Ultra Wideband Communications

Past, Present, and Future

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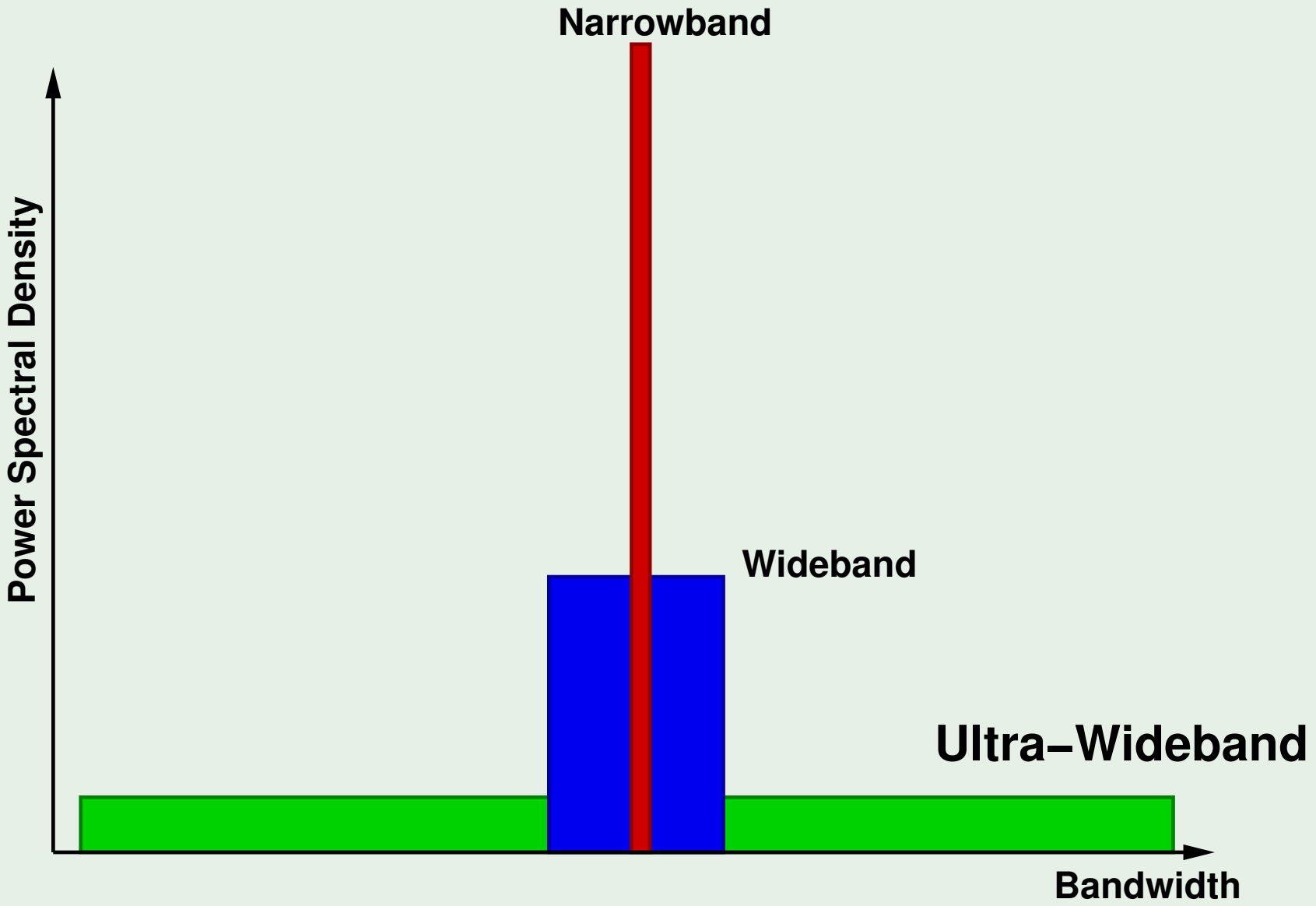
A Matter of Perspective: What Is UWB?

A picture $\equiv 10^3$ words



A Matter of Perspective: What Is UWB?

Ul·tra Wide·band Ra·di·o

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

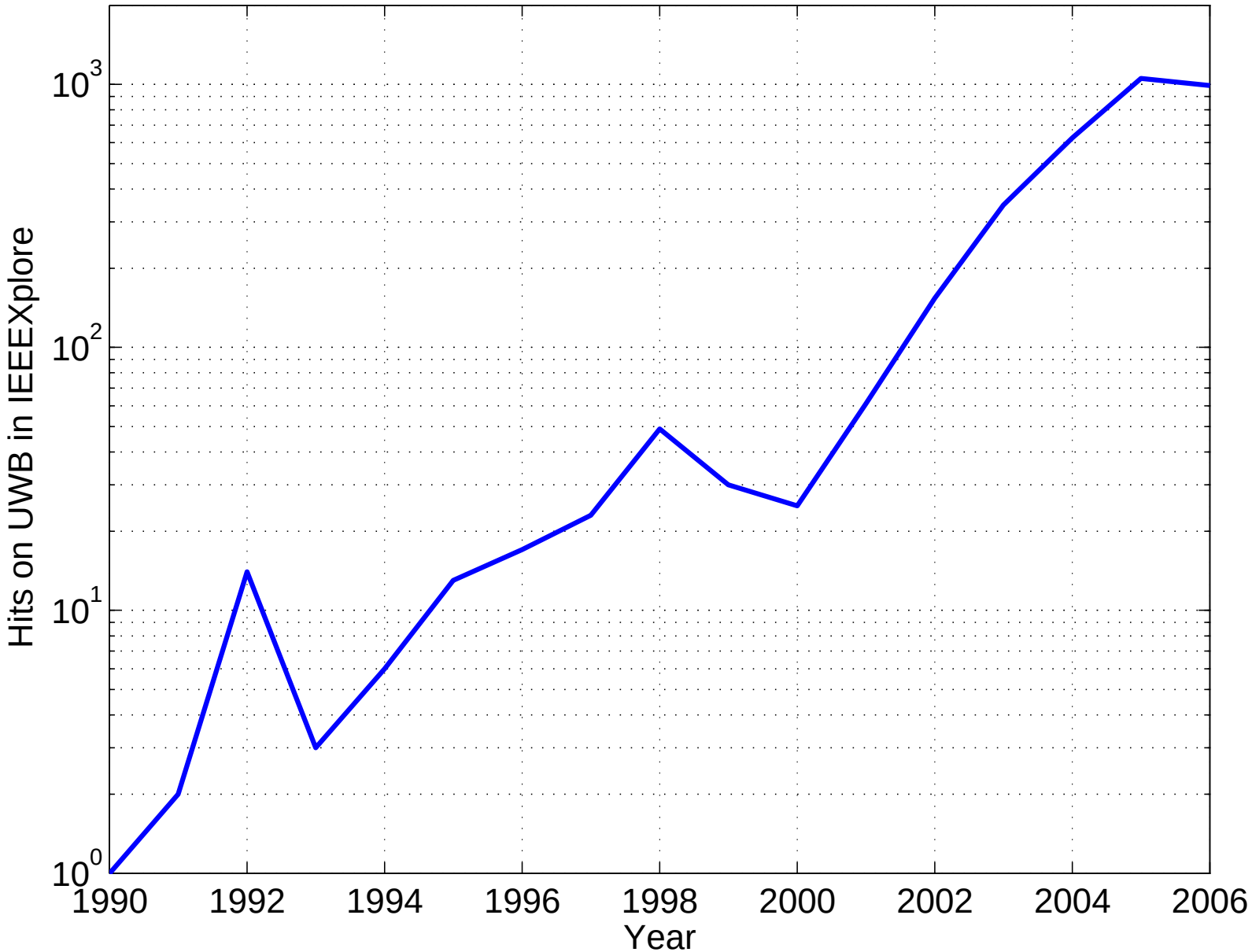
Synonyms: "impulse radio" or "carrierless radio" (maybe?)

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"

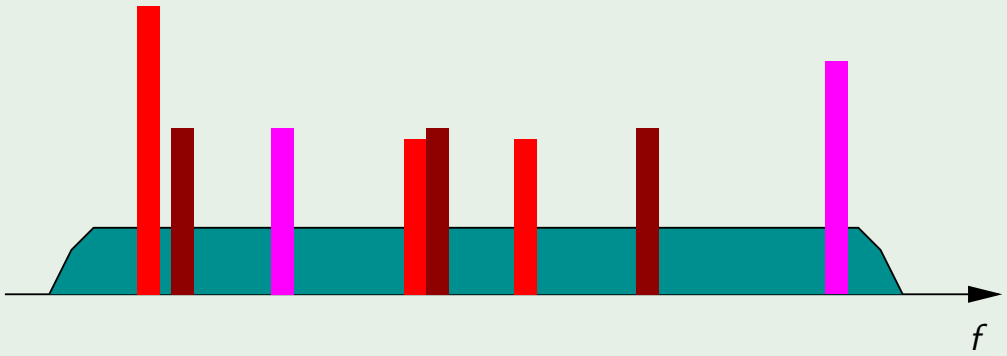


First Attempts: Impulse Radio

- First "modern" UWB designs were based on "impulse radio"
- Idea: send a sequence of very short, carrierless impulses
- Short time $\Leftrightarrow$ wide bandwidth
- Transmit data with the pulse position, pulse polarity, differential schemes
- Soon UWB expanded to other techniques

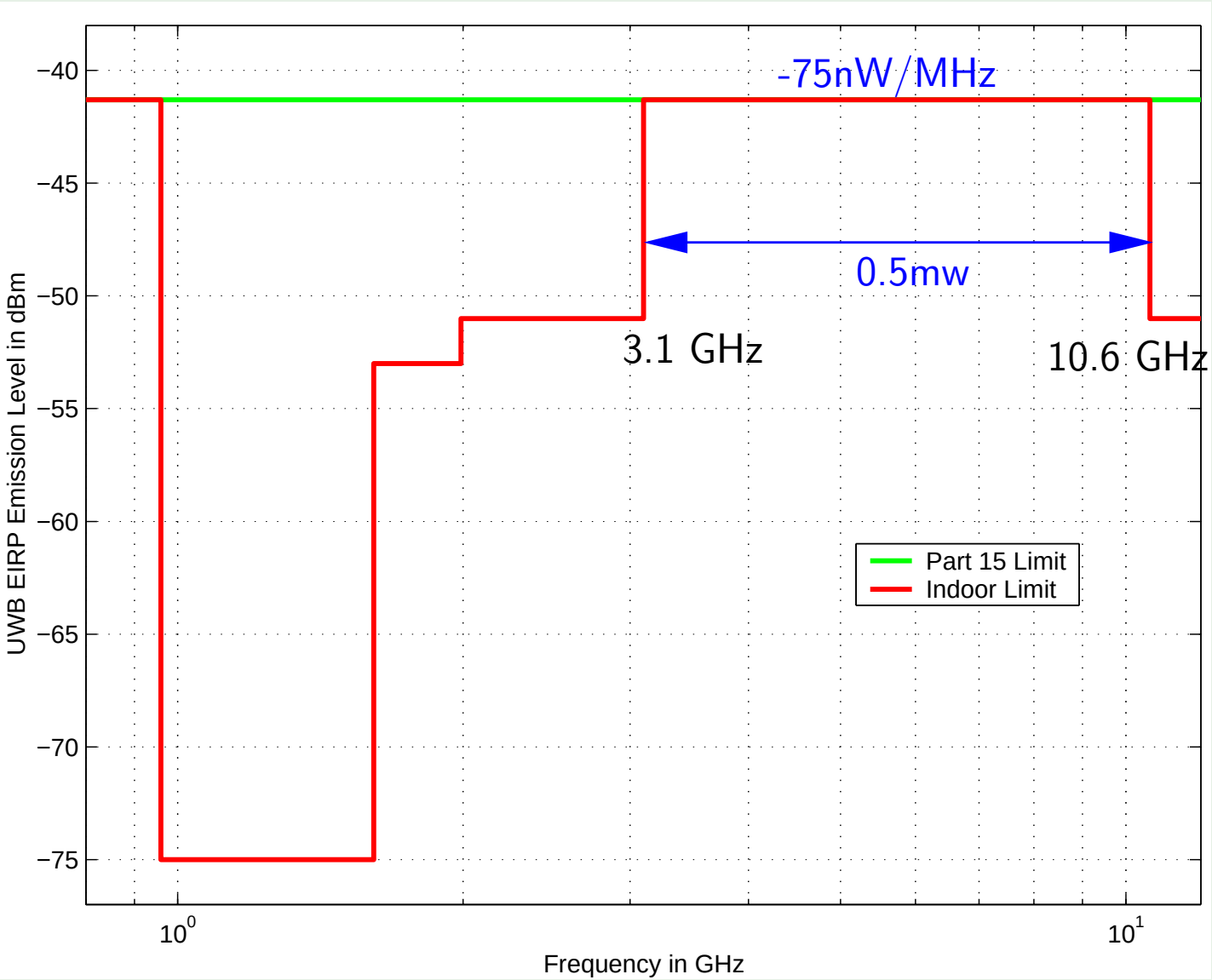
Be my Valentine: February 14, 2002

- FCC 02-48 First Report and Order in the matter of "Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems"
- 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



Death by Committee: Standardization Begins

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 $\rightarrow$ Bluetooth
- 802.15.3 $\rightarrow$ High Rate WPAN
- 802.15.4 $\rightarrow$ Low Rate WPAN (ZigBee)
- 802.15.5 $\rightarrow$ Mesh Networking

Apples and Oranges: Flavours of UWB

Two Task Groups were formed within 802.15:

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

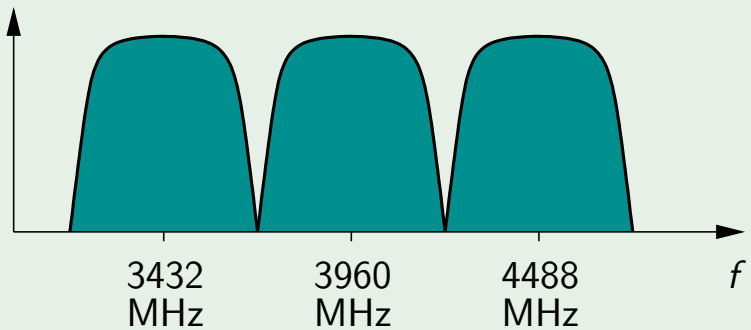
The Result

- Deadlock in final confirmation procedure
- TG3a disbanded without creating a standard
- Multiband OFDM $\rightarrow$ WiMedia Alliance $\rightarrow$ ECMA-368
- DS-UWB $\rightarrow$ UWB Forum

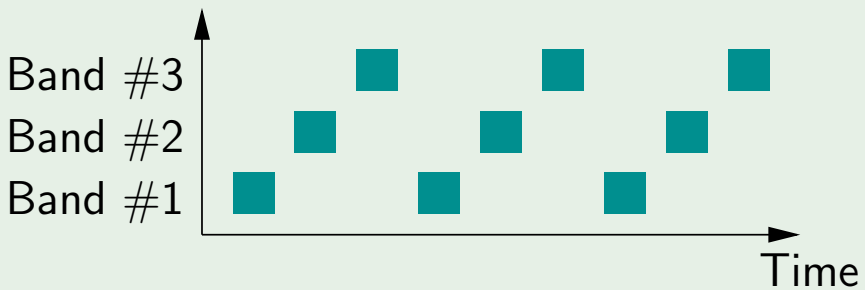
The Present

High-Rate: ECMA-368 / Multiband OFDM (1/3)

- 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



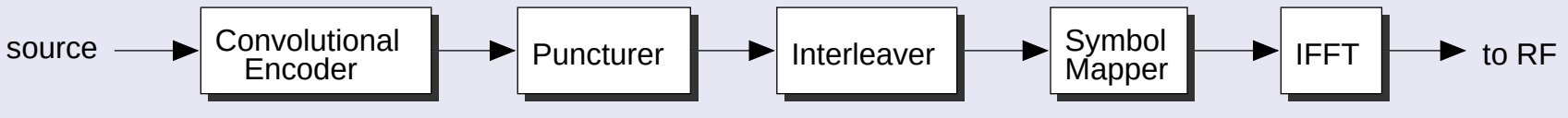
- Frequency hopping (simultaneously operating piconets)



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



Receiver

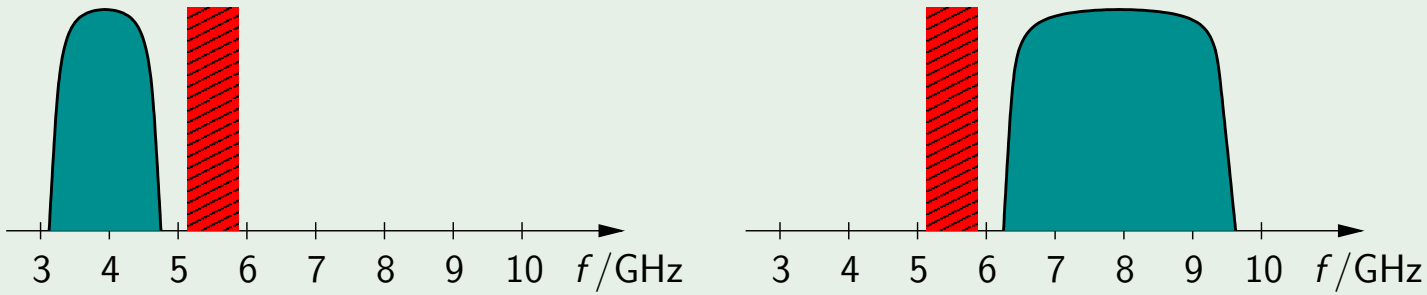
High-Rate: ECMA-368 / Multiband OFDM (3/3)

Type	Bit Rate (Mbps)	TX Power (mW)	μJ per MB	IC Power (mW)	μJ per MB
802.11b	11	50	36,400	200	145,000
802.11g	54	50	7,400	250	37,000
BT 2.0	3	1	2,700	60	160,000
ECMA 368	480	0.1	2	600	10,000

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 $\rightarrow$ needs rake filters
- MB-OFDM $\rightarrow$ fixed complexity FFT

Coexistence

- MB-OFDM facilitates cognitive radio
  - FFT RX processing $\rightarrow$ 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

Low-Rate: 802.15.4a, a study in compromise (1/2)

Two physical layers:

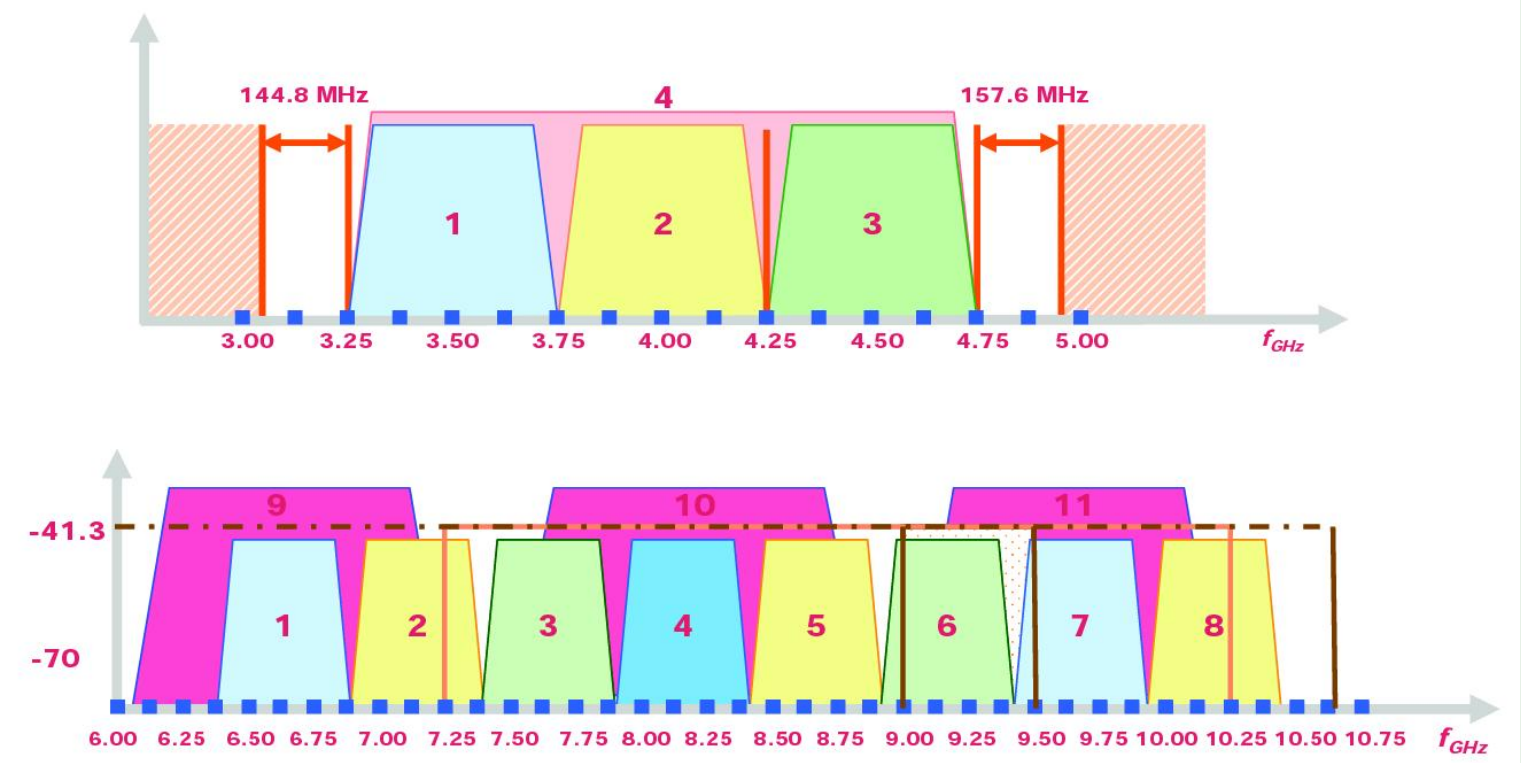
- Spread-spectrum in 2.4 GHz band (not UWB)
- UWB PHY layer
  - Spread-spectrum with several band options
  - BPM-BPSK (burst phase & position modulation)
  - Fixed pulse rate ($\sim$500 MHz)
  - Variable bandwidth (499, 1082, 1331, 1355 MHz)
  - Mandatory data rate: 0.811 Mbps

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 $\rightarrow$ flight time $\rightarrow$ distance

Low-Rate: 802.15.4a, a study in compromise (2/2)

Band Structure



All these rules: Worldwide UWB Regulatory Environment

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)

Worldwide UWB Regulatory Environment (2/3)

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

Worldwide UWB Regulatory Environment (3/3)

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
- O_2 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
- Nokia Canada
- Sierra Wireless
- Omnex Control Systems Inc
- Veri Chip Corporation
- NSERC

Thank you. Questions?

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