Principles of Communications

Chapter VII: Synchronization

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7.1 Introduction

- The so-called synchronization refers to that both receiver and transmitter is simultaneous in time. Generally, there are four kinds of synchronization in digital communication system.
- Carrier synchronization. Carrier synchronization refers to that in the coherent demodulation, the receiver need to provide a coherent carrier which has the same frequency and phase as modulated carrier of the receiving signal.
- Bit synchronization: When receiving a symbol of the digital symbol, the receiver must know the exact decision time for sampling and decision.
- Group synchronization: The bits are grouped into a block to form meaningful message. Group synchronization is also called frame synchronization.
- Network synchronization: In the multi-user communication networks, keeping synchronization between stations or users is necessary for swtiching.

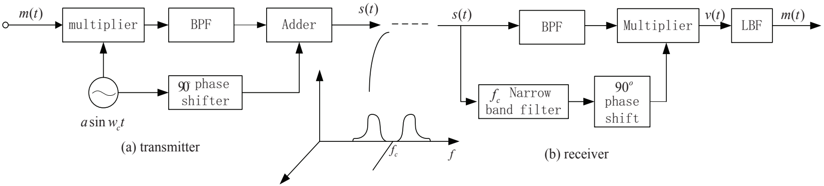
7.2 Carrier Synchronization

1. Pilot Insertion Method

- Insert a low power line-spectrum in modulated signal spectrum so that the receiver recover it as carrier synchronization signal.
- Some concerns:
  - The frequency of pilot signal should be related with the carrier frequency or just be carrier frequency.
  - Inserting pilot-frequency should be located in the zero point of signal spectrum and near signal spectrum should be as low as possible.
  - The insert pilot is orthogonal to the carrier.

Assume that the baseband signal is $m(t)$, carrier is $\cos\omega_c t$, the pilot should be $\sin\omega_c t$, and the channel fading factor is A. So the received signal is

$$r(t) = Am(t)\cos\omega_c t + A\sin\omega_c t.$$



Question: Why we need orthogonal pilot? There is DC component output in the receiver, which can effect the demodulation of digital signal. For example, $s(t) = Am(t)\cos\omega_c t + A\cos\omega_c t$

$$
\begin{aligned}
v(t) = s(t)\cos\omega_c t &= Am(t)\cos^2\omega_c t - A\cos^2\omega_c t \\
&= \frac{A}{2}m(t) + \frac{A}{2}m(t)\cos 2\omega_c t + \frac{A}{2} + \frac{A}{2}\cos 2\omega_c t
\end{aligned}
$$

The DC component can effect the decision for the bits.

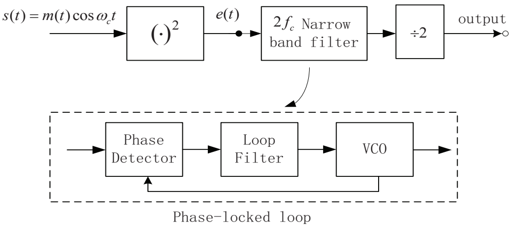
2. Direct Extraction Method

(1) Square method

Assume that the modulated signal $s(t) = m(t)\cos\omega_c t$. We do square operation to the signal

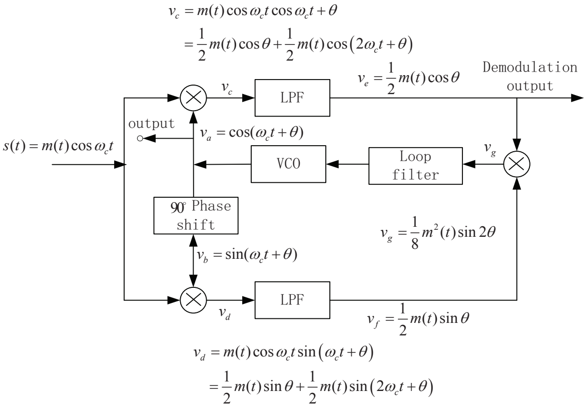
$$e(t) = [m(t)\cos\omega_c t]^2 = \frac{1}{2}m^2(t) + \frac{1}{2}m^2(t)\cos 2\omega_c t.$$

If m(t) is BPSK signal, we can filter out the $2f_c$ cosine signal, divide its frequency by 2, and obtain the $\cos\omega_c t$.



(2) Costas Loop method

It is also named in-phase and orthogonal loop method. PLL is applied to extract the carrier frequency, but there is no need of square operation.



Question: How about M-ary signal?

3. Performance of Carrier Synchronization

1. Precision of carrier synchronization: $\cos\omega_c t$ and $\cos\omega_c t + \theta$.
2. Establishing time and hold time of synchronization.
3. Influence of carrier error on P_e: the demodulated signal $s(t) = \frac{1}{2}m(t)\cos\theta$.

$$P_e = \frac{1}{2}\text{erfc}(\sqrt{\frac{E}{n_0}}\cos\theta)$$

7.3 Bit Synchronization

For the decision of the received symbol, the accurate start-stop instants of the symbol must be known. (Examples)

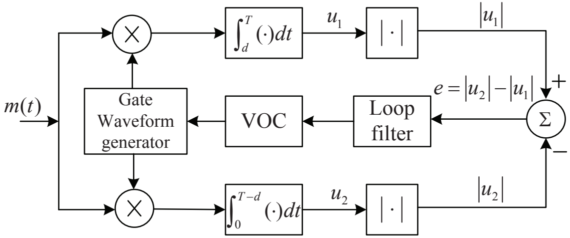
1. External Synchronization

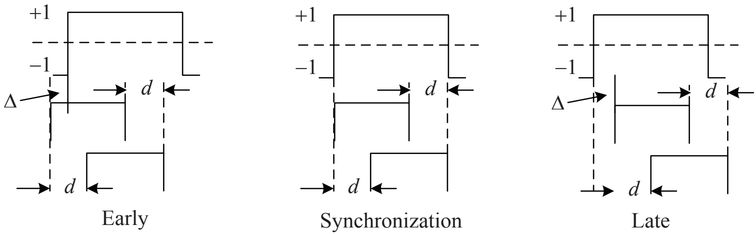
It is quite similar to the carrier synchronization and pilot signals are applied.

2. Self Synchronization

- (1) Open-loop Symbol Synchronization: nonlinear filtering synchronization. These schemes can guarantee that symbol synchronization is accurate enough only if the received signal-to-noise ratio is large.
- (2) Closed-loop Symbol Synchronization: A widely used scheme is called "early/late gate" loop.

Early-late Gate Synchronization





3. Influence of Bit Synchronization Error on Symbol Error Rate

$$Pe = \frac{1}{4}\mathrm{erfc}(\sqrt{\frac{E_b}{n_0}}) + \frac{1}{4}\mathrm{erfc}(\sqrt{\frac{E_b}{n_0}(1 - \frac{2\triangle}{T})}\ ).$$

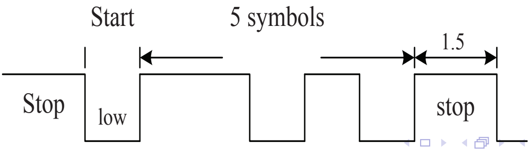
7.4 Group Synchronization

1. Introduction

In order to make the received symbols understood, it is necessary to know its grouping. The main idea of grouping synchronization is to insert unique codeword in the transmitting end and the receiver is to detect the unique code. There are two inserting styles:

- Concentrated insertion: the unique codeword is inserted in front of the symbols of the group.
- Dispersed insertion: the unique codeword is inserted dispersedly in the signal sequence.

Besides the above two approaches, start-stop synchronization is another method.



2. Concentrated Insertion Method

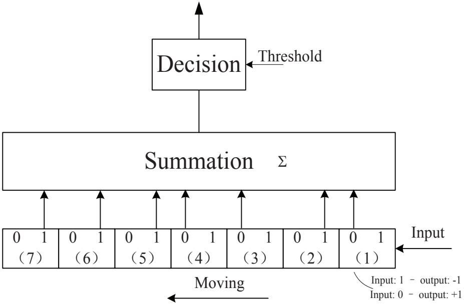
The point of concentrated insertion method is to determine unique codeword $\{x_1, \cdots, x_N\}$, the auto-correlation function of which is with correlation-peak and low sidelobes levels. The widely used unique is the Barker codeword.

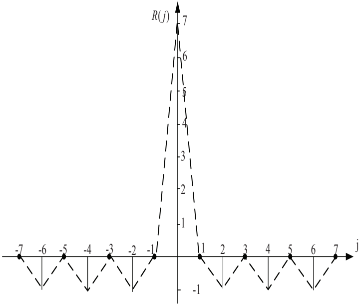
Barker Codeword

$$R(j) = \sum_{i=1}^{N-j} x_i x_{i+j} = \begin{cases} N, & j = 0, \\ 0 \text{ or } \pm 1 & 0 < j < N \\ 0, & j \geq N \end{cases}$$

N	Barker Codeword
5	$+ + + - +$ (11101)
7	$+ + + - - + -$ (1110010)
11	$+ + + - - - + - - + -$ (11100010010)
13	$+ + + + + - - + + - + - +$ (1111100110101)

Barker Codeword Detector





3. Dispersed Insertion Method

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4. Performance of Group Synchronization

In practice, lost synchronization probability P_ℓ and false synchronization probability P_f are used to evaluate the performance of group synchronization.

(1) Lost synchronization

- Because of BER, the unique codeword cannot be recognized.
- Assume that the number of the error bits doesn't exceed m in the unique codeword, detector can still recognize it.
- The probability of the event that there are r error bits in the unique word is $C_n^r p^r (1-p)^{n-r}$.

- Then the probability of the event that error bits are less than m, i.e., the probability of the unique codeword can be detected is

$$\sum_{r=0}^{m} C_n^r p^r (1-p)^{n-r}$$

.

- So the lost synchronization probability is

$$P_\ell = 1 - \sum_{r=0}^{m} C_n^r p^r (1-p_e)^{n-r},$$

where p_e is the bit error rate.

(2) False Synchronization Probability

- There are similar codeword in the information sequence to the unique word. The information symbols could be regarded, wrongly, as synchronization symbols.
- Consider n-length binary information sequence.
- The probability, that it is same to the unique word, is $1/2^n$.
- The probability, that there is only single different bit to the unique word, is $C_n^1/2^n$.
- Similar case, the probability, that there are r different bits to the unique word, is $C_n^r/2^n$.
- Assume that the detector are allowed to have m error bits. It means that when the number of the different bits are less than m, the information sequence will be regarded as the unique word. In this case, false synchronization happens.
- So the probability of the false synchronization is

$$P_f = 2^{-n} \sum_{r=0}^{m} C_n^r.$$

(3) Strategies of Group Synchronization

Improve lost synchronization probability P_ℓ by increasing the allowed error bits number m. However, it can declines the performance of false synchronization probability P_f. In practice, we divide the group synchronization into two status: capturing and tracking.

1. Capturing status: We wish the captured synchronization is accurate. In this case, decreasing m or increasing the decision threshold, we can get lower P_ℓ. (宁漏勿假)
2. Tracking status: We wish the tracked synchronization is stable. By increasing m or decreasing the decision threshold, we can get lower P_f. (宁假勿漏)