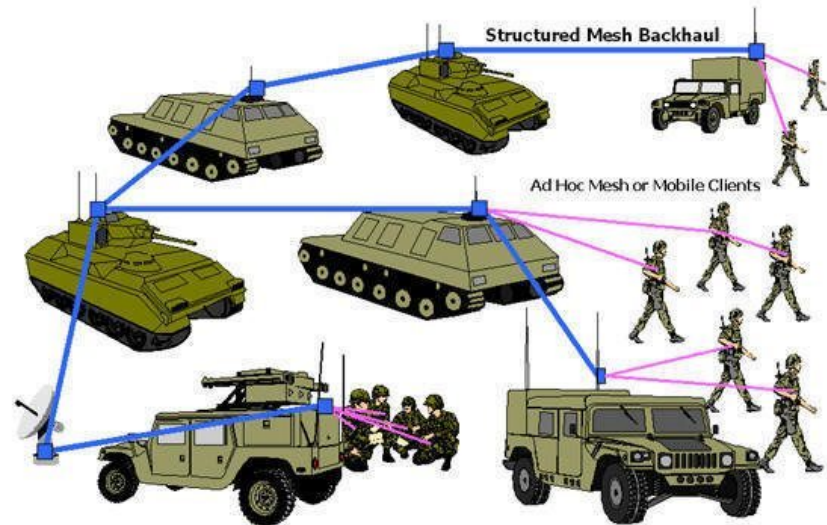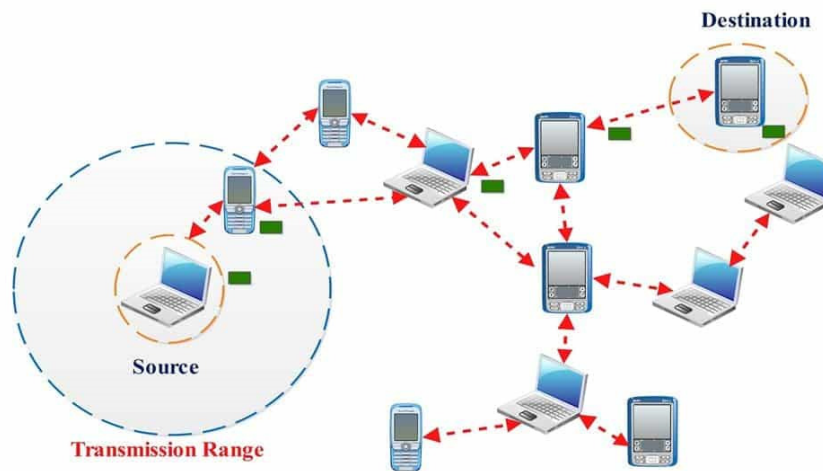
  ➢ *5G mobile communications system*

增强型移动宽带
Enhanced Mobile Broadband

G比特秒传
Gigabytes in a second

3D video, UHD screens 3D视频、超高清屏幕

智能家居/楼宇
Smart home/building

Work and play in the cloud 云端和娱乐

语音
Voice

Augmented reality 增强现实

Industry automation 工业自动化

智慧城市
Smart city

Mission critical application 重要应用

Self driving car 自动驾驶车辆

**Massive Machine Type
Communications**
大规模机器通信

**Ultra-Reliable and Low Latency
Communications**
超可靠低时延通信

History of Communications

● *2000s: New Technologies and New Scenarios*

➢ *Wireless secure transmission*
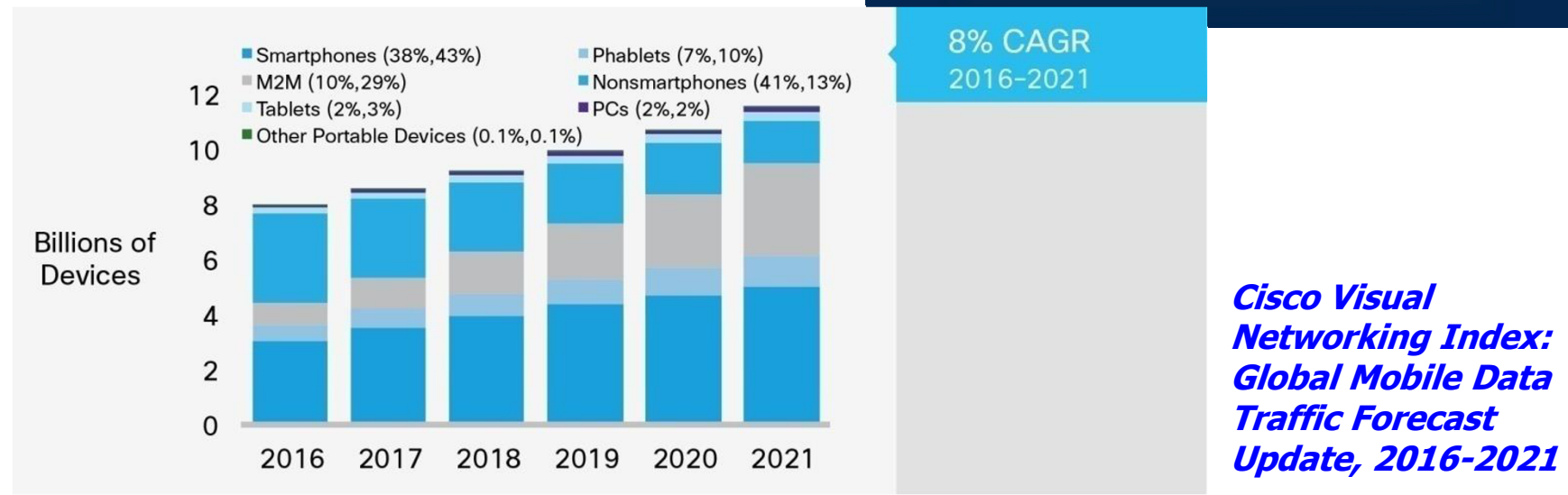
History of Communications

● *2000s: New Technologies and New Scenarios*

  ➤ *Big data*

History of Communications
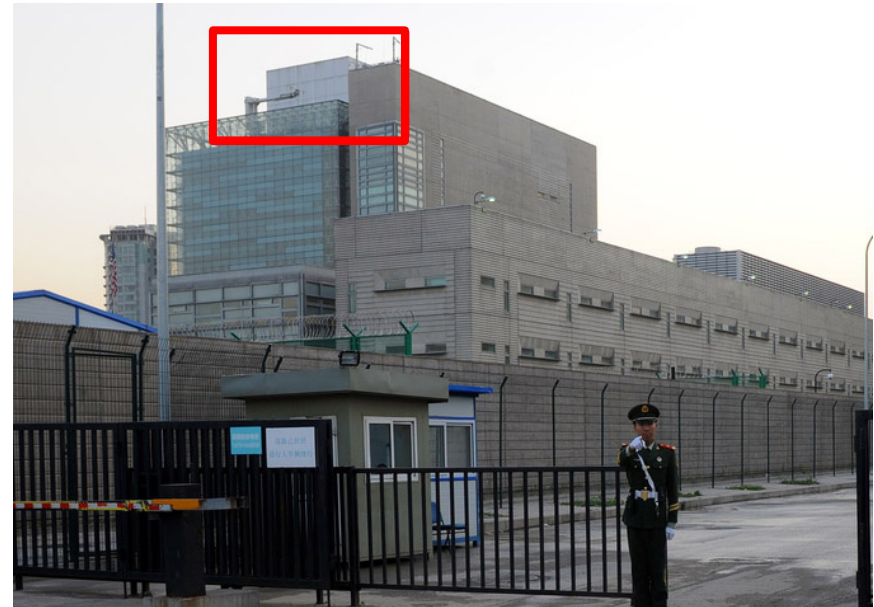
● *2000s: New Technologies and New Scenarios*

➢ *6G mobile communications system*
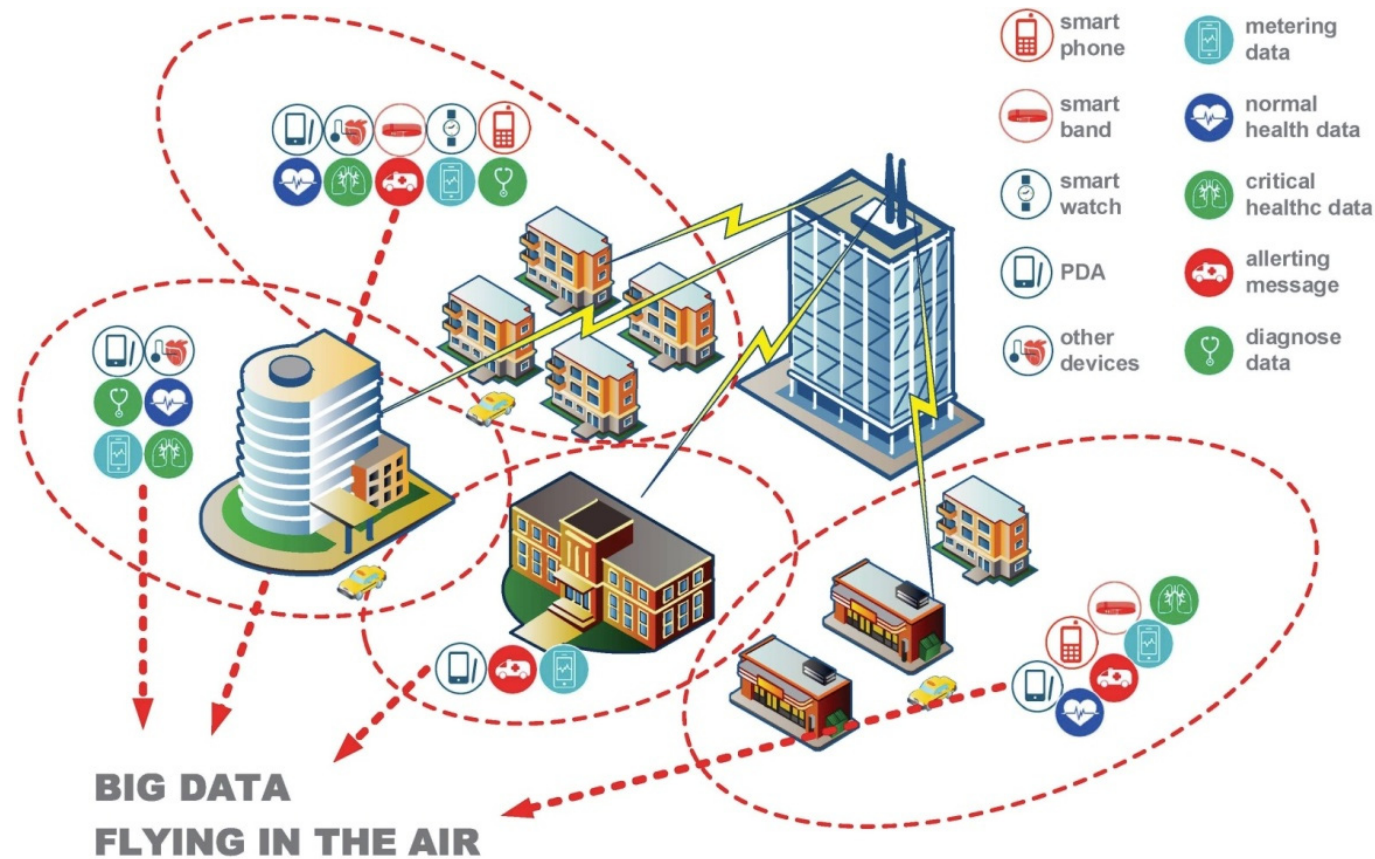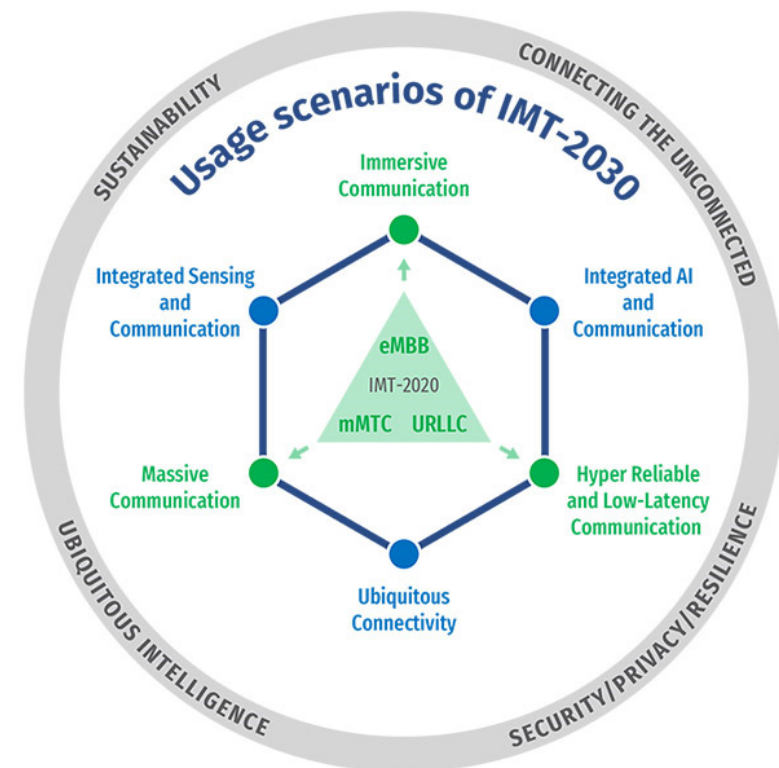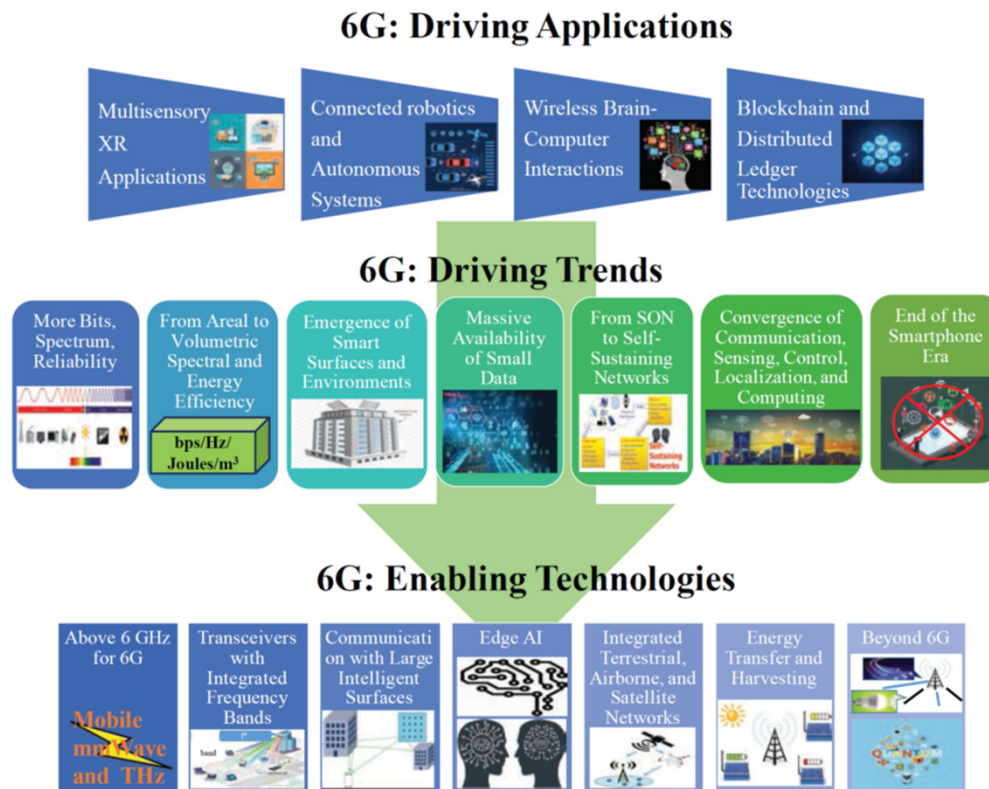
Outlines

- **Introduction to The Course**

- **History of Communications**

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Communications System

● **Block Diagram of Communications System**

Noise

| Source | → | Encoder | → | Channel | → | Decoder | → | Destination |
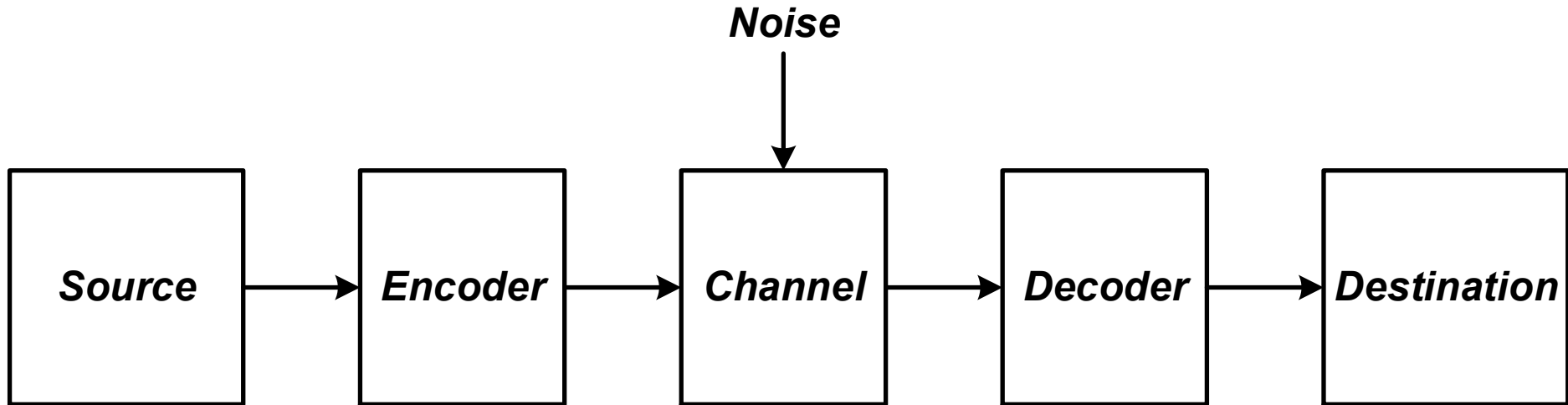
Source: Producing the objects that we want to deliver

Encoder: Processing of source output performed prior to transmission

Channel: Medium through which signal goes from source to destination

Decoder: Processing of channel output

Destination: place where the replica of the source output is produced

Communications System

● **Block Diagram of Communications System**

Encoder ➔ *Source encoder + Channel encoder*

Decoder ➔ *Source decoder + Channel decoder*
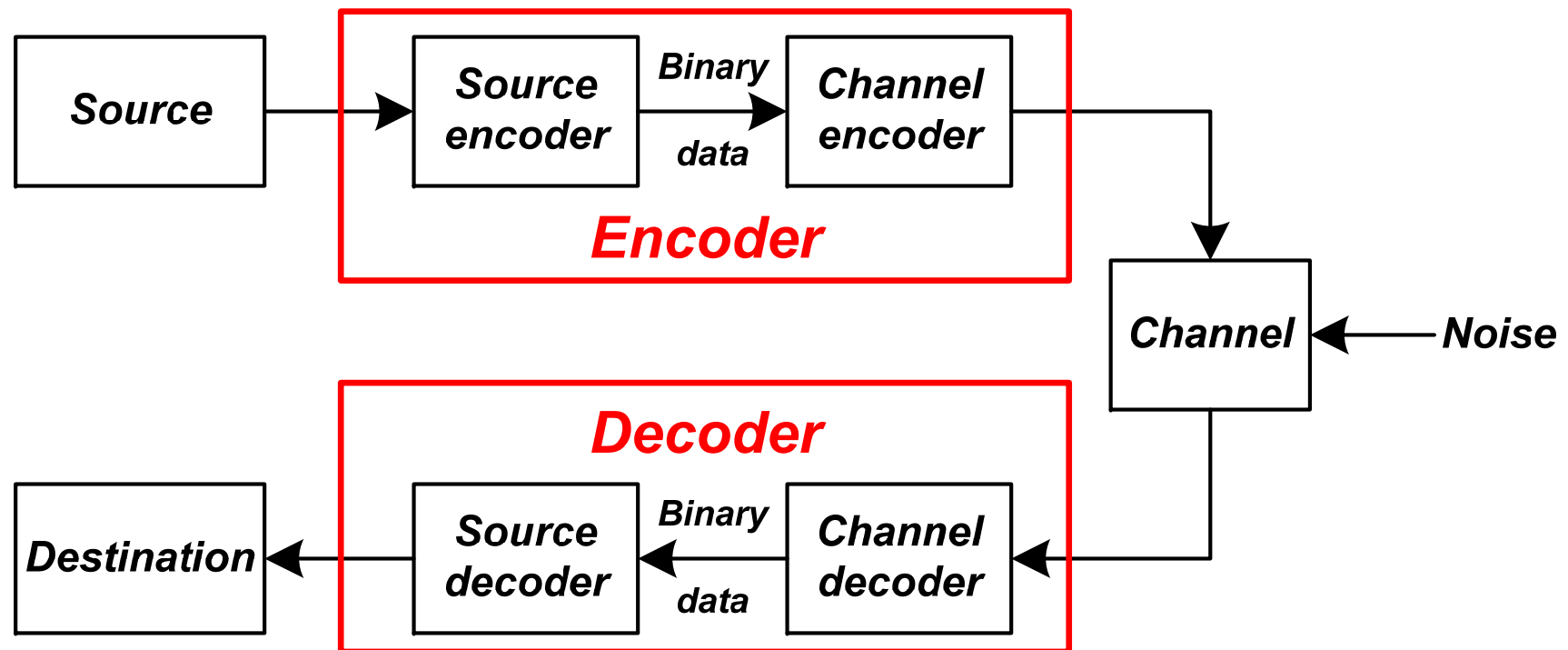
Communications System

● **Block Diagram of Communications System**

Standardized interfaces + Layering
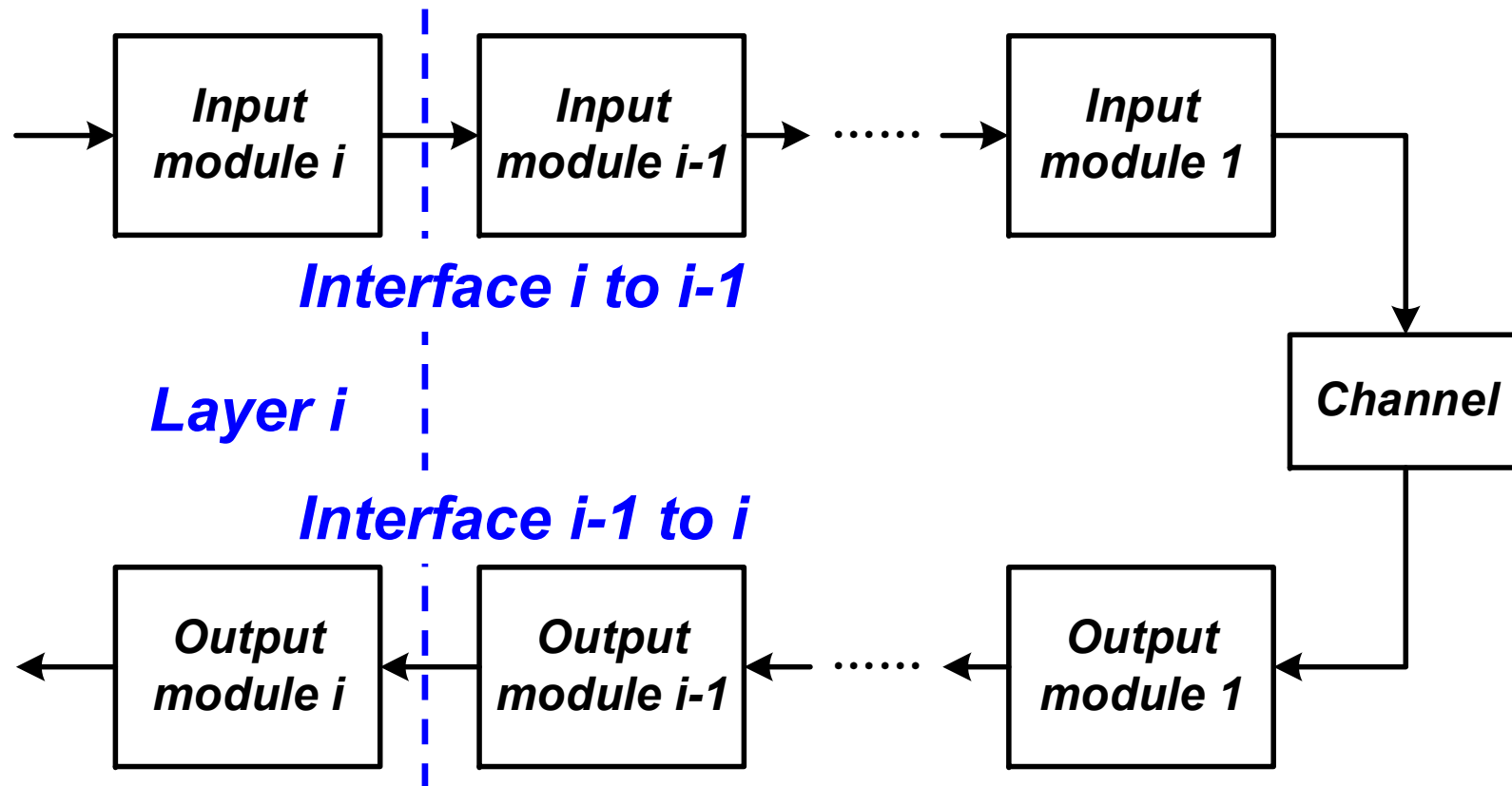
Communications System

Source Encoder

➢ **Represent the source output by a sequence of binary digits**

➢ **How many binary digits per unit time are required to represent the output of any given source model**

> ✓ *Text: ASCII, GB2312, GBK*
>
> ✓ *Sound: MP3*
>
> ✓ *Voice: PCM*
>
> ✓ *Image: BMP, JPEG*
>
> ✓ *Video: AVI, RMVB,FLV*

Communications System

Source Encoder

Input waveform → **Sampler** → **Quantizer** → **Discrete encoder** → **Binary channel**

Analog sequence | **Symbol sequence** | **Binary interface**

Output waveform ← **Analog filter** ← **Table lookup** ← **Discrete decoder** ←
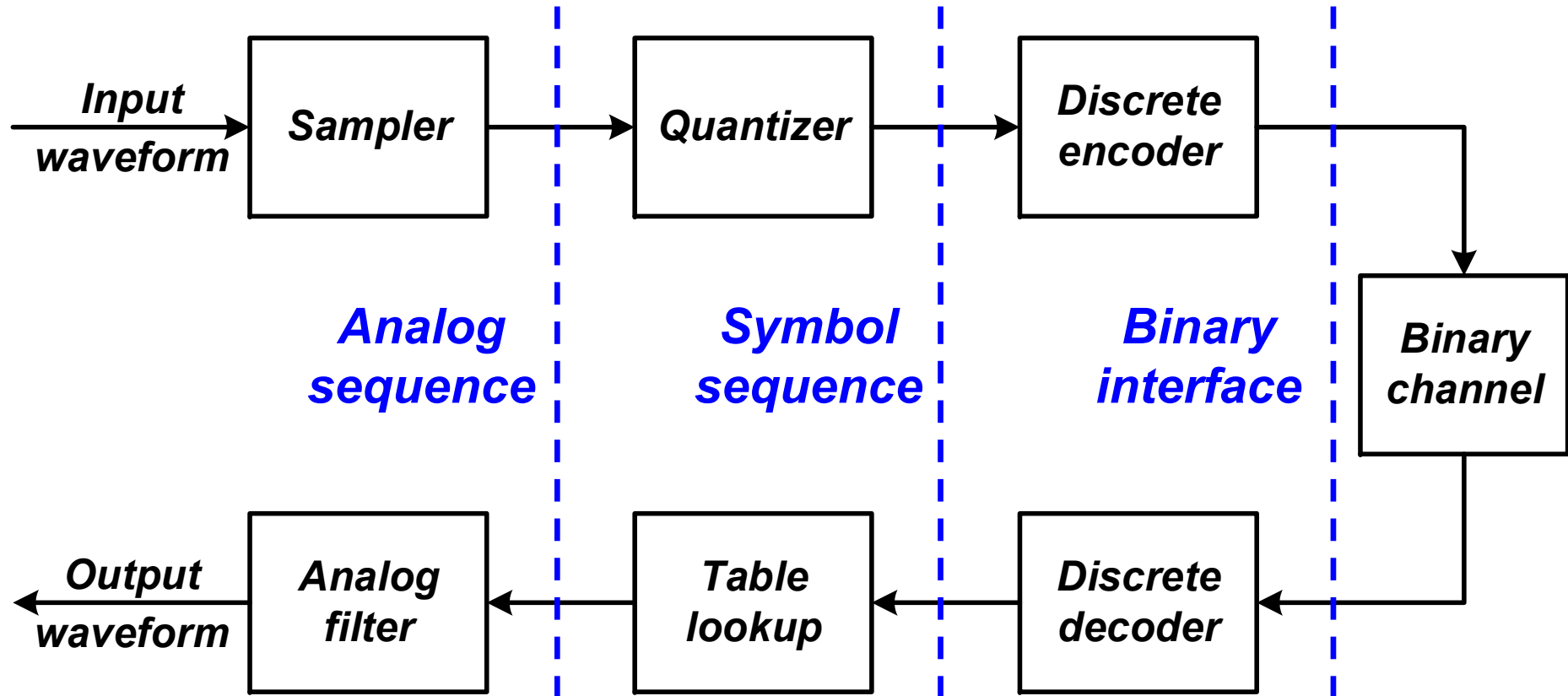
Communications System

Channel Encoder

➢ *Make the binary data sequences to be reliably reproduced at the output of the channel decoder*

➢ *How the reliable transmission can be done*

> ✓ **1950 Hamming block code**
> ✓ **1960 Reed Soloman code**
> ✓ **1967 Viterbi decoding**
> ✓ **1993 Turbo code**
> ✓ **1963 LDPC**

Communications System
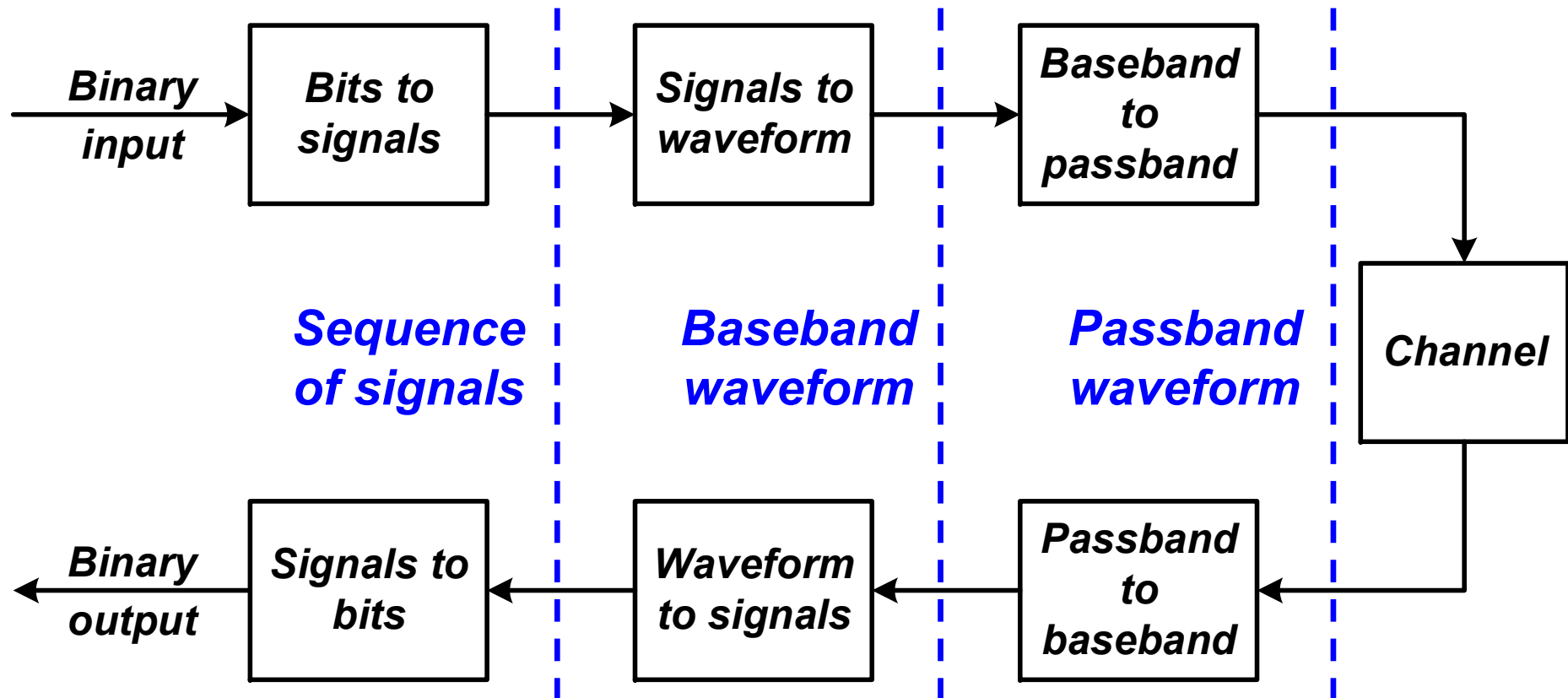
Channel Encoder

Binary input → **Bits to signals** → *Sequence of signals* → **Signals to waveform** → *Baseband waveform* → **Baseband to passband** → *Passband waveform* → **Channel**

Channel → **Passband to baseband** → **Waveform to signals** → **Signals to bits** → Binary output

Outlines

➢ **Introduction to The Course**

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➢ **Introduction to The Contents**

Introduction to Information Theory

> ➤ *How to understand "information"?*

> ➤ *Information v.s. Message v.s. Signal*

> ➤ *How to understand "information theory"?*

Information theory answers two fundamental questions in communication theory: what is the ultimate data compression and what is the ultimate transmission rate of communication.

Introduction to Information Theory

Shannon Information Theory

Compression Theory — *Transmission Theory* — *Security Theory*

Without Noise — *With Noise* — *Secure Information Theory*

Lossy Source Coding *Lossless Source Coding* *Channel Coding Theorem* → *Network Channel*

Shannon (1949)
Diffie and hellmen (1976)

Shannon (1961)
Cover (1972)

Rate Distortion Theory *Fixed Length Coding* *Variable Length Coding*

Shannon (1948)
Feinstein (1954)
Gallager (1965)
Cover (1975)

Network Information Theory

Shannon (1949)
(1959)
Gallager (1968)
Berger (1969)

Shannon (1948)
McMillan (1953)

Shannon (1948)
McMillan (1956)

Optimal Code ← *Code Design* → *Optimal Network Code*

Compression Coding ← → *Secure Code*

Error-Correction Code

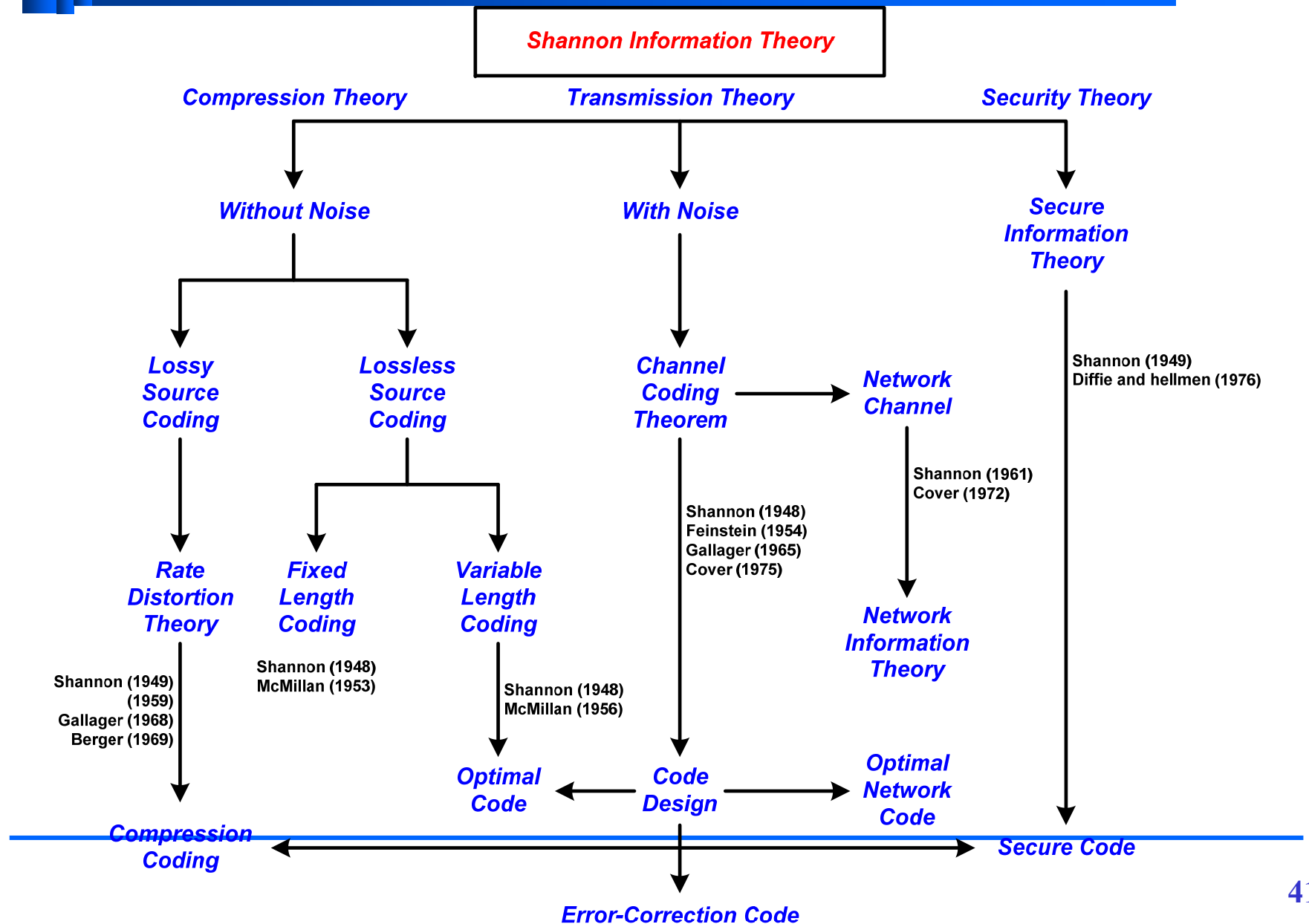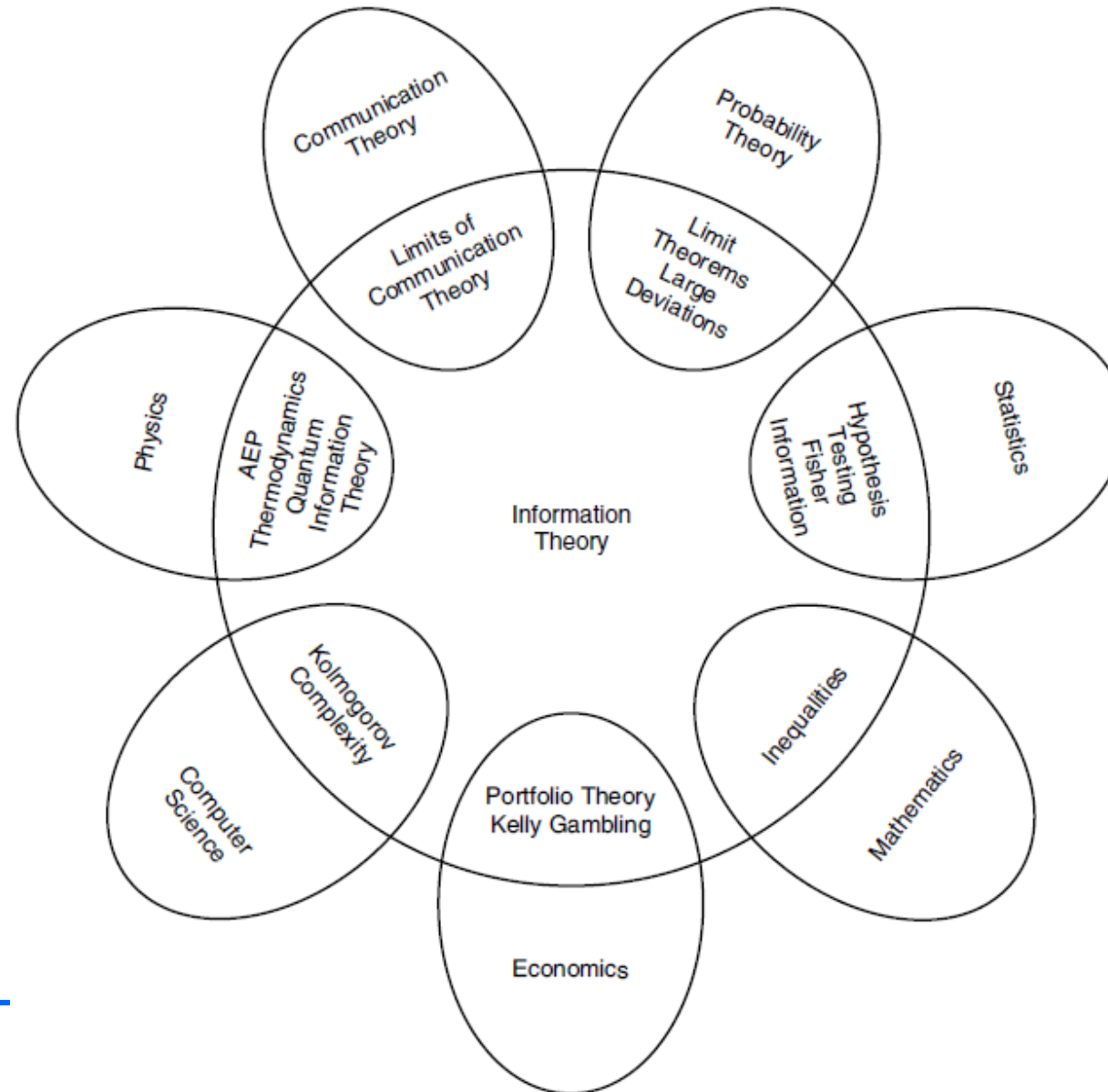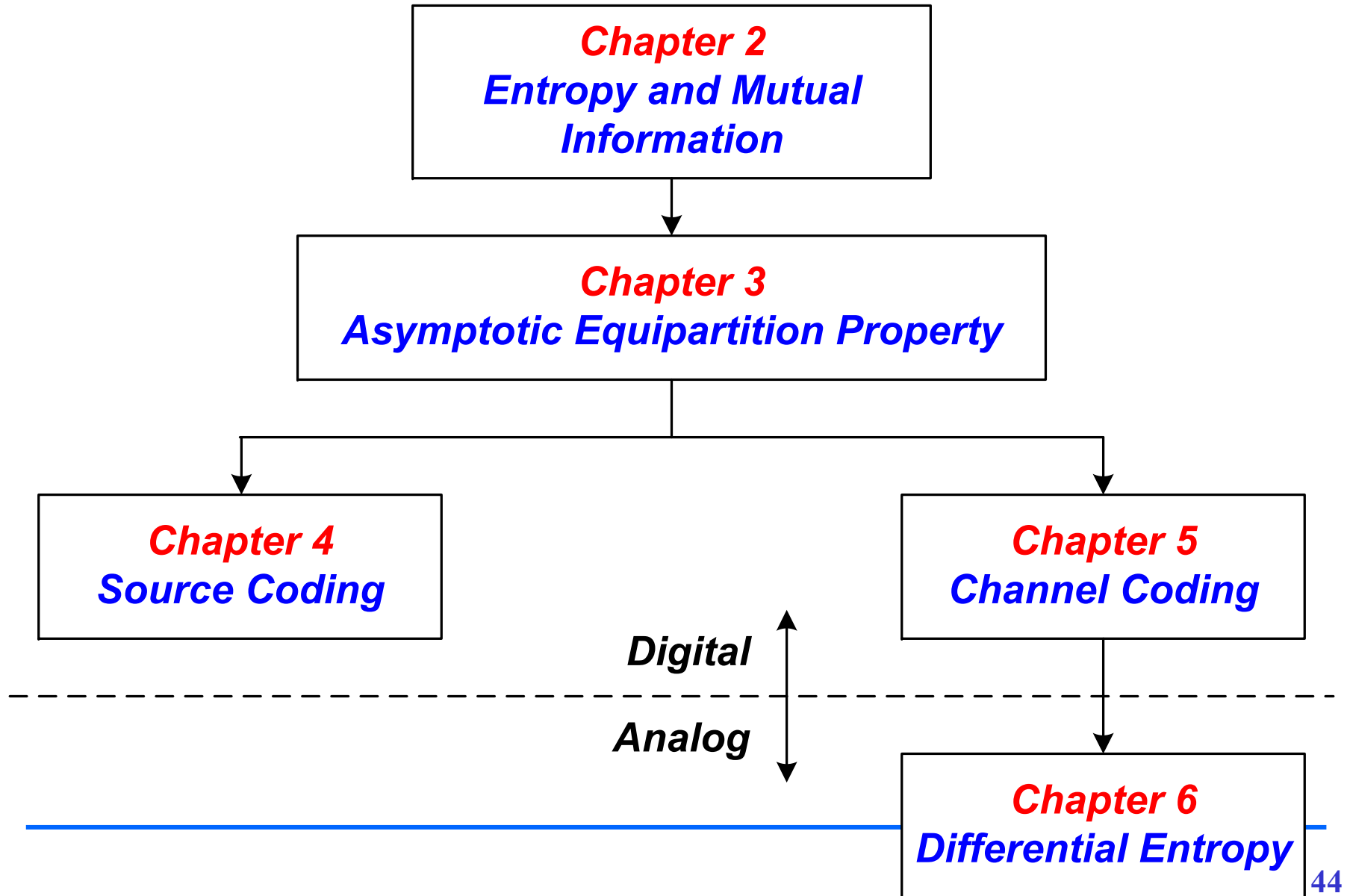# Introduction to Information Theory

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Introduction to Contents

Chapter 2
Entropy and Mutual Information

Chapter 3
Asymptotic Equipartition Property

Chapter 4
Source Coding

Chapter 5
Channel Coding

Digital

Analog

Chapter 6
Differential Entropy

Thanks