ULTRA WIDEBAND LOW RATE COMMUNICATIONS IN EMBEDDED APPLICATIONS: A CHAOS-BASED APPROACH

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I. Introduction

UWB wavelets where the power of transmitted signal is spread over an extremely wide frequency band make the reuse of frequency bands already occupied by conventional narrowband radio systems possible. Low data rate wireless communication systems are required in many embedded applications where such LR-UWB system should operate in an ad-hoc network for years without maintenance and the price of one UWB device has to be less than USD10.00. Therefore CMOS technology and simple transceiver architecture has to be used in implementation. To satisfy these requirements a brand new approach is needed where new carriers, modulation schemes and transceiver architectures are used.

II. Wavelets in UWB radio

The only restriction on UWB wavelets defined by ESTI and FCC is the power spectral density (psd) of transmitted signal. It has to be kept as low as -41.3 dBm in 1-MHz bandwidth. The UWB frequency band goes from 3.1 GHz to 10.6 GHz. Since psd allowed for UWB wavelets is extremely low to get a useable radio coverage ultra-wideband wavelets must be used. The typical bandwidths of UWB signals are 500 MHz and 2 GHz. The wavelets are fixed waveforms and chaotic signals in impulse radio [1] and chaotic UWB radio [2], respectively.

III. Demodulation schemes in UWB applications

Wavelets used in UWB radio have very short duration (about 0.5 ns). Coherent demodulation cannot be implemented because the recovery of UWB wavelets is not feasible. Proposed noncoherent demodulation schemes are: (i) Pulse Polarity Modulation (PPoM) with one wavelet and template detection [1], and (ii) Transmitted Reference (TR) system with two wavelets and autocorrelation detection [2, 3].

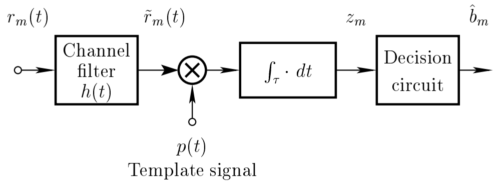

Figure 1: Detection of PPoM with a template signal $p(t)$.

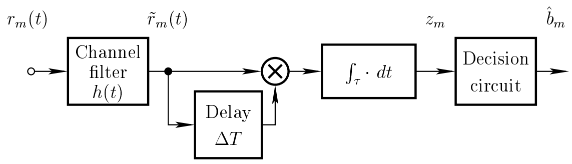

Figure 2: Block diagram of TR autocorrelation receiver.

A. *PPoM with Template Detection*

In PPoM one arbitrary but fixed waveform $g(t)$ is used to carry digital information. Because of its excellent spectral properties, a bell-shaped Gaussian impulse is generally used as $g(t)$[3]. Information is mapped to the sign of $g(t)$. Let $r_m(t) = g(t)+n(t)$ and $\tilde{r}_m(t) = \tilde{g}(t)+\tilde{n}(t)$ denote the received noisy signal before and after channel filtering, respectively. The information $\hat{b}_m$ is recovered by correlating $\tilde{r}_m(t)$ with a template signal $p(t)$ as shown in Fig. 1 where z_m is the observation signal.

The template signal is a windowing function

$$p(t) = \begin{cases} \frac{1}{\sqrt{\tau}}, & \text{if } |t| < \frac{\tau}{2} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where τ is the observation time period.

The drawback of template detection is that the demodulator is very sensitive to errors in window width (see Fig. 3) and timing. Any error reduces the separation of message points in the observation space and results in a considerable performance degradation.

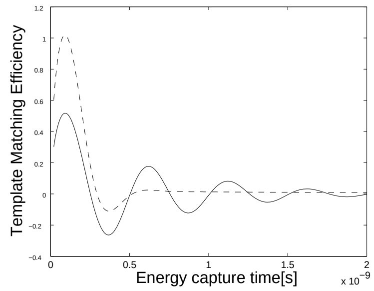

Figure 3: Template matching efficiency as a function of the width of template signal. RF bandwidths of Gaussian impulses are 4 GHz (dashed curve) and 1 GHz (solid curve).

B. *Transmitted Reference (TR) system*

In TR system two wavelets, called chips, are used to transmit one bit information [2, 3]. The first chip serves as a reference, while the second one carries the information. Bit 1 is sent by transmitting the chip twice. For bit 0, the reference chip is transmitted, followed by an inverted copy of the same signal. The reference chip also serves as a test signal used to measure the actual channel characteristics.

Due to the special structure of TR signal, information bits may be recovered from the sign of the correlation between the reference and information bearing chips as shown in Fig. 2.

Noise performances of template detector and TR system [2] can be seen in Figs. 4 and 5, respectively. According to the BER curves the two systems are very similar in their noise performances.

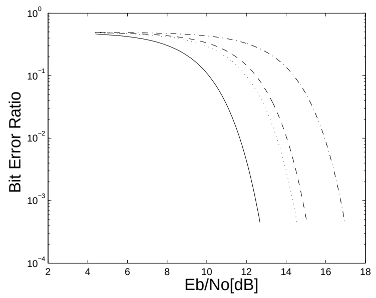

Figure 4: Noise performance of pulse polarity modulation built with template detection.

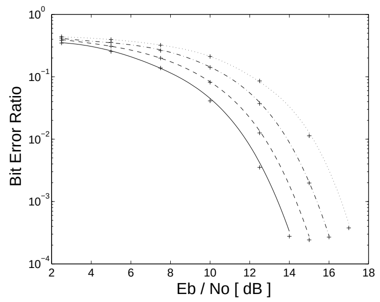

Figure 5: Noise performance of a TR system built with autocorrelation receiver.

IV. Conclusions

The main advantage of template detection is that template signal is a noise-free signal, its application results in a better noise performance if the template is perfectly matched to the UWB wavelet. However, even a small timing error corrupts the noise performance considerably, it may even prevent the communications.

FM-DCSK [2] and the TR modulation scheme offer an alternative noncoherent UWB modulation scheme that may be used with either chaotic or deterministic wavelets. TR system is very robust against the timing error and a TR signal may be demodulated by a simple autocorrelation receiver.

References

[1] K. Siwiak and D. McKeown, *Ultra-Wideband Radio Technology*, Wiley, Chichester, UK, 2004.

[2] G. Kolumbán and T. Krébesz, "UWB radio: A real chance for application of chaotic communications," in *Proc. NOLTA'06*, pp. 475–478, Bologna, Italy, September 11–14 2006.

[3] M. Ghavani, L. B. Michael, and R. Kohno, *Ultra-Wideband Signals & Systems in Communication Engineering*, Wiley, 2nd edition, 2006.