Timing Metrics of Joint Timing and Carrier-Frequency Offset Estimation Algorithms for TDD-based OFDM Systems

Extended Abstract

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***Abstract*— In joint timing and carrier offset estimation algorithms for Time Division Duplexing (TDD) OFDM systems, different timing metrics are proposed to determine the beginning of a burst or symbol. In this contribution we investigated the different timing metrics in order to establish their impact on the joint time and carrier-frequency offset estimation.**

***Index Terms*— Timing synchronization, carrier-frequency offset estimation, HiperLAN/2.**

I. Introduction

In our *Software Defined Radio* (SDR) project we have combined two different standards, Bluetooth (CPM) and HiperLAN/2 (TDD-based OFDM) on one common platform [1]. For OFDM synchronization and carrier-frequency offset estimation purposes we decided to use joint-estimation time-domain methods that utilize the redundancy present in the transmitted waveforms (as e.g. reported in [2], [3], [4]). In our SDR system we only execute burst synchronization, as symbol synchronization was observed not to be needed.

Three observations were made: 1/. The joint estimation algorithms all execute the same '*building blocks*' for correlation purposes, however the '*timing metrics*' used by the estimation algorithms combine these building blocks differently (see below). 2/. In the HiperLAN/2 (burst synchronization) case, a multitude of parameter choices for these building blocks is possible, and 3/. Different burst-types need to be distinguished in HiperLAN/2, each with their own correlator structure and parameters. The latter two problems are for instance addressed in [5] and [6]. In this paper we focus on the first observed issue: we compared the different timing metrics in order to assess their impact on the joint time and carrier-frequency offset estimation.

II. Building Blocks

The joint estimation methods above can be described in a unified fashion by introducing as 'building blocks' the correlation function $z(j)$ and segment energies $e_1(j)$ and $e_2(j)$:

$$z(j) = \sum_{m=0}^{C-1} r^*(j+m).r(j+m+L), \quad (1)$$

$$e_1(j) = \sum_{m=0}^{C-1} |r(j+m)|^2 \text{ and} \quad (2)$$

$$e_2(j) = \sum_{m=0}^{C-1} |r(j+m+L)|^2 \quad (3)$$

with $\{r(k)\}$ the received (discrete-time, complex) baseband signal, C the correlation length, L the correlation period and j the time index of the first sample of the first of the two segments. In all methods, a *Timing Metric* TM is used to estimate the start time j_0 of the symbol or burst. This timing metric uses the magnitude of the correlation function and, depending on the algorithm used, the segment energies. Formally, $TM = TM(|z(j)|, e_1(j), e_2(j))$. At the estimated start time $\hat{j_0} \triangleq arg(max_j\,(TM))$, the phase of the correlation function $\angle z(\hat{j_0})$ is used as a *Frequency Metric* FM that enables the estimation of the carrier-frequency offset. As the joint estimation algorithms differ only in the timing metric TM they use, while all algorithms evaluate the same frequency metric FM, the difference in performance can be attributed to the difference in timing estimation.

III. Timing Metrics

In this contribution we investigate the effects of four timing metrics $TM_a \ldots TM_d$ on the timing estimate and frequency-offset estimate, using the HiperLAN/2 case as an example. The algorithms used are:

Alg. a $\quad TM_a = |z(j)|$, [4].
Alg. b $\quad TM_b = |z(j)|^2/e_2(j)^2$, [2].
Alg. c $\quad TM_c = |z(j)|^2/(e_1(j).e_2(j))$.
Alg. d $\quad TM_d = |z(j)| - \frac{\rho}{2}.(e_1(j) + e_2(j))$, with $\rho = \frac{SNR}{SNR+1}$, [3].

Algorithm c by [Hoeksema], which is basically taken from Schwarz's inequality, is to the authors' knowledge *and* surprise not reported before for this purpose. This may be due to the fact that in algorithm a, a good AGC system is assumed, or that in algorithm b it is assumed that the energy of the first segment is equal to the energy in the second. While algorithm c is computationally more involved than algorithm a or algorithm b, it is not *that* involved, especially not in case of burst synchronization. Basically algorithm c computes the same quantities as algorithm b, but combines them in a different fashion.

So, what timing metric performs best?

IV. Comparison of Algorithms

Using results in [6], we compare the algorithms for an AWGN channel by presenting analytical results for the statistical properties of the timing metric at a correctly estimated time instant and at a timing instant in which no symbol is present.

As an example consider figure 1 in which the variance of the timing metric at correct timing instant for the parameters $(L, C) = (64, 16)$ is shown. This parameter choice corresponds to the case of HiperLAN/2 symbol synchronization[1]. As can be seen, algorithm c has lowest variance in the region of interest.

Also we present results regarding the detection probability, false alarm rate and the variance of the timing and carrier-offset estimation errors, e.g. see figure 2) and figure 3).

[1]A deterministic signal was used here, a more profound analysis could used Gaussian distributed random variables.

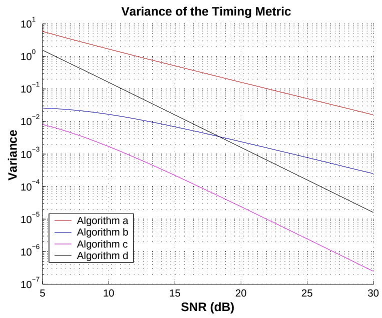

Fig. 1. Variance of Timing metric for $(L, C) = (64, 16)$. Signal power $\sigma_s^2 = 0.5$.

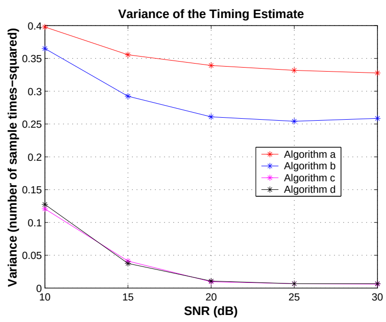

Fig. 2. Variance of the timing estimation error as a function of the SNR, $(L, C) = (64, 16)$.

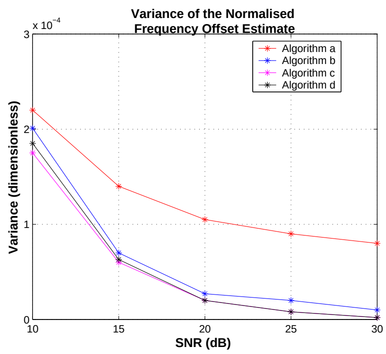

Fig. 3. Variance of the frequency offset estimation error as a function of the SNR, $(L, C) = (64, 16)$.

V. Conclusions and Ongoing Work

Based on our analysis [6], Algorithm c appears to outperform the other algorithms in case it is used for the purpose of burst synchronization.

As timing estimator and frequency offset estimator algorithm c and algorithm d compare about equal and both outperform algorithm b and algorithm a.

As the analysis pertains to AWGN channels we currently are investigating the performance of the metrics for the (more realistic) fading channels.

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