Ultra Wide Band Radio Fundamentals

UWB Receivers in AWGN channels

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Outline

Outline

Framework (1/3)

Channel model hypothesis

- multipath-free
- AWGN (and any other gaussian interference)
- amplitude gain: $\alpha = c_0/\sqrt{D^\gamma}$, so $\alpha \equiv c_0$ @ $D = 1[\mathrm{m}]$.

Optimum receiver (for AWGN channels)

- **Correlator**: it correlates $r(t)$, the rx noisy signal (*input*), with the orthonormal waveforms $(\psi_i)_{i=0}^{N-1}$ of the signal space basis, giving a vector $\mathbf{Z} \in \mathrm{R}^N$ of decision variables (*output*).
- **Detector**: it decides which waveform was transmitted by applying the ML criterion, i.e. by maximizing $p(\mathbf{Z}|s(t))$.

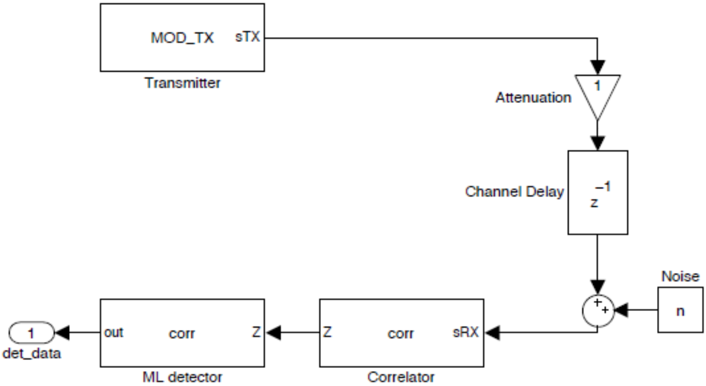
Framework (2/3)

Two decision detection strategies may be used in case of multi-pulse signals:

- **SOFT**: only one decision based on the whole multi-pulse signal $(\mathrm{SNR}_{mp} = N_s\,\mathrm{SNR}_{sp})$
- **HARD**: N_S independent decisions (each with error probability p), and final decision obtained by applying a majority criterion, leading to:

$$P_e = \sum_{k=N_s/2}^{N_s} \binom{Ns}{k} p^k (1-p)^{N_s-k}$$

Framework (3/3)



Remind:

Transmitted UWB signal $s(t)$ → Multipath-free radio channel, distance *D* → $r(t)$ Received UWB signal plus AWGN noise

$$r(t) = r_u(t) + n(t)$$ Received signal

$$r(t) = \underbrace{\alpha s(t-\tau)}_{r_u(t)} + n(t)$$

$n(t)$ Thermal noise: realization of a stochastic Gaussian process with bilateral PSD $N_0/2$

channel gain $\alpha = \frac{c_0}{\sqrt{D^\gamma}}$

c_0 Reference channel gain at distance D = 1 m

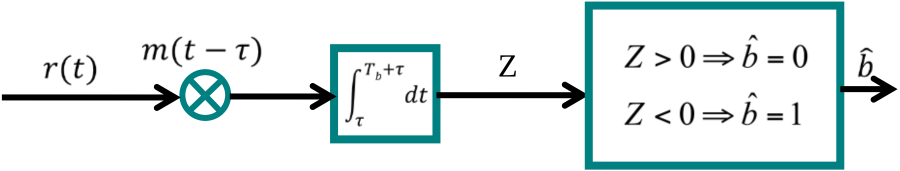
γ Path-loss exponent

channel delay $\tau = \frac{D}{c}$

c speed of light in vacuum

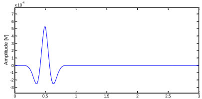
Remind: Case 1: single-pulse PPM signals

2PPM-TH receiver architecture based on a single correlator



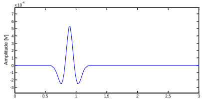
Mask correlator: $m(t) = p_0(t - c_j T_C) - p_0(t - c_j T_C - \varepsilon)$

Received signal for transmitted bit "0"



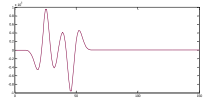
Z is positive

Received signal for transmitted bit "1"



Z is negative

Correlator Mask



Remind: **Case 2: multi-pulse PPM signals with Soft Decision Detection**

In soft decision detection, the signal formed by N_S pulses is considered as a single multi-pulse signal $s_{mp}(t)$

Transmitted waveform

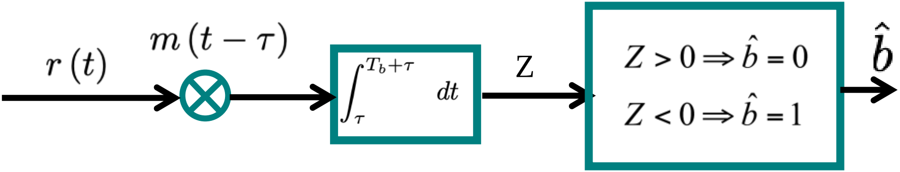
$$s_{mp}(t)=\begin{cases}\sqrt{N_S E_{TX}}\sum_{j=0}^{N_S-1}\frac{1}{\sqrt{N_S}}p_0\left(t-jT_S-c_jT_c\right) & for\ b=0\\ \sqrt{N_S E_{TX}}\sum_{j=0}^{N_S-1}\frac{1}{\sqrt{N_S}}p_0\left(t-jT_S-c_jT_c-\varepsilon\right) & for\ b=1\end{cases}$$

Received waveform

$$r(t)=\alpha\, s_{mp}(t-\tau)+n(t)$$

Remind: **Case 2: multi-pulse PPM signals with Soft Decision Detection**

2PPM-TH receiver architecture based on a single correlator



$$m(t) = \frac{1}{\sqrt{N_S}} \sum_{j=0}^{N_S-1} \left(p_0(t - c_j T_C) - p_0(t - c_j T_C - \varepsilon) \right)$$

$$Z = \begin{cases} +\sqrt{N_S E_{RX}}\left(1 - R_0(\varepsilon)\right) + (n_0 - n_1) & \text{for } b=0 \\ -\sqrt{N_S E_{RX}}\left(1 - R_0(\varepsilon)\right) + (n_0 - n_1) & \text{for } b=1 \end{cases}$$

Remind: Case 3: multi-pulse PPM signals with Hard Decision Detection

- In hard decision detection, the receiver implements N_S independent decisions over the N_S pulses that represent one bit.
- The final decision is obtained by applying a simple majority criterion.
- It can be shown that soft decision outperforms hard decision when considering propagation over AWGN channels

$$\Pr_b = \sum_{j=\left\lceil \frac{N_S}{2} \right\rceil}^{N_S} \binom{N_S}{j} \Pr_{b0}{}^{j} \left(1 - \Pr_{b0}\right)^{N_S - j} \qquad \Pr_{b0} = \frac{1}{2} erfc\left(\sqrt{\frac{1}{2}\frac{E_{RX}}{\mathcal{N}_0}\left(1 - R_0(\varepsilon)\right)}\right)$$

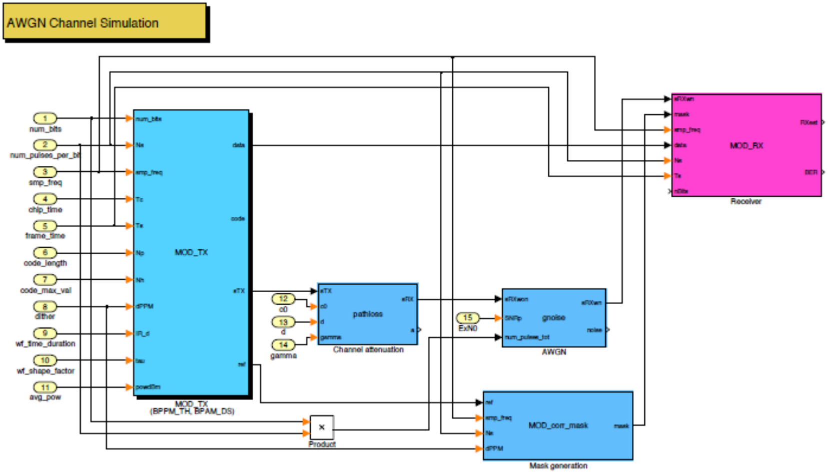
Outline

Channel model

Simulation time!

Results

Schematic


AWGN Channel Simulation
1
num_bits
2
num_pulses_per_bit
3
smp_freq
4
chip_time
5
frame_time
6
code_length
7
code_max_val
8
dither
9
wf_time_duration
10
wf_shape_factor
11
avg_pow
num_bits
Ns
smp_freq
Tc
Ts
Np
Nh
dPPM
IR_d
tau
powdBm
data
code
sTX
ref
MOD_TX
MOD_TX
(BPPM_TH, BPAM_DS)
12
c0
13
d
14
gamma
sTX
c0
d
gamma
sRX
a
pathloss
Channel attenuation
15
ExN0
sRXwn
SNRp
num_pulses_tot
sRXwn
noise
gnoise
AWGN
×
Product
ref
smp_freq
Ns
dPPM
MOD_corr_mask
mask
Mask generation
sRXwn
mask
smp_freq
data
Ns
Ts
nBits
RXest
BER
MOD_RX
Receiver

Routines (1/2)

- To implement the transmission blocks, you will use the old routines for the generation of PPM signals (see PW03)
- You will have to write functions for channel and receiver:

```
[sRX, alpha] = pathloss(sTX, c0, d, gamma)
```

It implements the pathloss formula (where `sTX` is the PPM-TH signal obtained from the function `TX_BPPM_TH`, while `alpha` is the amplitude gain of the channel)

```
[sRXwn, noise] = gnoise(sRXwon, ExN0dB, n_pulses_tot)
```

It adds noise with suitable power to attain the desired E_b/N_0: if $N_s > 1$, then $E_x/N_0 = E_b/(N_s N_0)$.

Routines (2/2)

```
mask = corrmask(ref, smp_freq, num_pulses, dPPM)
```

It performs two tasks:

1) energy normalization of `ref` signal (that is the TH-code signal from `TX_BPPM_TH`),
2) mask creation, by evaluating `ref-sref`, where `sref` is a version of `ref` delayed by `dPPM`.

```
[RXbits,BER] = mod_receiver(sRx,mask, smp_freq,
bits, Ns, Ts, mod, DDT)
```

It takes decisions and measures the BER. The function should implement both types of detection:

- `DDT=1`: hard detection
- `DDT=2`: soft detection

Input parameters:

```
c0= 10^(-30/20); %gain @1 m
d= 10; %[m]
gamma=2;
mod= 1;%PPM or mod=2%PAM
```

```
smp_freq = 50e9;
nBits = 20000;
Ts = 3e-9;
Ns = [1 3];
Tc = 1e-9;
Nh = 3;
Np = 60000;
IR_d = 0.5e-9;
tau = 0.25;
dPPM = 0.5e-9;
SNRb_dB = 0:2:10;
powdBm = -30;
```

Outline

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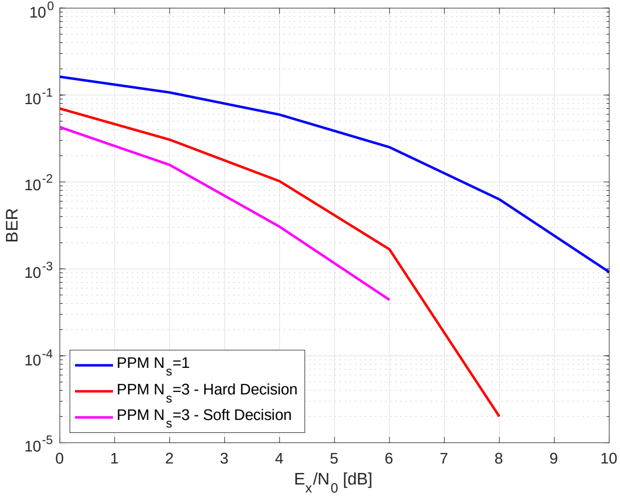
Simulation time!

Results

Expected result



Questions

You should be able to answer to the following questions:

1. What is the effect of N_s on P_e ?
2. What is the performance difference between soft and hard detection schemes?