Ultra-Wideband (UWB)

Seminar in Distributed Computing

Remo Marti

- **Ultra-Wideband Radio Technology: Potential and Challenges Ahead**
  D. Porcino, W. Hirt; IEEE Communications Magazine, 2003
- **Ultra-Wideband Technology for Short- or Medium-Range Wireless Communications**
  J. Foerster, E. Green, S. Somayazulu, D. Leeper; Intel Technology Journal Q2, 2001
- **Ultra Wideband Technology Update at Spring 2003 IDF**
  J. M. Wilson; Intel DeveloperUPDATEMagazine, 2003

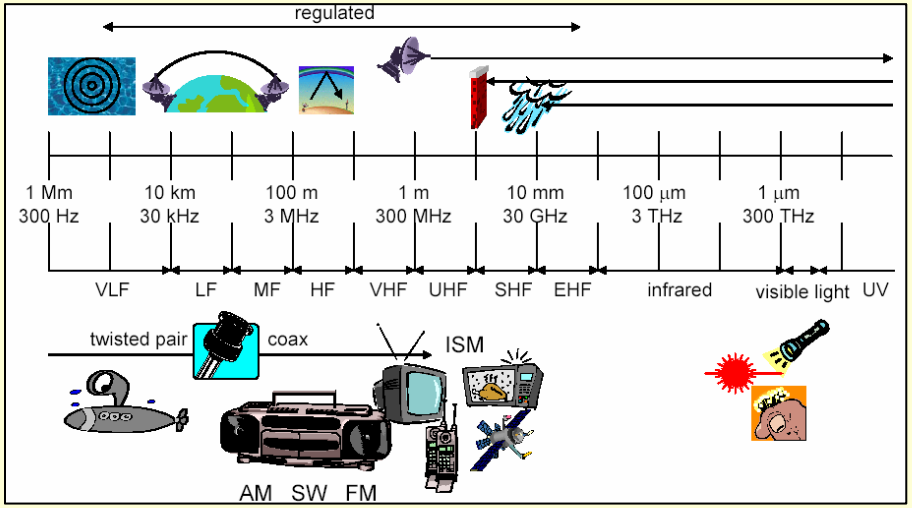
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Organization of the talk

1. Introduction / Motivation
2. Technical Aspects
3. Applications
4. Conclusion / Outlook
5. Questions

Why another wireless technology?

- Room for one more?
- Crowding in regulated frequencies!
- Demand for more speed
- Reduction of power consumption
- Contradiction?



Wattenhofer, Mobile Computing

UWB features - overview

- Wideband wireless transmission technology
- Uses band 3.1 – 10.6 GHz
- Pulsed signals spread over whole bandwidth
- High speed over distances < 10m
  (up to 480 – 1000Mbit/s)
- Accurate (indoor) positioning
- Reduction of multi-path fading
- Low power consumption
- Minimization of interference with existing technologies

Speed Comparison

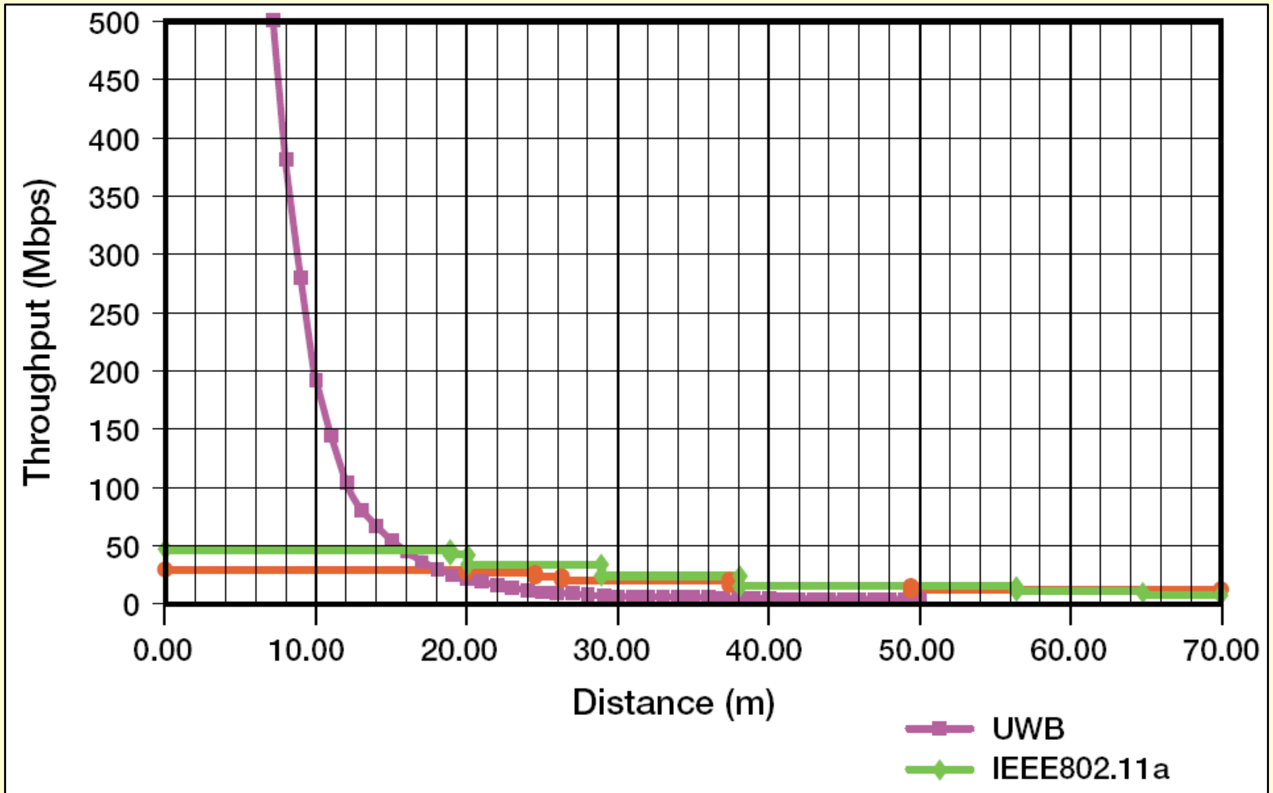


Figure 2. Theoretical Performance Over Range

Intel Developer Update Magazine

Spacial Capacity

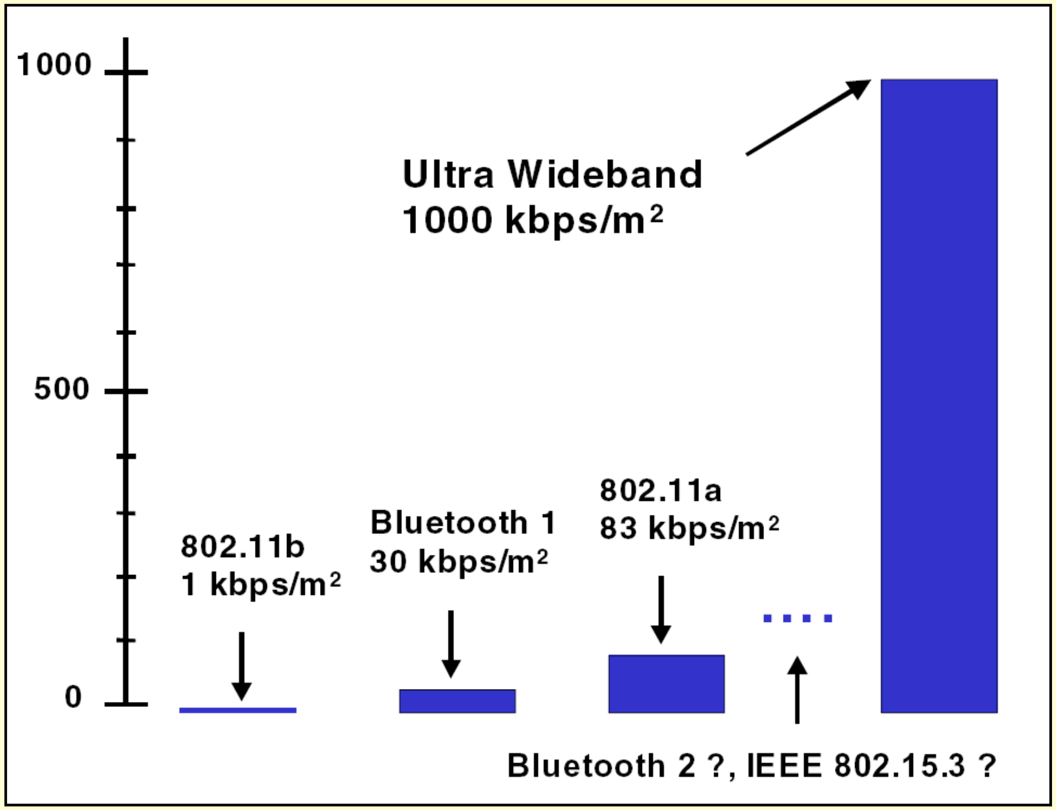
- Spacial Capacity defined by bits/sec/m^2
- Example WLAN (802.11b)
  - Radius 100 m
  - 80 MHz usable spectrum in 2.4GHz band
  - 3 22MHz systems can operate non-interfering, each with 11Mbps peak

  → 1'000 bps/m^2
- UWB
  - Radius 10m
  - 6 concurrent systems, each with peak 50Mbps

  → 1'000'000 bps/m^2

Intel (UWB Technology for Short-or Medium...)

Spacial Capacity



Intel (UWB Technology for Short-or Medium...)

The three papers

- Present the basics, are partially outdated

- **Ultra-Wideband Radio Technology: Potential and Challenges Ahead**
  IEEE Communications Magazine, 2003
  - Focuses on applications and implications of UWB

- **Ultra-Wideband Technology for Short- or Medium-Range Wireless Communications**
  Intel Technology Journal Q2, 2001
  - Presents first ideas and technical details

- **Ultra Wideband Technology Update at Spring 2003 IDF**
  Intel DeveloperUPDATEMagazine, 2003
  - Technical details, more up to date

History of UWB

- UWB is a much discussed topic!
- Theoretical background of „carrier-free“ waveforms was studied already in the 1960‘s
- Known under the name UWB since the 1980‘s, mainly for radar systems
- Efforts to bring UWB into the consumer electronics market in the last few years
- Large area for scientific research (ETH conference in October 2005)

http://www.aetherwire.com/CDROM/General/papers.html

2. Technical Aspects

- Frequency Range
- Signal transmission
  - Carrier-based / Carrier-less (pulsed)
  - Channel capacity
  - Modulation schemes
  - Multiplexing schemes
  - Multiband modulation
- Interference issues

Frequency range

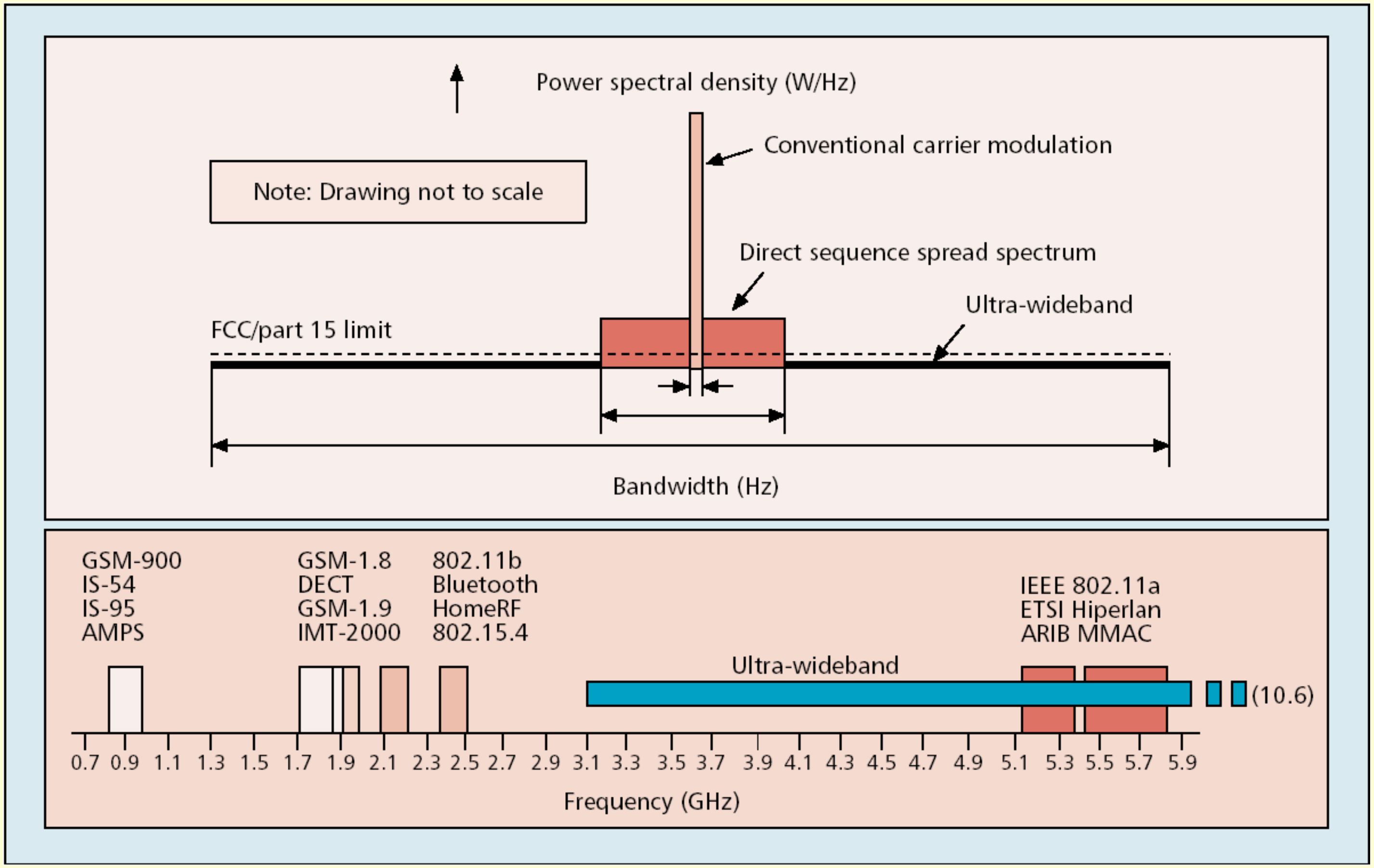
- Standard:

$$bandwidth \geq 0.2 \cdot f_C \quad \text{or} \quad bandwidth \geq 500MHz$$

$$f_C = \frac{f_H + f_L}{2}$$

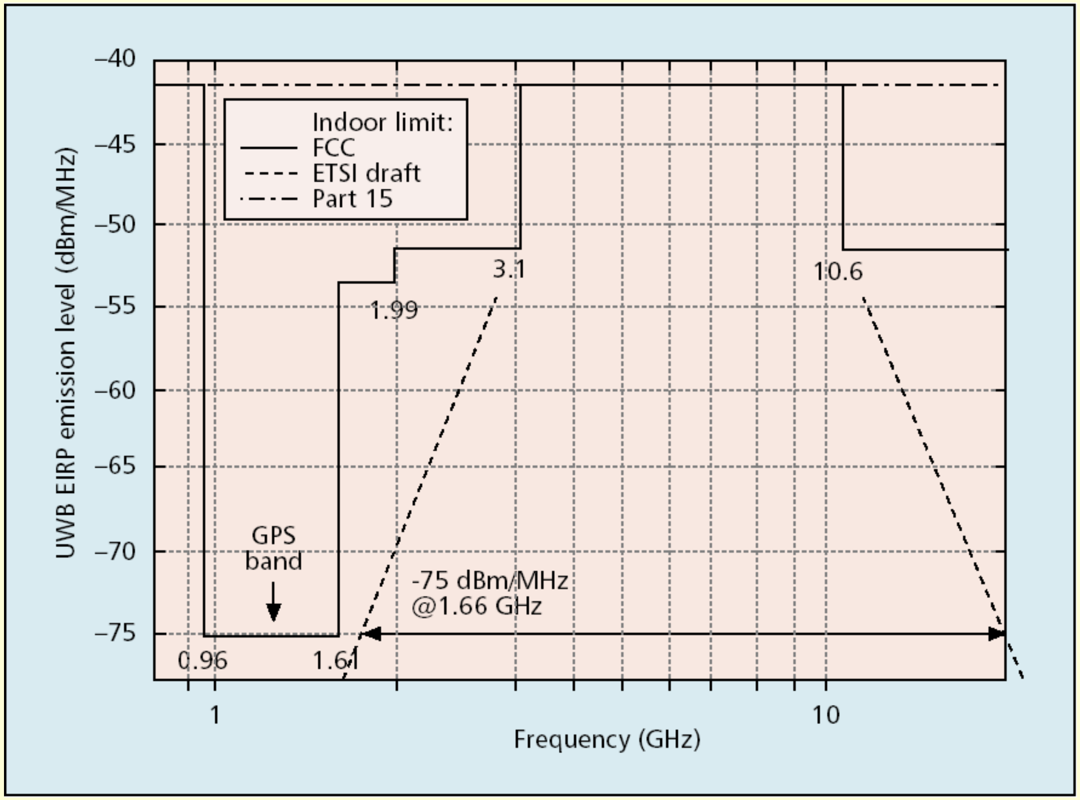
- Motivation: optimal sharing of existing radio spectrum resources rather than looking for new bands

Frequency range



UWB-RT: Potential and Challenges Ahead

Frequency range



UWB-RT: Potential and Challenges Ahead

Channel Capacity

- Why is UWB so fast?
- Channel capacity depends on bandwidth

$$C = B \cdot \log_2 (1 + \frac{S}{N})$$

- Shannon‘s Capacity Limit Equation defines upper bound
- B = bandwidth [Hz], C = Capacity [bits/s],
  S = Signal power [W], N = Noise Power [W]
- S/N = SNR (Signal to Noise Ratio)
- C grows **linearly** with B, but only **logarithmically** with S/N

Channel Capacity

$$C = B \cdot \log_2(1 + \frac{S}{N})$$

- With a bandwidth spanning several GHz, UWB achieves its extreme data rates
- Improving S/N would mean to increase sending power
  - Interference problems with other systems
  - Small devices won‘t have enough battery power

→UWB performs best over very short distances

Signal Transmission

- Capacity in practice not only depends on bandwidth
- Other important factors:
  - Modulation Schemes
  - Multiplexing Schemes

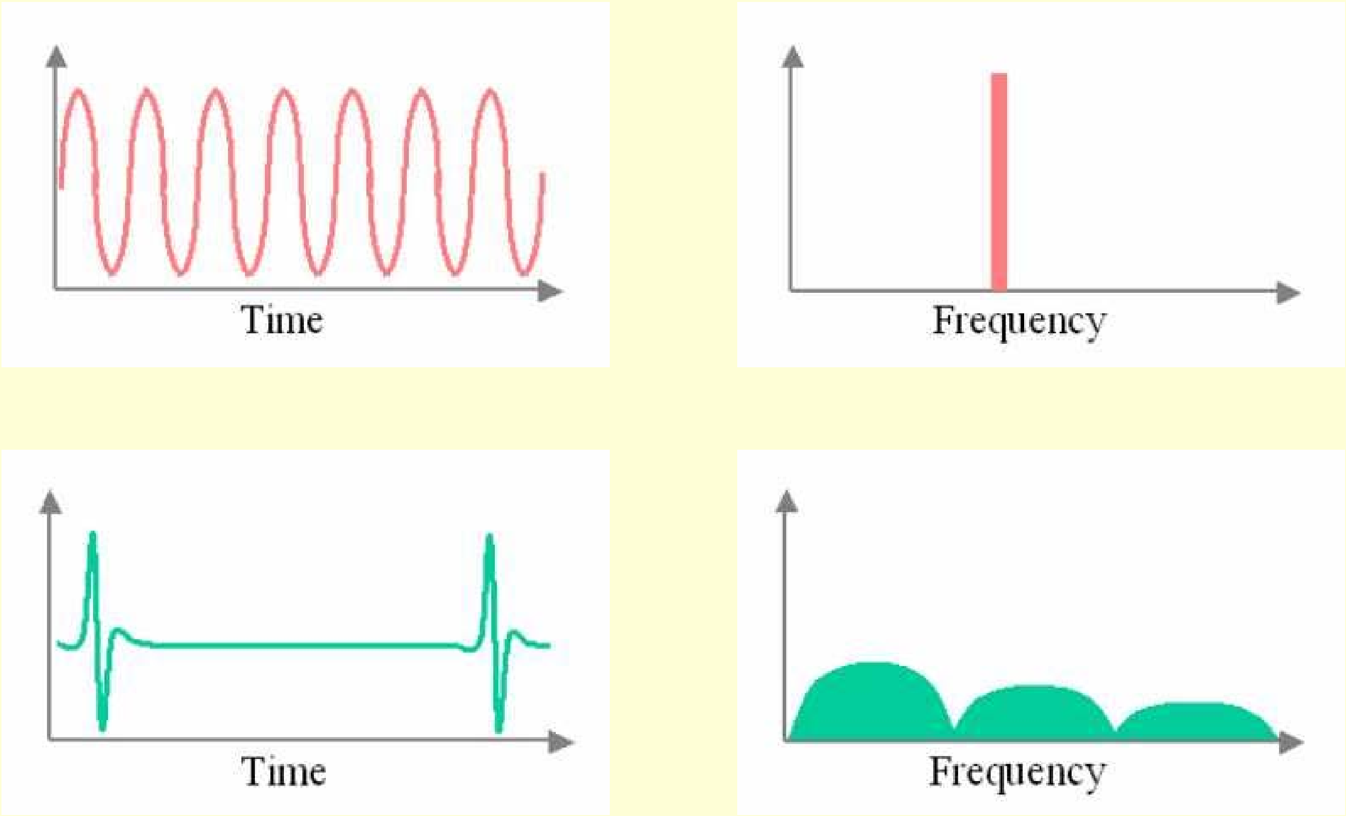
Modulation

- Conventional „narrowband“ systems use carrier-frequency for transmission
  - Oscillator creates wave form, modulator modulates information onto wave form
  - Different modulation techniques:
    - Amplitude
    - Phase
    - Frequency

Impulse-based transmission

- UWB is a carrier-less system. It produces short impulses with sharp rise and fall time
- This results in a waveform occupying several GHz of bandwidth
- Impulse duration in the time domain determines bandwidth in the frequency domain
- bandwidth ~ 1/duration

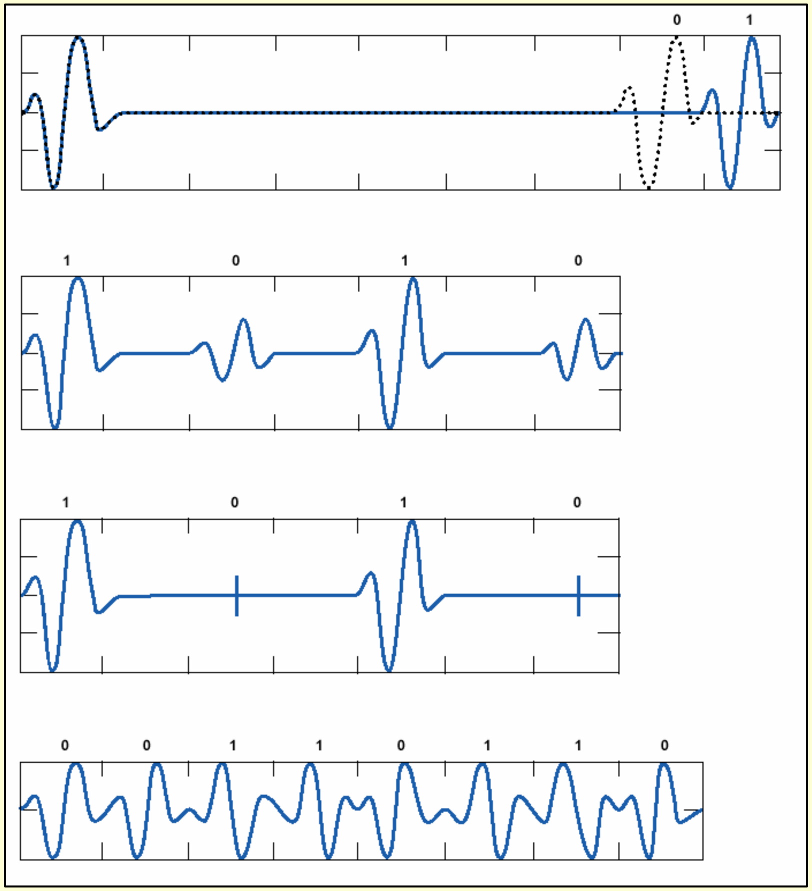
Carrier wave vs. Impulse



Berkeley

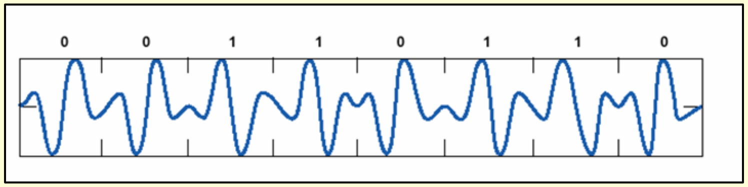
Modulation Schemes

- Pulse Position Modulation (PPM)
- Pulse Amplitude Modulation (PAM)
  - Special case: On-Off-Keying
- Phase Shift Keying



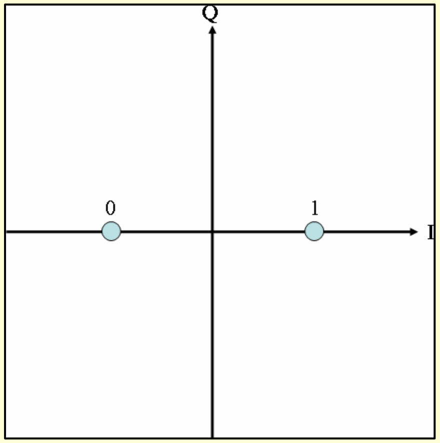
Young Man Kim, Ohio State University

Modulation Schemes



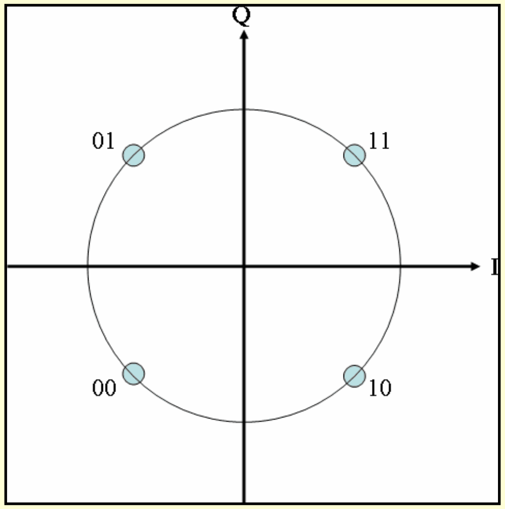
- Phase Shift Keying (PSK)
  - Robust against interference
  - Complex
  - Each phase encodes a certain # bits
  - bits represent the transmitted symbol

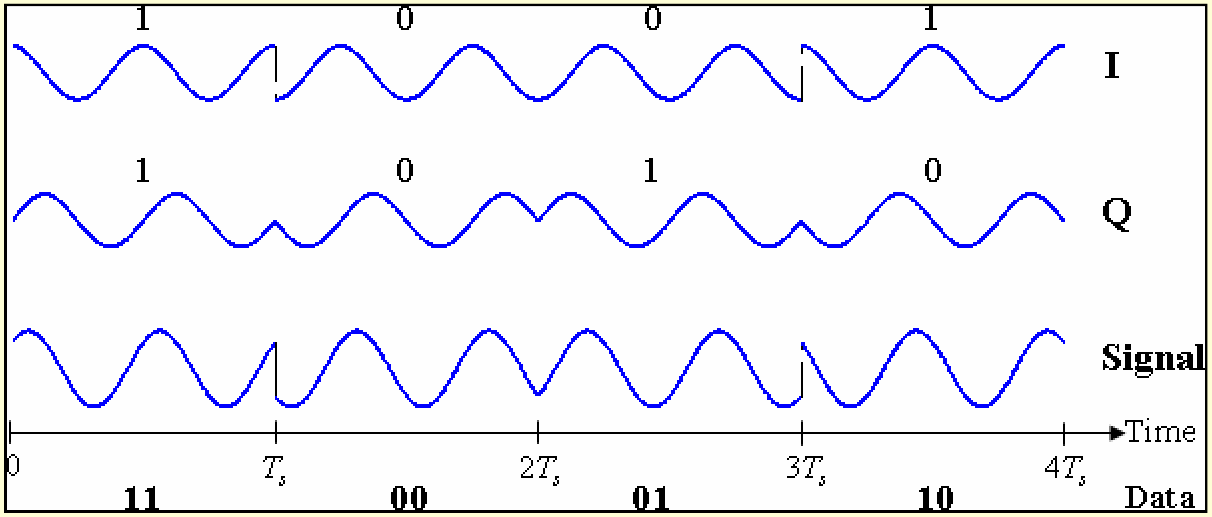
  - Simple case: BPSK (Binary Phase Shift Keying)
    - Sine wave for bit value 0
    - Inverted sine for bit value 1
    - Robust
    - Only 1Bit/symbol



Modulation Schemes

- Phase Shift Keying (PSK)
  - Quadrature Phase Shift Keying (QPSK)
  - 2bits / symbol





Throughput vs. Range

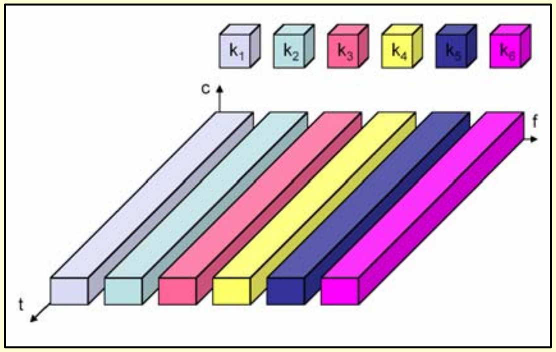
- UWB implementations can actively exploit trade off between throughput and range
  - To increase range, send several pulses per bit → increase SNR
- Application determines whether range or capacity is more important
- Also: high user data rates decrease the number of users in the same area

Multiplexing (refresher course)

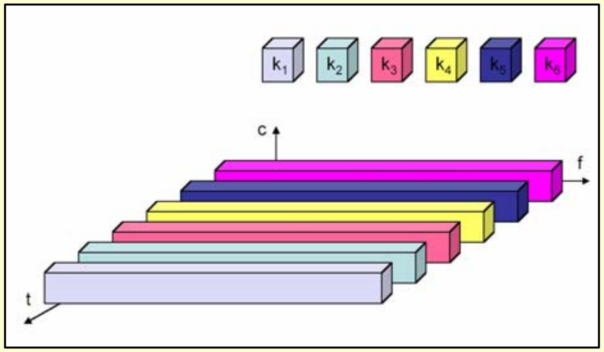
- Goal: multiple use of a shared medium
- Multiplexing in several dimensions possible:
  - Space
  - Time
  - Frequency
  - Code

Multiplexing

- Frequency Division Multiplex (FDM)
  - Split spectrum into smaller bands
  - No coordination necessary
  - But: inflexible



- Time Division Multiplex (TDM)
  - High throughput
  - Synchronization necessary



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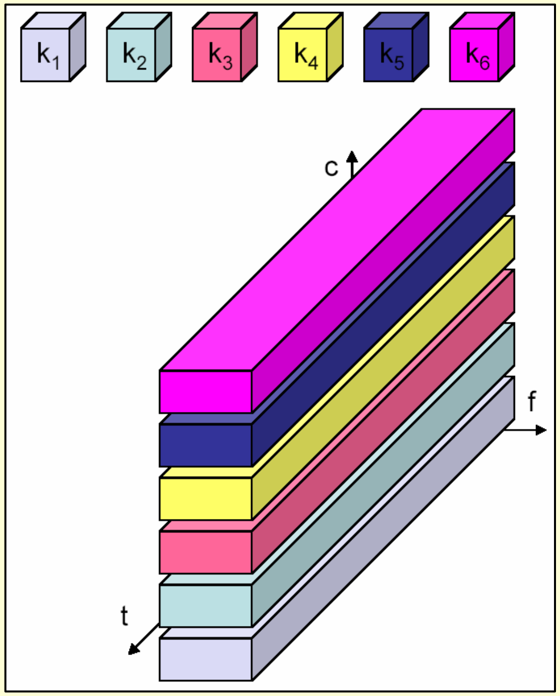
Code Division Multiplex (CDM)

- Each channel has unique code
- All channels transmit at the same time in the same spectrum
- No coordination or synchronization necessary
- But: lower user data rates

→ Receiver station chooses which user to decode

- Implementation via orthogonal codes



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Code Division Multiplex (CDM)

- Each sender has m-bit chipping code *v*, pair-wise orthogonal
- Transmit v for „1“, -v for „0“
- Interfering signals add up

→ Example

S_1: v_1= [1, -1]; S_2: v_2=[1, 1]

S_1: [1, 0, 1, 1] → [1, -1, -1, 1, 1, -1, 1, -1]

S_2: [0, 0, 1, 1] → [-1, -1, -1, -1, 1, 1, 1, 1]

Receiver gets [0, -2, -2, 0, 2, 0, 2, 0]

Code Division Multiplex (CDM)

Assuming receiver wants to detect what S_1 has sent:

→ Multiply received vector by S_1's chipping code [1, -1]

Received: [0, -2, -2, 0, 2, 0, 2, 0]

[0, -2]*[1, -1] = 2 ~ 1

[-2, 0]*[1, -1] = -2 ~ 0

[2, 0]*[1, -1] = 2 ~ 1

[2, 0]*[1, -1] = 2 ~ 1

Code Division Multiplex (CDM)

- Why a multiplication?

  Two orthogonal vectors v_1, v_2

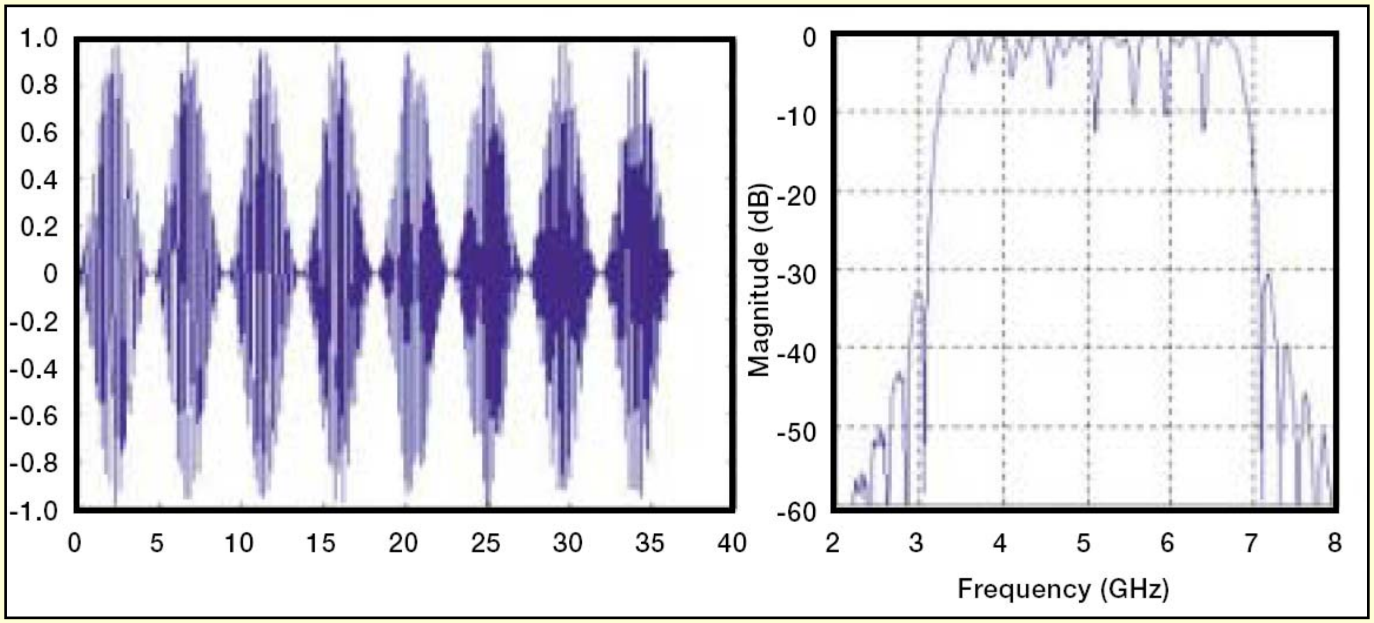
  $v_1 \cdot (v_1+v_2) = ||v_1||^2$, since $v_1 \cdot v_1 + v_1 \cdot v_2 = ||v_1||^2+0$

- Problems in practice:
  - Different signal strengths disrupt mathematical properties

  → Power control scheme necessary

Multiband modulation

- Split 7.5 GHz spectrum into smaller bands



time domain frequency domain

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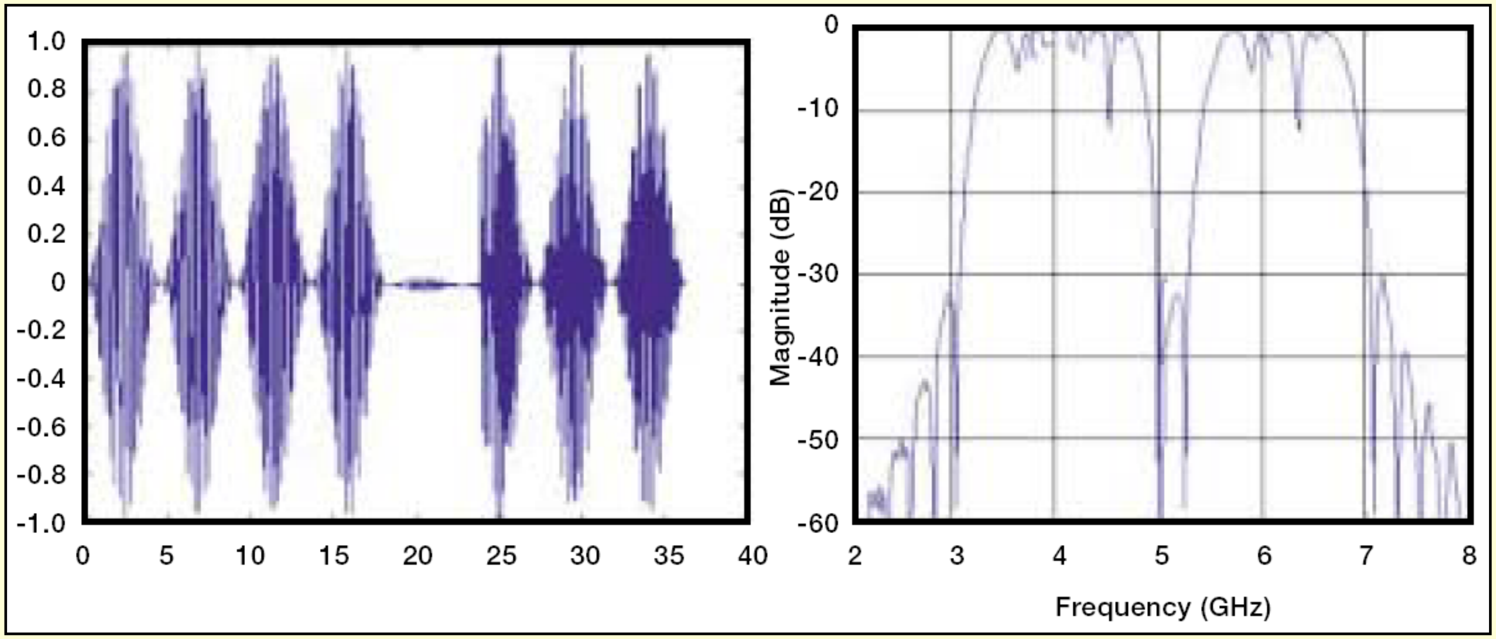
Multiband modulation



time domain

frequency domain

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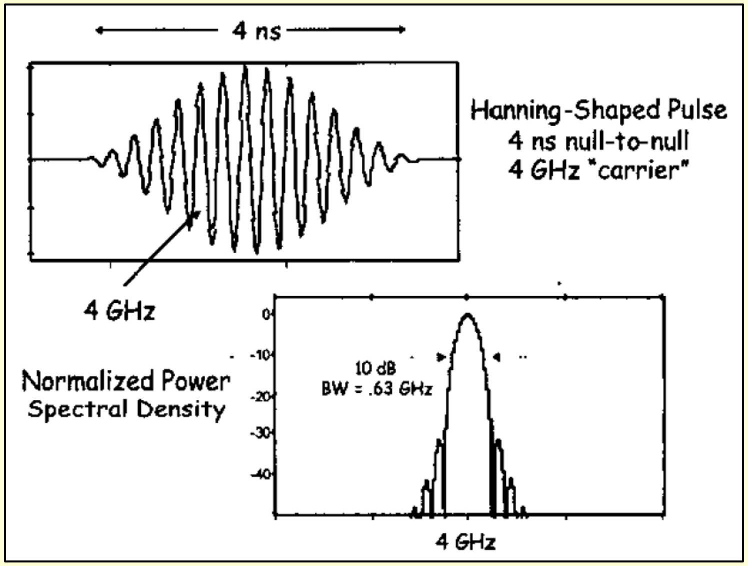
Multiband modulation

- Introduce pseudo carrier oscillation defining center frequency
- Impulse shape determines bandwidth within each band



Leeper, IEEE. UWB – the next step in short-range wireless

- Advantages:
  - Treat bands independently (flexible)
  - Selectively reduce interference in certain frequencies
  - Different worldwide regions have different regulatory requirements
  - High-speed / low speed devices

Interference issues

- How does UWB cooperate with other wireless technologies?
  - Multiband modulation
  - Detect And Avoid (DAA) – listen into medium, try to switch to unused frequency
  - Low sending power
  - Spread energy over huge frequency range
  - Aggregation?

- But what about reception?
  - Hardly ever mentioned
  - Possibility: receiver filters signal in time domain instead of frequency domain. Impulse peaks can be detected.
  - Requires special antenna design
  - Exact synchronization necessary (impulse duration ~ nanosecond)

Technologies used in „practice“

- **DS-UWB:** Freescale, Motorola, Mitsubishi, Samsung, …
  - Binary Phase Shift Keying (BPSK)
  - 2 large channels, each subdivided into 6 piconet channels
  - Direct sequence spreading:
    Data is multiplied by another, high frequency signal, which spreads the energy over a wide band.

- **OFDM-UWB:** Intel, Microsoft, Sony,…
  - Quadrature Phase Shift Keying (QPSK)
  - 14 channels (Multiband Modulation)
  - Orthogonal frequency division multiplexing:
    Use of orthogonal frequencies, here combined with a kind of band hopping.

3. Applications

- Sensor, Positioning and Identification Network
- High Data Rate Wireless Personal Area Network
- Wireless Ethernet Interface Link
- Intelligent Wireless Area Network
- Outdoor Peer-To-Peer Network

→ Often illusionary, somewhat inconsequent...

Sensor, Positioning and Identification Network

- High temporal resolution allows exact positioning
  - Time Of Arrival (TOA) (e.g. via Round-Trip-Time)
  - Time Difference Of Arrival (TDOA)
  - Positioning accuracy depends on accuracy of synchronization
    → UWB transmitters are closely synchronized!
  - Reduction of multi-path fading with pulsed signals

- Mainly for industrial factories, warehouses
- High density of devices
- Master-slave topology

High Data Rate Wireless PAN

- 5 – 10 transmitting devices per room
- 100 – 500 Mb/s
- Distance 1 – 10 m

- Seems most promising area of application
- Wireless connection of HDR devices (TV, speakers, printer, ...)
- Wireless USB!

Wireless Ethernet Interface Link

- Extremely high data rates (1 – 2.5 Gb/s)
- Wireless replacement for Ethernet cables
- High-quality video transfer

- Unlikely to enter the market soon…
- Restrictive transmission power limits

Intelligent Wireless Area Network

- High density of low cost devices
- Distances ~ 30m
- Low power consumption (1 – 10mW)
- „Smart appliances“
  - Accurate location tracking
  - Alarm zones
  - Child tracking
  - Electronic virtual guides

- RFID replacement?

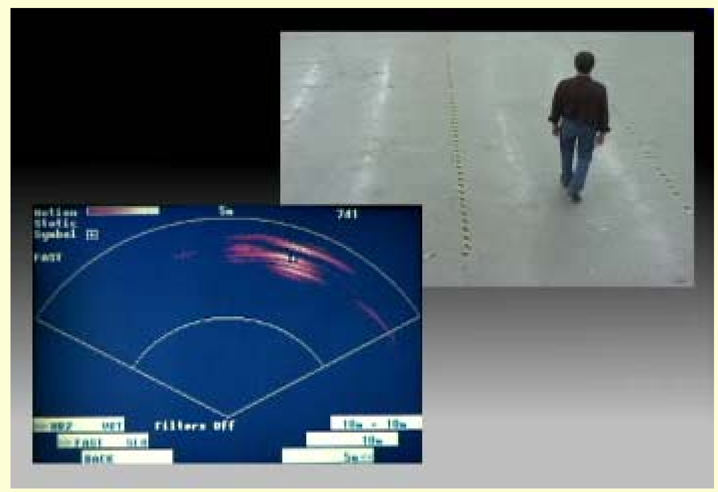
Outdoor Peer-To-Peer Network

- PDA linkup, information exchange
- Download of newspapers
- Automatic video rental

- Remember:
  Goal was to create a **fast** network operating over **short distances**.
  Outdoor model is quite the opposite...

Existing Applications

- Radar technology
  - Military
  - Medicine
  - Geology



UWB.org / Soldier Vision

4. Outlook / Conclusion

→ Standardization!

- Two competitors that cannot agree on a standard
  - **OFDM-UWB (WiMedia Alliance)**
    → Promotion of Wireless USB
  - **DS-UWB**
    → Entertainment electronics
- Several UWB versions are likely to enter the market
- Standardization and regulatory issues keep prices up → low incentive for investment.

What can we expect in the next years?

- **OFDM-UWB (WiMedia Alliance):**
  Our Mission
  *"To promote wireless multimedia connectivity and **interoperability** between devices in a personal area network."*

- **DS-UWB:**
  Statement on website
  *The UWB Forum is an industry organization […] dedicated to ensuring that Ultra-Wideband products from multiple vendors are truly **interoperable**.*

Reality?

- IEEE's TG3a aimed at merging both proposals in standard 802.15.3a
- On January 19, 2006, TG3a ceased to work.

UWB Forum and WiMedia Alliance Committed to Commercializing UWB

The TG3a's most commendable achievement is the consolidation of 23 UWB PHY specifications into **two proposals**: MultiBand Orthogonal Frequency Division Multiplexing **(MB-OFDM) UWB**, supported by the WiMedia Alliance, and direct sequence-UWB **(DS-UWB)**, supported by the UWB Forum.
[…]
"However, we concur that, at this stage in UWB market development, a more prudent course of action is necessary to allow the market to move forward with the **commercialization of multiple** UWB technologies."

Time for your Questions

?