Unified Performance Analysis for Ultra-Wideband Receivers with Timing Jitter

Brian M. Sadler†, Jin Tang‡, Zhengyuan Xu‡

† Army Research Laboratory, Adelphi, MD 20783

‡ Department of Electrical Engineering, University of California, Riverside, CA 92521

Abstract

In this poster, we introduce a generalized ultra-wideband system model which can cover some popular transmission schemes, such as conventional pulse position modulation, pulse amplitude modulation, transmitted-reference, and some newly proposed schemes, such as pulse interval amplitude modulation and multiuser transmitted-reference scheme. The advantage of this model is its easy applicability to wireless systems desiring adaptive modulations, for instance, the cognitive radio. Under this framework, we provide a unified analysis of system detection performance with timing jitter taken into account. Numerical results under several scenarios are presented.

System Model

In a multiple access environment with K active users, the transmitted signal from the k-th user can be described as:

$$s_k(t) = \sqrt{P_k/2}\sum_n [A_{k,n}p(t-nT_f) + I^n_{k,\lfloor n/N_f\rfloor}B_{k,n}p(t-nT_f-d_k-b_{k,\lfloor n/N_f\rfloor}\sigma)]$$

where P_k the transmission power; $p(t)$ monopulse waveform;

T_f frame duration; N_f the number of frames in each symbol period;

$A_{k,n}$, $B_{k,n}$ frame-rate PN sequence $\{0,\pm 1\}$;

$I^n_{k,\lfloor n/N_f\rfloor}$, $b_{k,\lfloor n/N_f\rfloor}$ two binary information bits;

d_k data pulse delay; α, σ PAM, PPM modulation parameter.

The received signal after a multipath channel and a front-end filter is:

$$r(t) = \sum_k\sum_n [A_{k,n}h_k(t-nT_f-\varepsilon_{k,n}) + I^n_{k,\lfloor n/N_f\rfloor}B_{k,n}h_k(t-nT_f-d_k-b_{k,\lfloor n/N_f\rfloor}\sigma-\varepsilon_{k,n})] + v(t)$$

where $h_k(t)$ unknown waveform incl. multipath, filter and power effect;

$\varepsilon_{k,n}$ random timing jitter for n-th frame; $v(t)$ AGN from the filter;

Special Cases

A. Conventional DS-PAM: $\sigma_A^2=0$, $\sigma=0$, $\alpha=1$, $d_k=0$

$$s_k(t) = \sqrt{P_k/2}\sum_n I_{k,\lfloor n/N_f\rfloor}B_{k,n}p(t-nT_f)$$

B. Conventional DS-PPM: $\sigma_A^2=0$, $\alpha=0$, $d_k=0$

$$s_k(t) = \sqrt{P_k/2}\sum_n B_{k,n}p(t-nT_f-b_{k,\lfloor n/N_f\rfloor}\sigma)$$

C. Pulse amplitude and position modulation (PAPM)

$\sigma_A^2=0$, $\alpha=1$, $B_{k,n}=1$, $d_k=0$

$$s_k(t) = \sqrt{P_k/2}\sum_n I_{k,\lfloor n/N_f\rfloor}p(t-nT_f-b_{k,\lfloor n/N_f\rfloor}\sigma)$$

D. Conventional delay-hopping TR: $A_{k,n}=1$, $B_{k,n}=1$, $\sigma=0$ or $\alpha=0$

PAM $s_k(t) = \sqrt{P_k/2}\sum_n [p(t-nT_f)+I_{k,\lfloor n/N_f\rfloor}p(t-nT_f-d_k)]$

PPM $s_k(t) = \sqrt{P_k/2}\sum_n [p(t-nT_f)+p(t-nT_f-d_k-b_{k,\lfloor n/N_f\rfloor}\sigma)]$

E. Preamble Training: $d_k=0$

Training period $\sigma_A^2=1$, $\sigma_B^2=0$: $s_k(t) = \sqrt{P_k/2}\sum_n A_{k,n}p(t-nT_f)$

Data period $\sigma_A^2=0$, $\sigma_B^2=1$:

PAM ($\alpha=1$, $\sigma=0$): $s_k(t) = \sqrt{P_k/2}\sum_n I_{k,\lfloor n/N_f\rfloor}B_{k,n}p(t-nT_f)$

PPM ($\alpha=0$): $s_k(t) = \sqrt{P_k/2}\sum_n B_{k,n}p(t-nT_f-b_{k,\lfloor n/N_f\rfloor}\sigma)$

F. Pulse Interval Amplitude Modulation (PIAM): $A_{k,n}=1$, $B_{k,n}=1$, $d_k=0$

$$s_k(t) = \sqrt{P_k/2}\sum_n [p(t-nT_f)+I_{k,\lfloor n/N_f\rfloor}p(t-nT_f-b_{k,\lfloor n/N_f\rfloor}\sigma)]$$

Receiver Design

Define the m-th segment of the received signal

$$r_m(t) = \begin{cases} r(t+mT_f) & (0 \le t < T_f) \\ 0 & (others) \end{cases}$$

l-th user's waveform $h_l(t)$ can be estimated as

$$\hat{h}_l(t) = N_p^{-1}\sum_{m'=1}^{N_p} A_{l,m'}r_{m'}(t)$$

Subtract the reference from the received signal

$$\bar{r}(l,m)(t) = r_m(t) - A_{l,m}\hat{h}_l(t)$$

Then multiply it with the PN code $B_{l,m}$ to obtain $\bar{r}_{l,m}(t) = B_{l,m}\bar{r}(l,m)(t+d_l)$

Construct two correlation templates for data demodulation

$$\Psi_l(t) = \tfrac{1}{2}[\hat{h}_l(t) + \hat{h}_l(t-\sigma)] \quad \text{for PAM}$$

$$\Phi_l(t) = \tfrac{1}{2}[\hat{h}_l(t) - \hat{h}_l(t-\sigma)] \quad \text{for PPM}$$

Outputs of correlation receivers and detection rules follow

$$y_{l,n,1} = \frac{1}{N_f}\sum_m \int_0^{T_f}\Psi_l(t)\bar{r}_{l,m}(t)dt, \quad \hat{I}_{l,n} = \mathrm{sign}(y_{l,n,1})$$

$$y_{l,n,2} = \frac{1}{N_f}\sum_m \int_0^{T_f}\Phi_l(t)\bar{r}_{l,m}(t)dt, \quad \hat{b}_{l,n} = \mathrm{sign}(y_{l,n,2})$$

Performance Analysis

Calculate the following statistics of estimated waveform as well as the true waveform with timing jitter for $p=1,\cdots,4$

$$\Theta_k^{(p)}(t_1,\cdots,t_p) \triangleq E\{\prod_{i=1}^p h_k(t_i-\varepsilon_{k,m})\}, \quad \Upsilon_k^{(p)}(t_1,\cdots,t_p) \triangleq E\{\prod_{i=1}^p \hat{h}_k(t_i)\}$$

among which, the former can be evaluated by using the characteristic function of $\varepsilon_{k,n}$

$$\Theta_k^{(p)}(t_1,\cdots,t_p) = \int\cdots\int \Phi_k(-\sum_{i=1}^p f_i)\prod_{i=1}^p H_k(f_i)e^{j2\pi f_i t_i}df_i$$

It is found the statistics $\Upsilon_k^{(p)}(t_1,\cdots,t_p)$ are related to the moments of $A_{k,n}$, $B_{k,n}$. When large sample size is used in estimating the waveform, for instance, $N_p \to \infty$

$$\Upsilon_k^{(p)}(t_1,\cdots,t_p) = \prod_{i=1}^p \Theta_k^{(1)}(t_i)$$

Then we calculate the mean and variance of $y_{l,n,1}$ and $y_{l,n,2}$ conditioned on all possible values of the unknown information bits. For example, the mean of $y_{l,n,1}$ can be expressed in a general form as

$$E\{y_{l,n,1}\} = \frac{1}{2}I^n_{l,n}\sigma_B^2\int_0^{T_f}[\Theta_l^{(1)}(t)+\Theta_l^{(1)}(t-\sigma)]\Theta_l^{(1)}(t-b_{l,n}\sigma)dt$$

and the variance

$$\mathrm{var}(y_{l,n,1}) = \frac{1}{4N_f}\sigma_A^2\sigma_B^2\int\int[\Upsilon_l^{(4)}(t1-\sigma,t_1+d_l,t_2-\sigma,t_2+d_l)+\cdots]dt_1dt_2+\cdots$$

which depends on MUI, noise power, jitter statistics, σ_A^2, σ_B^2, N_p, N_f and etc.

Average bit error rate (BER) can be approximated as

$$P_e \approx Q\left(\frac{E\{y_{l,n,1}|(I_{l,n}=1,b_{l,n}=0)\}}{\mathrm{var}(y_{l,n,1}|(I_{l,n}=1,b_{l,n}=0))}\right)$$

Simulations

- IEEE CM1 channel with 80% energy capture
- Large sample size $N_p \to \infty$
- Uniformly distributed timing jitter with zero mean
- $K=4$, $d_k \in [1, 6]$ ns, $T_f=30$ns, $N_f=2$, $\sigma=0.27$ ns

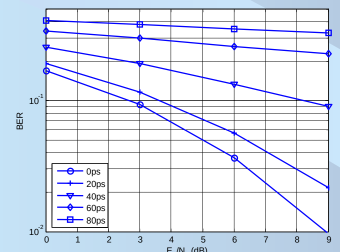

Fig.1 PAM bits performance in a MU-TR hybrid system

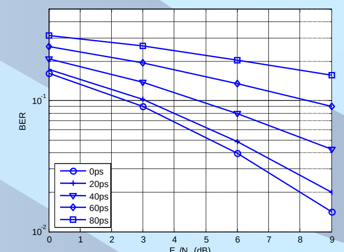

Fig.2 PPM bits performance in a MU-TR hybrid system

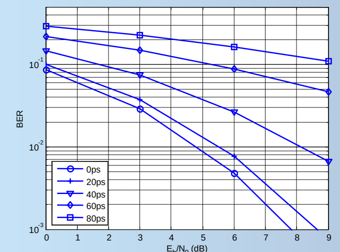

Fig.3 Performance of a DS-PAM system with preamble training

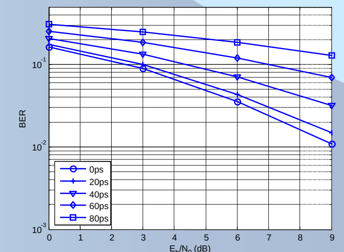

Fig.4 Performance of a DS-PPM system with preamble training