Transmit Power Allocation among PSWF-based Pulse Wavelets in Cognitive UWB Radio

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Presentation Outline

- Introduction on Cognitive UWB Radio
- Relevant Works and Current Status
- Dynamic Power Allocation Scheme among Multiple Pulse Wavelets based on Soft-Spectrum Adaptation Philosophy
- Double Water-filling Approach for Soft-Spectrum Adaptation
- Simulation Results and Discussion
- Conclusion
Introduction on Cognitive UWB Radio

- Innovation of Cognitive UWB Radio
  - UWB pulse waveforms spread over large bandwidth (>500MHz), transmit over existing (licensed) bands producing a controlled-level interference.
  - UWB represents a VERY example of enabler technology suitable for the realization and implementation of cognitive radio concept.

- We discuss convex optimization approach by utilizing water-filling scheme for adaptive transmit power allocation in cognitive UWB radio scenarios.
- Concretely, each user transmits its symbols with a number of orthogonal PSWF-based UWB wavelets.
**UWB: Underlay Approach**

- **Emitted Signal Power**
  - GPS
  - PCS
  - ISM band
  - Bluetooth, 802.11b WLAN
  - Cordless Phones
  - Microwave Ovens
  - 802.11a WLAN
  - Cordless Phones

- **Frequency (GHz)**
  - 1.6
  - 1.9
  - 2.4
  - 3.1
  - UWB Spectrum
  - 5
  - U-NII band
  - “FCC Part 15 Limit”
  - 10.6

**Note:** not to scale

- Simultaneous usage via low power levels:
  - Transmission can’t harmfully interfere with current signals
  - UWB transmits at -41dBm/MHz and after even short propagation distances – it can look like “noise”
  - No **cognition** required at this point
Characteristics of UWB Signals

- Short electric pulses (sub-nanosecond) are generated, transmitted, received and processed
  - Variable duty cycle pulses
  - No energy content at 0Hz
  - Occupied bandwidth >> information bandwidth
- Alternative terms: *impulse radio/ radar, carrier-less, carrier-free, base-band, time-domain*
- Main advantages:
  - Low power consumption
  - Low probability of detection
  - Low cost, nearly “all digital” transmitter/ receiver
  - Multipath fading robustness with space, time and frequency diversity
Especially Why is UWB Relevant to Cognitive Radio?

- UWB radio faces/causes severe interference from/to nearby narrowband systems - it will surely benefit from utilizing Cognitive Radio techniques implementing collaborative coexistence schemes.

- UWB is by definition an underlay technology, coexisting with traditional narrowband non-CR devices - we believe this is the most realistic and pragmatic scenario for introducing CR concepts.

- Inherent capability of UWB devices to observe large bandwidths, as well as intrinsic scalability of UWB technology makes it an ideal candidate for realizing a versatile PHY layer, adaptable to various wireless environment conditions.
Previously Relevant Works

- The philosophy of designing orthogonal pulse wavelets for high data rate UWB systems
- Orthogonal pulse wavelets generation based on Prolate Spheroidal Wave Functions (PSWF)
Cognitive UWB Radio Modulation by Pulse Shape Modulation (PSM)

Soft-Spectrum Pulse Shape Modulation (PSM) using orthogonal function

- Transmit 1 or 2 bits by using BPSK or QPSK modulation in each Soft-Spectrum pulse (inner-keying)
- Transmit other more bits by defining different Soft-Spectrum orthogonal pulse shapes and sequences (Outer-keying)
Spectrum-agile UWB Waveform Achieving Cognitive Radio Concept (Soft-Spectrum Adaptation)

- Linear combination of orthogonal PSWF-based multiple UWB wavelets
- The spectrum-agile waveform has the expected spectral features (notches) minimizing interference with coexisting systems
In a cognitive UWB radio environment with multiple users, with respect to the case of one sub-band accessed by one user, whose transmitting signal is $M$-ary pulse shape modulated, we get different eigenvalues by transmitting these pulses in a multipath fading channel.

Then, in orthogonal $M$-ary pulse shape modulation environment, water-filling rule allocates more power to the sub-channel with higher eigenvalue.

Here, the eigenvalue indicates the ability of its corresponding orthogonal wavelet concentrating energy inside the desired spectral mask and the pulse width.

We propose the water-filling scheme, according to the different eigenvalues, to optimize the power allocation among them.
We would like to describe our problem as:

“In a M-ary pulse shape modulation (PSM) transmission scheme, optimize the transmit power levels of M pulse wavelets of the Nth user so as to jointly maximize their data transmission rates (capacity), subject to the constraint that the interference-temperature limit (e.g. FCC spectral mask) is not violated.”
Convex Optimization Approach with Water-filling

- By transmitting the PSWF-based pulse wavelets through the multipath fading channel, we get each wavelet’s eigenvalue, then we perform water-filling algorithm to these wavelets corresponding to their different eigenvalues.

- The convex optimization problem can be described as:

\[
C_n = \sum_{m=1}^{M} \log_2(1 + \gamma_0 \lambda_{n,m} r_{n,m})
\]

\[
\begin{align*}
\text{maximize} & \quad \sum_{m=1}^{M} \log_2(1 + \gamma_0 \lambda_{n,m} r_{n,m}) \\
\text{subject to} & \quad \sum_{m=1}^{M} r_{n,m} = 1 \\
& \quad r_{n,m} \geq 0
\end{align*}
\]
Convex Optimization Approach with Water-filling (cont.)

- By citing the ideas of convex optimization, we introduce Lagrange multipliers $\lambda_i$ for the inequality constraint $\gamma_{n,m} \geq 0$, and a multiplier $\nu$ for the equality constraint $\sum_{m=1}^{M} \gamma_{n,m} = 1$, we get KKT conditions as follows:

$$-r_{n,m} \leq 0$$

$$\sum_{m=1}^{M} r_{n,m} = 1$$

$$\lambda_l \geq 0$$

$$\lambda_l \cdot r_{n,m} = 0$$

$$\sum_{m=1}^{M} \frac{\gamma_0 \lambda_{n,m}}{1 + \gamma_0 \lambda_{n,m} r_{n,m}} - \lambda_l + \nu = 0$$
Solve these conditions, we further get the solution as:

\[ r_{n,m} = \begin{cases} \frac{1}{\nu} - \alpha_{n,m} & \nu < 1/\alpha_{n,m} \\ 0 & \nu \geq 1/\alpha_{n,m} \end{cases} \]
Convex Optimization Approach with Water-filling (cont.)

This algorithm can be implemented as follows.
1) Set a small positive termination threshold \( r_{thr} \) and step size \( \xi \), initialize \( \nu \) and \( r_{total} \) to be zero.
2) while \( |r_{total} - 1| > r_{thr} \), do
   for \( m = 1 : M \)
     {
       if \( \nu \geq \frac{1}{\alpha_{n,m}} \), \( r_{n,m} = 0 \);
       else
         find \( r_{n,m} \) that satisfies \( \frac{1}{\alpha_{n,m} + r_{n,m}} = \nu \) by the following steps:
         a) set a small positive termination threshold \( \nu_{thr} \) and step size \( \mu \);
         b) initialize \( r_{n,m} = 0 \);
         c) while \( |\nu - \frac{1}{\alpha_{n,m} + r_{n,m}}| > \nu_{thr} \), do
            find derivative \( \delta \) of \( (\nu - \frac{1}{\alpha_{n,m} + r_{n,m}})^2 \) with respect to \( r_{n,m} \):
            \[ \delta = \frac{1}{(\alpha_{n,m} + r_{n,m})^2} (\nu - \frac{1}{\alpha_{n,m} + r_{n,m}}) \]
            update
            \( r_{n,m} = r_{n,m} - \mu \delta \)
         }
     compute \( r_{total} = \sum_{m=1}^{M} r_{n,m} \)
     update \( \nu \) as \( \nu = \frac{\nu}{\nu} + \xi(1 - r_{total}) \).
3) Output all \( r_{n,m} \).
Simulation Results and Discussion

Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of PSWF-based orthogonal wavelets</td>
<td>8</td>
</tr>
<tr>
<td>Chip pulse duration (direct-sequence UWB)</td>
<td>1 ns</td>
</tr>
<tr>
<td>Direct-sequence code assigned to 8 different pulse wavelets</td>
<td>8 by 8 ternary complementary code sets</td>
</tr>
<tr>
<td>Multipath channel model</td>
<td>IEEE 802.15.3a S-V model (CM1,CM3)</td>
</tr>
<tr>
<td>No. of selected paths for Rake combining receiver</td>
<td>5</td>
</tr>
</tbody>
</table>

![Graphs showing amplitude gain over time](image1.png)
BER performance of water-filling scheme and equal power allocation scheme (in CM1)
Throughput of proposed scheme and equal power allocation scheme (in CM1)
BER performance of water-filling scheme and equal power allocation scheme (in CM3)
Throughput of proposed scheme and equal power allocation scheme (in CM3)
Simulation Analyses and Discussions

- The simulation shows that when the SNR is in lower area (below 10dB), the proposed scheme improves about 1 dB at the same BER, compared with the equal power allocation scheme.

- However, we can further observe that the proposed scheme performs almost similar with the equal power allocation scheme when SNR is in the higher area (above 10dB).

- The throughput is significantly improved about 20Mbps when SNR is below 10dB. When SNR is above 10dB, the proposed scheme performs almost similar with the equal power allocation scheme.

- The reason behind the small difference in the throughput and the BER performance is that since the capacity is a logarithmic function of SNR, the data rate is usually insensitive to the exact power allocation, except when the SNR is low.
Conclusions

- Water filling was used among multiple orthogonal PSWF pulse wavelets in a cognitive UWB environment to improve system performance (e.g. data throughput).

- The scheme improves the sub-band channel data throughput compared with the equal power allocation scheme when the SNR is relatively low.
Thank You!
And, see you at CrownCom 2007