
通訊系統 (II)

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Chapter 6

Comparison of Digital Modulation Schemes Using a Single Carrier

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Probability of Error

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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

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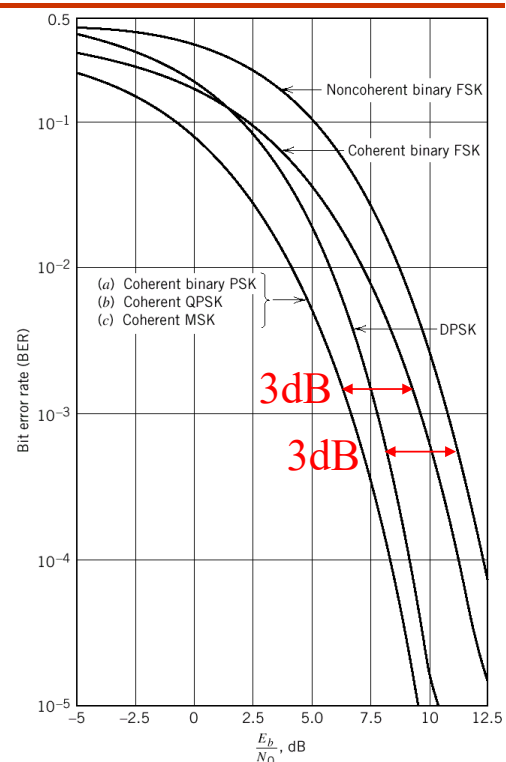
Probability of Error

- 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	$\frac{1}{2} \text{erfc}\left(\sqrt{E_b/N_0}\right)$
(b) Coherent BFSK	$\frac{1}{2} \text{erfc}\left(\sqrt{E_b/2N_0}\right)$
(c) DPSK	$\frac{1}{2} \exp(-E_b/N_0)$
(d) Noncoherent BFSK	$\frac{1}{2} \exp(-E_b/2N_0)$

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

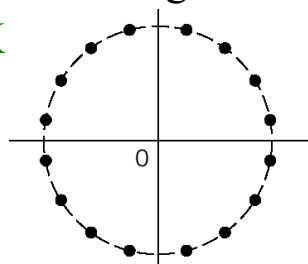
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7

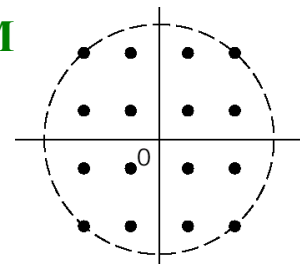
Bandwidth Efficiency (M -ary PSK & QAM)

- 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
 - Channel fading

M -ary PSK



M -ary QAM



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8

Power 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**
 - Channel bandwidth of M -ary FSK: $B = R_b M / 2 \log_2 M$
- For M -ary PSK **increasing** M results in a **increased** power requirement for a **fixed probability of error**
 - But achieve **better spectral efficiency**

Synchronization

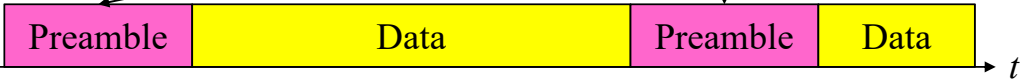
Introduction

- 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 \Rightarrow **carrier recovery** or **carrier synchronization**
 - **Timing synchronization:** To perform demodulation, the receiver has to know the **starting** and **finishing times** of the individual symbols \Rightarrow **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
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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.

Degrade bandwidth and power efficiency



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

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

- where τ is the propagation delay

- The received signal may be expressed as **$z(t)$: noise related term**

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

- 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 \Rightarrow additional phase error
 - 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 .
 - $\pm 1\%$ of T is adequate for practical applications
 - Because $f_c \gg 0$, the $\pm 1\%$ precision is generally inadequate for estimating the carrier phase, even if $\phi = -2\pi f_c \tau$
 - For a small **estimation error** $\Delta\tau$, $2\pi f_c \Delta\tau \gg 2\pi$ for $f_c \gg 0$

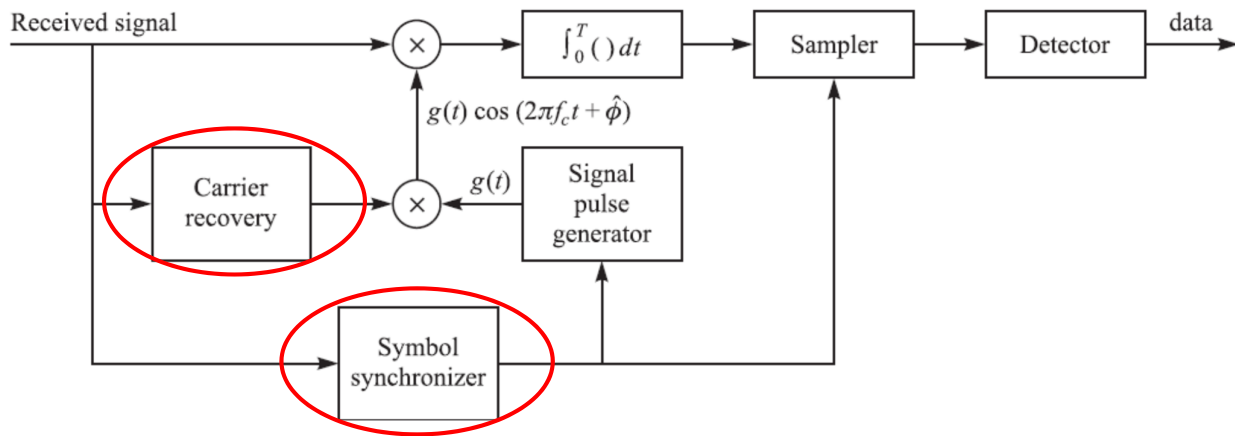


Signal Parameter Estimation (Cont.)

- There are basically two criteria that are widely applied to signal parameter estimation:
 - **Maximum-likelihood** (ML) criterion: the signal parameter vector θ is treated as deterministic but unknown
 - **Maximum a posteriori probability** (MAP) criterion: the signal parameter vector θ is modeled as random and characterized by an a priori probability density function $p(\theta)$
- If there is **no prior knowledge** of the parameter vector θ , we may assume that $p(\theta)$ 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 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**.



Decision-Directed Approaches

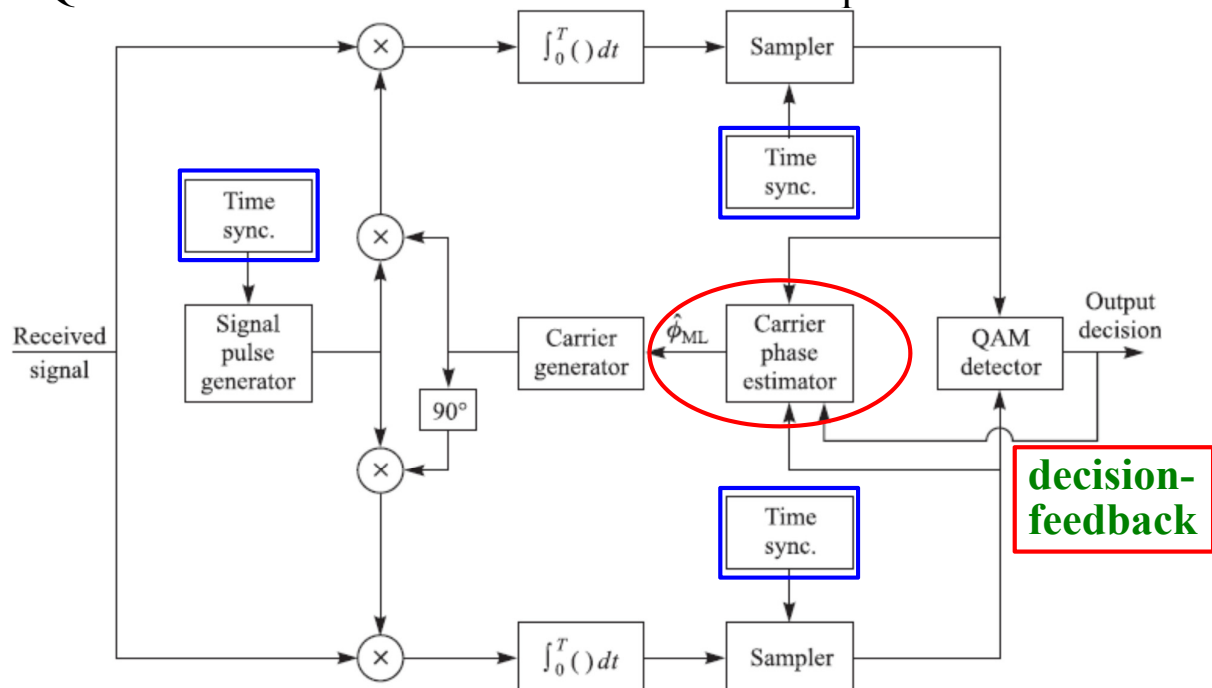
- For **Non-data-aided synchronization**, the received signal used for signal parameter estimation contains **the uncertainty of the carried information (data)**
 - The uncertainty may impact the estimation of parameters, e.g., the **phase** estimation of PSK modulated signal
 - The estimation of some 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
 - **Short term:** Assume that the data information is **known**
 - Quick response based on the **decision results**
 - **Long term:** Treat the data information as a **random sequence** and **average over** its statistics
 - Only suitable for a comparatively **static** parameter

Decision-Directed Approaches (Cont.)

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

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;