Introduction to and some results on DS-UWB, multiband UWB, and multiband OFDM

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Outline

• UWB Background
• IEEE UWB Channel Model
• Single-Band Impulse Radio
• Multiband Impulse Radio
• Multiband-OFDM
• Discussion and Conclusions
UWB Background

• A signal is UWB when the bandwidth is larger than 0.25 times the carrier freq.
• FCC requires the -10 dB bandwidth to be at least 500 MHz
• FCC has defined a spectrum mask
  – -41.3 dBm/MHz is the maximum EIRP between 3.1 GHz to 10.6 GHz (556 µW in the whole band, 111 µW in 1.5 GHz)
FCC spectrum mask

5GHz ISM band!
Single-band vs multiband

- **Single-band**: using the whole available spectrum
  - transmitting very short pulses (impulse radio)
- **Multiband**: dividing the available spectrum into several bands, each having a minimum of 500 MHz of bandwidth, to comply with the FCC requirements
  - Introduces orthogonality in the freq. domain
  - Impulse radio with longer pulses in each band
  - OFDM in each band
IEEE UWB Channel Model

• Based on the Saleh-Valenzuela channel model where multipath components arrive in clusters.

\[ c(t) = \sum_{{l \geq 0}} \sum_{{k \geq 0}} \alpha_{k,l} \delta(t - T_l - \tau_{k,l}) \]

• \( T_l \) arrival of cluster \( l \), \( \tau_{k,l} \) arrival of ray \( k \) within cluster \( l \)

• Shadowing with \( X = 10^{\text{normal(}\mu=0,\sigma=3 \text{ dB})} \)

\[ h(t) = Xc(t) \]

• Four models
  – CM1: LOS 0-4 meter, (RMS delay spread 5 ns)
  – CM2: NLOS 0-4 meter, (RMS delay spread 8 ns)
  – CM3: NLOS 4-10 meter, (RMS delay spread 14 ns)
  – CM4: NLOS RMS delay spread 25 ns

• Block fading models!
Single-band TH-UWB and DS-UWB Impulse Radio

- **Time-Hopping Ultra-wideband (TH-UWB)**
  
- **Direct-Sequence Ultra-wideband (DS-UWB)**
Numerical Results

- IEEE UWB model with shadowing
- 2.5 to 6.8 GHz pulse with a duration of 0.5 ns
- Processing gain is 20 or 13 dB
- Data rate **100 Mbps**
- Channel estimation included
- Fractionally and chip spaced Rake receiver
Symbol-, chip- and fractionally spaced Rake with perfect channel estimate for DS-UWB on CM1 with shadowing

- Symbol spaced 100 MHz
- Chip spaced 2 GHz
- Fractionally spaced 20 GHz

12 dB @ 0.001
TH-UWB and DS-UWB with fractionally spaced Rake and successive channel estimation algorithm

Degradation due to IPI

- CM1 LOS 0-4 meter
- CM2 NLOS 0-4 meter
- CM3 NLOS 4-10 meter
- CM4 NLOS RMS delay 25 ns

BER vs. Average $E_b/N_0$ [dB]
Multiband MB-UWB Impulse Radio

- No interpulse interference
- One Rake per band
- Fewer taps

4-5 ns transmitted chip time
Numerical Results

- IEEE UWB model with shadowing
- 6 Bands with between 3.1 and 6.1 GHz
- 4 ns pulse duration and 24 ns pulse repetition
- Pulse rate 250 Mpulses/s
- Repetition code 1/2
- Processing gain 12
- Data rate **125 Mbps**
- Sliding window channel estimation
- Fractionally and chip spaced Rake receiver
Multiband-UWB

250 MHz sampling rate
1 tap Rake!
IEEE multiband OFDM approach

- **Group A**: 3.1-4.9 GHz. Assigned for 1st generation devices
- **Group B**: 4.9-6 GHz. Designated for future use
- **Group C**: 6-8.1 GHz. Intended for devices with improved SOP (Simultaneously operating piconets) performance
- **Group D**: 8.1-10.6 GHz. Designated for future use
Multiband OFDM

OFDM symbol with 528 subcarriers
## OFDM system data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>fs</strong>: sampling frequency</td>
<td>528 MHz</td>
</tr>
<tr>
<td><strong>$N_{DS}$</strong>: # of data subcarriers</td>
<td>100</td>
</tr>
<tr>
<td><strong>$N_{PS}$</strong>: # of pilot subcarriers</td>
<td>12</td>
</tr>
<tr>
<td><strong>$N_{TS}$</strong>: total # of subcarriers used</td>
<td>112</td>
</tr>
<tr>
<td><strong>$\Delta F$</strong>: subcarrier frequency spacing</td>
<td>4.125 MHz ($=528$ MHz$/128$)</td>
</tr>
<tr>
<td><strong>$T_{FFT}$</strong>: FFT/IFFT period</td>
<td>242.424 ns ($1/4.125$ MHz)</td>
</tr>
<tr>
<td><strong>$T_{Gi}$</strong>: guard interval duration</td>
<td>60.6 ns ($=32$ samples$/528$ MHz)</td>
</tr>
<tr>
<td>(prefix+postfix duration)</td>
<td></td>
</tr>
<tr>
<td><strong>$T_{GT}$</strong>: guard time</td>
<td>9.47 ns ($=5$ samples$/528$ MHz)</td>
</tr>
<tr>
<td><strong>$T_{SYM}$</strong>: total OFDM symbol duration</td>
<td>312.5 ns ($T_{SYM} = T_{FFT} + T_{Gi} + T_{GT}$)</td>
</tr>
<tr>
<td><strong>Channel bit rate</strong></td>
<td>640 Mbps</td>
</tr>
</tbody>
</table>
Numerical Results

- IEEE UWB model with shadowing
- 3 bands of 528 MHz between 3.1- 4.6 GHz
- Convolutional codes with rate 1/2 and 1/4 with constraint length equal to 7
  - Channel coding required to obtain diversity
- Information data rate **320 and 160 Mbps**
- Block interleaver
- *Perfect channel estimator*
Numerical Result of Coded OFDM

![Graph showing bit error rate vs. Eb/N0 for different modulation schemes and rates]
Summary and Conclusions

• Three systems
  – DS-UWB system: 10 Rake fingers, sampling frequency of 20 GHz, data rate 100 Mbps, 2.8-6.8 GHz
  – MB-UWB: one Rake finger per band, sampling frequency 0.25 GHz, data rate 125 Mbps, 6 bands, 3.1-6.1 GHz
  – MB-OFDM: data rate 320 and 160 Mbps, sampling frequency 528 MHz, 3 bands, 3.1-4.6 GHz
  – Results should be compared with care!

• MB-UWB performs almost equally well as DS-UWB and TH-UWB with much fewer Rake taps
• MB-OFDM has much better performance than the other two
• The impulse radio systems might improve with more advanced channel coding (only repetition coding used now)
• MB-OFDM seems to be a very promising UWB solution
Thank you!

Any questions or comments?