Ultra-Wideband (UWB)

Klaus Witrisal
(Witrisal@tugraz.at; www.spisc.tugraz.at)

Outline

• What is Ultra-Wideband? Why UWB?
  – Understanding UWB radio propagation
  – Features and potential advantages

• Regulation
  – Where can we find UWB spectrum?

• Implementation of UWB Systems
  – Challenges and proposed solutions

• Standardization

• Summary
What is UWB?

- Transmission technology for wireless data comms.
  - Signal modulation for **robust** transmission over physical channel
- Bandwidth Classification
  - Motivated by **channel** impact on **data signal**
  - Narrowband
  - Wideband
  - **Ultra-Wideband**
    - Channel impulse response vs. **symbol period** $T$ of TX signal

### Bandwidth Classification

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol period $T$</th>
<th>Multipath components (MPCs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrowband</td>
<td>$T = 1/B$</td>
<td></td>
</tr>
<tr>
<td>Wideband</td>
<td>$T = 1/B &lt; \tau_{\text{max}}$</td>
<td></td>
</tr>
<tr>
<td>Ultra-Wideband (High Data Rate)</td>
<td>$T = 1/B &lt;&lt; \tau_{\text{max}}$</td>
<td></td>
</tr>
</tbody>
</table>
Each MPC is a delayed/attenuated carrier wave

- Phase shifts due to delays
- Interference between carriers → fading
- RX power varies with time/location (animation)

RX Solutions
- fading margin: many extra dB power needed
- diversity: multiple parallel links (multiple antennas)
- only low data rate is achieved with NB systems

Greater data rate is achieved/needed
Still superposition of many MPCs
- → fading RX power
Also overlap of consecutive symbols
- → signal distortion (inter-symbol-interference - ISI)
RX Solutions
- equalization / multicarrier modulation – parallel transmission
Ultra Wideband (Spread Spectrum)

- wide bandwidth but low symbol rate
- spread spectrum: rake receiver:
  - resolves parts of channel response (corresponding to $\sim 1/B$)
  - each part fades independently $\rightarrow$ less fading through Rake combining
- Problems
  - higher complexity for synch.; more bandwidth needed

Ultra-Wideband (Spread Spectrum)

- individual MPCs can be resolved
  - $\rightarrow$ no/little fading remains
- Start of channel response can be found
  - positioning at $< 1m$ accuracy (for indoor apps.)
- UWB for high-rate
  - potentially achieves huge data rates
  - e.g. multicarrier parallel transmission (OFDM)
Where can we find UWB spectrum?

- Spectrum is scarce! (remember UMTS auctions)
- **UWB Idea:**
  - underlay UWB signals under existing services
  - spreading gain reduces these signals
  - obey emission limits for *unintended* emag. radiation
  - → since data transmission is “intended”, **regulation** is needed!
  - → very low TX power (< 0.5 mW) → low range
- **Regulation**
  - United States: FCC allows UWB in 2002 (3.1 – 10.6 GHz @ -41.3 dBm/MHz)
  - Europe: ECC; March 06: (6 – 8.5 and 3.1 – 4.8 GHz (DAA) @ -41.3 dBm/MHz)
  - Japan: MIC; expected: (3.4 – 4.8 & 7.25 – 10.25 GHz @ -41.3 dBm/MHz, DAA)
- **UWB definition** (FCC):
  - BW > 500 MHz; or fractional BW \( \frac{BW}{f_c} > 0.2 \)

---

### Emission masks for UWB (draft)

![Emission masks graph for UWB](image_url)
Summary of UWB Features

- **Large bandwidth** (> 500 MHz, up to 7 GHz)
  - High data rates or user densities are possible

- **Low radiated power** (0.5 mW for 7 GHz BW – FCC)
  - Limited range (< 10m)

- **Localization capabilities**
  - Location based services
  - Location enhanced network protocols

- **Applications**
  - Cable replacements (Wireless USB2) – IEEE 802.15.3a
    - No agreement reached; MB-OFDM adopted by ECMA-368/ISO
    - High data rate (at least 480 MBit/s)
  - Localization; Sensor networks – IEEE 802.15.4a
    - Issued 2006; low data rates (typically 1 MBit/s)

Realizing UWB Communications

- **Various modulation / spreading schemes** (known from conventional DCS)
  - orthogonal frequency division multiplexing (OFDM)
    - Well-suited for high-rate
  - direct sequence spread spectrum (DS-SS)
    - UWB chip-level pulses are used
  - frequency hopping

- **A special proposal: Impulse Radio**
  - Use ultra-short pulses to generate UWB signals
  - No carrier needed → low power designs possible
    - Pulse position modulation and time-hopping for multiple access
UWB-Impulse Radio – Transmitted Signal

Transmitted monocycle (first derivative of Gaussian pulse)

Transmitted pulse sequence for one bit with time-hopping code

2\textsuperscript{nd} derivative of Gaussian pulse; $\tau_m = 0.29$ ns

Power Spectrum Magnitude (dB)

Time-Hopping Multiple Access

- Receiver knows time-hopping sequence
- Co-channel user (multiple access):
  - only one collision per symbol

[Moisch: Wireless Communications]
UWB-Impulse Radio – Received Signal

Tx; $s(t)$:

Channel; $g(t)$:

Rx; $r(t)$:

Implementation Challenges

- Basically, UWB signals must be processed
  - Nyquist theorem: sampling at $f_s > 2BW > 1$ GHz !!!
- Coherent receiver: *ideal*, but highly complex

Optimal template = matched filter:
Problems: implementation complexity; synchronization; channel estimation

Sub-optimal template, single pulse:
Problem: collects only fraction of energy
Non-coherent receivers

- **sub-optimal** but simple
- **energy detector**
  - can only use precise timing for suppression of interference

- transmitted reference w/ **autocorrelation receiver**
  - two pulses are transmitted (pulse doublet)
  - first pulse is reference for demodulation of second pulse
  - trade-off: complexity/performance
  - problem: UWB delay line!

---

Transmitted Reference (IR) Systems
(Autocorrelation Receiver Frontend)

- Delay $D$
- Multipath
- $T_I$ integration interval
- $t_1$, $t_2$ integration times
- Output: DSP
- Sync. clock
- $t_{1'}$, $t_{2'}$ pulse doublet
Standardization: 802.15.3a – ECMA-368

- High speed data transmission for Personal Area Networks (PANs)
  - Range below 10 m (even less)
-Proposal 1: Implementation as **Direct Sequence Spread Spectrum**
-Proposal 2: multiband OFDM
  - 528 MHz Signals; 128 sub-carriers; frequency (band) hopping

---

Standardization: 802.15.4a

- **Low data rate** standard (typically 1Mbps)
- **Positioning** applications
- Transmit positioning information and data
  - **Reference pulses** (root-raised-cosine)
  - Long, known **training sequence** for channel estimation/positioning
  - Allows coherent and non-coherent receivers
    - pulse-bursts are sent; information bits are encoded twice:
      - **PAM** modulation: only for coherent receivers
      - **Burst position modulation** (BPM): also for noncoherent ED
- Standard issued in 2006
Preamble Sequences – IEEE 802.15.4a

• Ternary sequences

<table>
<thead>
<tr>
<th>Code No.</th>
<th>31-chip Ternary Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>000 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>2</td>
<td>0 0 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>3</td>
<td>-0 +0 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>4</td>
<td>0 0 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>5</td>
<td>-0 +0 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>6</td>
<td>-0 +0 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>7</td>
<td>-0 +0 00 00 00 00 00 00 00 00</td>
</tr>
<tr>
<td>8</td>
<td>-0 +0 00 00 00 00 00 00 00 00</td>
</tr>
</tbody>
</table>

• Perfect autocorrelation properties
  – For coherent and non-coherent receivers

Diagram shows timing of one data symbol

- $N_c$ pulses in one burst are sent per symbol
  - Random spreading sequence
    - $N_c = 512, 128, 32, 16, 8, 4, 2, 1$
- Modulation
  - Burst position modulation; Burst polarity modulation
    - Burst hopping ($N_{hop} = 2, 8, 32$)
    - Guard Interval

K. Witrisal
Graz, 22-Jan-08
Ultra Wideband (UWB)
Signal Example

- Modulation: Burst polarity and burst position
- No burst-hopping in this example
- Pulse repetition frequency: 499.2 MHz (2 ns)
  → Inter-Pulse-Interference
  → “fading” effects due to random channel and code

Optimal Coherent Receiver

- Optimal Matched Filtering
- Disadvantage
  - High sampling rates (Nyquist)
  - (Perfect / good) channel estimation
  - Many channel taps
Energy Detection Receiver

- Analog receiver front-end
  - Simple, **low complexity**, low power
- **Only for burst position** modulation $s_0$
- Low robustness against narrowband interference

Summary

- **Potentials**
  - ultra-high data rate
  - **positioning!**
  - potentially low power transmitters (impulse radio)
- **Challenges**
  - high receiver complexity
  - sensing capabilities of UWB signals
- **An example:**
  - **tracking of emergency personnel** – project “EUROPCOM”
  - (EC FP6 funded. Partners: Thales Research, UK, IMST GmbH., D, TU Delft, NL, TU Graz)
EUROPCOM – Emergency UWB Radio for Positioning and Communications

Further Reading …

- **Books:**
  - Molisch et al., *UWB Communication Systems – A Comprehensive Overview*
  - Oppermann et al., *UWB*
  - Ghavami et al., *UWB Signals and Systems in Communication Engineering*
  - Arslan et al., *Ultra Wideband Wireless Communication*

- **Papers:**