Pilot tone frame synchronisation of OFDM signals for BDSL applications

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Abstract

In this paper, we consider a broadband digital subscriber line (BDSL) service over twisted pair telephone lines. The data is transmitted over a short twisted pair cable by using multicarrier modulation, based upon discrete Fourier transforms (DFT). In order to detect the transmitted data symbols reliably, a frame synchronisation algorithm is needed, estimating the boundaries of the transmitted frames. We propose a frame synchronisation algorithm making use of two pilot carriers. As shown in the results, fast acquisition (within ten frames) can be obtained, even in the presence of transmitted data.

1 INTRODUCTION

Telephone companies intend to supply broadband digital subscriber line (BDSL) services (>10Mbit/s) over their networks existing of fibre to the curb and twisted pair cables in the last drop. New data services will coexist with or replace the existing data services such as ISDN (or the analogue POTS). These high data rates over twisted pair cables can be obtained using baseband OFDM. In baseband OFDM, data symbols $\{a_{m,n}\}$, where $a_{m,n}$ the n^{th} data symbol transmitted during the m^{th} frame, are modulated on 2N orthogonal carriers using an inverse fast Fourier transform. A guard time interval ν, containing a cyclic extension of the transmitted signal, is inserted to cope with channel dispersion [1].

As several twisted pair cables are bundled, the transmission over a pair is mainly restricted by crosstalk [2]-[3], coupled from the other pairs of the bundle. Assuming no spectral overlap between the upstream and downstream BDSL channels, the dominating noise mechanism is far end crosstalk (FEXT). Nonetheless the transmitted signal is affected by a various number of disturbances, we only consider far end cross talk (FEXT) and additive white Gaussian noise (AWGN).

At the receiver, the signal is evaluated at the instants $(\ell+\ell_\varepsilon+i(2N+\nu))T$, ℓ_ε denoting the timing offset between the receiver and transmitter symbol clock, and can be expressed as :

$$r_{\ell,i} = \sum_{m=-\infty}^{+\infty} \sum_{k=-\nu}^{2N-1} \sum_{n=0}^{N-1} 2\,\mathrm{Re}\left(a_{i,n} e^{j2\pi\frac{kn}{2N}} \right) g\Big((\ell+\ell_\varepsilon - k + (i-m)(2N+\nu))T \Big) + w_{\ell,i} \quad (1)$$

where g(t) is the impulse response of the channel and T the duration of a sample. The guard interval is removed and the resulting samples are fed to the FFT, in order to obtain the transmitted data symbols.

To detect the transmitted data symbols reliably, the receiver should be able to distinguish the boundaries of the successive transmitted frames of length $2N+\nu$, i.e. an estimation of the timing offset is needed. In this contribution, we propose a frame synchronisation algorithm making use of two pilot carriers.

2 SYNCHRONISATION ALGORITHM

A block diagram of the proposed frame synchronisation mechanism is illustrated in Figure 1. The phase difference between W_{k_1} and W_{k_2}, the outputs of the FFT of the pilot carriers k_1 and k_2 respectively, can be used to determine the synchronisation error ℓ_ε. This phase difference is extracted from the imaginary part of the product $W_{k_1}W_{k_2}^*$,

$$\mathrm{Im}\left[W_{k_1} W_{k_2}^* \right] \quad (2)$$

The imaginary part (2) is fed to a low pass filter F(z) and an integrator I(z) in order to obtain an estimation of the timing offset to position the frame. Notice the periodicity of W_{k_1} and W_{k_2}, thus (2), in ℓ_ε with period $(2N+\nu)T$. In the following, we restrict to a timing offset $\ell_\varepsilon \in [-\nu, 2N-1]$.

We first assume that only the two pilot carriers are transmitted and that the transmitted signal is not disturbed by FEXT or AWGN. Observing $W_{k_1}W_{k_2}^*$, some restrictions to the pilot carriers can be found. The first restriction requires that the pilot carriers are adjacent carriers, i.e. $k_2=k_1+1$. When this restriction is not fulfilled, (2) will show more than one stable zero crossing such that frame synchronisation can not be achieved. The second restriction demands that the discontinuity of the signals transmitted by the pilot carriers between successive frames is minimal, which is expressed in $k_i\nu \cong 2nN$, $i=1,2$, $n \in \mathbb{N}$. Figures 2a-b show the real and imaginary parts of $W_{k_1}W_{k_2}^*$ as function of the synchronisation error ℓ_ε, when the discontinuity of the signals between the successive frames is minimal ($k_i\nu \approx 2nN$) and maximal ($k_i\nu \approx (2n+1)N$) respectively. In Figure 2a, (2) shows one stable and one non-stable zero crossing, while Figure 2b shows various stable and non-stable zero crossings for (2).

Next, we allow transmitted data symbols, causing intercarrier interference to the pilot carriers, and the presence of FEXT and AWGN, and we investigate the influence of these disturbances on the product $W_{k_1}W_{k_2}^*$. We define the signal to noise ratio SNR as :

$$\mathrm{SNR} = \frac{P_U}{P_{ICI} + P_{FEXT} + P_{AWGN}} \qquad (3)$$

The contribution P_U is the useful contribution, containing the contributions of the pilot carriers. The contribution P_{ICI} contains the intercarrier interference, caused by the data carriers. The contribution P_{FEXT} is engendered by the FEXT and the contribution P_{AWGN} by the AWGN. Observing (3) as function of the synchronisation error ℓ_ε, we find that near synchronisation (ℓ_ε small), the dominant noise mechanism is FEXT while in acquisition (ℓ_ε large), the intercarrier interference becomes the major disturbance. This intercarrier interference can be avoided by not transmitting data carriers during acquisition.

Far end crosstalk can be modelled by a transfer function $H_{FEXT}(f) \sim f^\alpha$, where α approximately equals 2. This implies that at higher frequencies the signal is disturbed by a higher amount of FEXT. As near synchronisation the FEXT is the dominant noise mechanism, the performance of the synchronisation algorithm will depend on the choice of the pilot carriers. Placing the pilot carriers at lower frequencies will therefore engender a higher precision of the synchronisation algorithm, while to obtain the same performance for pilot carriers at higher frequencies, to gain in transmission capacity as the data carriers can use the frequencies which are least affected by the noise, the effective bandwidth of the synchronisation loop needs to be smaller, which is more difficult to implement.

The proposed synchronisation algorithm examines the imaginary part of the product $W_{k_1}W_{k_2}^*$ and we allow transmitted data symbols during acquisition. As the channel introduces to the pilot carriers a different phase shift, a non-zero synchronisation error is obtained in tracking mode as (2) differs from 0 when no synchronisation error occurs. This problem can be solved by an estimation of the channel characteristics before the frame synchronisation which will be used to correct (2). To obtain synchronisation, the frame is shifted over an integer number of samples $\Delta\ell$, which is related to (2) :

$$\Delta\ell = \mathrm{round}\left(K.\mathrm{Im}\left[\frac{W_{k_1}W_{k_2}^*}{\left(E\left[W_{k_1}\right] E\left[W_{k_2}^*\right]\right)_{\ell_\varepsilon=0}} \right] \right) \qquad (4)$$

where round(.) is the projection of a real value to the nearest integer value and K is a constant. In this case, no correction will take place if no synchronisation error occurs.

However, for large synchronisation errors, near the non-stable zero crossing of (4), the influence of the disturbances (FEXT, interference) becomes dominant and slows down acquisition. To avoid this delay, the real part of the product $W_{k_1}W_{k_2}^*$, which is negative for large synchronisation errors, is evaluated. In case of a negative real part, the frame is shifted over N samples, which accords to almost half a frame. Some simulations are depicted in Figure 3, where the evolution of the synchronisation error is shown as function of the number of transmitted frames for various initial values ℓ_{ε_o} of the synchronisation error. Figure 3 illustrates that if the constant K is chosen too large, a fluctuation of the synchronisation error appears when synchronisation is reached. It can be shown that the constant K will not lead to a fluctuation if limited by N/π. On the other hand, if K is chosen too small, a non-zero synchronisation error occurs. Analogously as the upper limit was found, a lower limit for K ($K>N/2\pi$) can be derived. We observe that frame synchronisation can be reached within ten frames, even in the presence of transmitted data.

3 CONCLUSIONS

In this paper, a synchronisation algorithm for OFDM signals based on pilot carriers is analysed. The pilot carriers are required to be adjacent carriers and depend on the guard interval. The synchronisation algorithm makes use of both real and imaginary parts of the product $W_{k_1}W_{k_2}^*$ in order to speed up acquisition. It is shown that fast acquisition (within ten frames) can be obtained, even in the presence of transmitted data.

References

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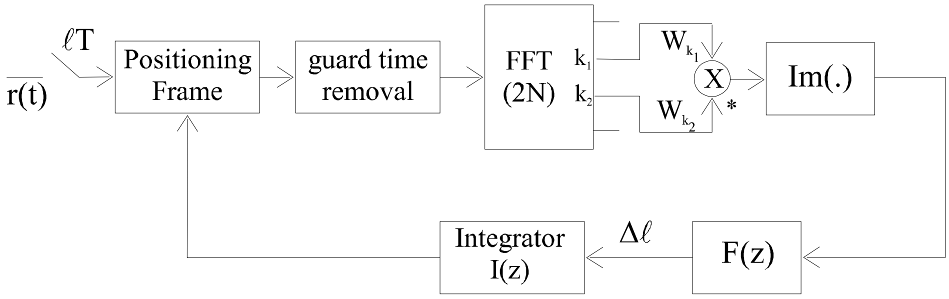

Figure 1 : Block diagram of the synchroniser structure

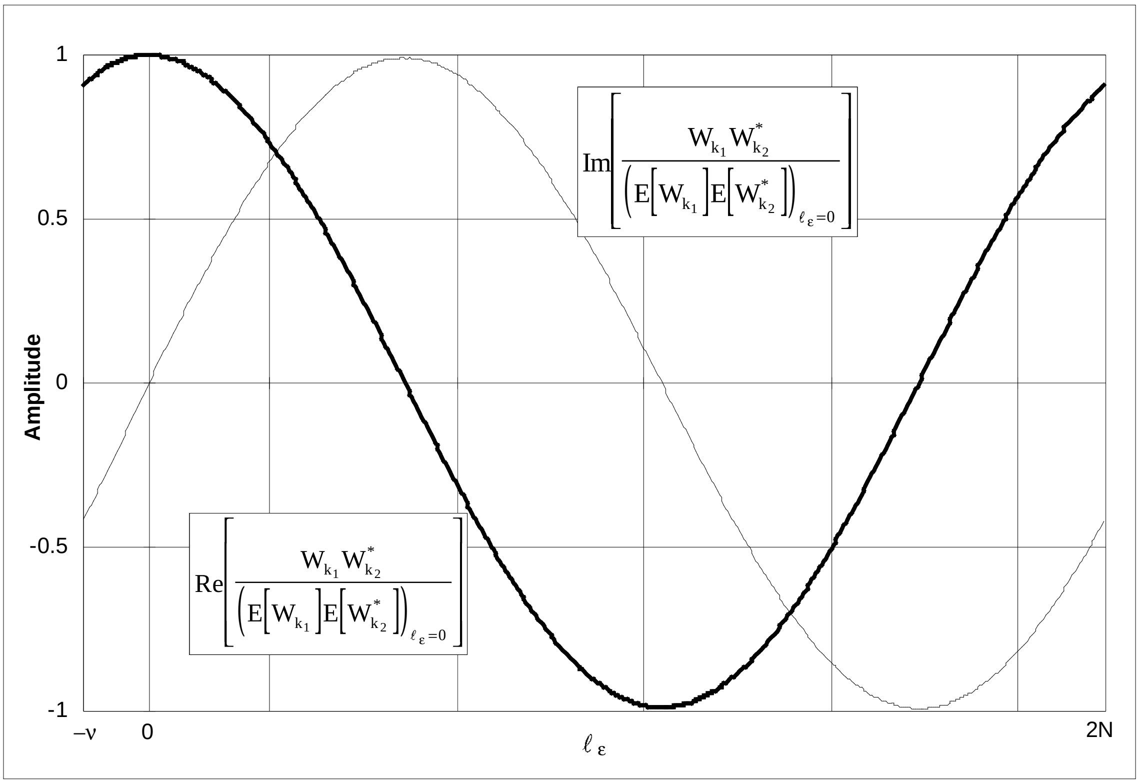

Figure 2a : Real and imaginary parts of the product $W_{k_1}W_{k_2}^*$: minimal discontinuities

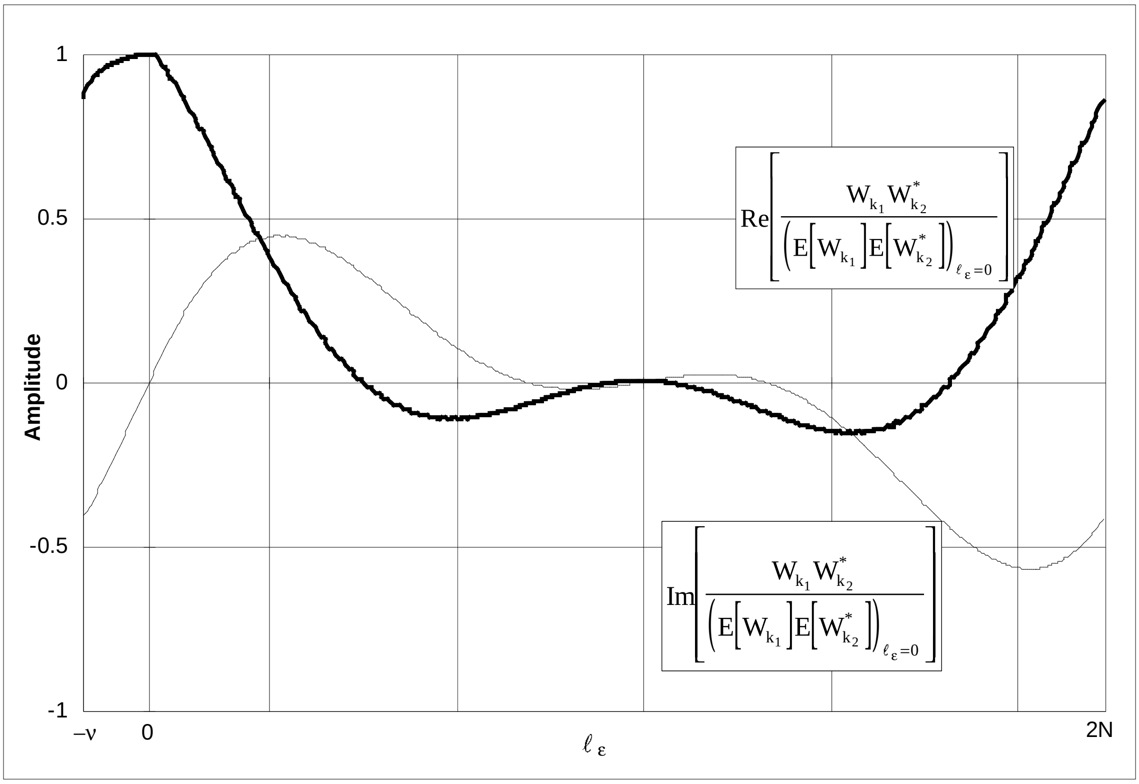

Figure 2b : Real and imaginary parts of the product $W_{k_1}W_{k_2}^*$: maximal discontinuities

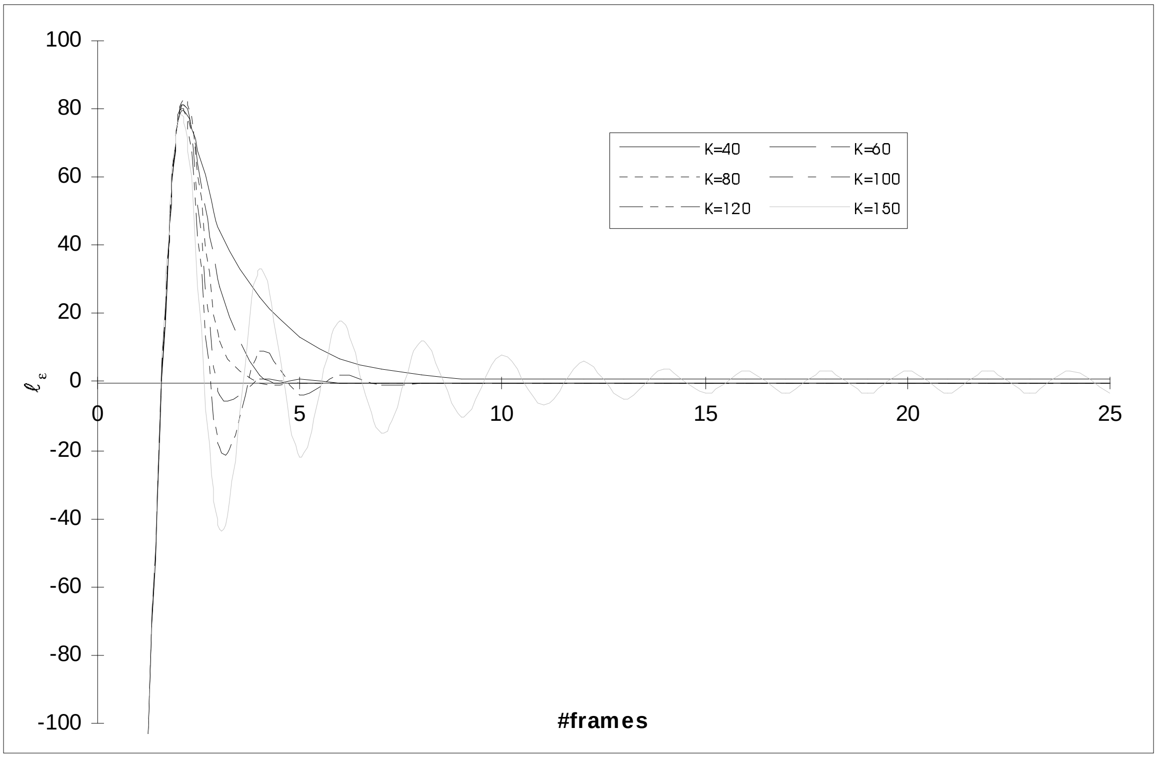

Figure 3 : Evolution of the synchroniser error as function of the number of frames