Introduction to Ultra Wideband (UWB)

Ou Yang
WCNG @ UR
4/2/2007

Outline

- What is UWB
- Why UWB
- How it works
  - Multiple Access
  - Modulation
  - Tx and Rx
  - Channel Model
- Regulations and PHY considerations
- Standardization and MAC issues

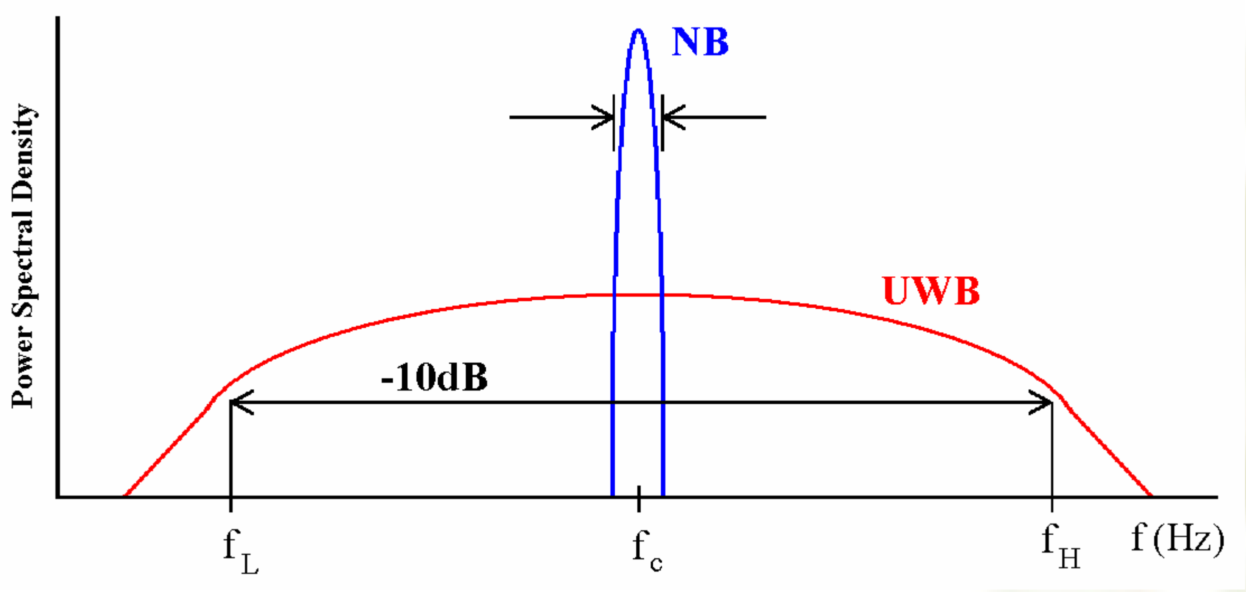
What is UWB

Principles of UWB

- Time Domain
  - Extremely short pulses
  - Very low duty cycle
- Frequency Domain
  - Ultra wide spectrum
  - Low power spectral density
  - Acceptable interference with other users

Definition of UWB

- FCC Definition
  - $B_f = 2\dfrac{f_H - f_L}{f_H + f_L} > 0.2$
  - Total bandwidth >500MHz



Why UWB

Why UWB - Advantages

- Spectrum reuse
  - 3.1-10.6 GHz, coexist with other users
- High data rate in short range
  - 500 Mbps at 10 feet
- Multipath immunity
  - Path delay >> pulse width
- Low power
  - Baseband modulation (no carrier)
- Low cost
  - Almost “all digital”, simple analog module

Why UWB - Applications

- Communications
  - Wireless Personal Area Network
  - Military communications
- Radar
  - Ground penetrating radar
  - Through-wall radar
  - Buried victim rescue
- Intelligence Sensors
  - Telemetry
  - Intelligent airbag, driving and parking aids
  - Intelligent transport system
- Location finding

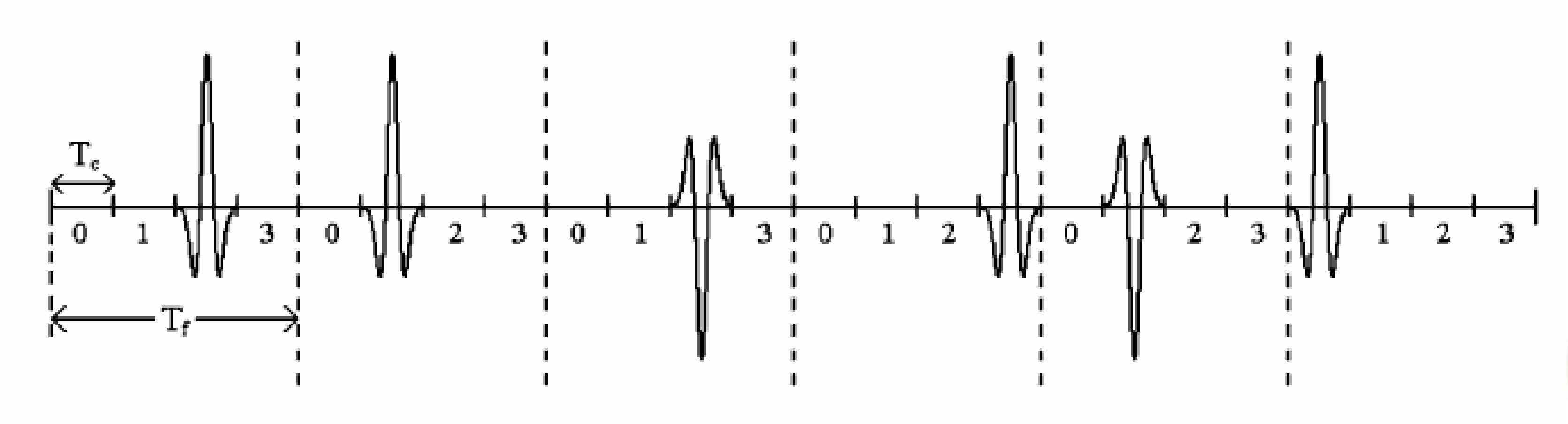
How UWB works

- Multiple Access Mechanism
- Modulation Schemes
- Transmitter and Receiver
- Channel Models

Multiple Access Techniques

- Time Hopping - TH-UWB
- Direct Spread - DS-UWB

TH-UWB



- Ns=6 (6 frames per symbol)
- TH sequence={2,1,2,3,1,0}
- Tf=4Tc

TH-UWB

- $$S^{(k)}(t^{(k)}) = \sum_{j=-\infty}^{\infty} w(t^{(k)} - jT_f - c_j^{(k)}T_c - dd^{(k)}_{\lfloor j/N_s \rfloor})$$
- $S^{(k)}$ the kth user's tx signal
- $t^{(k)}$ the kth tx's clock
- $w(t)$ pulse wave
- T_f pulse repetition time
- T_c TH chip duration
- $c_j^{(k)}$ TH sequence
- N_s the number of frames per symbol
- $d^{(k)}_{\lfloor j/N_s \rfloor}$ data sequence
- d modulation index

DS-UWB

- $$S^{(k)}(t^{(k)}) = \sum_{j=-\infty}^{\infty} \Gamma_j^{(k)} d^{(k)}_{\lfloor j/N_s \rfloor} w(t^{(k)} - jT_f)$$

- $\Gamma_j^{(k)}$ Direct spreading code
- $T_f = T_m$ Pulse width
- N_s Spreading factor

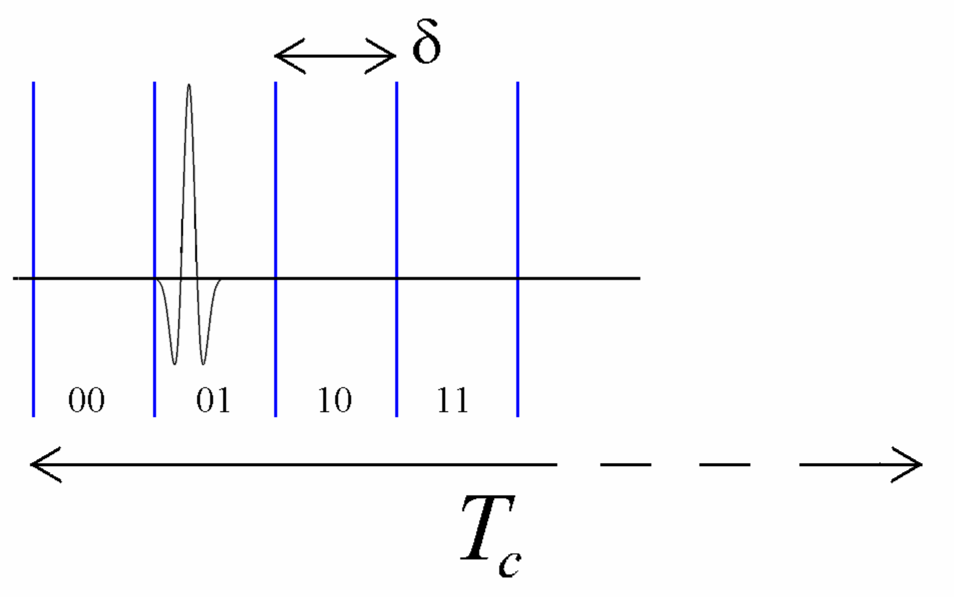
Modulation Schemes

- Pulse Position Modulation (PPM)
  - Binary/M-ary
- Bipolar Signaling (BPSK)
- Pulse Amplitude Modulation (PAM)
- On/Off Keying (OOK)
- Pulse-Shape Modulation
  - Orthogonal pulses
  - Using Hermite Polynomials

Modulation Examples

- Pulse Position Modulation (PPM)
  - Usually used with TH-UWB

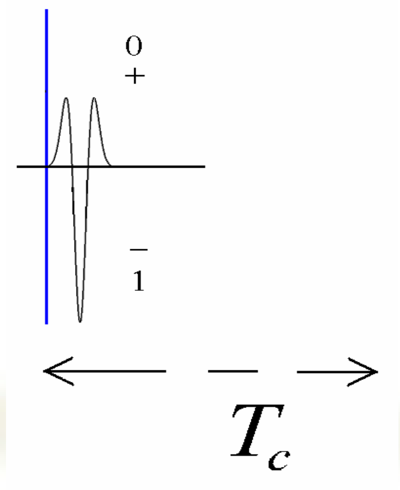
Example [1] : 4-ary PPM,
with data 01



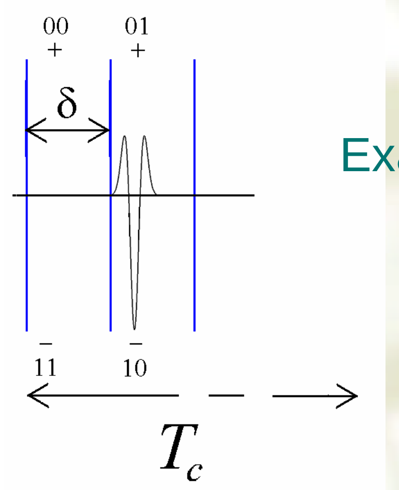
Modulation Examples

- Bipolar signaling (BPSK)
  - very energy efficient
  - Usually used in TH-UWB and DS-UWB

Example: bipolar with data 1



- Bi-orthogonal Keying (BOK)
  - PPM + BPSK
  - Used in Std 802.15.3

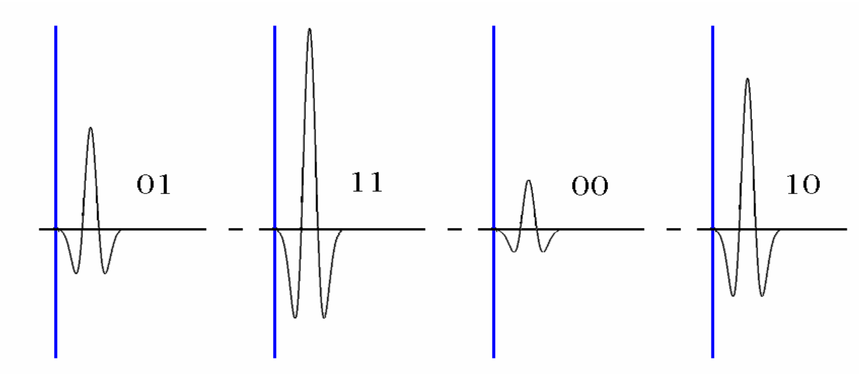


Example: 4-ary bi-orthogonal, with data 10

Modulation Examples

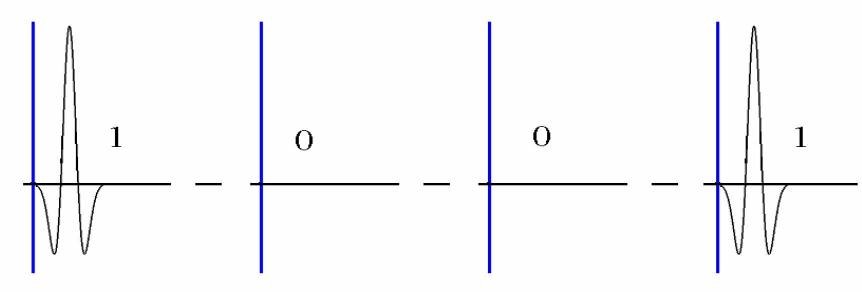
- PAM
  - Poor energy efficiency.

Example: 4-ary PAM
with data sequence: 01, 11, 00, 10

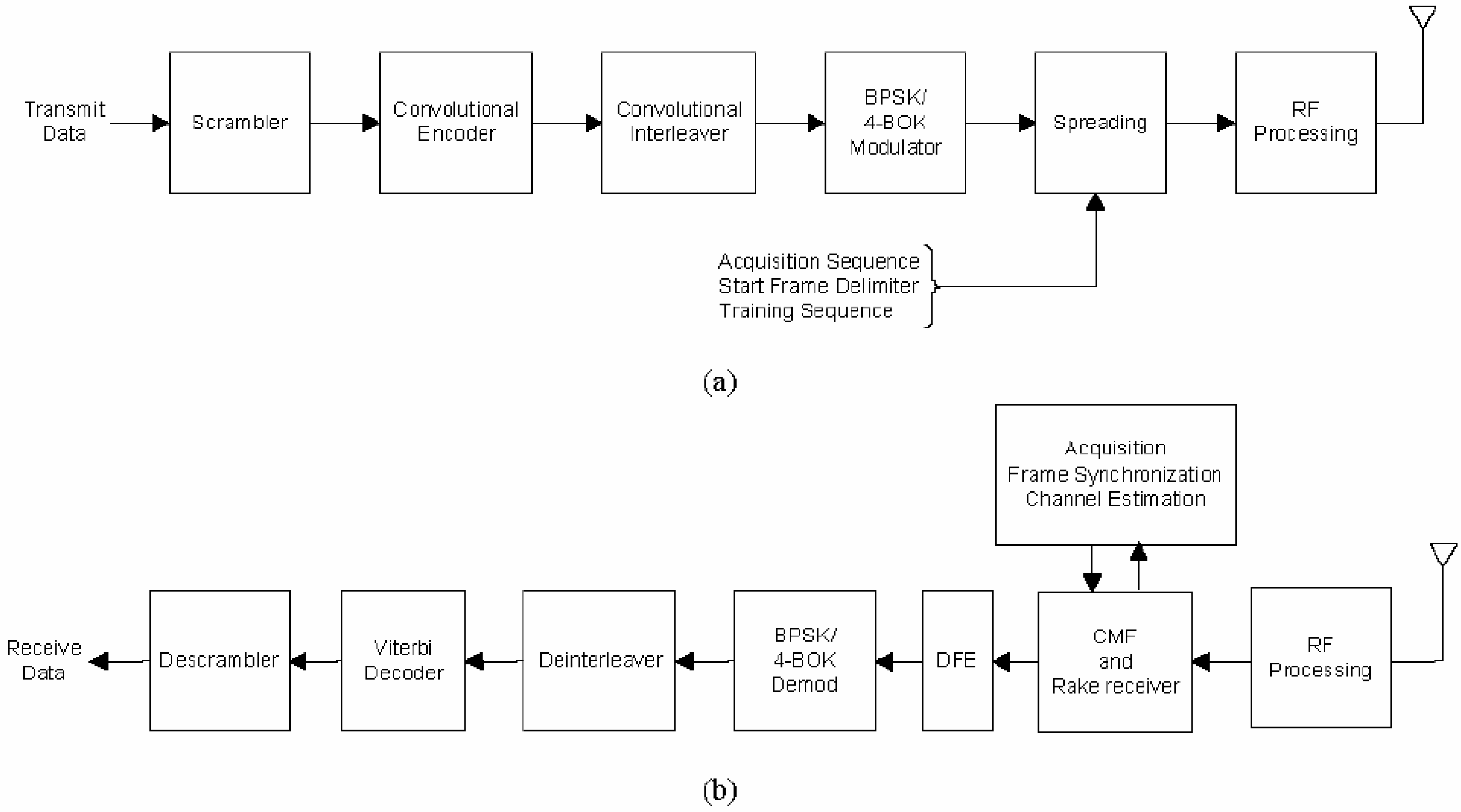


- OOK
  - Simple implementation
  - Poor energy efficiency.

Example: OOK
with data sequence: 1, 0, 0,1



Transmitter and Receiver [2]



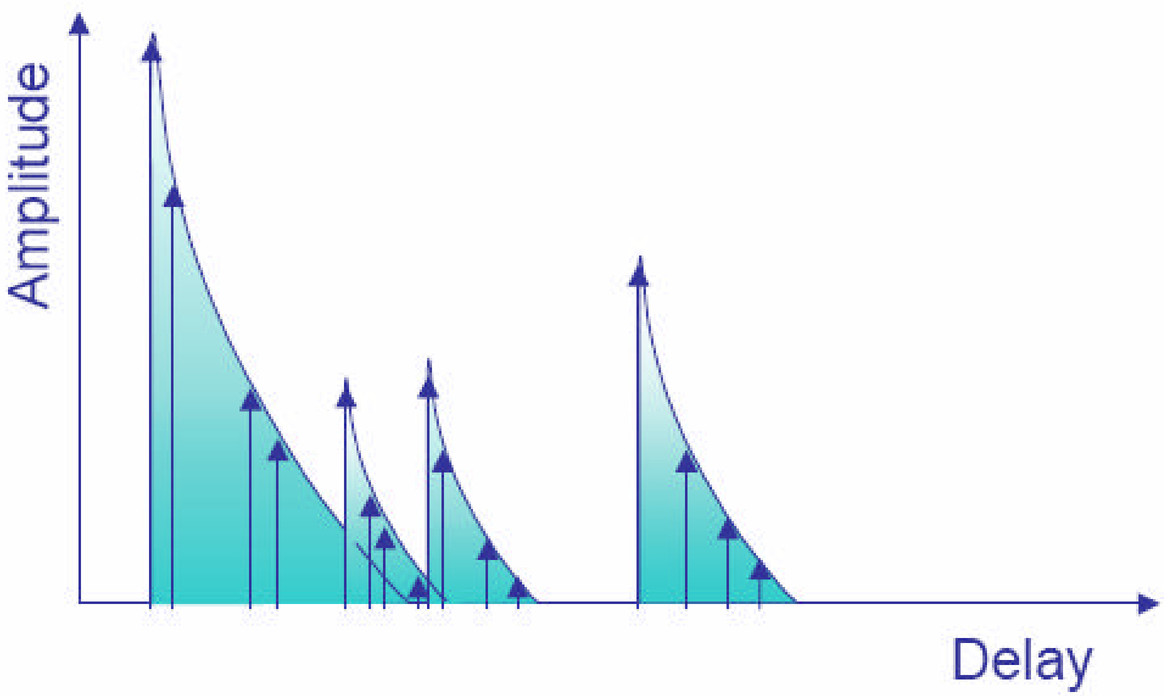
IEEE UWB Indoor Channel Model [3][4]

- Modified Saleh-Valenzula channel model
  - cluster arrival rate
  - ray arrival rate within a cluster
  - cluster decay factor
  - ray decay factor

Channel Characteristics	CM1	CM2	CM3	CM4
Distance (m)	0-4	0-4	4-10	–
Line of Sight	yes	no	no	no
Mean Excess Delay (ns)	5.05	10.38	14.18	–
RMS Delay	5.28	8.03	14.28	25
NP_{10db}	–	–	35	–
$NP_{85\%}$	24	36.1	61.54	–

Multi-path Arrives in Clusters [5]

- 0.3m distance -> 1ns apart receiving signals
- 7.5GHz UWB has resolution at 133ps
- Cluster -> reflection from different obstacles

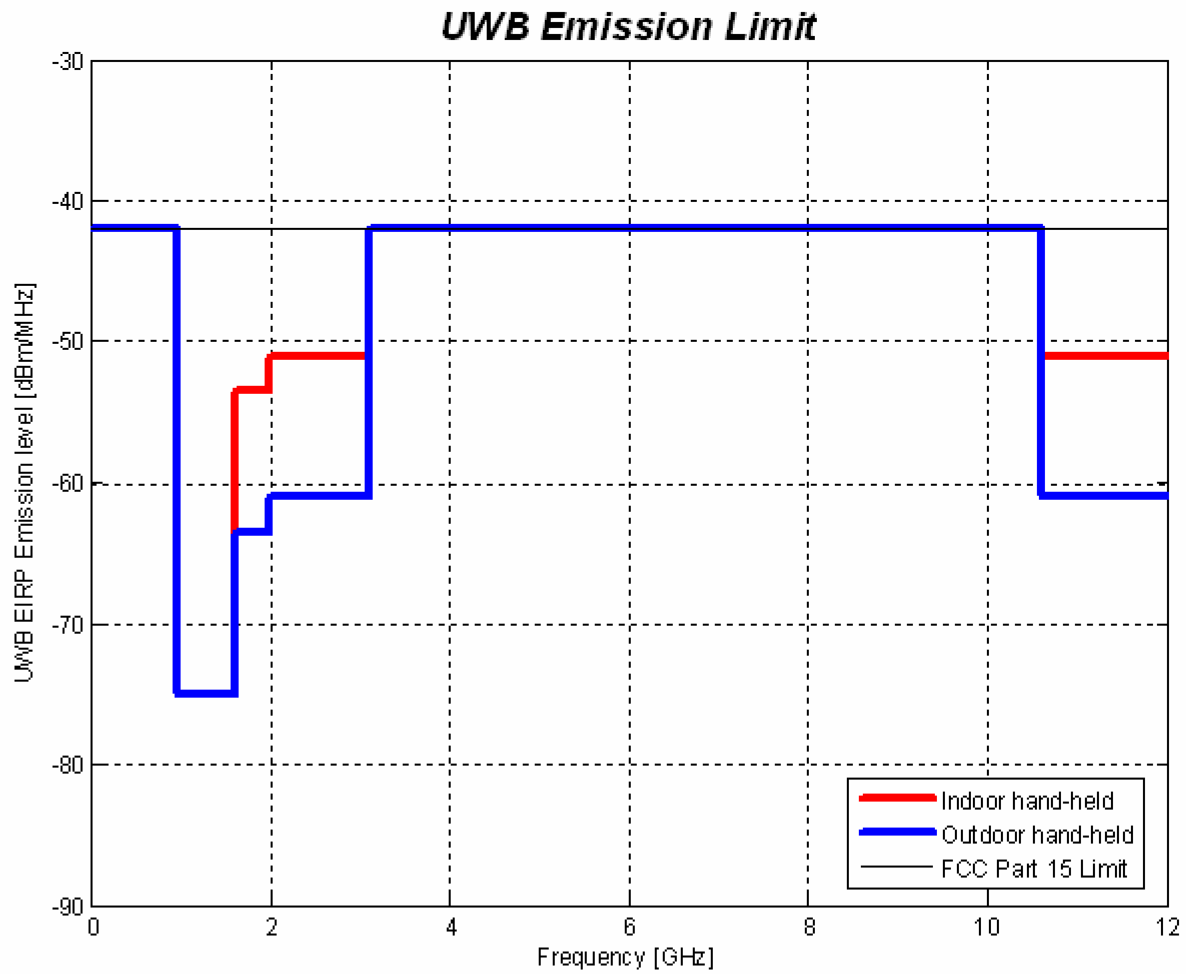


Modifications to S-V Model

- Amplitude
  - No Rayleigh
  - But lognormal or Nakagami distribution
- Shadowing term added
  - Account for total received multi-path energy variation

Regulation and PHY Considerations

FCC Regulations [6]



PHY Considerations

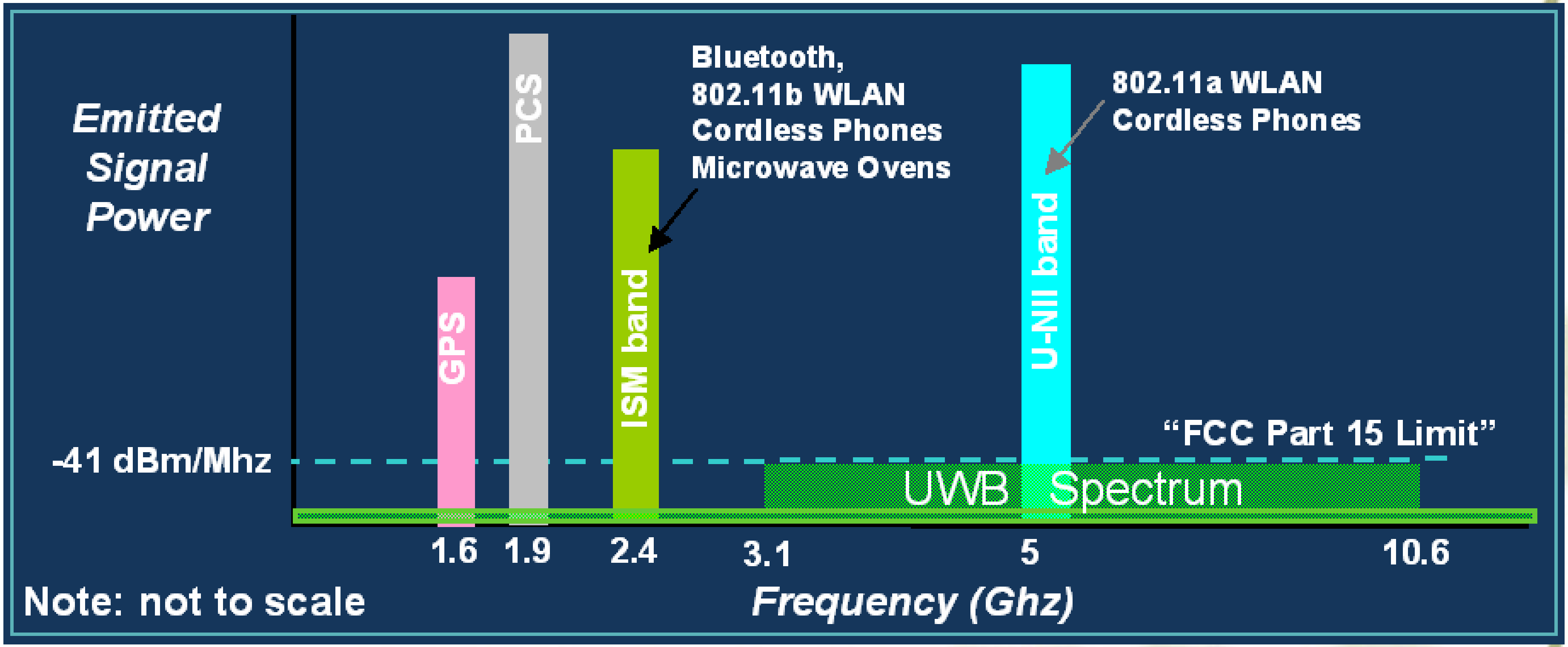
- Pulse spectrum design
  - Fit FCC regulations
- Spectrum spreading sequence design
  - Reduce multiple-access interference (MAI)
- Synchronization
  - Reduce long acquisition time

Pulse Spectrum

- Pulse generator
  - Close to FCC regulation
- Spectrum spreading sequence
  - Smooth but not eliminate spectral line
  - Violate FCC regulation
  - Power back-off
- Modulation
  - Carefully design can eliminate spectral line

Pulse Spectrum Design [7]

- Notch the pulse spectrum
  - avoid existing narrowband interference
- Soft Spectrum Adaptation



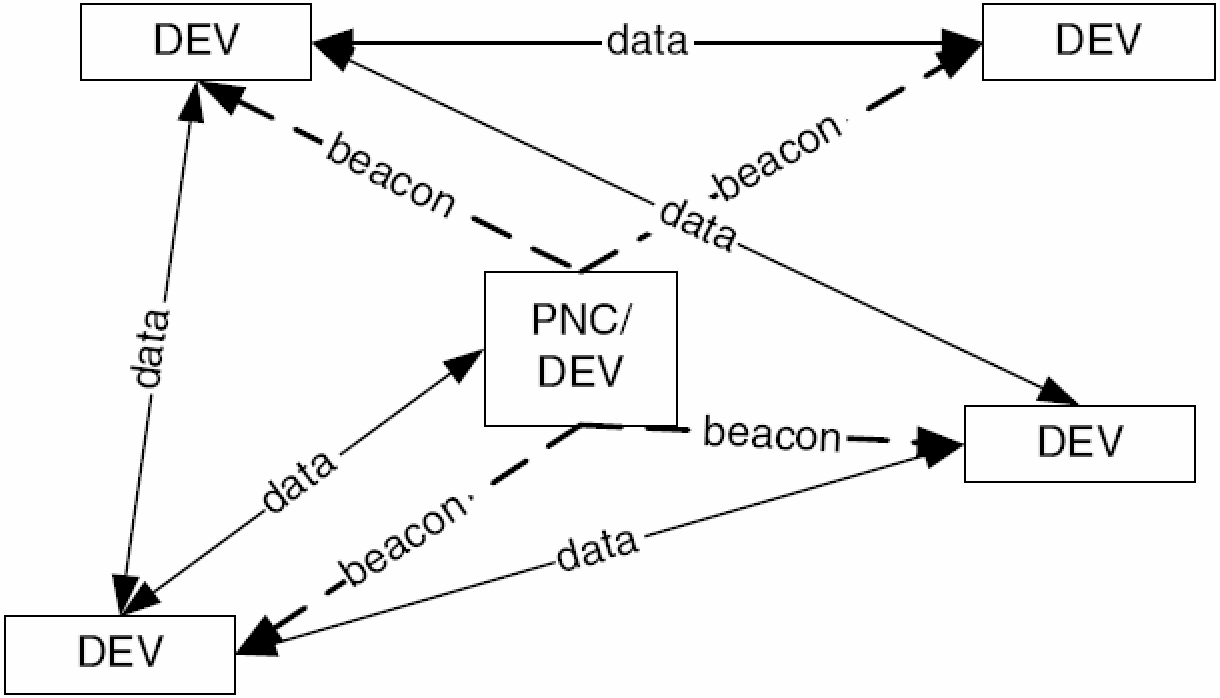
Standardization and MAC Issues

Standardization

- Wireless Personal Area Networks using UWB as PHY options
  - IEEE Std of 802.15.3a for high data rate
  - IEEE Std of 802.15.4a for low data rate
- IEEE802.15.3a
  - DS-UWB vs. MB-OFDM-UWB
  - Proposal withdrawn on Jan 2006
  - Market will decide the surviving technology
- IEEE802.15.4a (Draft)
  - Communications
  - High precision ranging and location
  - In progress

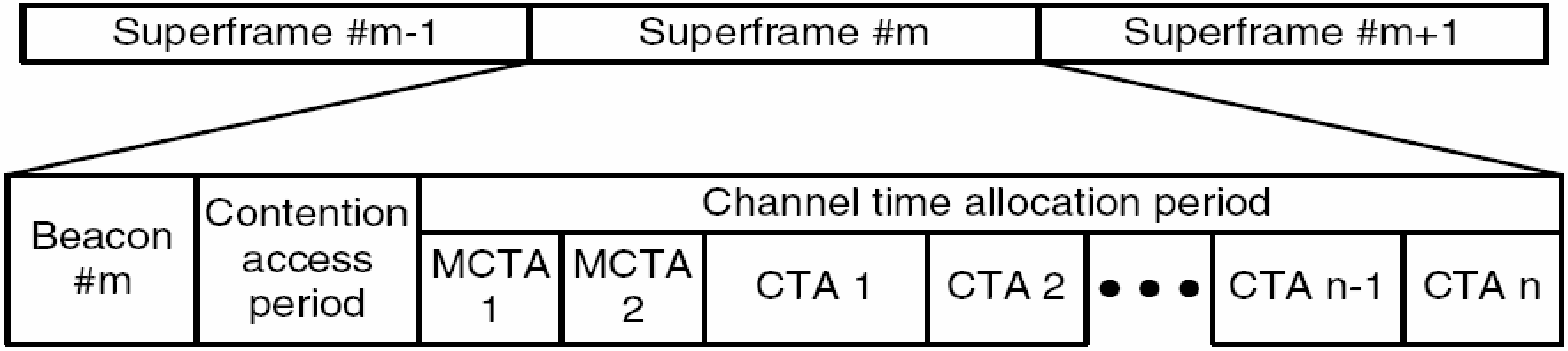
IEEE 802.15.3 MAC [8]

- Concept of Piconet
  - PNC
  - DEV



IEEE 802.15.3 MAC [8]

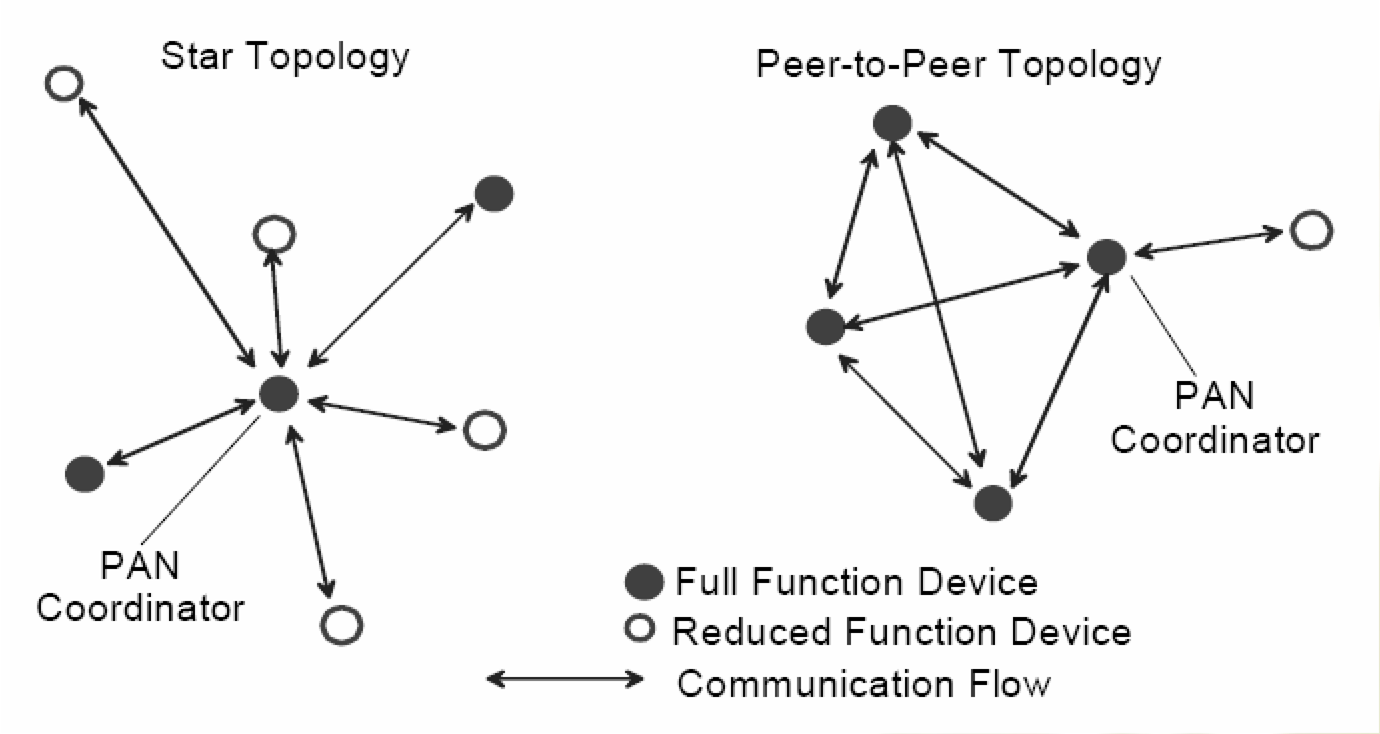
- Beacon
  - synchronization, time allocation, power control
- Contention Access Period (CAP)
  - commands and asynchronous data
- Channel Time Allocation Period (CTAP)
  - MCTA: management
  - CTA: isochronous streams, asynchronous data



IEEE 802.15.4 MAC [9]

- Topology
  - Star Topology
  - P2P Topology

- Beacon-enabled
  - slotted CSMA/CA
- Non beacon
  - unslotted CSMA/CA



MAC Issues

- Rate Adaptation
  - Modulation order
  - Spreading gain
  - Channel code rate
- Power Control
  - Ranging accuracy
- Pulse Shape Adaptation
  - Combined with Soft Spectrum Adaptation

Q & A
Thank You

References

- [1] Dr. Jeffrey Reed, Dr. R. Michael Buehrer, Dr. Dong S. Ha, “Introduction to UWB: Impulse Radio for Radar and Wireless Communications”.
- [2] Oh-Soon, Saeed S. Ghassemzadeh, Larry J. Greenstein, Vahid Tarokh, “Performance Evaluation of MB-OFDM and DS-UWB Systems for Wireless Personal Area Networks”.
- [3] Anderas F. Molisch, Jeffrey R. Foerster, Marcus Pendergrass, “Channel Models for Ultrawideband Personal Area Networks”, IEEE Wireless Communications, Dec 2003.
- [4] Eduardo Cano, Sean McGrath, “TH-UWB and DS-UWB In Lognormal Fading Channel and 802.11a Interference”.
- [5] Jari Iinatti, “Ultra Wideband Systems”, UWB_251103Iinatti.pdf.
- [6] Lic.Tech. Matti Hämäläinen, ”Introduction to existing ultra wide band (UWB) technologies”, UWB_070406.ppt.
- [7] Fred Bhesania, Brad Hosler, “UWB: A High-Speed Wireless PAN Technology”, TWMO05003_WinHEC05.ppt.
- [8] IEEE Computer Society, Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs), 2003.
- [9] IEEE Computer Society, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs), 2006.