Frame Synchronization using Superimposed Sequences

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Abstract — **We present a new technique for synchronizing frames of length n, using a sync sequence of the same length n with good cyclic autocorrelation properties. This sequence is modulated and superimposed on the modulated data sequence. The energy of the modulated sync sequence is uniformly distributed and small compared to the energy of the data sequence. For AWGN channels, we give a general upper bound on the correct frame synchronization probability as a function of the frame length and the signal-to-noise ratio. The new technique approaches this upper bound to less than 1 dB, and outperforms standard methods. For fading channels the performance is considerably better than for the standard methods. By increasing frame length n, the correct frame synchronization probability becomes nearly the same as for AWGN channels.**

I. System Description

Traditional frame synchronization methods periodically insert short sync words of length k in the data sequence to mark the boundaries of each frame of length n. These methods have, despite their low complexity, the disadvantage that relatively long sync sequences have to be used to suppress deterioration in performance due to additional occurrences of the sync sequence in the data, of which the probability is proportional to $n/2^{k+1}$. Precoding of the data to prevent additional occurrences is often not applicable [1] due to the coding complexity and the risk of error propagation. In addition, the sync word is susceptible to fades, as they can easily destroy the relatively short sync word.

To overcome these problems, a new technique is proposed, which uses a sync sequence $\boldsymbol{s}$ of length n having good cyclic autocorrelation properties. This sequence is modulated and superimposed on the modulated data sequence $\boldsymbol{x}$ of length n in such a way, that the total average energy E is constant. The sync signal energy E_s can therefore only be increased if the data signal energy E_d is reduced by the same amount. Linear modulation methods are used.

At the receiver side, bit synchronization is performed, after which the transmitted data sequence $\boldsymbol{x}$ is estimated. The frames are detected by correlating the sync sequence with the received sequence after having subtracted the estimated data signal to minimize the influence of the data on the correlation. Since the superimposed sync sequence is long, the probability of occurrence of the same sequence in the data part is low. The sync energy is uniformly spread over the entire frame, which significantly reduces the impact of fades on the synchronization process.

Once synchronization is acquired, the estimated sync signal is subtracted from the received signal to minimize its influence on the detection of the data signal. Optionally a feedback channel can be used to regulate the sync energy at the transmitter side. In this way the sync energy can be adapted for the actual channel conditions and the confidence level for correct synchronization at the receiver side.

II. Performance

To determine the performance of the new synchronization technique, the system has been implemented using MSK modulation, selected for being linear and bandwidth efficient [2]. For AWGN channels, the synchronization error rate (SER) of the system has been determined as a function of the signal-to-noise ratio E/N_o. The performance of the synchronization technique is basically determined by the total energy E_c of the sync sequence.

We now consider the situation where only one sync sequence is transmitted, i.e., $E_s = E$ and $E_d = 0$. This is identical to synchronizing with markers of length $k = n$. Since this is the ideal situation for synchronization, the corresponding frame synchronization rate can be considered as an upper bound. By considering this case as a multi-orthogonal transmission system [2], the following lower bound on the synchronization error probability P_{SE} has been derived:

$$P_{\mathrm{SE}} = \frac{1}{\sqrt{\pi N_o E_c}} \int_{-\infty}^{\infty} \left[1 - \frac{1}{2}\operatorname{erfc}\left(\frac{z}{\sqrt{N_o E_c}}\right)\right]^{n-1} \cdot \exp\left[-\frac{(z-E_c)^2}{N_o E_c}\right] dz. \qquad (1)$$

Theoretical analysis and simulation results show, that the synchronization technique using superimposed sequences has a significantly lower synchronization error probability than the marker synchronization technique [2]. It also approaches P_{SE}, the bound for ideal synchronization, to less than 1 dB in cases where the sync energy is very low relative to the data signal energy.

For Rayleigh fading channels, the synchronization acquisition probability of marker synchronization techniques rapidly deteriorates, due to the fact that significant parts of the short sync word are destroyed by fades. Synchronization using superimposed sequences, on the other hand, can employ very long sequences for synchronization without having to sacrifice additional sync energy. In most cases sufficient synchronization energy will arrive at the receiver in the presence of fades. For long sequences the same sync performance as for an AWGN channel can be achieved.

References

[1] R. A. Scholtz, “Frame synchronization techniques,” *IEEE Trans. Commun.*, vol. COM-28, pp. 1204–1213, Aug. 1980.

[2] J. G. Proakis, *Digital Communications*, McGraw-Hill, 2nd ed., 1989.

[3] A. Steingaß, “Pseudo Co-Channel Rahmensynchronisation unter Verwendung von nicht orthogonalen Trägern”, Master's Thesis, Univ. of Ulm, 1996.