IEEE 802.15.4a
Introduce the Standard

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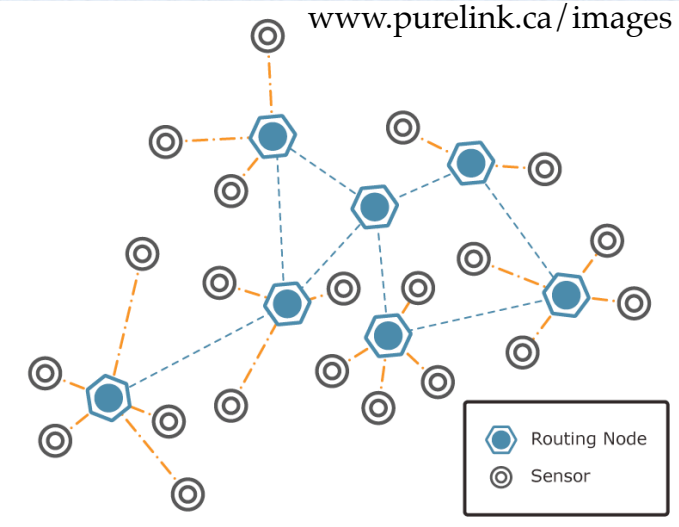
Outline

- Introduction
  - Network Topologies
- Ultra Wide Band UWB
  - Receiver - Requirements and Types
  - Frequency Bands
- 802.15.4a Structure
  - Packets and Symbols
  - Collision Detection
- Ranging

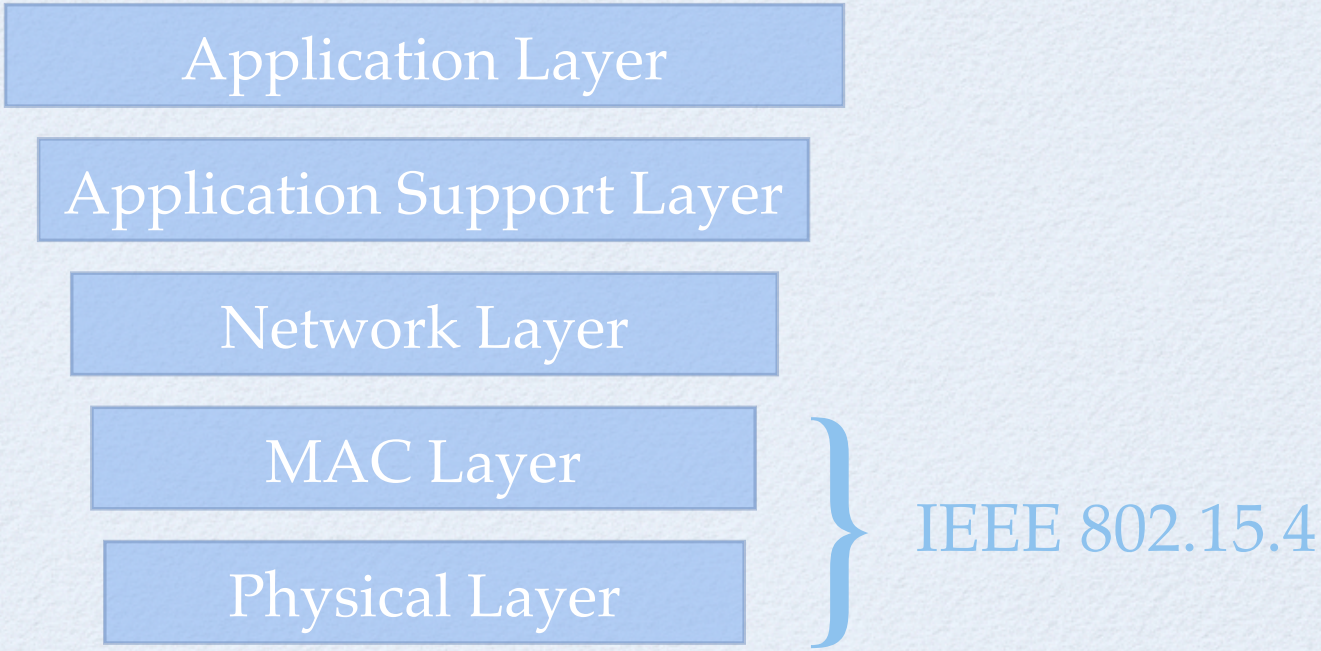
Distributed Networks

- Sensor Networks
- Capabilities
  - Cheap , smart, and multiple sensors
  - Data processing on-board
- Infrastructure
  - a-priori, ad-hoc
- Existing standard



Existing Solution

- Low Rate Wireless Personal Area Networks



IEEE 802.15.4 Successors

- IEEE 802.15.4b
  - Removes ambiguities of IEEE 802.15.4
  - Released in 2006
- IEEE 802.15.4a
  - Special need for ranging capability
  - Measure distance between nodes
  - Released in March, 2007

Time Schedule

- First Use Cases in 2003
  - Define first channel models
- Formed Subgroups in 2004
  - Modulation, coding schemes, multiple access, and different waveforms
  - Baseline proposal
- First Ballot in 2005
- Final Approval in 2007

IEEE 802.15.4a Networks

- Sensor Network Nodes
  - Different capabilities and requirements
- Heterogenous Structure
  - No restrictions
- Two Different Types of Nodes
  - Mapped from the 802.15.4 standard

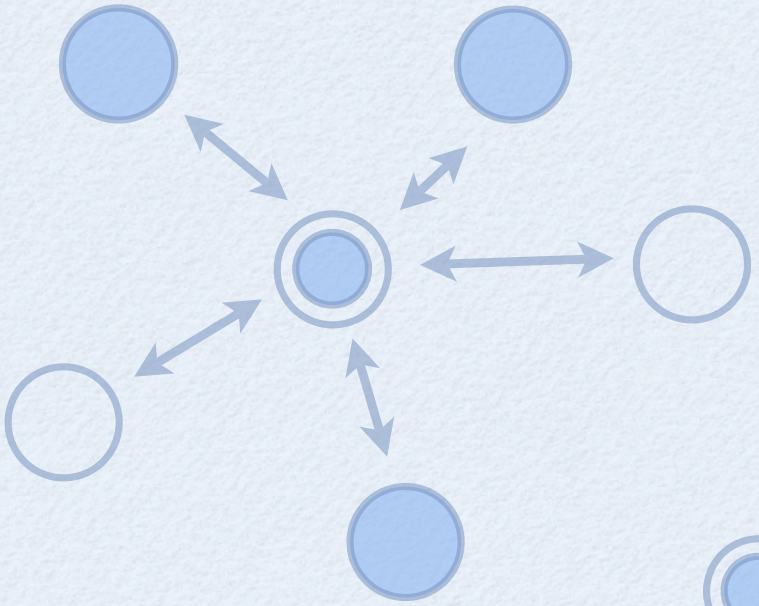
Device Types

- Full Function Devices FFD
  - Small number of core nodes with no restrictions
  - Neither power nor size limitations
  - Permanent power supply
- Reduced Function Devices RFD
  - Sensor Nodes
  - Tight limits on complexity and power consumption

Network Topology

- Personal Area Network PAN
  - Self organization of nodes
  - Controlled by Full Function Device
  - Setup and maintenance
- Two Different Topologies
  - Star topology
  - Peer-to-peer topology

Star Topology

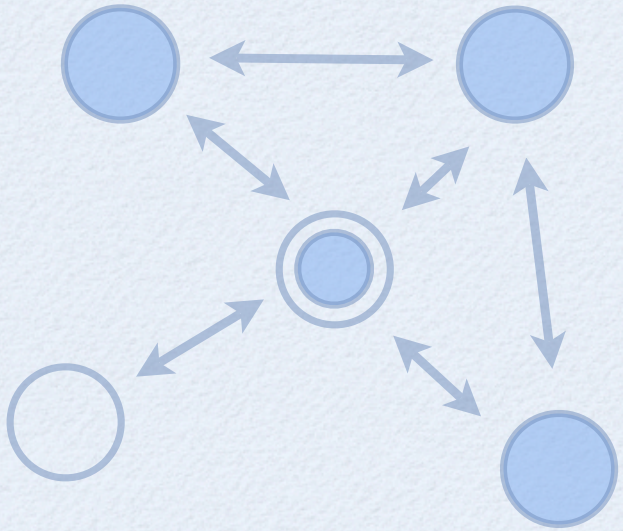


PAN coordinator

Reduced Function

Full Function

Peer-to-Peer Topology



PAN coordinator

Reduced Function

Full Function

Receiver Requirements

- Large Number of Nodes
  - Low cost, *e.g.* RFID - price: 1% of product
- Form Factor and Power Consumption
  - Stick chip on product
  - Several years without battery change
- Communication Robustness
  - Interference, small scale fading, and shadowing
- Geo-Spatial Information

Introduce Ultra Wide Band

- Existing Sensor Networks
  - Narrowband modulation with multiple access
  - *e.g.* Zigbee standard with 1MHz code shift keying modulation
- Ultra Wide Band UWB
  - Bandwidth 500 MHz - 2 GHz
  - Lower cost and less power consumption
  - Increased robustness
  - Introduce ranging
  - Transmission distance 10 - 50 Meter

UWB Frequency Spreading

- Direct Sequence Code Division Multiple Access
  - Modulate signal onto high frequent pseudo random noise
  - Transmit signal
  - Receiver correlates signal with origin pseudo random noise
- Frequency Hopping
  - Use different frequency slots
  - Error correction codes and repetition codes

Ultra Wide Band Channels

- Impact of Propagation Channel
  - Design of entire network
- Additive White Gaussian Noise AWGN
  - Receiver is a simple energy detector
  - Detect pulse - given or not
- Delay Dispersivity
  - Rake Receiver

Rake Receiver

- One Receiver - Multiple Sub-Receivers
  - Collect different multi path components
  - Contribution yields in origin signal
  - Higher Signal-to-noise ratio
- Eliminates Small Scale Fluctuations
- IEEE 802.15.4a
  - Several 100 Sub-Receivers to collect half signal energy

UWB in IEEE 802.15.4a

- Large Bandwidth > 500MHz
  - Relative bandwidth > 20%
  - Less system interference than existing solutions
- Overlapping Spectrum
  - Free use with no restrictions
  - Restricted power spectral density 41.3 dBm/MHz

Frequency Bands

- Three Different Frequency Bands

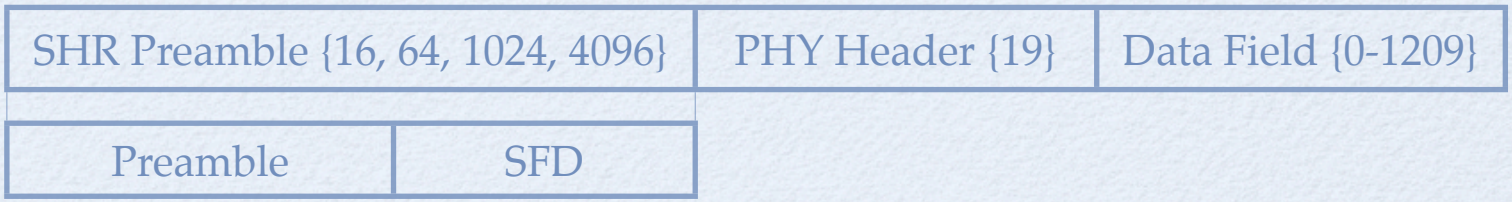
	Frequency	Channel
Sub Band	< 1 GHz	0
Low Band	3 - 5 GHz	1 - 4
High Band	6 - 10 GHz	5 - 15

Mandatory Channels

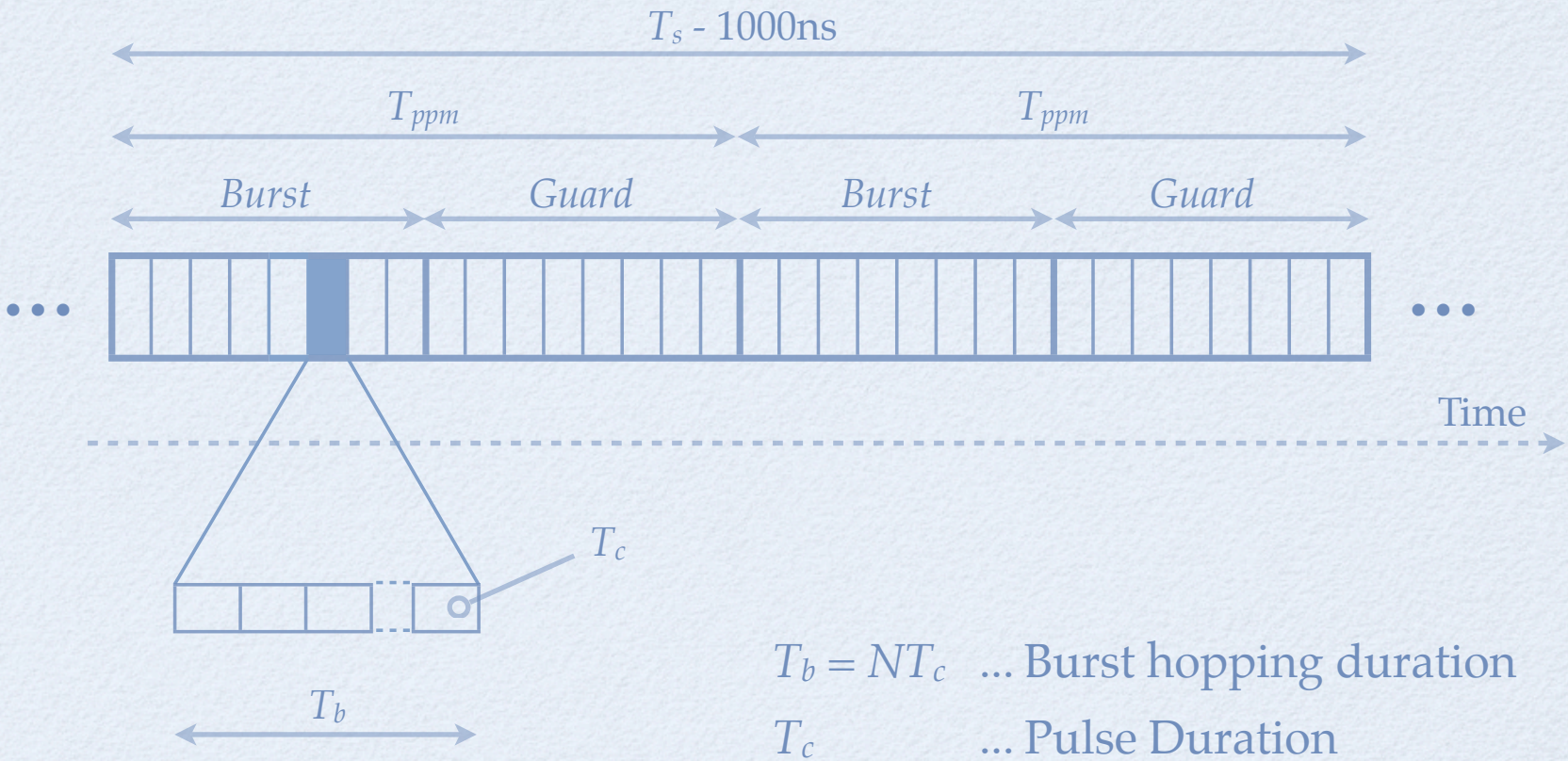
Channel	Center Frequency MHz	Bandwidth MHz
0	499.2	499.2
1	3494.4	499.2
2	3993.6	499.2
3	4492.8	499.2
4	3993.6	1331.2
...	...	...
8	7488.0	499.2
9	7987.2	499.2
10	8486.4	499.2
...	...	...
15	9484.8	1355.2

802.15.4a Packet Structure

- Packet Definitions
  - SHR ... Synchronization header
  - SFD ... Start of frame delimiter



Symbol Structure



$T_b = NT_c$ ... Burst hopping duration

T_c ... Pulse Duration

T_{ppm} ... Modulation Interval

Symbol Definition

- Carrying Two Bits of Information
  - Position of burst of pulses - both receivers
  - Polarity of the same burst - coherent receiver
- Binary Pulse Modulation
  - Divided into two Intervals
- Time Hopping
- Burst - Guard
  - Multipath interference

Prototype Waveform

- Pulse Burst Symbol *s(t)*

$$s_i(t) = \sum_{n=0}^{N-1} \widetilde{b}_i \; p(t - nT_c - b_i T_{ppm}) d_{i,n}$$

$n = 0 \ldots N-1$	... Pulses per symbol
T_c	... Pulse Duration
$p(t)$	... Base Pulse
$d_{i,n}$	... Pseudorandom Scrambling
$b_i, \widetilde{b}_i$	... encoded - unencoded bit

Bandplan

- Modulation, Coding, Multiple Access Schemes
  - Work with both
  - Reduced Function Device, Full Function Device
- Coherent Receivers
  - Detect two bits - position and phase of the burst
- Non-coherent Receivers
  - Detect one bit - position of the burst
  - Simple Energy Detector

Hybrid Modulation

- Different Bit-Rate
  - Coherent receiver: two bit per symbol
  - Non-coherent receiver: one bit per symbol
- Heterogenous Network
  - Both types - no doubled data-rate
  - Reed-Solomon (63, 55) - corrects eight 6-bit errors
- Used for Coding Gain
  - Systematic code - visible to both types

Collision Detection UWB

- Two Devices Exchange Messages
  - Probability of a collision
- Detect and Avoid DAA
  - Detect communication of other devices
- Low Duty Cycle LDC
  - Transmit for short time
  - Retry if collision occurs

CSMA-CA

- IEEE 802.15.4 - MAC Layer
- Carrier Sensing Multiple Access with Collision Avoidance
- Send Data Through a Channel
  - Sender picks random delay
  - Clear Channel Assessment CCA operation
  - Transmit if idle
  - Choose new backoff delay else

IEEE 802.15.4a MAC

- Inherits the same Strategy as 802.15.4
- Different Channel Access: ALOHA
  - Carrier sense multiple access with collision detection
  - Multi-user interference robustness
  - Good throughput for light and medium traffic load
- Time Hopping Scheme
  - Additionally
  - Different delay on each burst
  - Reduced Collisions

Ranging in IEEE 802.15.4a

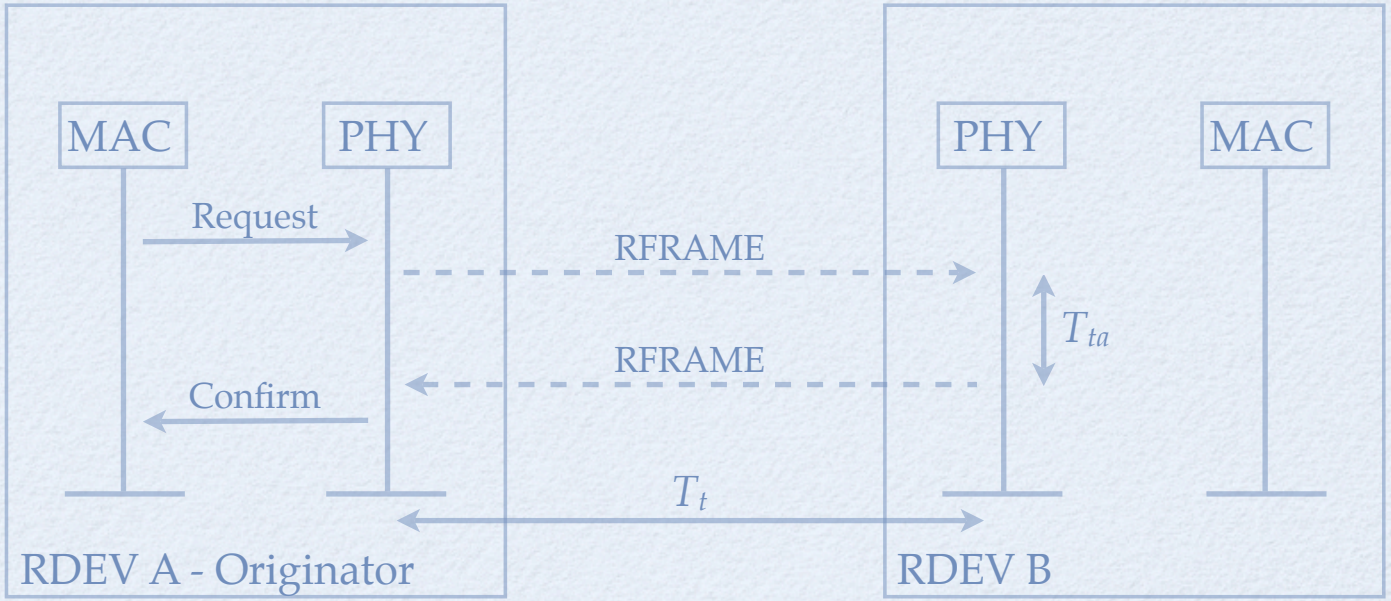
- Determine Distance Between Devices
- Accuracy Depends on Frequencies
  - 500 MHz channels - 1 meter
  - Precision proportional to bandwidth
- Basic Standard Definitions

  RDEV X ... Ranging Device X

  RFRAME ... Ranging Frame

Basic Ranging

- Two Way Message Exchange
  - Approximately $T_r = 2\ T_t + T_{ta}$

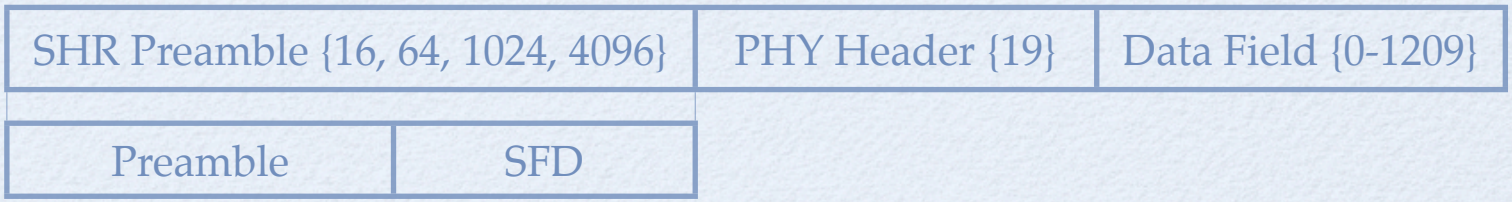


Precision Ranging

- Main Problems
  - Multipath propagation and non line-of-sight
  - Multi users interference
- Challenge
  - Detect first peak of the signal
- Arriving Signals
  - Need only the first peak
  - Not necessarily the strongest due to superposition
- Solution: Preamble

Packet Structure

- Packet Definitions
  - SHR ... Synchronization header
  - SFD ... Start of frame delimiter

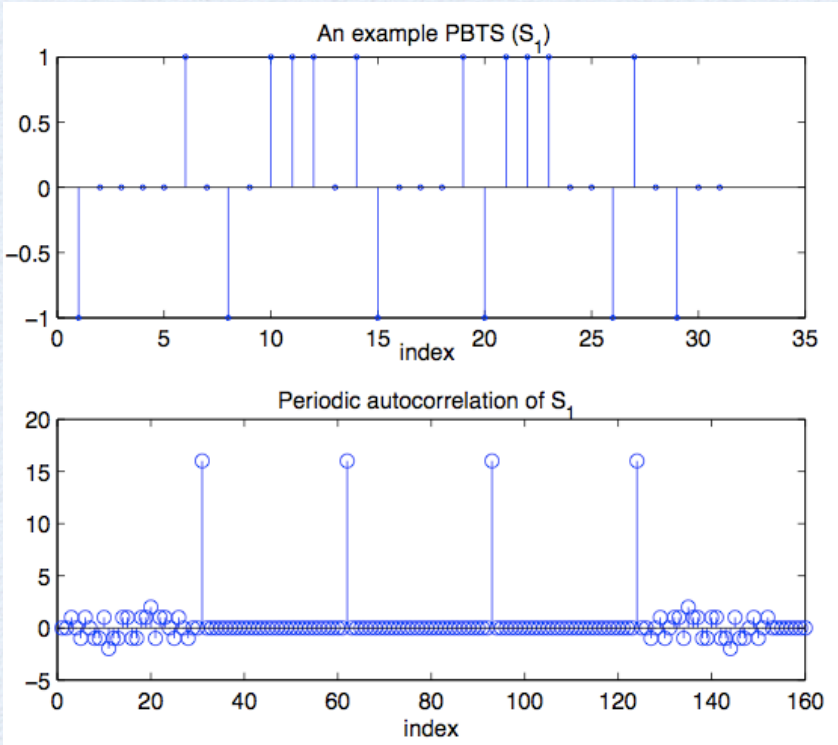


Synchronisation

- Precautions for Transmission
  - Acquire channel, synchronize, and channel estimation
  - Detectable by both receiver types
- Perfectly Balanced Ternary Sequences
  - Length 31 or 127
  - Side-lobes of the periodic auto-correlation are zero
  - Standard defines eight preamble symbols S_1 - S_8

Example Sequence

- S_1: -0000+0-0+++0+-000+-+++00-+0-00



Packet Preamble

- Length of Preamble
  - 16, 64, *1024*, or 4096 symbols
  - Depends on application requirements
  - Capabilities of the RDEVs - (non)coherent Receiver
- Symbols with Length 31
  - S_1 - S_8 mentioned before (periodic autocorrelation)

Preamble Waveform

$$w(t) = \sqrt{\frac{E_s}{N_s}} \sum_{j=0}^{L-1} \mathbf{S}[j]\phi(t - jT_{pri})$$

$$P(t) = \sum_{n=0}^{N_{sym}-1} \mathbf{N}[n]w(t - nT_{sym})$$

$\phi(t)$	...	Transmitted UWB pulse waveform
T_{sym}	...	Symbol duration
N_{sym}	...	Number of symbol repetitions
N_s	...	Pulses per symbol
E_s	...	Energy per symbol
$S_i[j]$	...	j^{th} element in S_i
N	...	$[1\ 1\ \ldots\ 1]_{\{1 \times Nsym\}}$

Frame Delimiter

- End of Preamble
  - T_{ta} accuracy depends on detection
- 8 Symbols or 64 Symbols
  - High and medium data rate (1Mbps) or
  - Low data rate (106Kbps)
- SFD Waveform
  - Outer Sequences

Waveform

- Bases on *w(t)*

$$Z_i(t) = \sum_{m=0}^{L_{sfd}-1} \mathbf{M}[m] w_i(t - mT_{sym})$$

- Entire SHR Waveform

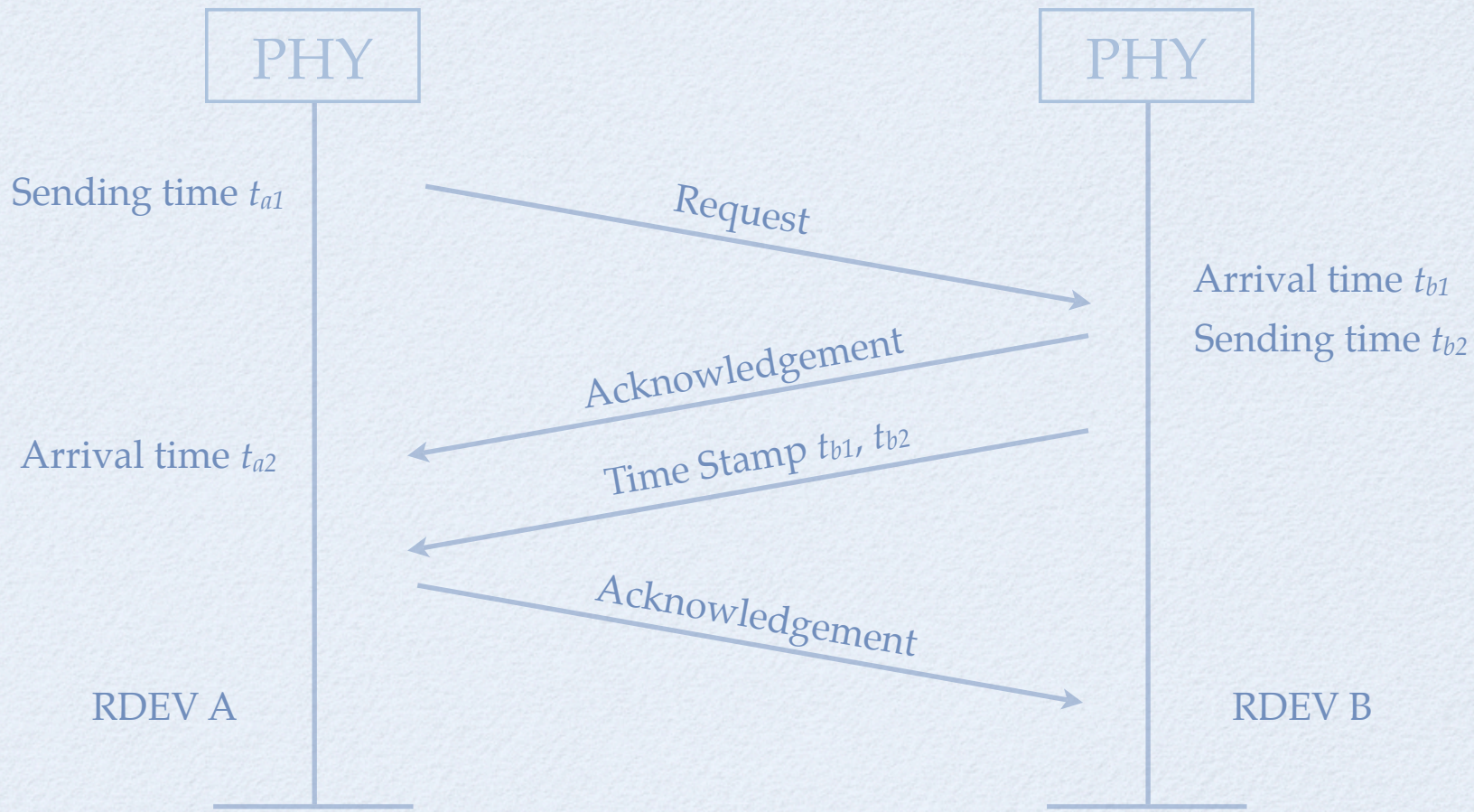
$$Y_i(t) = P_i(t) + Z_i(t - N_{sym}T_{sym})$$

- ***M[m]*** outer sequence
  - 0+0–+00–0+0–+00—00+0–0+0+000–0 –0–00+0—0–+0000++00—+–++0000++

Ranging Protocols

- Adopts Two-Way Time-of-Arrival
- Three Different Protocols
  - Mandatory Ranging
  - Optional Symmetric Double Sided TW TOA
  - Optional Privat Ranging

Mandatory Ranging



Mandatory Ranging

- Information Transmission
  - RDEV B detects request's SFD marker arrival time t_{b1}
  - RDEV B detects first acknowledge sending time t_{b2}
  - RDEV B sends t_{b1} and t_{b1} with the Time Stamp Report
- Both Values Instead of Difference
  - Provide additionally flexibility
- Oscillator Frequency Differences
  - Optionally transmitted in the Time Stamp Report

Optional Protocols

- Optional Symmetric Double Sided TW-TOA
  - Reduces effect of finite crystal tolerances e_A and e_B
- Optional Private Ranging Protocol
  - Exchanges sequence information before actual ranging
  - Authentication - Ranging
  - Snooper attacks, impostor attacks, and jamming attacks
  - No crypto - just make attack more difficult

Conclusion

- Framework for Low Data Transmission
  - Bases on IEEE 802.15.4 - introduces Ultra Wide Band
  - Different channels with bandwidth > 500MHz
  - Typically for sensor networks
- Non-Coherent and Coherent Receivers
- Ranging Capability
  - Location aware network nodes
  - Requirement for applications

References

A. Molisch, P. Orlik, Z. Sahinoglu, and J. Zhang, “UWB-based sensor networks and the IEEE 802.15.4a standard - a tutorial,” in International Conference on Communications and Networking in China, CHINACOM, Oct. 2006, pp. 1–6.

IEEE, Approved Draft Amendment to IEEE Standard for Information technology-Telecommunications and information exchange between systems-PART 15.4:Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs): Amendment to add alternate PHY (Amendment of IEEE Std 802.15.4), IEEE Std. P802.15.4a/D7, Januari 2007.

L. De Nardis and M.-G. Di Benedetto, "Overview of the IEEE 802.15.4/4a standards for low data rate Wireless Personal Data Networks," 4th Workshop on Positioning, Navigation and Communication 2007 (WPNC'07), March 22 2007, Hannover, Germany, pp. 285 - 289.

Z. Sahinoglu and S. Gezici, “Ranging in the IEEE 802.15.4a standard,” in IEEE Wireless and Microwave Technology Conference, WAMICON, Dec. 2006.

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