NONLINEAR CORRELATION RECEIVER PERFORMANCE IN UWB RADIO SYSTEM

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Abstract – The rejection of QPSK interference in a TH-PPM UWB system using complex adaptive filter and a nonlinear correlation receiver (NCR) with a soft-limiter will be considered in this paper. This system brings a significant performance improvement compared to the system which uses complex adaptive filter and a linear receiver, particularly in the case of high interference power, where its absence leads to the reception loss.

1. INTRODUCTION

Time hopping combined with pulse position modulation (TH-PPM) was the original proposal for UWB (Ultra Wide Band) system [1]. An analysis of this modulation and multiaccess scheme performance in terms of bit error rate was proposed in [2] for AWGN (Additive White Gaussian Noise) channel. The performance of UWB communications in the presence of interference are analyzed in [3]. Closed-form expressions are provided for the jam resistance of UWB communications with binary pulse position modulation utilizing rectangular pulses. In [4] a method is proposed to evaluate the bit error rate performance of TH-PPM system in the presence of multiuser interference and AWGN channel. Gaussian quadrature rules are used in this approach.

The rejection of QPSK interference in TH-PPM UWB radio system using a complex adaptive filter and a nonlinear correlation receiver with a soft-limiter will be considered in this paper. Transversal filter removes most of the QPSK interference, but, at the same time, it produces impulse jamming at the moment when there is a phase shift in the QPSK signal. Because of that, using the NCR with a soft-limiter and choosing the optimal limiting constant brings significant performance improvement of TH-PPM UWB radio system (the decrease of error probability for more than an order of magnitude for signal to noise ratios being of practical importance). The use of the complex ATF and the NCR is especially important in the case of strong interference (for example J/S = 40 dB) where the linear receiver has very poor performances (Pe ≈ 0.34), and, under the same circumstances, the nonlinear receiver significantly rejects the interference (Pe ≈ 10^{-4} for the signal to noise ratio of 14.6dB).

It should be noted that the complexity of the proposed nonlinear receiver is not considerably higher, since only the limiting is performed at the frame rate, and the LMS weights adaptation is performed at the bit rate.

2. SYSTEM MODEL

The receiver block diagram is shown in Fig. 1. When several time-hopping signals are simultaneously transmitted over a channel with \( L_s \) paths, the composite waveform at the output of the receiver antenna may be written as:

$$ r(t) = \sum_{l=1}^{L_s} \left( \gamma^{(l)}_i s(t - \tau_l) \cos \omega_c t + \gamma^{(Q)}_i s(t - \tau_l) \sin \omega_c t \right) + n(t) + j(t) $$

(1)

$$ r^{(1)}(t) = r(t) \cos \omega_c t, \quad r^{(Q)}(t) = r(t) \sin \omega_c t $$

(2)

where \( \omega_c \) is the channel carrier frequency, \( n(t) \) is noise, and \( f(t) \) is the total interference, \( \gamma^{(l)}_i = \gamma^{(1)}_i + j\gamma^{(Q)}_i \) is the complex attenuation and \( \tau_l \) is the delay in \( l \)-th path.

![Fig. 1. Receiver block diagram](image)

The signal transmitted by the desired user is modeled as:

$$ s(t) = \sum_i b(t - iNT_f - (1 - a_i)\Delta) \cos \omega_c t $$

(3)

where \( i \) represents the index of the considered information bit, and

$$ b(t) = \sum_{n=0}^{N-1} g(t - nT_f - h(n)T_c), $$

(4)

\( g(t) \) represents basic pulse shape (rectangular pulse) and \( T_f \) represents frame duration during which there is only one pulse with \( T_c \) seconds width. The sequence \( h(n) \) is the user’s time-hopping code and its elements are integers taking values in the range \( 0 \leq h(n) \leq N - 1 \). The parameter \( T_c \) is the duration of an addressable time bin. In other words, the right hand side of Eq. (4) consists of a block of \( N \) time-hopped monocycles. \( a_i \) represents information bits (0, 1). Equation (3) says that if \( a_i \) were all zero, the signal would be a repetition of \( b(t)\)-shaped blocks with the period \( NT_f \). \( \Delta \) may be viewed as the time shift impressed by a unit data symbol on the monocycles of a block. It is clear that the choice of \( \Delta \) affects the detection process and can be exploited to optimize the system performance. To summarize, the transmitted signal consists of a sequence of \( b(t)\)-shaped position-modulated blocks. The code sequence restarts at every data symbol.
If we consider signal sampled at the chip interval $T_c$, we have:
\[ r(k) = r^{(1)}(k) + jr^{(2)}(k), \quad k = t/T_c \] (5)

The interference is rejected using two two-sided adaptive transversal filters of length $2M$, denoted as ATF1 and ATF2. In order to predict the interference signal, sampling is performed at the frame rate, and the adaptation of filter weights using LMS algorithm is performed at the bit rate. The labels $\text{ATF}_1$ and $\text{ATF}_2$ are related as follows:

\begin{align*}
\text{ATF}_1 & = (n_{11}, n_{12}) = \left( \frac{T_f}{T_c}, \frac{T_f}{T_c}, n \right), \\
\text{ATF}_2 & = (n_{21}, n_{22}) = \left( \frac{T_f}{T_c}, \frac{T_f}{T_c}, n \right)
\end{align*}

where $n$ is the index of the considered frame ($n = 0, N - 1$), and $m$ is the index of the ATF weight.

As a consequence of narrowband QPSK interference adaptive filtering there is strong impulse jamming at the output of the adaptive filter at the moment of QPSK interference phase shift. Because of this there is a rapid decrease of filtering gain. The dominant impulse jamming is the main cause of making a wrong decision. That is why a soft limiter is applied before summing and making a decision. The limiting is performed at a frame level, and may be described with the following equations:

\[ e_j^\prime(n) = A_j^\prime(n) = \begin{cases} \\
A_j^\prime(n) & |e_j^\prime(n)| \leq C \\
C \times \text{sgn}(e_j^\prime(n)) & |e_j^\prime(n)| > C
\end{cases} \] (11)

where $C$ is the limiting constant. $e_j^\prime(n)$ ($j = 1, 2$) may be written as:

\[ e_j^\prime(n) = A_j^\prime(n) - \sum_{m=0}^{M} A_{m}^\prime(n)W_{m}(i) \] (12)

\[ e_j^\prime(n) = B_j^\prime(n) - \sum_{m=0}^{M} B_{m}^\prime(n)W_{m}(i) \] (13)

The decision variable is:

\[ d(i) = \sum_{j=1}^{L} \left( \text{Re}\{e_j^\prime(i)\} - \text{Re}\{e_j^\prime(i)\} \right) + \text{Im}\{e_j^\prime(i)\} + \text{Im}\{e_j^\prime(i)\} \] (14)

where $\text{Re}(\cdot)$ is the average of $\text{Re}(\cdot)$, and the variables from Eq. (14) are defined by:

\[ e_j^\prime(n) = \sum_{m=0}^{M} e_j^\prime(n), \quad j = 1, 2 \] (14)

3. NUMERICAL RESULTS

The error probability is computed using Monte-Carlo simulation. The error probability of the system as a function of limiting constant $C$, with the interference to signal ratio as a parameter ($a - J/S = 20$ dB, $b - J/S = 40$ dB, $c - J/S = 60$ dB), is shown in Fig. 2. It can be noticed that there is a minimum of error probability for the particular value of parameter $C$, and that is the parameter $C$ optimal value.

![Fig. 2. Error probability as a function of limiting constant C](image-url)

The effect of limiting can be noticed if we consider the error probability with the optimal value of $C$ and error probability if there is no limiting, and it is shown in Fig. 3. The labels $a$, $b$, and $c$ have the same meaning as in Fig. 2. The use of the NCR brings the significant performance improvement compared to the system which uses only complex ATF.
The use of the complex ATF and the NCR is especially important in the case of strong interference (for example J/S = 40 dB), where the linear receiver has very poor performances (Pe ≈ 0.34), and, under the same circumstances, the proposed nonlinear receiver significantly rejects the interference (Pe ≈ 10^{-4} for the signal to noise ratio of 14.6 dB).

4. CONCLUSION

The influence of the nonlinear correlation receiver on the performances of TH-PPM UWB system which uses transversal filter in the presence of QPSK interference is analyzed in this paper. The transversal filter removes most of the QPSK interference, but, at the same time, it produces impulse jamming at the moment when there is a phase shift in the QPSK signal. Because of this, limiting process is very significant in this case, especially in case of high interference power, where the absence of the NCR would lead to the reception failure.

REFERENCES


