Ultra Wide Band (UWB) Technology and Applications

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July 10, 2003
What is Ultra Wideband?

Radio technology that modulates impulse based waveforms instead of continuous carrier waves.
Information Modulation

Pulse length \(\sim 200\text{ps}\); Energy concentrated in 2-6GHz band;
Voltage swing \(\sim 100\text{mV}\); Power \(\sim 10\mu\text{W}\)

- Pulse Position Modulation (PPM)
- Pulse Amplitude Modulation (PAM)
- On-Off Keying (OOK)
- Bi-Phase Modulation (BPSK)
UWB Spectrum

- FCC ruling permits UWB spectrum overlay

- FCC ruling issued 2/14/2002 after ~4 years of study & public debate

- FCC believes current ruling is conservative
Theoretical Data Rates over Range

UWB shows significant throughput potential at short range
Performance Analysis with encoding rules
So why is UWB so Interesting?

• 7.5 Ghz of “free spectrum” in the U.S.
  – FCC recently legalized UWB for commercial use
  – Spectrum allocation overlays existing users, but its allowed power level is very low to minimize interference
• Very high data rates possible
  – 500 Mbps can be achieved at distances of 10 feet under current regulations
• “Moore’s Law Radio”
  – Data rate scales with the shorter pulse widths made possible with ever faster CMOS circuits
• Simple CMOS transmitters at very low power
  – Suitable for battery-operated devices
  – Low power is CMOS friendly
Ultra Wideband Characteristics

- Extremely low transmission energy (less than 1mW)
- Very high bandwidth within short range (200Mbps within 10m)
- Extremely difficult to intercept
  - Short pulse excitation generates wideband spectra – low energy densities
  - Low energy density also minimizes interference to other services
- Multipath immunity
- Commonality of signal generation and processing architectures
- Radar
  - Inherent high precision – sub-centimeter ranging
  - Wideband excitation for detection of complex, low RCS targets
- Geolocation/Positioning
  - Sub-centimeter resolution using pulse leading edge detection
  - Passes through building blocks, walls, etc. (LOS not required)
- Low Cost
  - Nearly “all-digital” architecture
  - Ideal for microminiaturization into a chipset
- Frequency diversity with minimal hardware modifications
UWB Advantages

• Capacity
  – possibility of achieving high throughput
• Low power & Low cost
  – Can directly modulate a baseband pulse
  – Can be made nearly all digital
  – High capacity with lower Tx power levels
• Fading robustness
  – Wideband nature of the signal reduces time varying amplitude fluctuations (?)
  – Relatively immune to multipath cancellation effects
    • Path delay ~ 1ns > pulse duration
    • But don’t we build RAKE just to rebuild the multipath thing?
    • What about ISI?
• Position location capability
  – Developed first as radar technology (!)
• Flexibility
  – Can dynamically trade-off throughput for distance
UWB Application 1: WPAN

- Desktop and Laptop PCs
  - High res. printers, scanners, storage devices, etc
  - Connectivity to mobile and CE devices

- Mobile Devices
  - Multimedia files, MP3, games, video
  - Personal connectivity

- CE Devices
  - Cameras, DVD, PVR, HDTV
  - Personal connectivity

One PHY for Personal Computing, Consumer Electronic and Mobile, Wireless Personal Area Connectivity Connectivity
• **Positioning, Geolocation, Localization**
  High Multipath Environments
  Obscured Environments

• **Communications**
  High Multipath Environments
  Short Range High Data Rate
  Low Probability of Intercept/ Interference

• **Radar/Sensor : MIR (motion detector, range-finder, etc.)**
  Military and Commercial: Asset Protection
  Anti-Terrorist/Law Enforcement
  Rescue Applications
Related Standards

- IEEE 802.15: Wireless Personal Area Network (WPAN)
- IEEE 802.15.1: Bluetooth, 1Mbps
- IEEE 802.15.3: WPAN/high rate, 50Mbps
- IEEE 802.15.3a: WPAN/Higher rate, 200Mbps, UWB
- IEEE 802.15.4: WPAN/low-rate, low-power, mW level, 200kbps
UWB Geopositioning Example
High resolution, geolocation system

- Design Characteristics
  - 3-D position from precise time-of-flight measurements
    - UWB Rover with multiple UWB Beacons
  - 2W peak, 400 MHz instantaneous BW
    - Spectrally shaped waveform design
    - L-band (27% BW)
    - Packet burst, 100 updates/second
  - Leading edge detector for sub-foot resolution
  - Range
    - Up to 2 km outdoors
    - Up to 300 feet indoors (5-25 dB/wall attenuation)
Three Principles of Positioning

- **TOA (Time of Arrival) & RTD (Round Trip Delay)**

- **TDOA (Time Difference of Arrival)**

- **AOA (Angle of arrival)**
UWB Industries

Æther Wire & Location (USA) (http://www.aetherwire.com)
- Low power, miniature, distributed position location (“Localizers”) and communication devices.
- DARPA Projects (Defense Advanced Research Projects Agency)

Intel (USA) (http://www.intel.com/technology/itj/q22001/articles/art_4.htm)
- UWB for communicating between devices, instead of networking PCs (wireless USB);

Pulse-Link (USA) (Fantasma Networks IP) (http://www.pulselink.net/default.htm)
- Very active on patents and IP;
- Development of UWB platform for wireless video, short and long (km) range communication, positioning.

Time Domain (USA) (Pulse-ON technology) (http://www.time-domain.com)
- Wireless Communications (Home WLAN), Precision Location and Tracking and High Definition Portable Radar
- Already a 5-chip chipset: PulseONÆÊ chipset (IBM foundry)

MultiSpectral Solutions, Inc (MSSI) (USA) (http://www.multispectral.com)
- High-speed communications networks and data links, collision and obstacle avoidance radars, precision
  geolocation systems for personnel location and mapping, intelligent transportation systems.

XtremeSpectrum (USA) (http://www.xtremespectrum.com)
- First product announced for middle 2002

McEwan Technologies (USA) (http://www.mcewantechnologies.com)
- McEwan Technologies licenses its wideband and ultra-wideband (UWB) radar sensor technology to
  industry. Thomas McEwan is the inventor of the MIR Rangefinder UWB radar developed at the
  Lawrence Livermore National Laboratories (LLNL).

Wisair (Israel) (http://www.wisair.com)
Academic Activity

University of California, Berkeley (USA), “Berkeley Ultra-Wideband Group” (http://bwrc.eecs.berkeley.edu/Research/UWB/default.htm)
- Design of UWB transceiver realized in a conventional CMOS technology, low power implementation.

University of Southern California (USA), “The UltraLab” (http://ultra.usc.edu/New_Site/index.html)
- UWB propagation and antenna measurements and modeling; Coexistence with existing radio systems; signal processing integration, and custom chip and circuit design.

University of Massachusetts (USA) (http://www.ecs.umass.edu/ece/labs/antlab.html)
- Analysis, design, and development of microstrip antennas and arrays; including a broader interest in related radiation and scattering problems.

Rutgers Winlab (USA), WINLAB research and partnerships are aimed at developing the architectural and technical underpinnings that will enable the Mobile Internet (http://www.winlab.rutgers.edu/pub/docs/focus/UWB.html)
- Design and prototyping of an ultra-wide band (UWB) physical layer (modem) and medium access control (MAC), optimized for short-range, super high-speed (~100’s of Mbps) applications.

INSA Rennes (France), Laboratoire Composants et Système de Télécommunication (LCST), Groupe Diffraction (http://www.insa-rennes.fr/l-lcst/gdid/)
- Analysis of UWB radio and radar systems.

Università di Padova (Italy), CESP, Communication Engineering staff in Padova (http://www.dei.unipd.it/ricerca/cesp/research/iruwb.html)
- Investigation of the physical layer, use of existing models for the UWB channel, definition of appropriate time-hopping codes, modeling the multi-user interference, implementation and performances of an IR receiver, etc…

Università di Roma (Italy), UWB Group, (http://wsfalco.ing.uniroma1.it/Projects/UWB/Uframes.html)
- At the origin of the proposal of an IST research project called whyless.com focused on the design of an Open Mobile Access Network based on UWB radio technique. The project started in January 2001.

Whyless.com (Europe), „The open mobile access network“, IST Project 2000-25197
- whyless.com will research scalable radio technology and network resource trading principles in where UWB is a candidate.

UCAN „Ultra-wideband Concepts for Ad-hoc Networks“, (Europe), IST Poject 2001-32710 (http://www.ucan.biz)
- UCAN is a Research and Technological Development (RTD) Project sponsored by the EU’s ISTProgram (Information Society Technologies), action line IV.5.2 „Terrestrial wireless system and networks“.
- The objective of UCAN is to provide a generic platform for a self-organizing WPAN containing high accuracy indoor-positioning functionality: called "UWB-Demonstrator".

ETHZ, Communication Theory Group, (http://www.nari.ee.ethz.ch/commth/research/topics.html)
- Establishing realistic UWBM channel models, establishing the ultimate information-theoretic performance limits, and devising modulation and coding schemes for UWBM taking into account real-world propagation conditions.
**UWB Test/Evaluation Kit**

- **PulsON 200 - UWB Evaluation Kit (Price : ?)**
  
  Time Domain's PulsON 200TM Ultra Wideband (UWB) Evaluation Kit (EVK) allows product developers to examine the performance, capabilities and properties of ultra wideband technology. The EVKs can be configured for testing or as elements of an application demonstration. The EVK radio is compliant with the U.S. FCC spectrum rules (FCC 15. 517, 15.209).
  
  The Kit contains 2 UWB radios, each with:
  
  - PulsON 200TM Chipset:
    - 2 timer chips (each chip includes 2 independent timer circuits)
    - 2 correlator chips (each chip includes 2 correlator pairs)
    - 1 digital baseband chip
    - StrongARM™ Microprocessor for Embedded Applications Development
    - Ethernet and RS 232 External Connections
    - Bi-Phase UWB Pulser
    - RF Receiver Front-end
    - PulsON 200 Antenna Assembly
    - Power Supply
  

- **XtremeSpectrum Test kit (Price : $50,000)**

- **Aether Links ($50,000-100,000)**
Possible Research Topics for UWB

• UWB as WPAN (IEEE 802.15.3a)
  currently, debating with PHY layer and MAC layer
  - optimal MAC vs. 802.15.3 MAC vs. 802.11a MAC
  - QOS scheduling algorithm for multimedia stream
  - Interoperability with 802.11, Bluetooth, wired LAN, sensor network(?)
  - security policy

• UWB as Localization device (in sensor network or other mobile node)
  - optimal localization protocol in ad hoc network
    (task dispatching between UWB and RF unit)
  - security issue

• UWB as alternate RF component (in sensor network or other mobile node)
  - optimal MAC
  - routing algorithm
  - QOS scheduling
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