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OFDM Timing Jitter Reduction by Oversampling

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Abstract: OFDM offers many advantages in terms of resilience to fading, reflections and the like. OFDM also offers a high level of spectrum efficiency. However to reap the rewards, it is necessary that the OFDM system operates correctly, and to achieve this, it is necessary for the OFDM synchronization to be effective. There are a number of areas in which the OFDM synchronization is critical to the operation of the system, but this paper only deals with OFDM synchronization in terms of clock accuracy and proposes an oversampling based technique to ensure that the samples are synchronized and data errors are minimized.

Keywords: OFDM, Timing Jitter, Oversampling.

1. Introduction

While OFDM has been successfully deployed in many different radio communications systems, one of the main problems that needs to be overcome is that if OFDM synchronization. Effective OFDM synchronization enables the data error rates to be kept to a minimum, whereas if the system is not accurately synchronized, then errors will result and the system will become less effective. The problem of timing jitter grows rapidly for higher data rate systems specially for optical communication where the data rate becomes too high than RF communication, at these very high data rates, timing jitter is emerging as an important limitation to the performance of OFDM systems. A major source of jitter is the sampling clock in the very high speed analog-to-digital converters (ADCs) which are required in these systems. Timing jitter is also emerging as a problem in high frequency band pass sampling OFDM radios [2].

Regarding our timing estimation performance measure in the context of OFDM, the additional interference power caused by timing estimation might be considered, rather than the timing offset estimation variance, since the former reflects the actual impact of timing synchronization error on the system's performance. However, the interference power may also depend on the mean of the timing estimate. Hence, in this paper, we introduce a more revealing performance measure for the timing characterization of OFDM systems. This paper is organized as follows. Section II describes the OFDM system considered. Section III briefly presents the OFDM synchronization problem and the effects of synchronization errors. In Section IV, the proposed synchronization scheme is presented. Performance evaluation, simulation results, and discussions are provided in Section V. Finally, our conclusions are provided in Section VI.

2. OFDM System

Consider the high-speed OFDM system shown in Fig. 1 is directly taken from [1]. The OFDM symbol period, not including the cyclic prefix, is T. At the transmitter, in each symbol period, up to N complex values representing the constellation points are used to modulate up to N subcarriers. Timing jitter can be introduced at a number of points in a practical OFDM system but in this letter we consider only jitter introduced at the sampler block of the receiver ADC. Fig. 2 shows how timing jitter is defined. Ideally the received OFDM signal is sampled at uniform intervals of T/N. The dashed lines in Fig. 2(a) represent uniform sampling intervals. The solid arrows represent the actual sampling times. The effect of timing jitter is to cause deviation τ_n between the actual sampling times and the uniform sampling intervals. Fig. 2(b) shows the discrete timing jitter τ_n for this example. In OFDM systems while timing jitter degrades system performance, a constant time

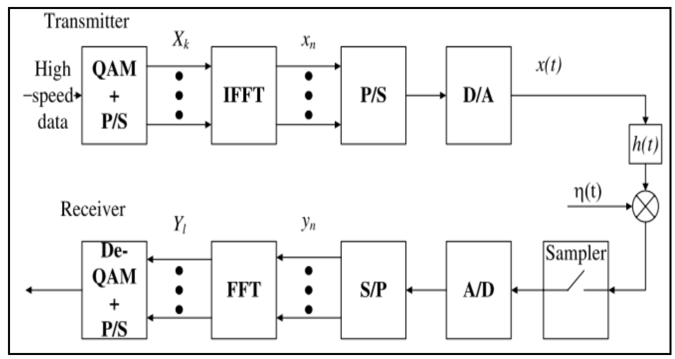

Fig. 1 OFDM block diagram [1].

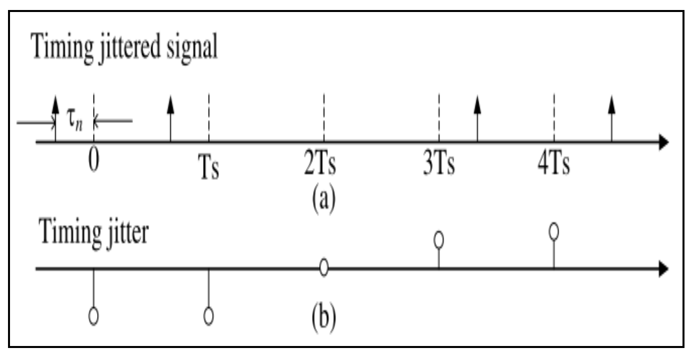

Fig. 2 Definition of timing jitter [1].

Offset from the 'ideal' sampling instants is automatically corrected without penalty by the equalizer in the receiver.

3. Need of Synchronization in OFDM

The need for OFDM synchronization OFDM offers many advantages in terms of resilience to fading, reflections and the like. OFDM also offers a high level of spectrum efficiency. However to reap the rewards, it is necessary that the OFDM system operates correctly, and to achieve this, it is necessary for the OFDM synchronization to be effective.

There are a number of areas in which the OFDM synchronization is critical to the operation of the system:

A. OFDM synchronization in terms of frequency offset: It is necessary that the frequencies are accurately tracked to ensure that orthogonality is maintained.

B. OFDM synchronization in terms of clock accuracy: It is necessary that the sampling occurs at the correct time interval to ensure that the samples are synchronized and data errors are minimized.

In order to ensure that the OFDM system works to its optimum, it is necessary to ensure that there are schemes in place to ensure the OFDM synchronization is within the required limits.

A. Frequency offset OFDM Synchronization: it is particularly important that the demodulator in an OFDM receiver is able to synchronize accurately with the carriers within the OFDM signal. Offsets may arise for a number of reasons including any frequency errors between the transmitter and the receiver and also as a result of Doppler shifts if there is movement between the transmitter and receiver.

If the frequency synchronization is impaired, then the orthogonality of the carriers is reduced within the demodulation process and error rates increase. Accordingly it is essential to maintain orthogonality to reduce errors and maintain the performance of the link. First look at the way that sampling should occur. With the demodulator in synchronization, all the contributions from the other carriers sum to zero as shown. On this way all the carriers are orthogonal and the error rate is at its minimum [8].

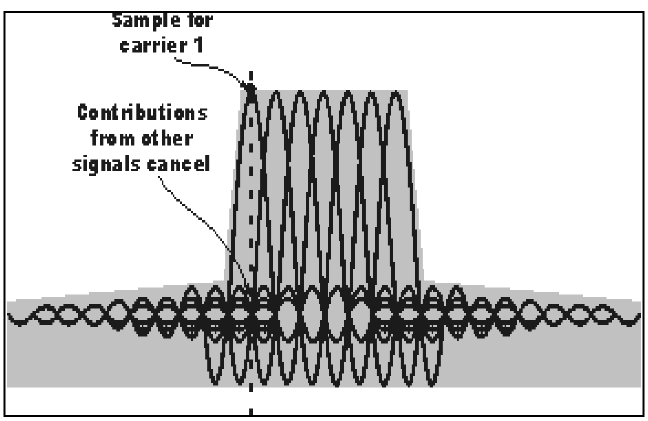

Fig.3 OFDM signal where demodulation is in synchronization [8].

If a situation is encountered where the OFDM synchronization for the frequency aspects are poor, then the demodulator will centre its samples away from the peak of the signal, and also at a point where the contributions from the other signals do not sum to zero. This will lead to a degradation of the signal which could in turn lead to an increase in the number of bit errors.

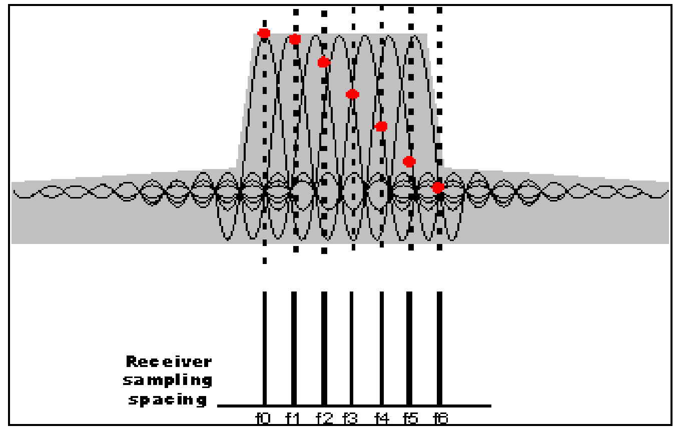

Fig.5 OFDM synchronization problem with clock offset problem [8]

4. Proposed Synchronization Technique

We now analyze the effect of both fractional and integral oversampling in OFDM and show that either or both can be used to reduce the degradation caused by timing jitter. To achieve integral oversampling, the received signal is sampled at a rate of MT/N, where is an integer. For fractional oversampling some band-edge subcarriers are unused in the transmitted signal. When all N subcarriers are modulated, the bandwidth of the baseband OFDM signal is N/2T, so sampling at intervals of T/N as shown in Fig. 2 is Nyquist rate sampling. If instead, only the subcarriers with indices between $-N_L$ and $+N_U$ are non zero, the bandwidth of the signal is $(N_L+N_U)/2T$ in this case sampling at intervals of T/N is above the Nyquist rate. The degree of oversampling is given by $(N_L+N_U)/N$. In the general case, where both integral and fractional oversampling are applied, the signal samples after the ADC in the receiver are given by

$$y_{n_M} = y\left(\frac{n_M T}{NM}\right) = \frac{1}{\sqrt{N}}\sum_{k=-N_L}^{N_U} H_k X_k e^{\left(\frac{j2\pi k}{T}\times\frac{n_M T}{NM}\right)} + \eta\left(\frac{n_M T}{NM}\right)$$

Now the power of jitter for such system can be written as

$$\frac{P_j(l)}{\sigma_s^2} = \frac{\pi^2}{3M}\left(\frac{N_v N}{T_N^2}\right) E\left\{\tau_n^2\right\}$$

If there is no integral oversampling or fractional oversampling, M = 1 and N_v = N, therefore

$$\frac{P_j(l)}{\sigma_s^2} = \frac{\pi^2}{3}\left(\frac{N^2}{T_N^2}\right) E\left\{\tau_n^2\right\}$$

Comparing both it can be seen that the combination of integral oversampling and fractional oversampling reduces the jitter noise power by a factor of N_v/NM.

5. Simulation Results

We now present simulation results for 2000 OFDM symbols, N = 512 and jitter variance E $\{\tau_n^2\}$ = $(0.3T_N/N^2)$. Note that the jitter variance is not changed when oversampling is applied, so the jitter represents a larger fraction of the sampling period for the oversampled systems. Fig. 6 shows the variance of the noise due to jitter as a function of received subcarrier index when band-edge subcarriers are unused. It shows that the power of the jitter noise is not a function of subcarrier index and that removing the band-edge subcarriers reduces the noise equally across all subcarriers.

Fig. 7 shows both the theoretical and simulation results for average jitter noise power as a function of the oversampling factor. There is close agreement between theory and simulation. Increasing the sampling factor gives a reduction of $10\log_{10}(N_v/NM)$ in jitter noise power, so every doubling of the sampling rate reduces the jitter noise power by 3 dB.

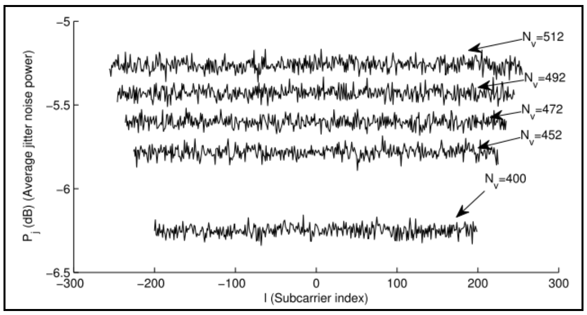

Fig. 6. Average jitter noise power versus subcarrier index when leaving band-edge subcarrier unused.

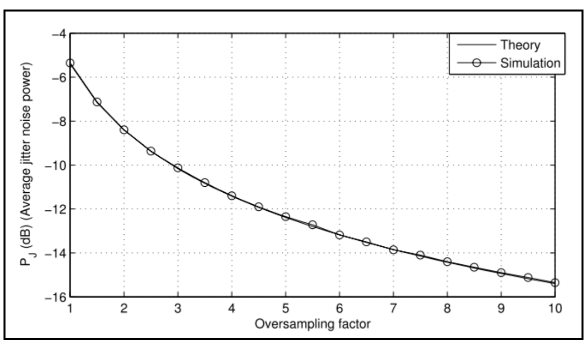

Fig. 4. Average jitter noise power versus sampling factor.

5. CONCLUSIONS

It has been shown both theoretically and by simulation that oversampling can reduce the degradation caused by timing jitter in OFDM systems. Two methods of oversampling were used: fractional oversampling achieved by leaving some of the band-edge subcarriers unused, and integral oversampling implemented by increasing the sampling rate at the receiver. For the case of white timing jitter both techniques result in a linear reduction in jitter noise power as a function of oversampling rate. Thus oversampling gives a 3 dB reduction in jitter noise power for every doubling of sampling rate. It was also shown that in the presence of timing jitter, high frequency subcarriers cause more ICI than lower frequency subcarriers, but that the resulting ICI is spread equally across all subcarriers.

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