Robust Symbol Timing Recovery for Telephone Line Modems

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Abstract: The authors propose a robust symbol timing recovery (STR) for telephone line modems supporting data rates up to 32 Mbps. The STR is initialized by a start signal from carrier sensor, and the novel method is proposed which resolves the difference between the frequency of the transmitter's clock and the receiver's clock, called baud frequency offset. The proposed method is applied on digital receiver in a 16 frequency diverse quadrature amplitude modulation (FDQAM) system.

1. Introduction

The home phoneline networking alliance (HomePNA), an industrial organization that comprises several companies, releases the HomePNA 2.0 in 1999. The HomePNA 2.0 system operates in burst transmission mode with data rates up to 32 Mbps using the existing telephone line. Thus a fast symbol timing recovery (STR) is needed, and feedforward recovery schemes are more appealing than feedback schemes. Furthermore, in a real system, the clocks at the transmitter and receiver are not perfectly synchronized. The difference between the modulation clock and the local reference clock is called the baud frequency offset. In the HomePNA 2.0 system, there exists a baud frequency offset up to +/-100 ppm. To prevent the degradation in the performance of the demodulator, it is important to track the differences in clock rates. In this letter, we propose a novel method to resolve the baud frequency offset and a robust STR structure which is initialized by a start signal from carrier sensor.

2. Proposed Symbol Timing Recovery

The proposed symbol timing recovery using the feedforward scheme is shown in Fig. 1. Since the HomePNA 2.0 system operates in burst transmission mode, the feedforward recovery schemes are more appropriate than feedback schemes. Usually, the feedforward schemes have shorter acquisitions and are better suited for bust transmission mode. Moreover, before the frame is arrived at demodulator, the STR performance can be deteriorated by a meaningless value. Hence the timing estimator and interpolator should be initialized by a start signal from carrier sensor.

The timing estimator under consideration operates with 4 samples per symbol, and uses the nonlinearities and the discrete Fourier transform (DFT) to extract the timing

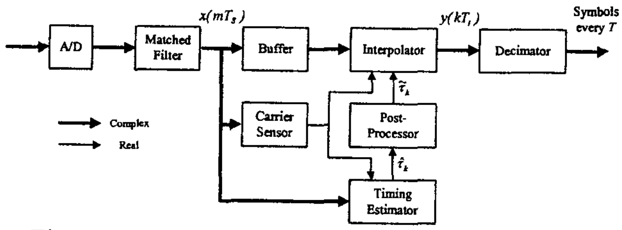


Figure 1. Proposed feedforward STR block diagram

information[1]. The most common nonlinearities are square-law, absolute law, and fourth law. The timing estimate $\tilde{\tau}_k$ is divided into the integer offset m_k and the fractional offset μ_k, which are compensated by decimator and interpolator, respectively. After multiplying the timing estimate by the oversampling factor *SPS*, the integer offset m_k and the fractional offset μ_k are calculated by the timing offset classifier as

$$m_k = int[\tilde{\tau}_k * SPS] \quad (1)$$

$$\mu_k = \tilde{\tau}_k * SPS - int[\tilde{\tau}_k * SPS] \quad (2)$$

where *int*[*x*] means the largest integer not exceeding *x* and *SPS* is the number of samples per symbol used in the timing estimator.

In the HomePNA 2.0 system, there exists a baud frequency offset up to +/-100 ppm of the symbol rate. We effectively resolve the baud frequency offset using the proposed method as shown in Fig. 2.

3. Proposed Method for Resolving Baud Frequency Offset

In practice timing phase is not constant, there exists a slight frequency offset between the frequency of the transmitter's clock and the receiver's clock. If the baud frequency offset is not properly resolved, some strobes will be duplicated or missed. To cope with this problem, the various approaches are available[2][3]. In this letter, we propose a novel method which effectively resolves the baud frequency offset, as shown in Fig. 2. This algorithm has a simple implementation structure composed of delay elements, signal sample selector, and variable strobe extractor(in decimator).

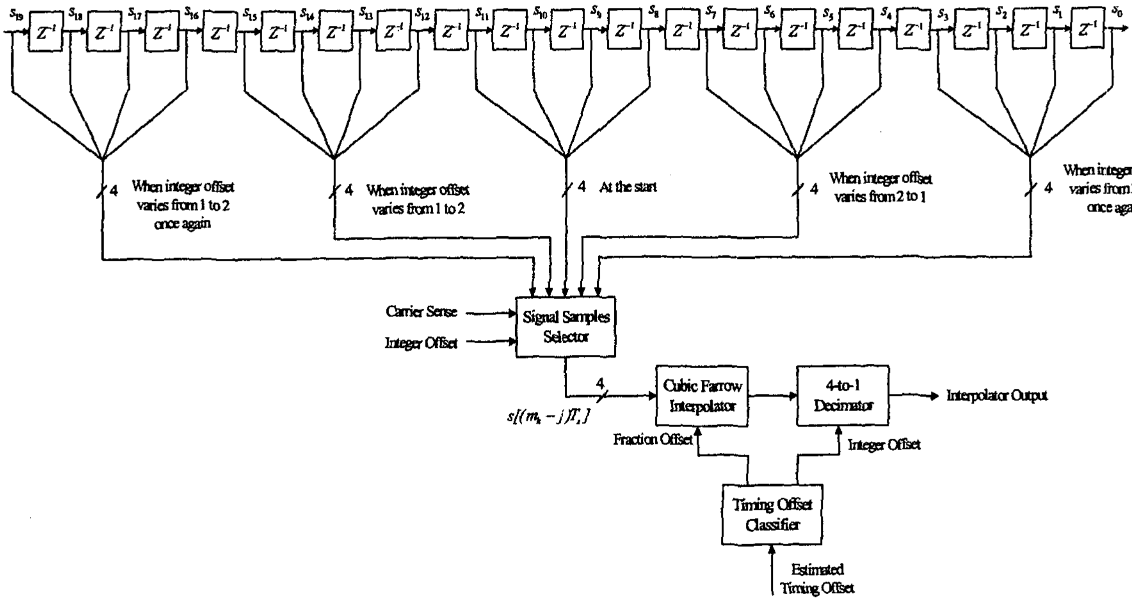


Figure 2. Proposed baud frequency offset compensation method

The interpolants are computed at time $kT_i = (m_k + \mu_k)T_s$, where $0 \le \mu_k < 1$, T_i is an interval between interpolants and T_s is a sample period. The interpolants are given by

$$y(kT_i) = y[(m_k + \mu_k)T_s] = \sum_{j=I_1}^{I_2} s[(m_k - j)T_s]\, h[(j + \mu_k)T_s] \tag{3}$$

$$s[(m_k - j)T_s] = \begin{cases} \vdots & \vdots \\ x[(m_k - j - 2I)T_s], & \textit{when integer offset varies from 1 to 2 once again} \\ x[(m_k - j - I)T_s], & \textit{when integer offset varies from 1 to 2} \\ x[(m_k - j)T_s], & \textit{at the start} \\ x[(m_k - j + I)T_s], & \textit{when integer offset varies from 2 to 1} \\ x[(m_k - j + 2I)T_s], & \textit{when integer offset varies from 2 to 1 once again} \\ \vdots & \vdots \end{cases} \tag{4}$$

where $s[(m_k - j)T_s]$ and $h[(j + \mu_k)T_s]$ are the $I = I_2 - I_1 + 1$ selected signal samples to be used for the kth interpolant and I interpolating filter coefficients which is identified by the fractional offset μ_k, respectively. The I signal samples $s[(m_k - j)T_s]$ are determined by the integer offset transition as equation (4), where $x[(m_k - j)T_s]$ is the I received and matched filtered signal samples

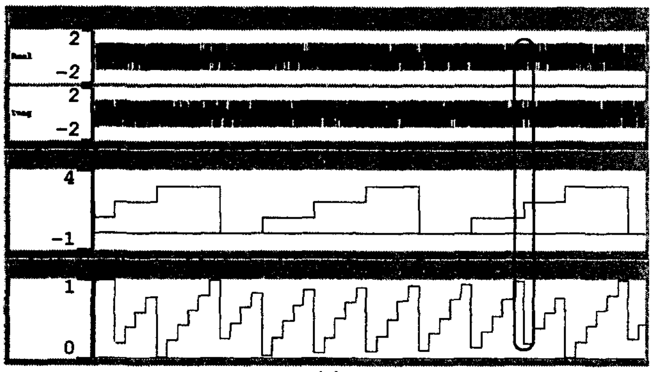
In this letter, we consider the Lagrange cubic interpolator by using a continuously variable delay element a Farrow architecture. The inherent problem is that some strobes are duplicated or missed due to the baud frequency offset. From the Lagrange cubic Farrow interpolator, when the integer offset varies from 1 to 2, some strobes are to duplicated. Likewise, when the integer offset varies from 2 to 1, some strobes are missed. To overcome this problem, at the beginning, the interpolants are calculated by using a set of signal samples which obtained at the start position($x[(m_k - j)T_s]$). When the integer offset varies from 1 to 2, the interpolants are calculated by using a set of signal samples which is advanced by 4 samples($x[(m_k - j - 4)T_s]$). Likewise, when the integer offset varies from 2 to 1, the interpolants are calculated by using a set of signal samples which is delayed by 4 samples($x[(m_k - j + 4)T_s]$). In the HomePNA 2.0 system, since all stations are able to transmit and receive the link-level frames with up to 1,526 octets and a baud frequency offset may be present up to +/-100 ppm, the timing drift normalized to the symbol period can be occurred up to +/-1.2208. Thus the maximum number of integer offset transition that cause the strobes to duplicate or miss, is two within a frame, in other words, the shift of 4 samples can be required up to two within a frame. Consequently, to cope with the phenomenon in which timing offset increases or decreases monotonously due to baud frequency offset, the proposed method should store a total of 19 samples of the received signal in a buffer. And the correct strobe is determined by the decimator using the relation between the integer offset m_k and the strobe index as shown in Table 1.

Table 1. The relation between timing offset and strobe index

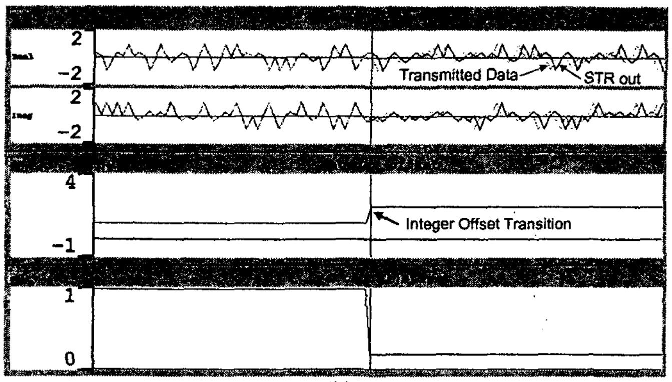
Normalized Timing Offset*4	Integer Offset	Fractional Offset	Strobe Index
0.0	0	0	2
0.25	0	0.25	2
0.5	0	0.5	2
0.75	0	0.75	2
1.0	1	0	3
1.25	1	0.25	3
1.5	1	0.5	3
1.75	1	0.75	3
2.0	2	0	0
2.25	2	0.25	0
2.5	2	0.5	0
2.75	2	0.75	0
3.0	3	0	1
3.25	3	0.25	1
3.5	3	0.5	1
3.75	3	0.75	1

4. Application in Digital Receiver

Here we consider a 16 frequency diverse quadrature amplitude modulation (FDQAM) system[4] where the signal to noise ratio (SNR) of 30 dB, roll-off factor of 1.0, and normalized baud frequency offset of 200 ppm are assumed. In addition, we consider the Lagrange cubic interpolator by using a continuously variable delay element a Farrow architecture. Fig. 3 shows the simulation results performed using signal processing worksystem (SPW) simulation package. When the integer offset varies from 1 to 2 for the first and second time, the strobes are successfully recovered. But when the integer offset varies from 1 to 2 for the third time, the strobe is duplicated. The eye diagrams of the STR output are shown in Fig. 4. The above result shows that in the absence of any baud frequency offset compensation method, the strobes of eye diagram are slipped due to the duplicated or missed symbols. However, by using the proposed method, this problem can be completely resolved.

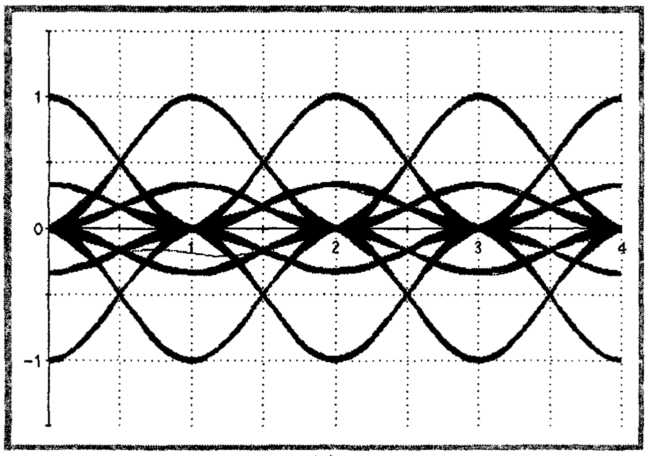


(a)

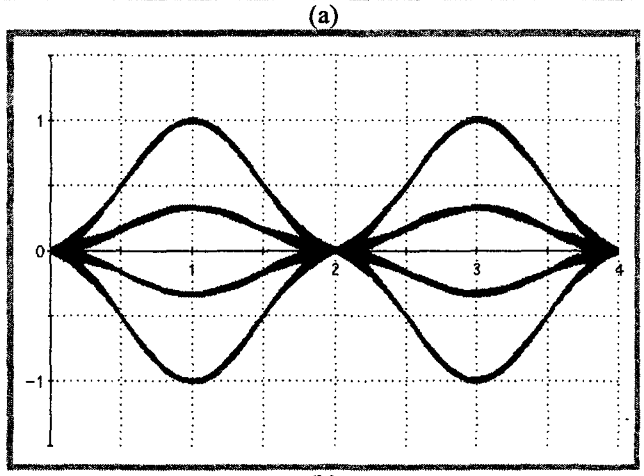


(b)

Figure 3. Simulation results for 16 FDQAM
(a) STR output and estimated integer and fractional offset
(b) Enlarged signal for the third integer offset transition (circled region)



(a)



(b)

Figure 4. Eye diagrams
(a) Without any baud frequency offset compensation method
(b) With the proposed baud frequency offset compensation method

5. Conclusions

We have proposed a robust symbol timing recovery for the HomePNA 2.0 system. In the proposed STR structure, the timing estimator and interpolator are initialized by a start signal from carrier sensor. Moreover, we have proposed the novel and simple method which effectively resolves the baud frequency offset up to +/-100 ppm.

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