Ultra Wideband Communications
Past, Present, and Future

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A Matter of Perspective: What Is UWB?

A picture $\equiv 10^3$ words

- Narrowband
- Wideband
- Ultra-Wideband
A Matter of Perspective: What Is UWB?

**Ultra Wideband Radio**

**Generic:** a wireless communications system employing a “very large” bandwidth

**versus**

**Regulatory:** “An intentional radiator that, at any point in time, has a fractional bandwidth equal to or greater than 0.20 or has a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth.” (FCC)

**versus**

**Synonyms:** “impulse radio” or “carrierless radio” (maybe?)
The Past
The “Ancient” Past

- Some of the first radio transmissions (spark-gap generators) were wideband, carrierless transmissions!

- Quickly, wireless communications moved to carrier-modulated transmissions, and forgot about UWB

- UWB returned first in radar applications from the 1940's onwards

- A surge in interest in the last 15 years
The IEEEXplore History of “UWB”

Year

Hits on UWB in IEEEXplore

10^3

10^2

10^1

10^0

First “modern” UWB designs were based on “impulse radio”

- Idea: send a sequence of very short, carrierless impulses
- Short time \iff wide bandwidth
- Transmit data with the pulse position, pulse polarity, differential schemes
- Soon UWB expanded to other techniques

The FCC allowed several categories of devices

1. Imaging Systems: Ground-penetrating radar, Through-Wall Imaging Systems, Surveillance Systems, Medical Systems
2. Vehicular Radar Systems
3. Communications and Measurement Systems

Bandwidth of at least 500 MHz

FCC envisioned UWB as a spectral underlay system
FCC Spectral Mask

For UWB emissions in the 3.1 – 10.6 GHz band

-75nW/MHz

0.5mw

-75nW/MHz

Part 15 Limit

Indoor Limit

3.1 GHz

10.6 GHz
IEEE 802

IEEE 802 standardization for many communications standards
- Ethernet (802.3)
- “WiFi” Wireless LAN (802.11)
- “WiMAX” Wireless MAN (802.16)

IEEE 802.15

Working Group for Wireless Personal Area Networks (WPAN)
- 802.15.1 → Bluetooth
- 802.15.3 → High Rate WPAN
- 802.15.4 → Low Rate WPAN (ZigBee)
- 802.15.5 → Mesh Networking
### High Rate UWB: 802.15 TG 3a
- Alternate PHY for high data rate communication
- Ultimate data rate: roughly 500 Mbps
- Short range (roughly 10 meters)
- Applications: high-speed video transfer, multimedia communications

### Low Rate UWB: 802.15 TG 4a
- Alternate PHY for low rate communication and ranging
- Support for thousands of nodes
- Very low power (for long battery life)
- Examples: Location-aware applications (e.g. smart home), tracking assets (e.g. pallets in warehouse)
802.15 TG3a: the great schism

The Problem
- Two competing technologies: Multiband OFDM and DS-UWB
- Both had $\sim 50\%$ support (of individuals)
- Multiband OFDM had many more supporting companies
- in IEEE 802, voting rights are held by individuals
- 75\% super-majority required for confirmation

The Result
- Deadlock in final confirmation procedure
- TG3a disbanded without creating a standard
- Multiband OFDM $\rightarrow$ WiMedia Alliance $\rightarrow$ ECMA-368
- DS-UWB $\rightarrow$ UWB Forum
The Present
Support from many companies (WiMedia Alliance)

MB-OFDM proposal standardized as ECMA-368

First-gen: use three 528 MHz bands in 3.1–4.8 GHz

Frequency hopping (simultaneously operating piconets)
High-Rate: ECMA-368 / Multiband OFDM (2/3)

- Employs Orthogonal Frequency Division Multiplexing (OFDM)
- Convolutional codes + interleaving for error correction
- Classical QPSK modulation on each OFDM subcarrier

Transmitter

source → Convolutional Encoder → Puncturer → Interleaver → Symbol Mapper → IFFT → to RF

Receiver

from RF → FFT → Soft Demapper → Deinterleaver → Depuncturer → Viterbi Decoder → sink
ECMA-368 requires less power per megabyte of data
High-Rate: DS-UWB

- Two bands: lower operating band 3.1-4.85 GHz, upper operating band 6.2-9.7 GHz

- (Almost) classical direct-sequence spread spectrum in each band
- BPSK and 4-ary bi-orthogonal keying (4BOK) modulation options
- RAKE and equalizer required for high-performance receiver
High-Rate: Comparing MB-OFDM and DS-UWB

**Complexity**
- Basic DS-UWB has simpler DSP hardware
- High performance DS-UWB → needs rake filters
- MB-OFDM → fixed complexity FFT

**Coexistence**
- MB-OFDM facilitates cognitive radio
  - FFT RX processing → a crude spectrum analyzer
  - Use to detect other radio types (e.g. WiMax, 4G)
  - Adaptively adjust transmit spectra to avoid interference
- TG3a DS-UWB can add extra filters for international regulatory compliance
Two physical layers:
- Spread-spectrum in 2.4 GHz band (not UWB)
- UWB PHY layer
  - Spread-spectrum with several band options
  - BPM-BPSK (burst phase & position modulation)
  - Fixed pulse rate (∼500 MHz)
  - Variable bandwidth (499, 1082, 1331, 1355 MHz)
  - Mandatory data rate: 0.811 Mbps

Ranging is a mandatory part of the 4a standard
- Spatial accuracy increases with bandwidth
- Time-based ranging system specified
  - Measure round-trip time (flight time + processing delays)
  - Calibrate out processing delays → flight time → distance
Band Structure
## USA
- Regulatory body: FCC
- 2002 regulations are still in force
- Several companies have approved UWB devices on the market
- Rumors that FCC may require interference mitigation in the future
- **Australia/New Zealand similar**

## Canada
- Regulatory body: Industry Canada
- Currently in development
- Historically has tended to follow FCC closely (cross-border operation)
Europe

- Regulatory body: CEPT (European Conference on Postal and Telecommunications)
- Low band: 3.1 – 4.8 GHz
- High band: 6.0 – 8.5 GHz
- Mitigation 3.1 – 4.2 GHz
- Mitigation may be required in 4.2 – 4.8 GHz after 2010
- ETSI will specify DAA compliance tests (later this year)
- China similar
Japan

- Regulatory body: MIC (Ministry of Internal Affairs and Communications)
- Low band: 3.4 – 4.8 GHz
- High Band: 7.25 – 10.25 GHz
- Current rules apply through 2009, subject to revision
- MIC will specify mitigation requirements separately
- Restricted to indoor use and mains-powered
- Korea similar (except for mains-powered requirement)
The Future
Future of UWB (1/2)

Coexistence

- Regulators are mandating Detection and Avoidance (DAA)
- Existing systems must be updated to comply with regulations
- Future standards will include DAA
- Currently waiting for DAA compliance tests to be agreed on (ETSI)

ECMA-368

Will be employed as PHY layer for
- Wireless USB
- Wireless Firewire (IEEE 1394)
- Bluetooth 3.0 (2008)
Future of UWB (2/2)

**UWB at 60 GHz**

- 7 GHz of *unlicensed* bandwidth available (57 – 64 GHz)
- High EIRP allowed
- O₂ absorption both a problem (pathloss) and benefit (frequency reuse)
- Rain fades also a problem
- Higher antenna directivity possible
- Potential data rates of 3+ Gbps

*To watch: IEEE 802.15.3c (2008)*
UWB @ UBC
UWB @ UBC: What we are doing

MB-OFDM / ECMA-368
- Fundamental limits of communication (capacity, cutoff rate)
- Extensions for higher data rates, better performance
- Error rate analysis for coded systems
- Impact of interference to MB-OFDM
- Impact of interference from MB-OFDM

DS-UWB
- Performance analysis and bounds
- Novel equalization schemes for 4-BOK modulation
# UWB @ UBC: What we are doing

## Low-Rate (802.15.4a)
- Performance limits for UWB communication
- Designing better receivers for low-rate UWB
- Better decoding for error-correction codes in UWB

## Funding / Support
- Bell Canada
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- Omnex Control Systems Inc
- Veri Chip Corporation
- NSERC
Thank you. Questions?

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