# Ultra-Wideband (UWB)

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spsc – signal processing and speech communication lab
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## Outline

- What is Ultra-Wideband? Why UWB?
  - Understanding UWB radio propagation
  - Features and potential advantages
- Regulation
  - Where can we find UWB spectrum?
- Implementation of UWB Systems
  - Challenges and proposed solutions
- Standardization
- Summary

# What is UWB?

- Transmission technology for wireless data comms.
  - Signal modulation for **robust** transmission over physical channel
- Bandwidth Classification
  - Motivated by **channel** impact on **data signal**

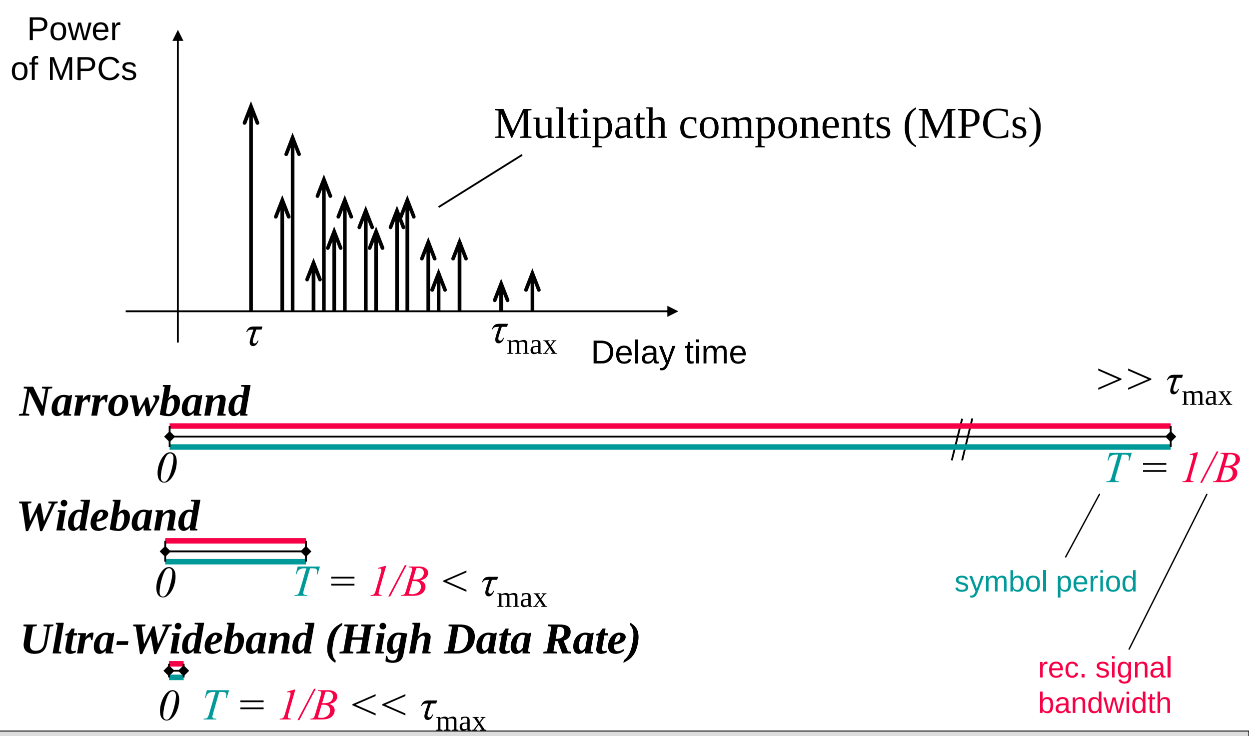
  - Narrowband
  - Wideband
  - **Ultra-Wideband**

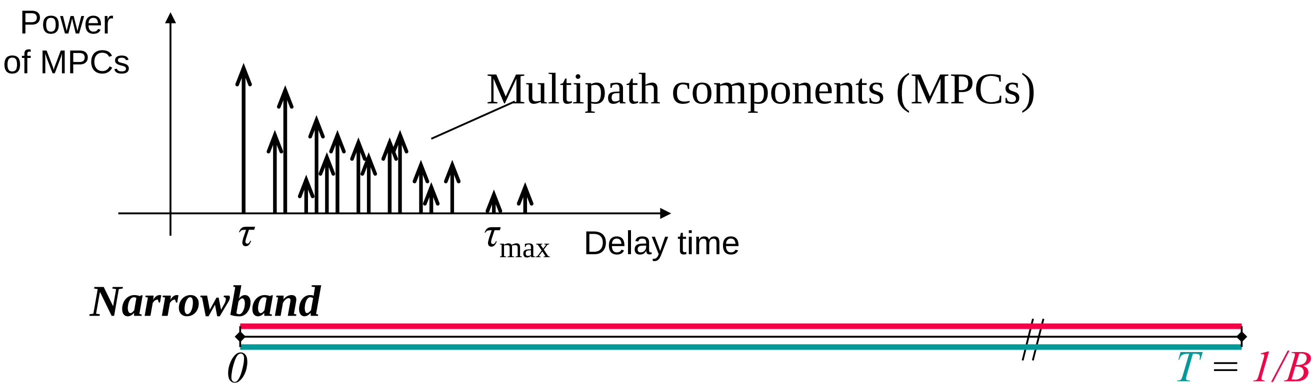
  - Channel impulse response vs. **symbol period** *T* of TX signal





# Bandwidth Classification

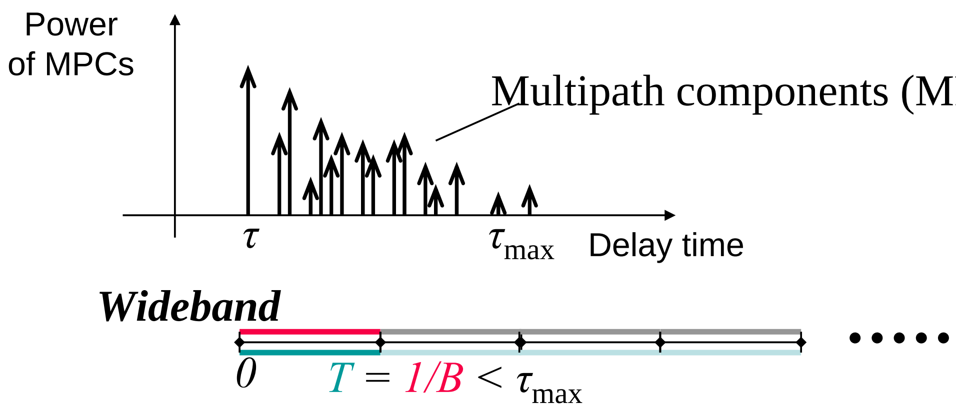




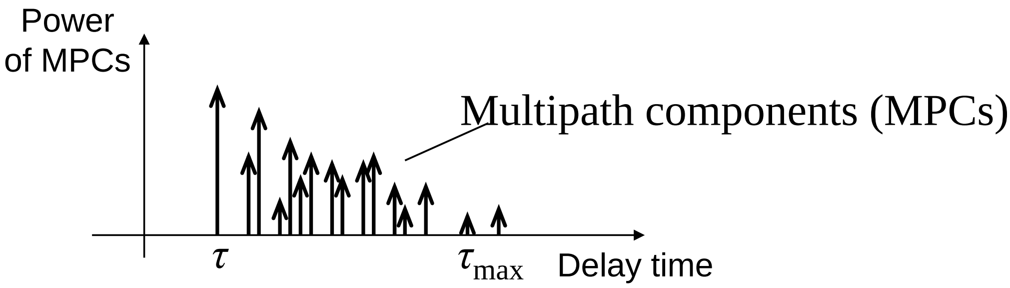

- Each MPC is a delayed/attenuated **carrier wave**
  - **Phase shifts** due to delays
  - **Interference** between carriers → **fading**
  - RX **power** varies with time/location (animation)
- RX Solutions
  - fading margin: many extra dB power needed
  - **diversity**: multiple parallel links (multiple antennas)
- only low data rate is achieved with NB systems








- Greater data rate is achieved/needed
- Still superposition of many MPCs
  - → **fading RX power**
- Also overlap of consecutive symbols
  - → signal **distortion** (inter-symbol-interference - **ISI**)
- RX Solutions
  - equalization / multicarrier modulation – parallel transmission

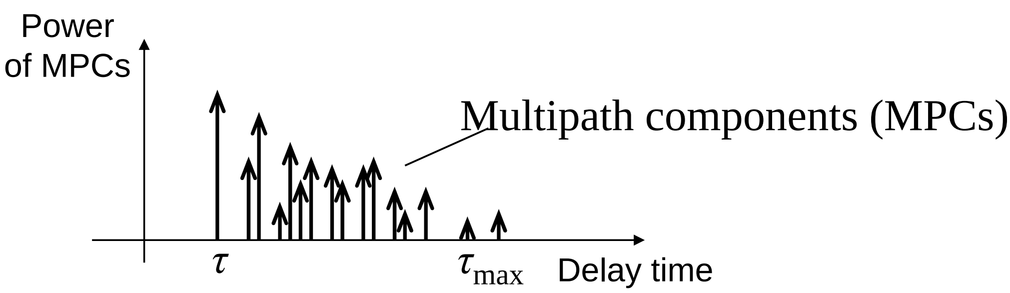



***Spread Spectrum***


- wide bandwidth **but** low symbol rate
- spread spectrum: **rake** receiver:
  - **resolves** parts of channel response (corresponding to ~1/*B*)
  - each part fades independently → less fading through **Rake combining**
- Problems
  - higher complexity for synch.; more bandwidth needed








***Ultra-Wideband (Spread Spectrum)***


- individual MPCs can be resolved
  - → no/**little fading** remains
- Start of channel response can be found
  - **positioning** at < 1m accuracy (for indoor apps.)
- UWB for high-rate
  - potentially achieves huge data rates
  - e.g. multicarrier parallel transmission (OFDM)

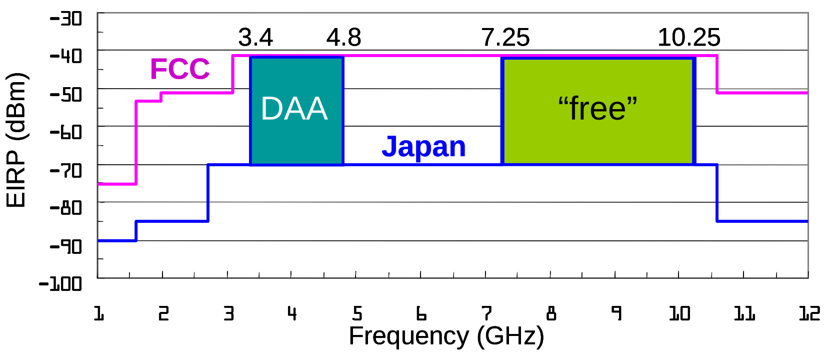
# Where can we find UWB spectrum?

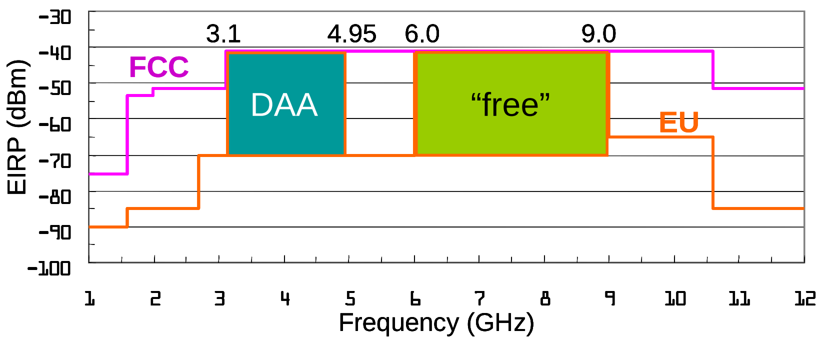
- Spectrum is scarce! (remember UMTS auctions)
- UWB Idea:
  - **underlay** UWB signals under existing services
  - spreading gain reduces these signals
  - obey emission limits for **unintended** emag. radiation
  - → since data transmission is “intended”, **regulation** is needed!
  - → very low TX power (< 0.5 mW) → low range
- Regulation
  - United States: FCC allows UWB in 2002 (3.1 – 10.6 GHz @ -41.3 dBm/MHz)
  - Europe: ECC; March 06: (6 – 8.5 and 3.1 – 4.8 GHz (DAA) @ -41.3 dBm/MHz)
  - Japan: MIC; expected: (3.4 – 4.8 & 7.25 – 10.25 GHz @ -41.3 dBm/MHz, DAA)
- **UWB definition** (FCC):
  - BW > 500 MHz; **or** fractional BW ($BW/f_c$) > 0.2





# Emission masks for UWB (draft)



# Summary of UWB Features

- **Large bandwidth** (> 500 MHz, up to 7 GHz)
  - High data rates or user densities are possible
- **Low** radiated **power** (0.5 mW for 7 GHz BW – FCC)
  - Limited range (< 10m)
- **Localization** capabilities
  - Location based services
  - Location enhanced network protocols
- **Applications**
  - Cable replacements (**Wireless USB2**) – IEEE 802.15.3a
    - No agreement reached; MB-OFDM adopted by ECMA-368/ISO
    - High data rate (at least 480 MBit/s)
  - **Localization**; Sensor networks – IEEE 802.15.4a
    - Issued 2006; low data rates (typically 1 MBit/s)

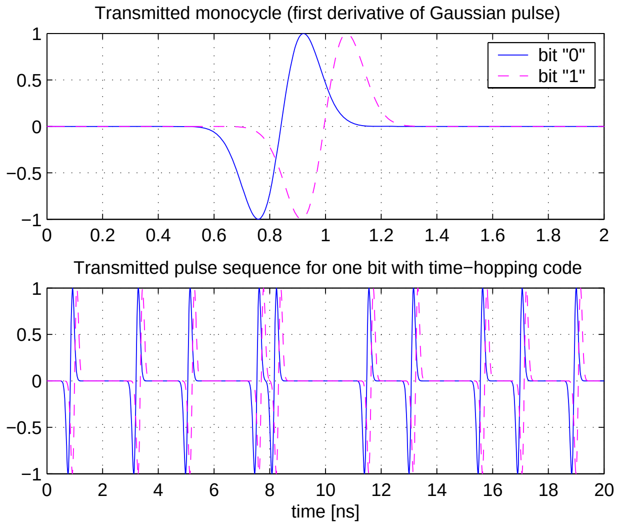


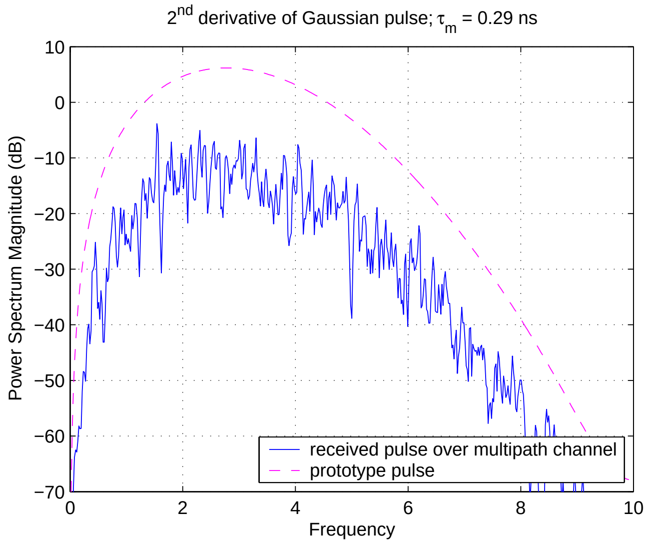


# Realizing UWB Communications

- Various modulation / spreading schemes (known from conventional DCS)
  - orthogonal frequency division multiplexing (OFDM)
    - Well-suited for high-rate
  - direct sequence spread spectrum (DS-SS)
    - UWB chip-level pulses are used
  - frequency hopping
- A special proposal: **Impulse Radio**
  - Use ultra-short pulses to generate UWB signals
  - No carrier needed → low power designs possible
  - Pulse position modulation and time-hopping for multiple access

# UWB-Impulse Radio – Transmitted Signal



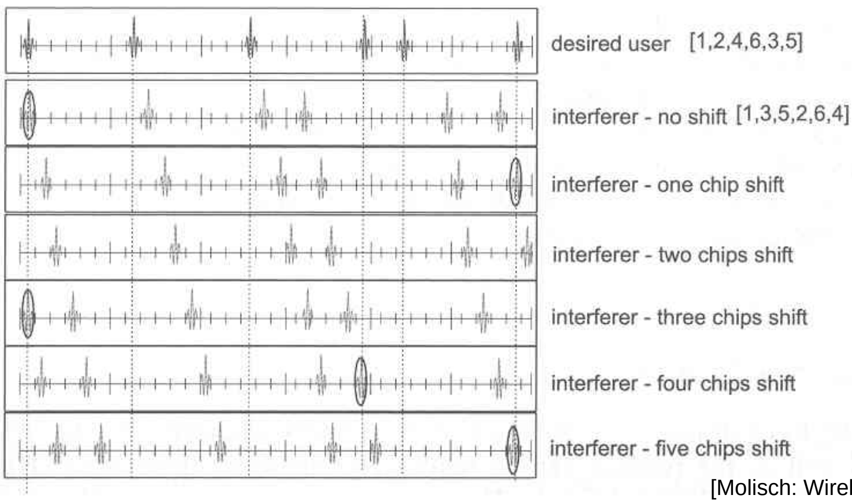







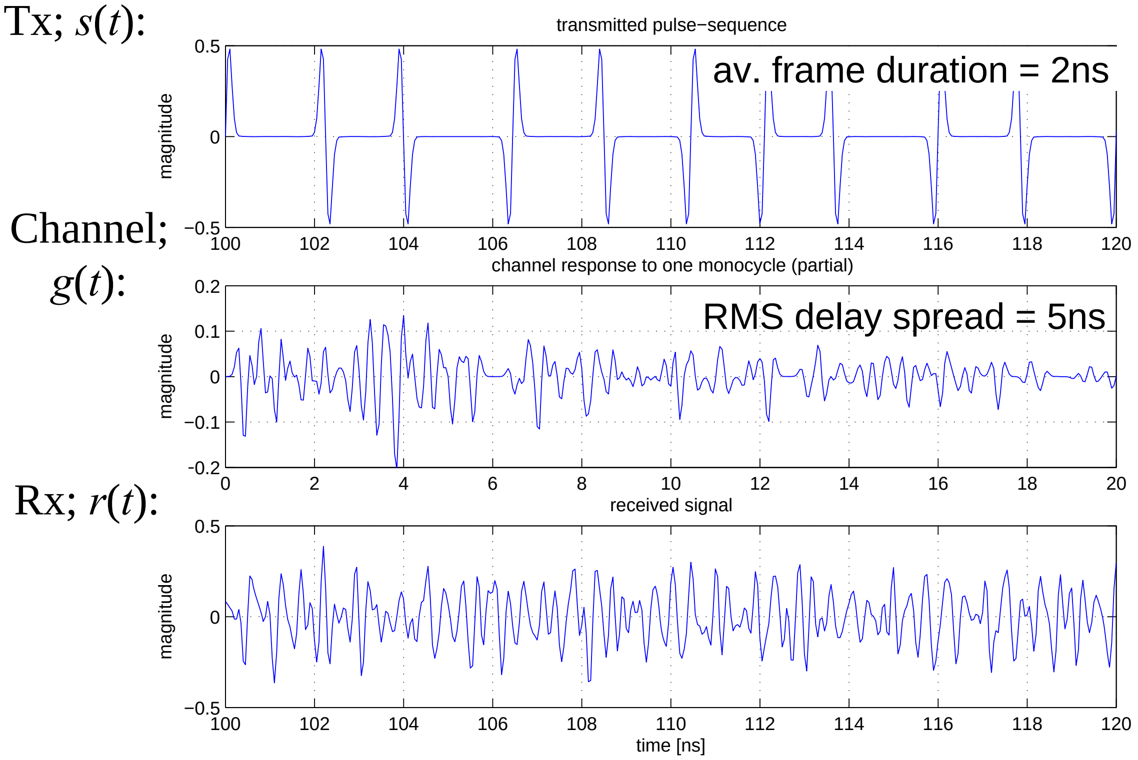

# Time-Hopping Multiple Access

- Receiver knows time-hopping sequence
- Co-channel user (multiple access):
  - only one collision per symbol




[Molisch: Wireless Communications]

# UWB-Impulse Radio – Received Signal

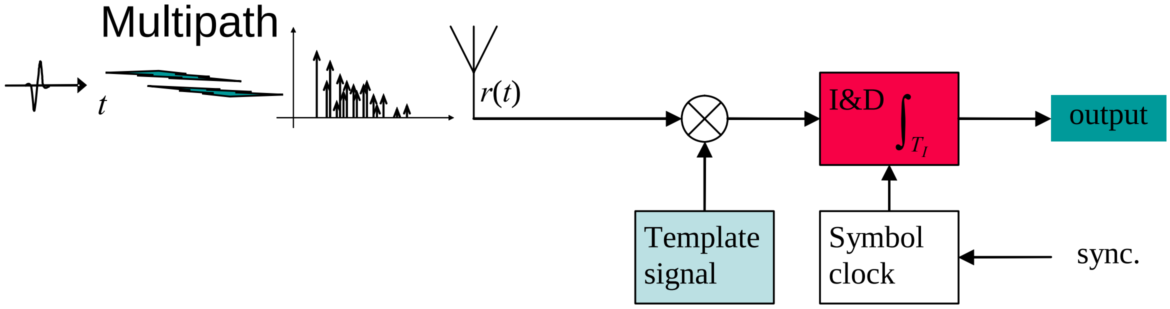




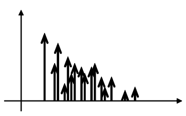



# Implementation Challenges

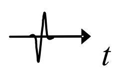
- Basically, UWB signals must be processed
  - Nyquist theorem: sampling at $f_s > 2BW > 1$ GHz !!!
- Coherent receiver: **ideal**, but highly complex




**Optimal template** = matched filter:
Problems: implementation complexity;
synchronization; channel estimation

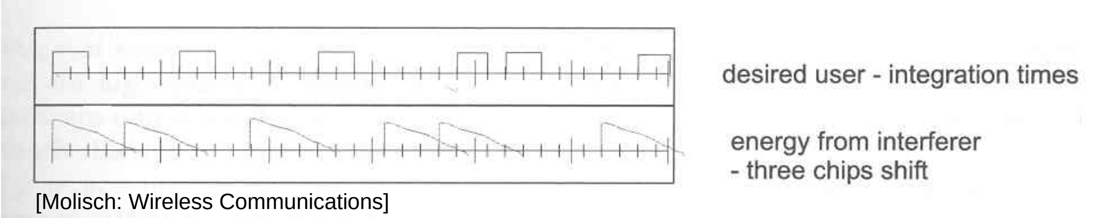


**Sub-optimal** template, single pulse:
Problem: collects only fraction of energy



# Non-coherent receivers

- **sub-optimal** but simple
- **energy detector**
  - can only use precise timing for suppression of interference



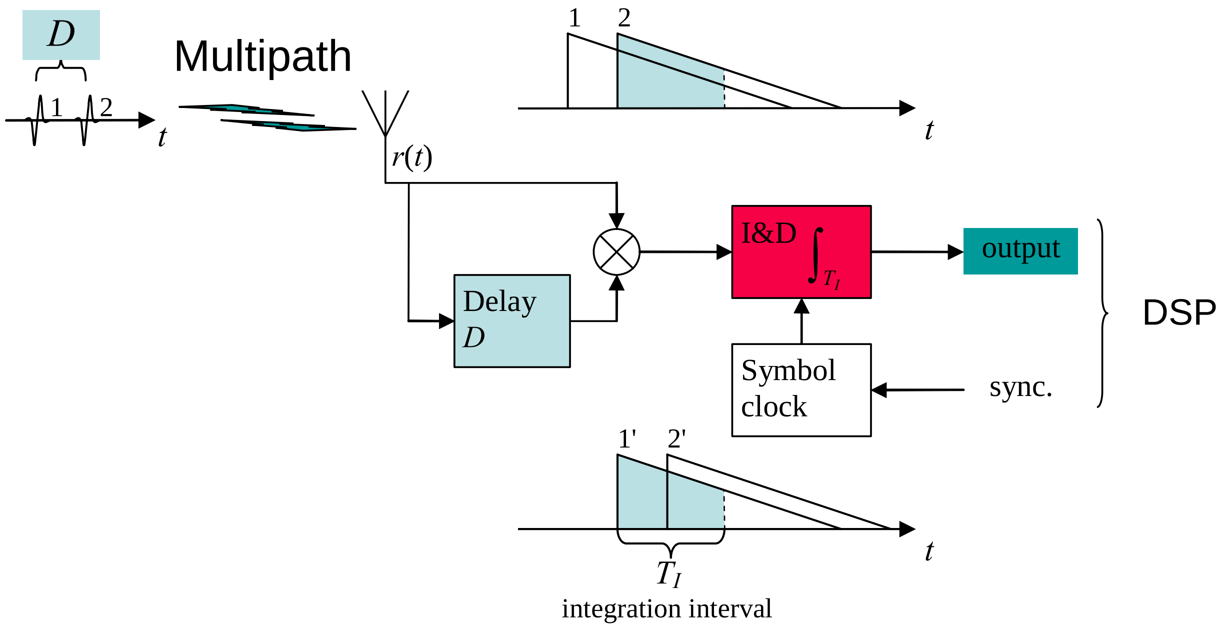
[Molisch: Wireless Communications]

- transmitted reference w/ **autocorrelation receiver**
  - two pulses are transmitted (pulse doublet)
  - first pulse is reference for demodulation of second pulse
  - trade-off: complexity/performance
  - problem: UWB delay line!



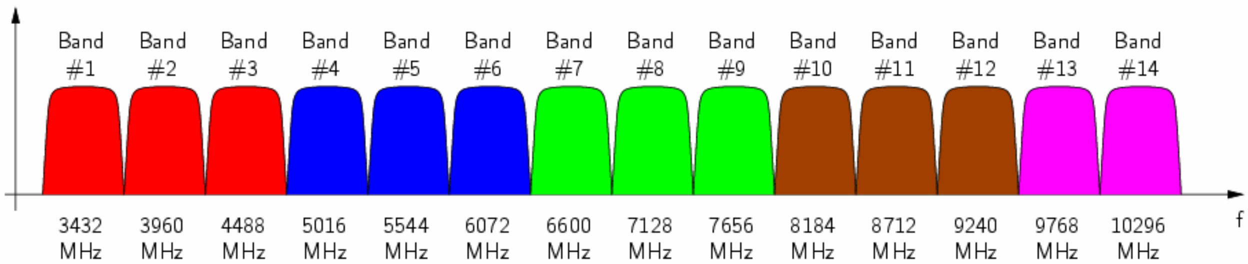


# Transmitted Reference (IR) Systems
## (Autocorrelation Receiver Frontend)



# Standardization: 802.15.3a – ECMA-368

- High speed data transmission for Personal Area Networks (PANs)
  - Range below 10 m (even less)
- Proposal 1: Implementation as **Direct Sequence Spread Spectrum**
- Proposal 2: multiband OFDM
  - 528 MHz Signals; 128 sub-carriers; frequency (band) hopping








# Standardization: 802.15.4a

- **Low data rate** standard (typically 1Mbps)
- **Positioning** applications
- Transmit positioning information and data
  - **Reference pulses** (root-raised-cosine)
  - Long, known **training sequence** for channel estimation/positioning
  - Allows **coherent and non-coherent** receivers

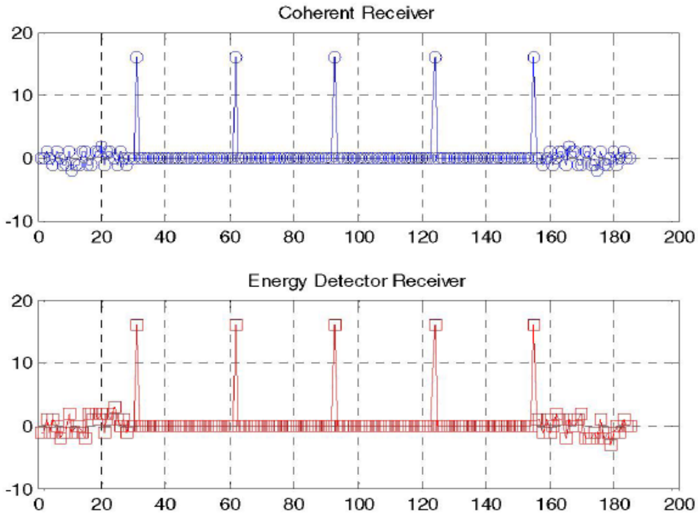
    **pulse-bursts** are sent; information bits are encoded twice:
    - **PAM** modulation: only for coherent receivers
    - **Burst position modulation** (BPM): also for noncoherent ED
- Standard issued in 2006

# Preamble Sequences – IEEE 802.15.4a

- Ternary sequences

| Code No. | 31-chip Ternary Codes (+, –, 0 corresponds to +1, –1, 0 respectively) |
|---|---|
| 1 | – 0 0 0 0 + 0 – 0 + + + 0 + – 0 0 0 + – + + + 0 0 – + 0 – 0 0 |
| 2 | 0 + 0 + – 0 + 0 + 0 0 0 – + + 0 – + – – – 0 0 + 0 0 + + 0 0 0 |
| 3 | – + 0 + + 0 0 0 – + – + + 0 0 + + 0 + 0 0 – 0 0 0 0 – 0 + 0 – |
| 4 | 0 0 0 0 + – 0 0 – 0 0 – + + + + 0 + – + 0 0 0 + 0 – 0 + + 0 – |
| 5 | – 0 + – 0 0 + + + – + 0 0 0 – + 0 + + + 0 – 0 + 0 0 0 0 – 0 0 |
| 6 | + + 0 0 + 0 0 – – – + – 0 + + – 0 0 0 + 0 + 0 – + 0 + 0 0 0 0 |
| 7 | + 0 0 0 0 + – 0 + 0 + 0 0 + 0 0 0 + 0 + + – – – 0 – + 0 0 – + |
| 8 | 0 + 0 0 – 0 – 0 + + 0 0 0 0 – – + 0 0 – + 0 + + – + + 0 + 0 0 |

- Perfect autocorrelation properties
  - For coherent and non-coherent recvrs



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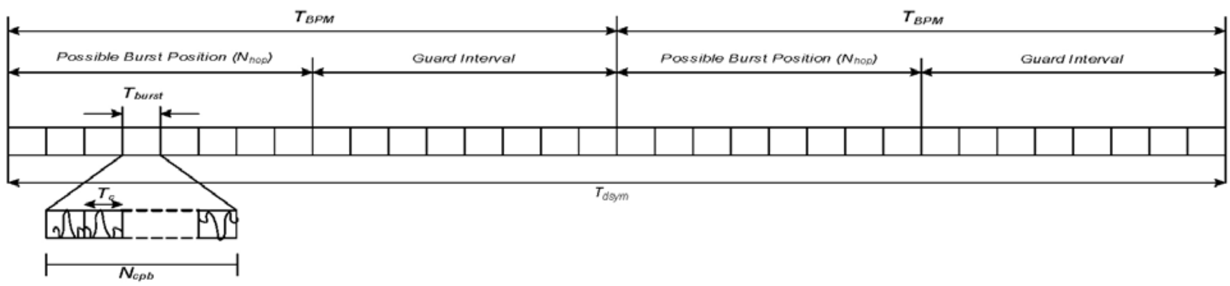
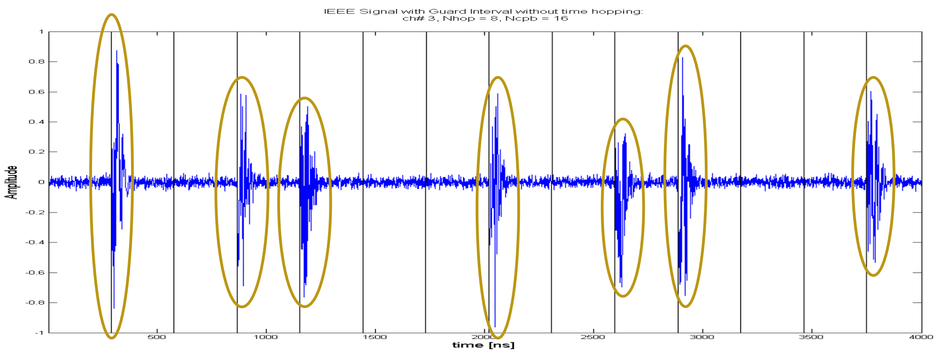
# Introduction – IEEE802.15.4a Modulation




- Diagram shows timing of **one data symbol**
  - $N_c$ pulses in **one burst** are sent **per symbol**
    - **Random spreading** sequence
    - $N_c$ = 512, 128, 32, 16, 8, 4, 2, 1
  - Modulation
    - Burst **position** modulation; Burst **polarity** modulation
  - Burst hopping ($N_{hop}$ = 2, 8, 32)
  - Guard Interval

# Signal Example

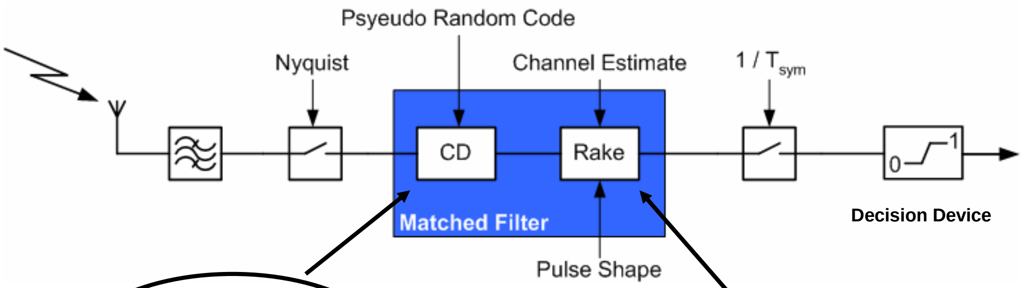



- Modulation: Burst polarity and burst position
- No burst-hopping in this example
- Pulse repetition frequency: 499.2 MHz (**2 ns**)
  - → **Inter-Pulse-Interference**
  - → “fading” effects due to **random channel and code**





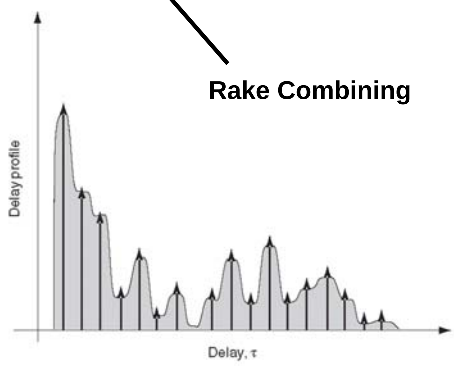
# Optimal Coherent Receiver



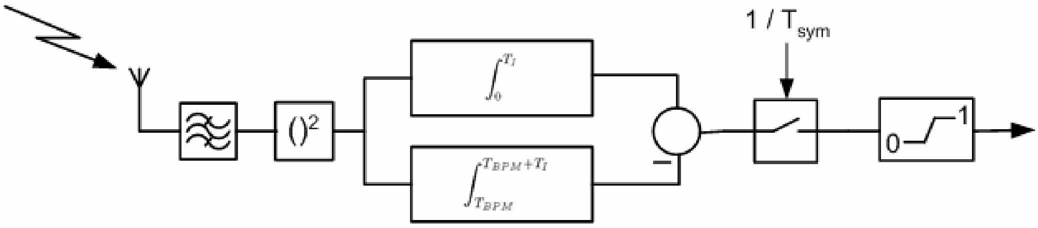

$$y[l] = \sum_{m=0}^{N_c-1} c_m x[l + Lm]$$

**Code Despreading**

- Optimal Matched Filtering
- Disadvantage
  - High sampling rates (Nyquist)
  - (Perfect / good) channel estimation
  - Many channel taps



# Energy Detection Receiver




- Analog receiver front-end
  - Simple, **low complexity**, low power
- **Only for burst position** modulation $s_0$
- Low robustness against narrowband interference

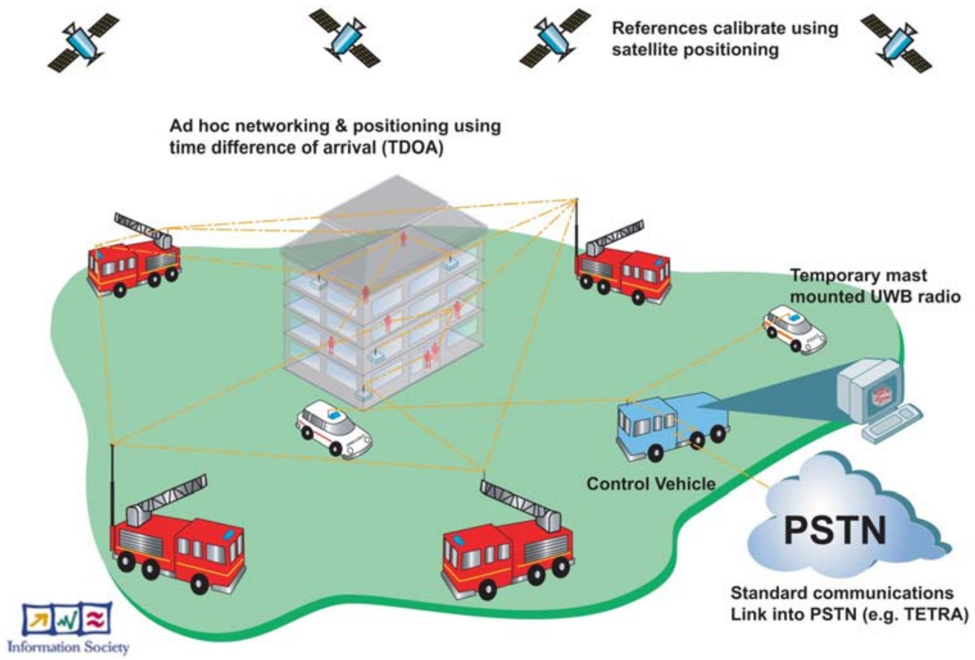




# Summary

- Potentials
  - ultra-high data rate
  - **positioning**!
  - potentially low power transmitters (impulse radio)
- Challenges
  - high receiver complexity
  - sensing capabilities of UWB signals
- An example:
  - **tracking of emergency personnel** – project "EUROPCOM"
  - (EC FP6 funded. Partners: Thales Research, UK, IMST GmbH., D, TU Delft, NL, TU Graz)

# EUROPCOM – Emergency UWB Radio for Positioning and Communications








# Further Reading …

- Books:
  - Molisch et al., *UWB Communication Systems – A Comprehensive Overview*
  - Oppermann et al., *UWB*
  - Ghavami et al., *UWB Signals and Systems in Communication Engineering*
  - Arslan et al., *Ultra Wideband Wireless Communication*
- Papers:
  - Win and Scholtz, "*Impulse Radio: How It Works*," IEEE Commun. Letters, Feb. 1998
  - Yang and Giannakis, "*Ultra-Wideband Communications: An Idea Whose Time Has Come*," IEEE Signal Processing Magazine, Nov. 2004
  - Gezici et al., "*Localization via Ultra-Wideband Radios*," IEEE Signal Processing Magazine, July 2005
  - Batra et al., "*Design of a Multiband OFDM System for Realistic UWB Channel environments*," IEEE Trans. On Microwave Theory and Techniques, Sept. 2004
  - K. Witrisal, *et al. "Noncoherent Ultra-Wideband Systems: An Overview of Recent Research Activities,"* IEEE Signal Processing Magazine, July 2009, http://www.spsc.tugraz.at/people/klaus/WitrisalSPM09.pdf