通訊系統 (II)

國立清華大學電機系暨通訊工程研究所
蔡育仁
台達館 821 室
Tel: 62210
E-mail: yrtsai@ee.nthu.edu.tw

Chapter 6
Comparison of Digital Modulation Schemes Using a Single Carrier

Probability of Error

Coherent and Noncoherent Detection

- The popular digital modulation schemes are classified into **two categories**, depending on the method of **detection** used at the receiver:
  - **Class I, Coherent detection**:
    - Binary PSK: two symbols, single frequency
    - Binary FSK: two symbols, two frequencies
    - QPSK: four symbols, single frequency—includes the QAM as a special case
    - MSK: four symbols, two frequencies
  - **Class II, Noncoherent detection**:
    - DPSK: two symbols, single frequency
    - Binary FSK: two symbols, two frequencies

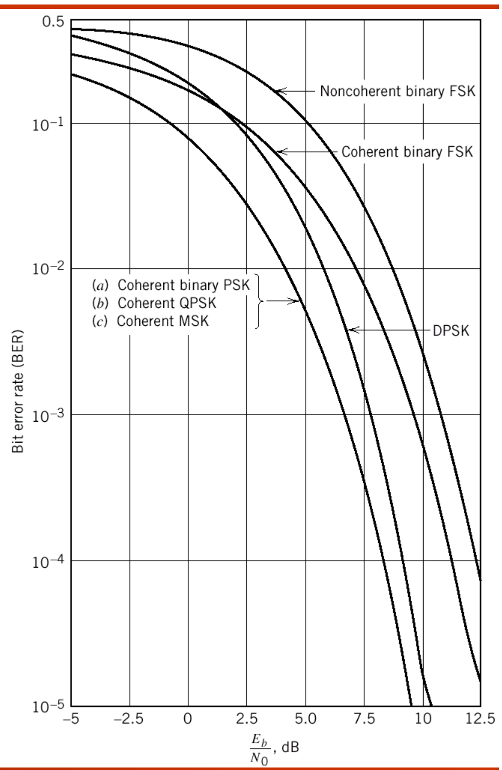
Probability of Error

- For Class I, the BER formulas are expressed in terms of the **erfc-function**
- For Class II, the BER formulas are expressed in terms of an **exponential function**

Signaling Scheme	Bit Error Rate
(a) Coherent BPSK Coherent QPSK Coherent MSK	$\frac{1}{2}\operatorname{erfc}\left(\sqrt{E_b/N_0}\right)$
(b) Coherent BFSK	$\frac{1}{2}\operatorname{erfc}\left(\sqrt{E_b/2N_0}\right)$
(c) DPSK	$\frac{1}{2}\exp\left(-E_b/N_0\right)$
(d) Noncoherent BFSK	$\frac{1}{2}\exp\left(-E_b/2N_0\right)$

Probability of Error (Cont.)

- The **coherent detection** schemes produce a smaller BER than those using **noncoherent detection**
- **BPSK** with coherent detection and **DPSK** with noncoherent detection, require an E_b/N_0 that is **3 dB less** than their **FSK** counterpart to realize the same BER
- At **high E_b/N_0**, DPSK and BFSK using **noncoherent detection** perform almost as well, to **within** about **1 dB** of their respective **coherent detection** counterparts



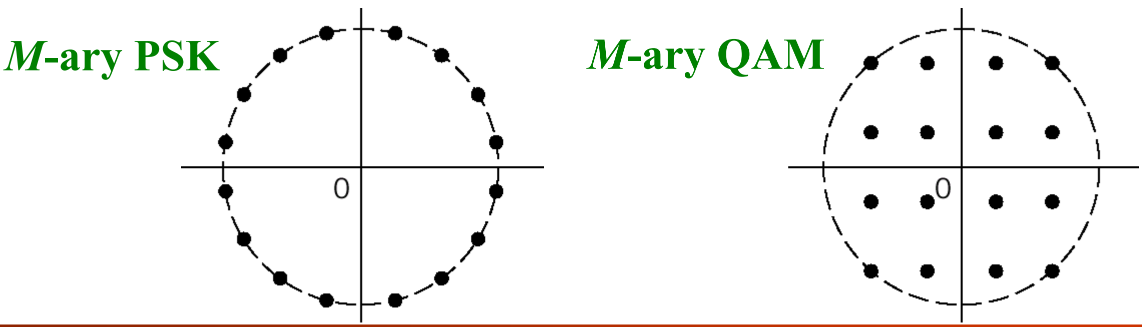
Bandwidth Efficiency (M-ary PSK)

- Considering the M-ary PSK schemes, the **power-bandwidth** requirements for the average probability of symbol error = 10^{-4}
  - **QPSK** ($M = 4$) offers the best trade-off between power and bandwidth requirements
  - For $M > 8$, **power requirements** become excessive
  - For $M > 8$, the **complexity** of signal generation and detection increases considerably

Value of M	$\dfrac{(\text{Bandwidth})_{M\text{-ary}}}{(\text{Bandwidth})_{\text{Binary}}}$	**Probability of symbol error = 10^{-4}** $\dfrac{(\text{Average power})_{M\text{-ary}}}{(\text{Average power})_{\text{Binary}}}$
4	0.5 Bad	0.34 dB Good
8	0.333	3.91 dB
16	0.25	8.52 dB
32	0.2 Good	13.52 dB Bad

Bandwidth Efficiency (M-ary PSK & QAM)

- M-ary PSK and M-ary QAM have similar characteristics, but **different signal constellations** for $M > 4$
- For a **fixed peak power**, the distance between the message points of M-ary PSK is **smaller** than that of M-ary QAM
  - M-ary QAM **outperforms** M-ary PSK in error performance
  - M-ary QAM has **smaller** average signal power
  - M-ary QAM is affected by the **variation** in signal amplitude



Bandwidth Efficiency (*M*-ary PSK & FSK)

- For *M*-ary FSK, **increasing** *M* results in a **reduced** power requirement for a **fixed probability of error**
  - At the cost of **increased channel bandwidth**
- For *M*-ary PSK **increasing** *M* results in a **increased** power requirement for a **fixed probability of error**
  - But achieve **better spectral efficiency**

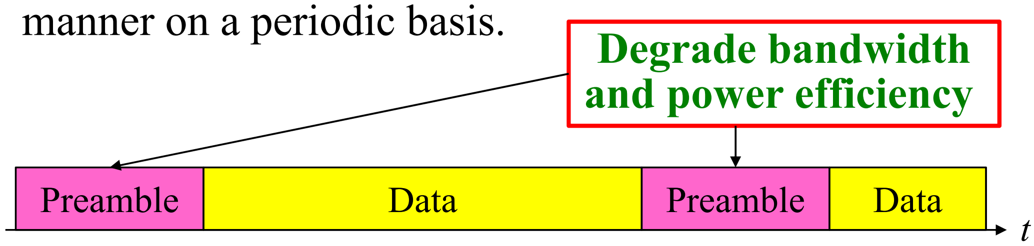
Synchronization

Introduction

- The coherent reception of a digitally modulated signal requires that the receiver be **synchronous** with the transmitter.
- There are two basic modes of synchronization:
  - **Carrier synchronization:** When coherent detection is used, knowledge of both the **frequency** and **phase** of the carrier is necessary ⇒ **carrier recovery** or **carrier synchronization**
  - **Timing synchronization:** To perform demodulation, the receiver has to know the **starting** and **finishing times** of the individual symbols ⇒ **clock recovery** or **symbol synchronization**
- In general, both **frequency** and **timing synchronization** are necessary for **coherent** detection and **noncoherent** detection
- **Phase synchronization** is necessary only for **coherent** detection

Synchronization Classification

- Synchronization schemes can be classified as:
  - **Data-aided synchronization:** A **preamble** is transmitted along with the data-bearing signal in a **time-multiplexed** manner on a periodic basis.



  - **Non-data-aided synchronization: No preamble** is transmitted.
    - Establishing synchronization by **extracting** the necessary information from the **noisy distorted** modulated signal
    - Increase the time taken to establish synchronization

Data-aided Synchronization

- In data-aided synchronization, the preamble contains information about the **frequency**, **phase** and **symbol timing**
  - Commonly used in **satellite** and **wireless communications** to **minimize the time** required for synchronization
- Limitations of data-aided synchronization are
  - Reduced **bandwidth efficiency**: Assigning a certain portion of each transmitted frame to the preamble
  - Reduced **power efficiency**: the allocation of a certain fraction of power to the transmission of the preamble

Signal Parameter Estimation

- Considering an AWGN channel that delays the transmitted signals and corrupts them by the addition of Gaussian noise
  - The received signal may be expressed as

$$r(t) = s(t-\tau) + n(t); \quad s(t) = \mathrm{Re}\left[\tilde{s}(t)e^{j2\pi f_c t}\right]$$

  - where τ is the propagation delay
- The received signal may be expressed as

$$r(t) = \mathrm{Re}\left[\tilde{s}(t-\tau)e^{j2\pi f_c (t-\tau)} + z(t)e^{j2\pi f_c t}\right] = \mathrm{Re}\left\{\left[\tilde{s}(t-\tau)e^{j\phi} + z(t)\right]e^{j2\pi f_c t}\right\}$$

  - where the carrier phase $\phi = -2\pi f_c \tau$
- If the carrier frequency is **fixed** and well-synchronized, it seems there is only one signal parameter τ to be estimated
  - To simultaneously achieve **phase** and **symbol synchronization**

Signal Parameter Estimation (Cont.)

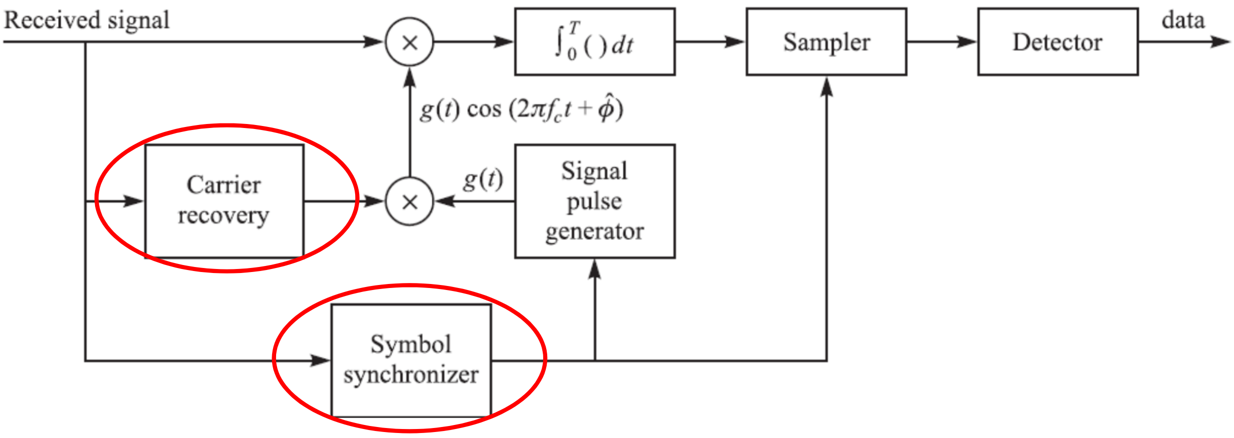
- However, the carrier phase ϕ is not directly related to f_c and τ
  - The oscillator at the receiver is generally **not synchronous** in phase with that at the transmitter
  - The two oscillators at the transmitter and at the receiver may be **drifting** slowly with time
- Therefore, both **phase** synchronization (targeting at ϕ) and **symbol** synchronization (targeting at τ) are required
- Usually, the **estimation error** in estimating τ must be a relatively small fraction of symbol duration T.
  - **± 1%** of T is adequate for practical applications
  - Because $f_c >> 0$, the ± 1% precision is generally inadequate for estimating the carrier phase, even if $\phi = -2\pi f_c \tau$

Signal Parameter Estimation (Cont.)

- There are basically two criteria that are widely applied to signal parameter estimation:
  - **Maximum-likelihood** (ML) criterion: the signal parameter vector $\boldsymbol{\theta}$ is treated as deterministic but unknown
  - **Maximum a posteriori probability** (MAP) criterion: the signal parameter vector $\boldsymbol{\theta}$ is modeled as random and characterized by an a priori probability density function $p(\boldsymbol{\theta})$
- If there is **no prior knowledge** of the parameter vector $\boldsymbol{\theta}$, we may assume that $p(\boldsymbol{\theta})$ is uniform (constant) over the range of values of the parameters.
  - In such a case, the MAP and ML estimates are identical

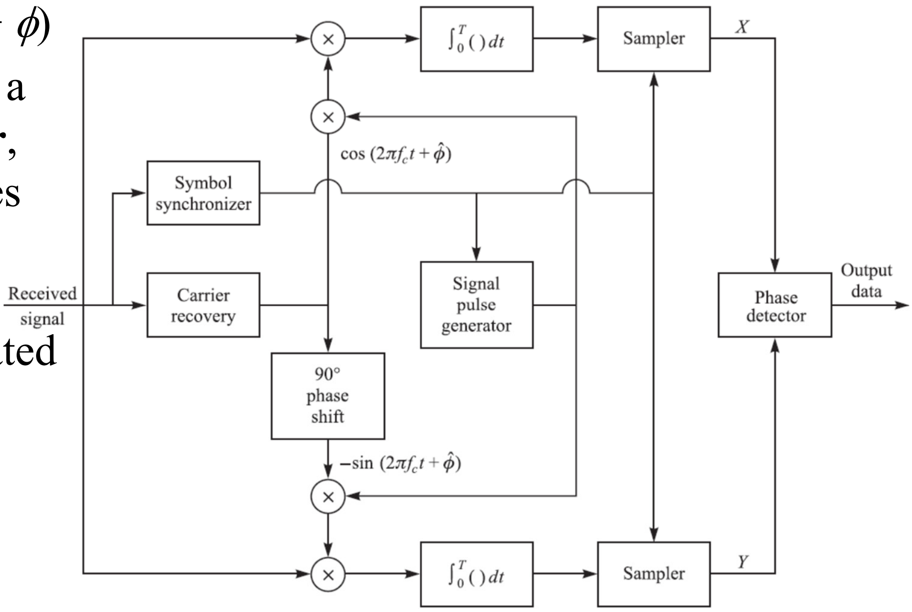
Block diagram of a binary PSK Demodulator

- The carrier phase estimate ϕ is used in generating the reference signal $g(t)\cos(2\pi f_c t + \phi)$ for the **correlator**
- The symbol synchronizer controls the **sampler** and the output of the **signal pulse generator**.



Block diagram of a binary MPSK Demodulator

- Two **correlators** are required to correlate the received signal with the two quadrature carrier signals $g(t)\cos(2\pi f_c t + \phi)$ and $g(t)\sin(2\pi f_c t + \phi)$
- The detector is a **phase detector**, which compares the received signal phases with the estimated **transmitted signal phase**



Decision-Directed Approaches

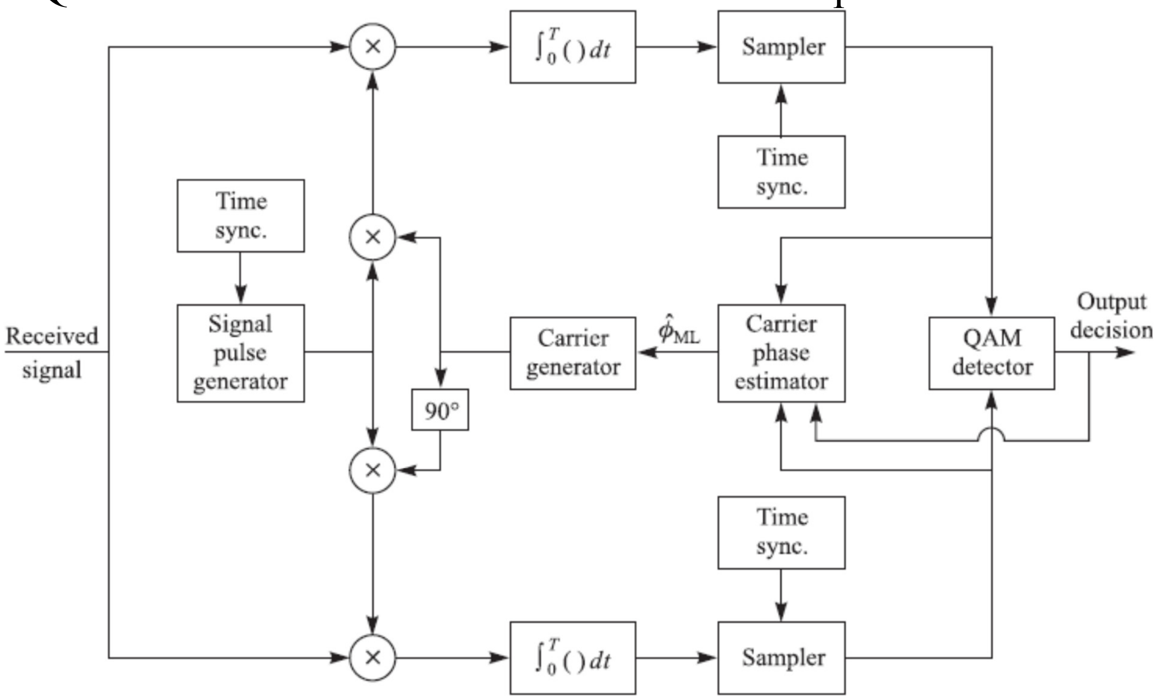
- For **Non-data-aided synchronization**, the received signal used for signal parameter estimation contains the uncertainty of the carried information (data)
  - The uncertainty may impact the estimation of parameters, e.g., the phase estimation of PSK modulated signal
  - The estimation of some parameters may not be influenced by the uncertainty, e.g., the estimation of symbol duration
- In this case, we can adopt one of two approaches
  - We assume that the carried information is **known**
  - We treat the carried information as a **random sequence** and **average over** its statistics

Decision-Directed Approaches (Cont.)

- In **decision-directed** (or **decision-feedback**) parameter estimation, we assume that the carried information over the observation interval **has been estimated** without **demodulation errors**
  - In this case, the carried information is completely **known**
- For **carrier phase** estimation, we generally need to use **decision-directed** approaches
- For **symbol duration** estimation, we can generally treat the carried information as a **random sequence** and **average over** its statistics

Decision-Directed Approaches (Cont.)

- QAM receiver with decision-directed carrier phase estimation



Homework

- **You must give detailed derivations or explanations, otherwise you get no points.**
- Communication Systems, Simon Haykin **(4th Ed.)**
- 6.35;
- 6.36;