Line Spectrum Analysis of Impulse Radio UWB Systems Using a Pulse Position Modulation

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Yun-Pyo Hong and Hong-Yeop Song

Yonsei University

Seoul, Korea

Outline

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- PSD of IR-UWB Systems Using a PPM
- Impulse PPM UWB Systems
- MA-Impulse PPM UWB Systems
- Concluding Remarks

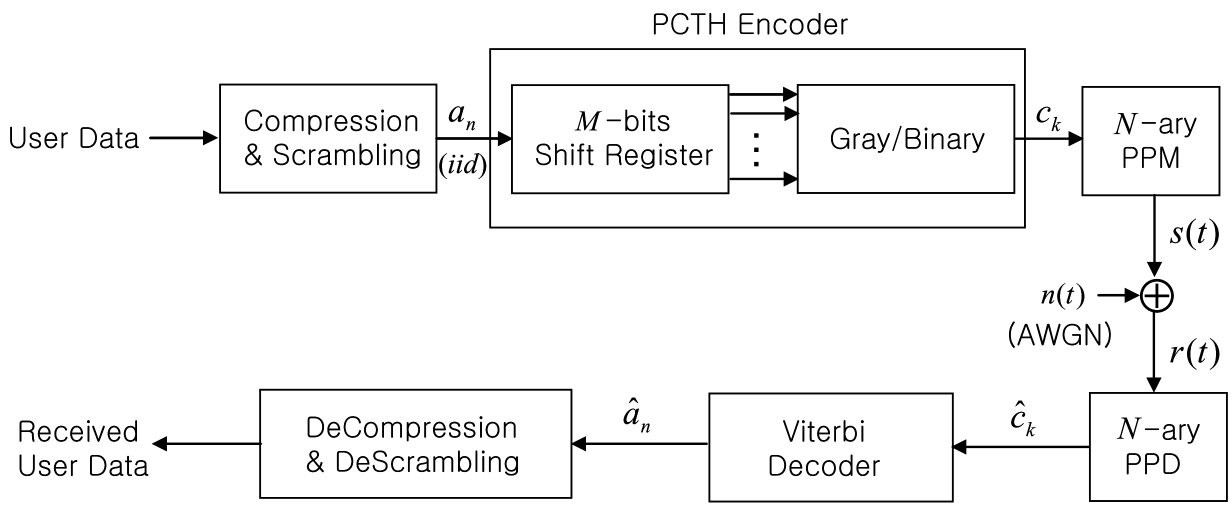
Motives

◇ Impulse radio (IR) ultra-wide bandwidth (UWB) Systems (Win and Scholtz ’98 ’00)

- IR systems for UWB communications
  - Baseband pulses of ultra short duration ($<$1ns), i.e. impulses
  - Extremely low power spectral density (PSD)
  - Time hopping (TH) binary pulse position modulation (PPM) for multiple access (MA)

- IR-UWB systems and conventional narrow bandwidth systems cannot help giving interferences to each other
  $\Rightarrow$ Reduction and management of the accompanying line spectrums of IR-UWB signals are essential for the coexistence

◇ Pseudo chaotic time hopping (PCTH) IR-UWB systems (Maggio *et al.* '01)

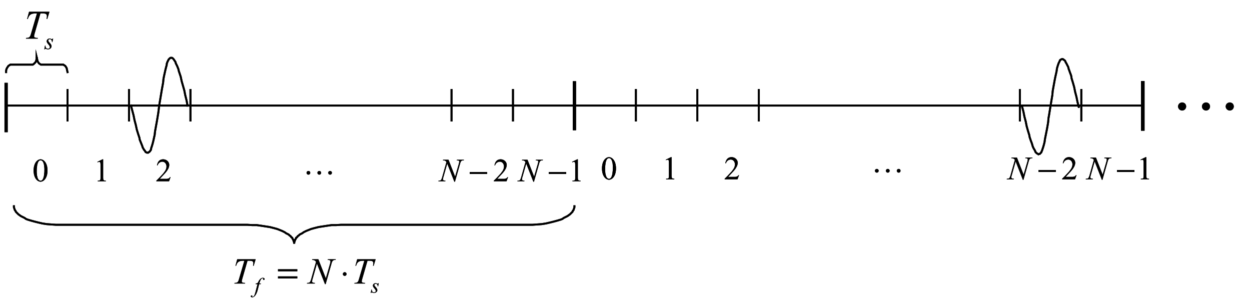


- Reduce line spectrums by using nonperiodic TH sequence depending on information bit streams
- In reality, "non-binary PPM with impulses combined with a PCTH code and a Viterbi decoder"

  $\Rightarrow$ If the PSD of IR-UWB systems using a PPM preserves the line spectrum property, we can replace the PCTH code with a better trellis code

PSD of IR-UWB Systems Using a PPM

◇ Preliminaries



- Transmitted signals using an N-ary PPM with uniform delay $\theta \in [0,\ T_f]$

$$s_{tr}(t) = \sum_{i=-\infty}^{\infty} w_{tr}(t - iT_f - d_i T_s - \theta) \tag{1}$$

  – Slot time index is *iid* discrete uniform RV determined from successive M data bits

$$d_k = \sum_{i=0}^{M-1} b_{Mk+i} 2^i \tag{2}$$

  – Gaussian monocycle

$$w_{tr}(t) = 2\sqrt{e} A \pi t f_c \exp[-2(\pi t f_c)^2] \tag{3}$$

◇ PSD Analysis

- PSD of IR-UWB Systems Using a PPM

$$\Phi_{s_{tr}}(f) = \mathcal{F}\{E[s_{tr}(t)s_{tr}(t+\tau)]\}$$
$$= G(f) + G(f)E[\exp\{-jrT_s 2\pi f\}] \left\{ \frac{1}{T_f} \sum_k \delta\left(f - \frac{k}{T_f}\right) - 1 \right\} \quad (4)$$

  - $G(f) = \frac{1}{T_f}\frac{e}{2\pi}\frac{A^2}{{f_c}^4} f^2 \exp\left[-\left(\frac{f}{f_c}\right)^2\right]$
  - r: discrete RV whose PDF is $p(r) = \frac{N-|r|}{N^2}$

- Most of line spectrums ($f = \frac{k}{T_f}$ Hz) vanish

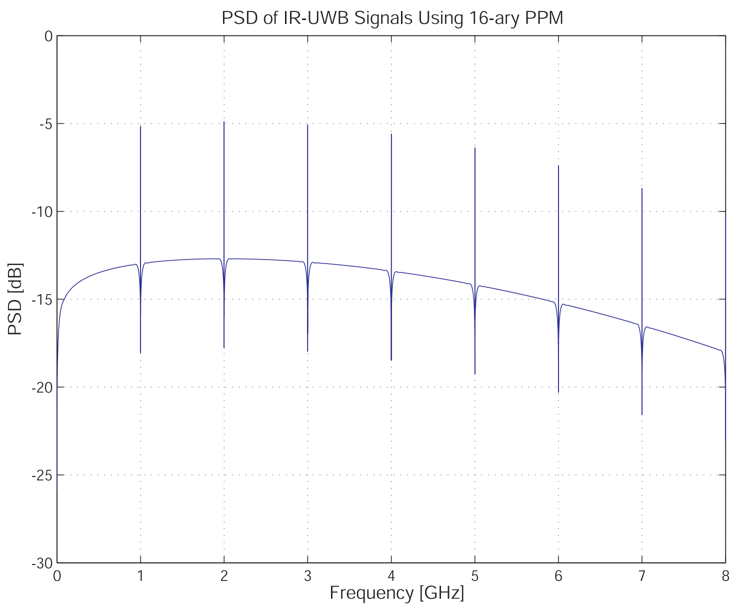
$$E[\exp\{-jrT_s 2\pi f\}] = \begin{cases} 1 & \text{if } f = \frac{n \cdot N}{T_f} = \frac{n}{T_s} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

- Final form of the PSD

$$\Phi_{s_{tr}}(f) = \begin{cases} \frac{1}{T_f} G(f) & \text{if } f = \frac{n}{T_s} \\ G(f)\left[1 - \left\{\frac{1}{N} + \sum_{r=1}^{N-1} \frac{2(N-r)}{N^2}\cos(rT_s 2\pi f)\right\}\right] & \text{otherwise} \end{cases} \quad (6)$$

$\Rightarrow$ Same line spectrum property as that of the PCTH IR-UWB system

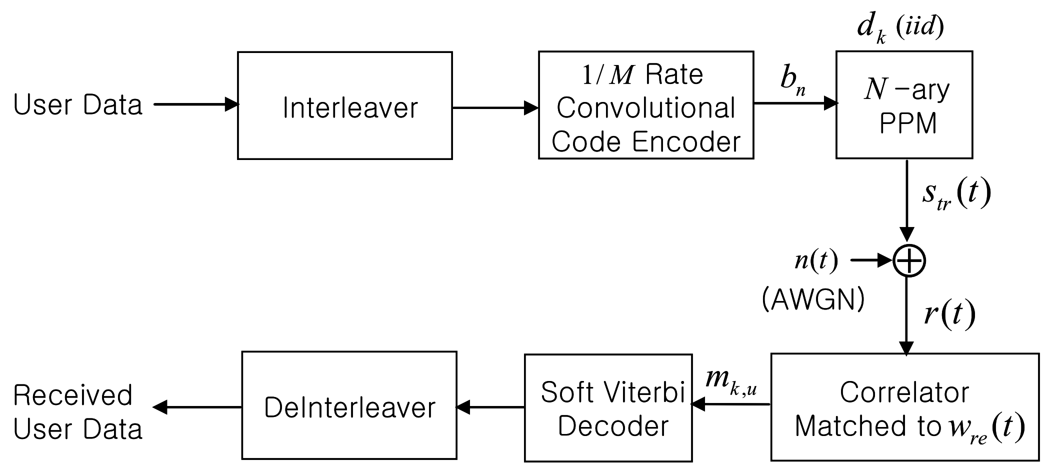
- $N = 16$, $T_s = 1$ ns, $f_c = 2$ GHz, and $E_b = 1$ W/Hz.



$\Rightarrow$ The duration of line spectrums, 1 GHz, is so sparse that we may solve the coexistence problem

Impulse PPM UWB Systems

◇ System Description



- Line spectrum property is given in (6)

  ⇒ More reduced and manageable line spectrums compared with conventional IR-UWB systems

- Received signals

$$r(t) = s_{re}(t) + n(t) \tag{7}$$

  - $s_{re}(t) = \sum_{i=-\infty}^{\infty} w_{re}(t - iT_f - d_i T_s)$
  - $w_{re}(t) = \frac{d}{dt} w_{tr}(t)$
  - $n(t)$: white Gaussian noise

- Correlator output for the u-th time slot in the k-th frame time

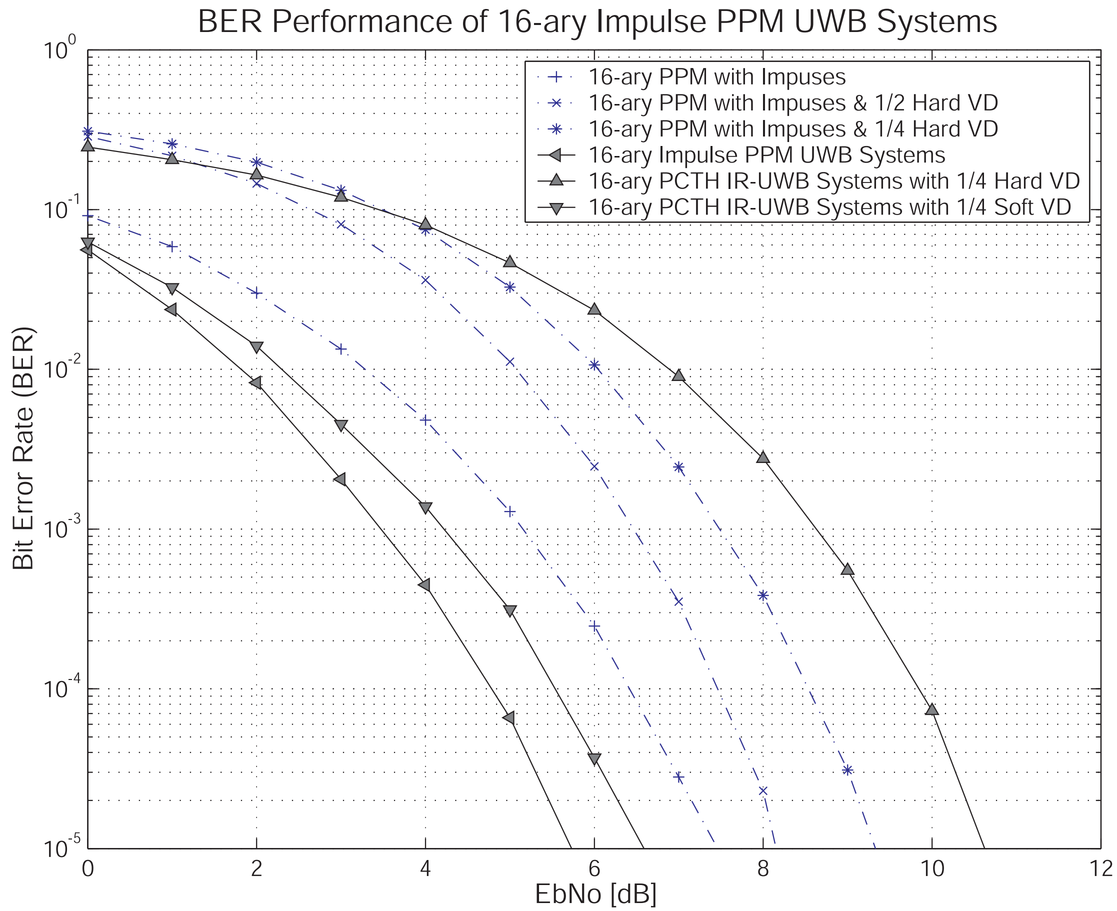
$$m_{k,u} = \int_{kT_f+(u-\frac{1}{2})T_s}^{kT_f+(u+\frac{1}{2})T_s} s_{re}(t) \cdot w_{re}(t - kT_f - uT_s)\, dt \tag{8}$$

  - Use as the soft branch metric of the branch whose output of decimal form is u

    $\Rightarrow$ Plays a major role for the good BER performance of the system

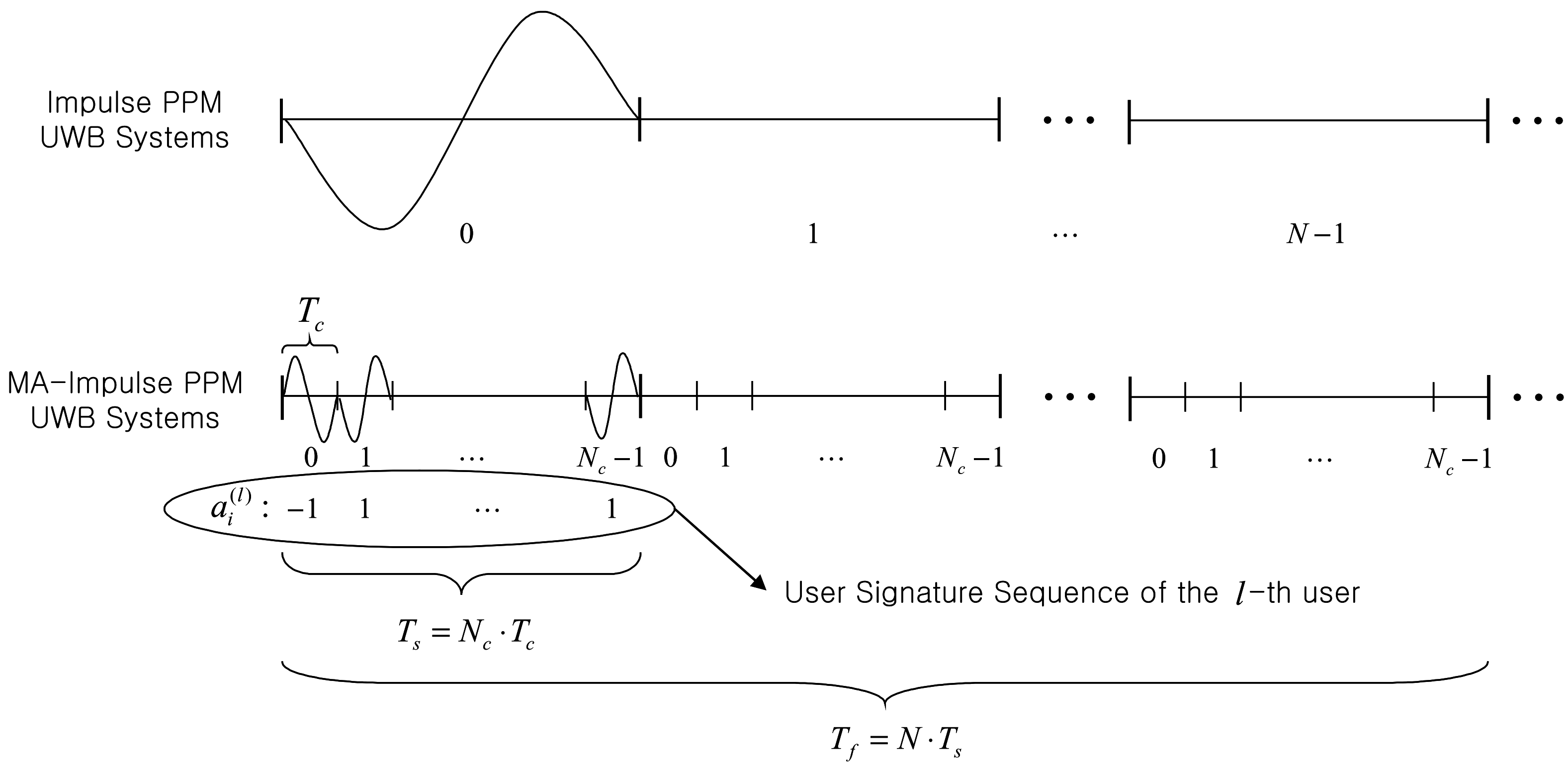
◇ BER Performance

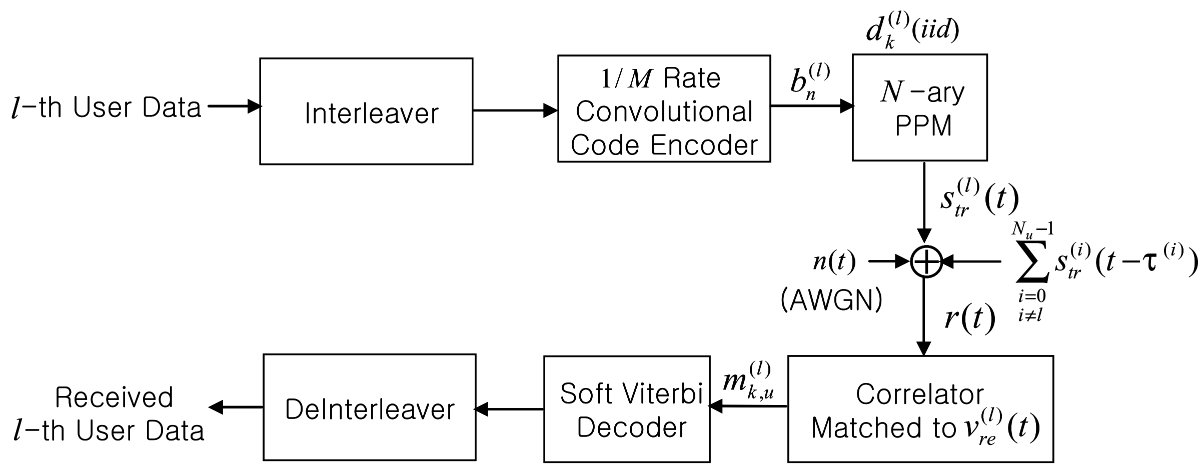
- $N = 16$, $M = 4$, $T_s = 1$ ns, and $f_c = 2$ GHz



Multiple Access Impulse PPM UWB systems

◇ System Description





- l-th user's own sequence of impulses

$$v_{tr}^{(l)}(t) = \sum_{i=0}^{N_c-1} a_i^{(l)} w_{tr}(t - iT_c) \tag{9}$$

  – $a_i^{(l)} \in \{1, -1\}$: user signature sequence of the l-th user

- Transmitted signals

$$s_{tr}^{(l)}(t) = \sum_{i=-\infty}^{\infty} v_{tr}^{(l)}(t - iT_f - d_i^{(l)} T_s - \theta) \tag{10}$$

- Received signals (assuming N_u users)

$$r(t) = s_{re}^{(l)}(t) + \sum_{\substack{i=0 \\ i \neq l}}^{N_u-1} s_{re}^{(i)}(t - \tau^{(i)}) + n(t) \tag{11}$$

  - $s_{re}^{(k)}(t) = \sum_{i=-\infty}^{\infty} v_{re}^{(k)}(t - iT_f - d_i^{(k)} T_s)$
  - $v_{re}^{(k)}(t) = \sum_{i=0}^{N_c-1} a_i^{(k)} w_{re}(t - iT_c)$
  - $\tau^{(i)}$: delay of an i-th user's signals

- Correlator output for the u-th time slot in the k-th frame time

$$m_{k,u}^{(l)} = \int_{kT_f+(u-\frac{1}{2})T_s}^{kT_f+(u+\frac{1}{2})T_s} r(t) \cdot v_{re}^{(l)}(t - kT_f - uT_s)\, dt \tag{12}$$

◇ PSD Analysis

- PSD of the l-th user's transmitted signals

$$\Phi_{s_{tr}^{(l)}}(f) = \begin{cases} \frac{1}{T_f} G'(f) & \text{if } f = \frac{n}{T_s} \\ G'(f)\left[1 - \left\{\frac{1}{N} + \sum_{r=1}^{N-1} \frac{2(N-r)}{N^2}\cos(rT_s 2\pi f)\right\}\right] & \text{otherwise} \end{cases} \quad (13)$$

  – $G'(f) = \frac{1}{T_f}\frac{e}{2\pi}\frac{A^2}{{f_c}^4} f^2 \exp\left[-\left(\frac{f}{f_c}\right)^2\right] \left|C^{(l)}(f)\right|^2$

  – $C^{(l)}(f) = \sum_{i=0}^{N_c-1} a_i^{(l)} \exp[-j2\pi f i T_c]$

  : dependent on the "user signature sequence" of the l-th user, $a_i^{(l)}$

⇒ Same line spectrum property as that of the "impulse PPM UWB system"

⇒ Includes that of the MA-PCTH IR-UWB system (Laney *et al.* '02) whose line spectrum property is not given

◇ User Signature Sequence

- Considering the MA-interferences, the BER performance mainly depends on the crosscorrelation property of “user signature sequences”

- When the slot time is synchronized (the case of a forward link)
  $\Rightarrow$ Hadamard sequences are good candidates
  $\Rightarrow$ Same BER performance as that of the “impulse PPM UWB system”

- When the slot time is not synchronized (the case of a reverse link)
  $\Rightarrow$ “User signature sequences” with optimal aperiodic crosscorrelation property are necessary

◇ Concluding Remarks

- We derive the general PSD of IR-UWB systems using a PPM and verify that the line spectrum property of the system is the same as that of the PCTH IR-UWB system.

- We propose a new IR-UWB system with a preferable line spectrum property whose BER performance exceeds that of the PCTH IR-UWB system.

- We propose a new MA-system for IR-UWB communications with its line spectrum property which includes that of the MA-PCTH IR-UWB system.