Using DecaWave UWB Transceivers for High-accuracy Multipath-assisted Indoor Positioning

Josef Kulmer, Stefan Hinteregger, Bernhard Grosswindhager, Michael Rath, Mustafa S. Bakr, Erik Leitinger, and Klaus Witrisal

Multipath-assisted Indoor Navigation and Tracking

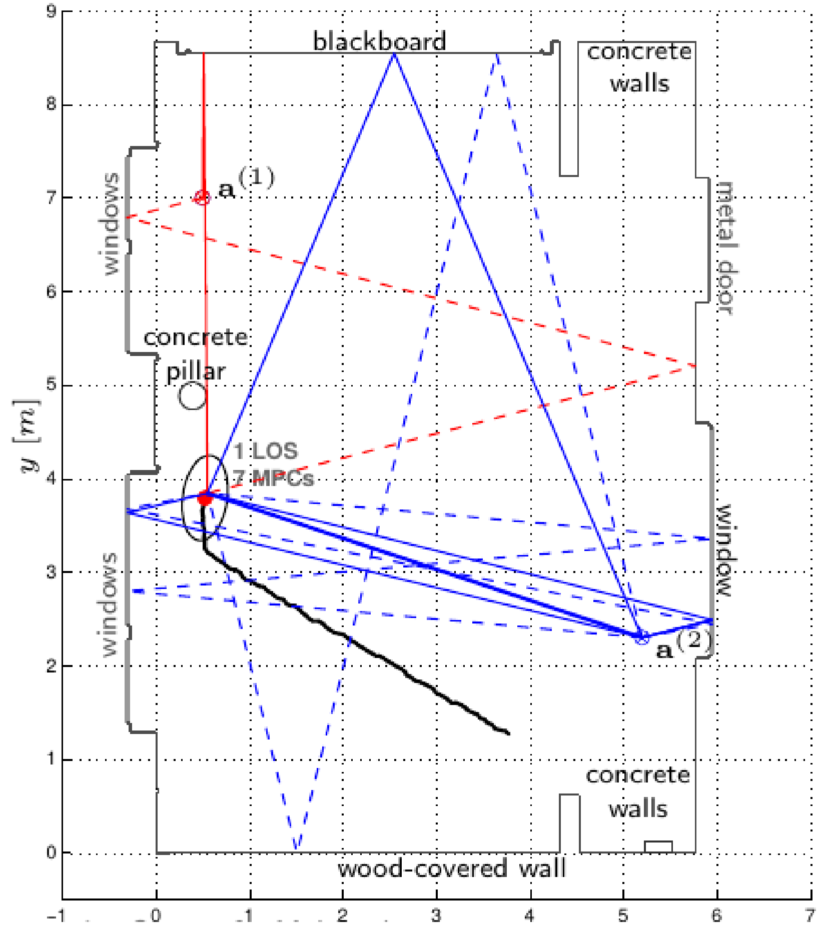
Idea

- Sensor nodes with known position at $\mathbf{a}$ and unknown positions at $\mathbf{p}$
- estimate agent position using range information in channel impulse response from *reflected* multipath

$$r(t) = \sum_k \alpha_k s(t - \tau_k)$$

Benefits:

- less anchor nodes
- more redundancy, i.e. robustness in NLOS
- higher accuracy



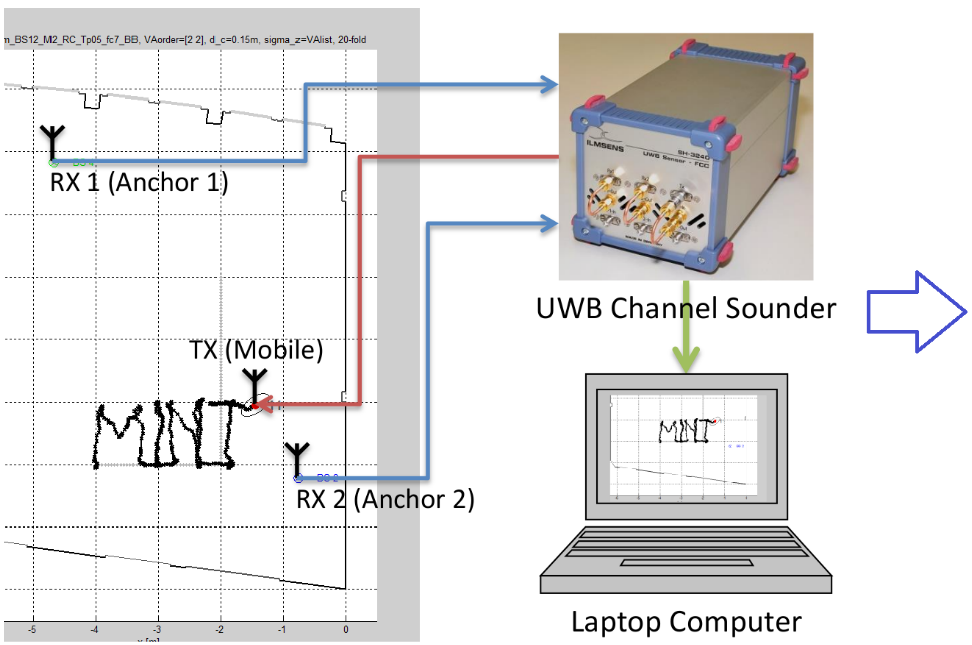
[J Kulmer, E Leitinger, P Meissner, S Hinteregger, K Witrisal, "Cooperative indoor localization using multipath channel information" in ICL-GNSS 2016]

[Meissner, Steiner, Witrisal, "UWB Positioning with Virtual Anchors and Floor Plan Information," in WPNC, Dresden, March 2010.]

Ultrawide-band measurements (1)

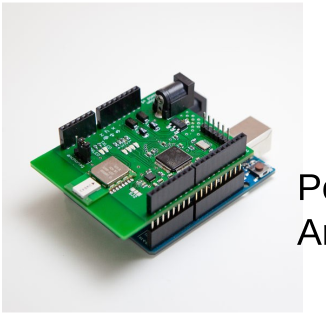
Replace lab-grade measurement equipment by low-cost hardware Decawave DW1000

- Implemented in various platforms
- Low price (25€)



Decawave EVK1000

Sequitur: DW1000 + Raspberry Pi



Pozyx: DW1000 + Arduino

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Ultrawide-band measurements (2)

Capabilities of the DecaWave DW1000

- Supports various IEEE 802.15.4 (2001) Channels
- Ranging accuracy of 10 cm
- Internal buffer with measured channel impulse response

Research question

- can we perform multipath-assisted indoor navigation on low-cost UWB transmitters or will it remain purely academic?

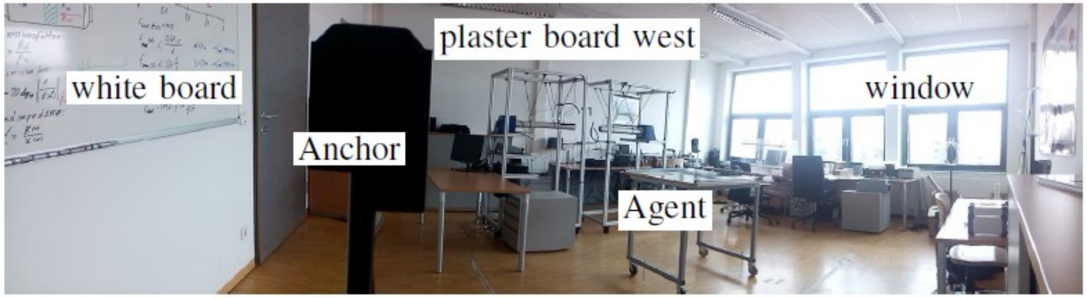
Analysis of the DecaWave DW1000

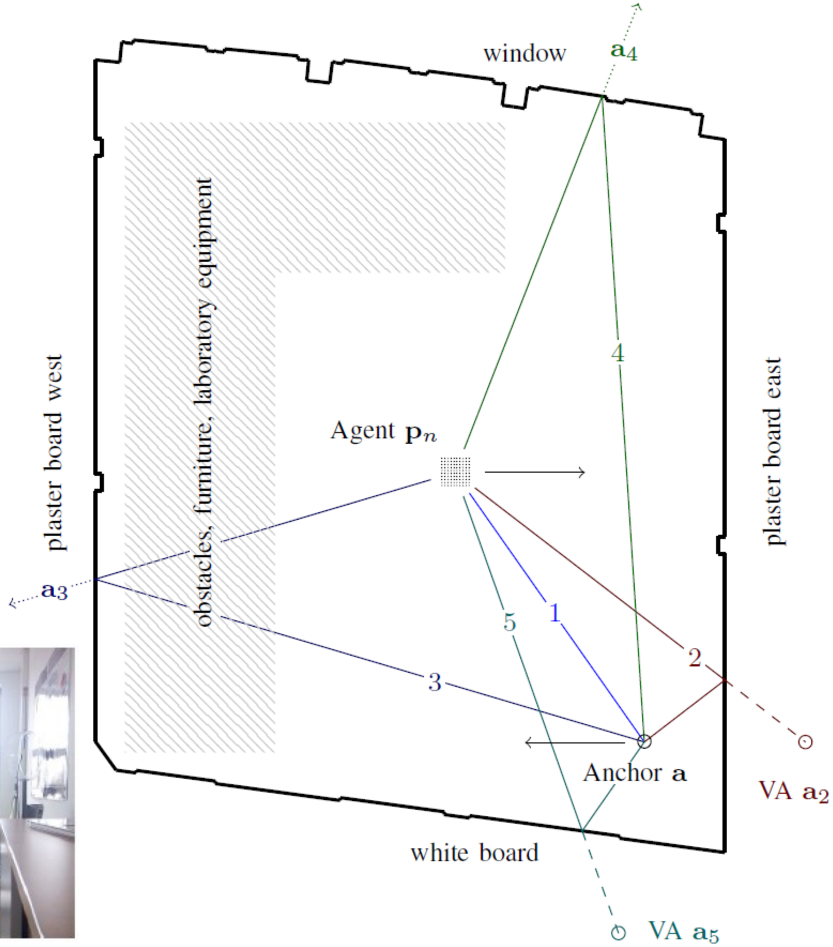
- Synchronization accuracy between nodes
- Analysis of the pulse shape in the received signal in time and frequency domain
- Comparison to lab-grade correlative channel sounder

Analysis of the DecaWave DW1000 (1)

Measurement Setup

- Measurements with both DW1000 and Ilmsens Channel Sounder
- Analysis of selected (blocked, overlapping) MPCs



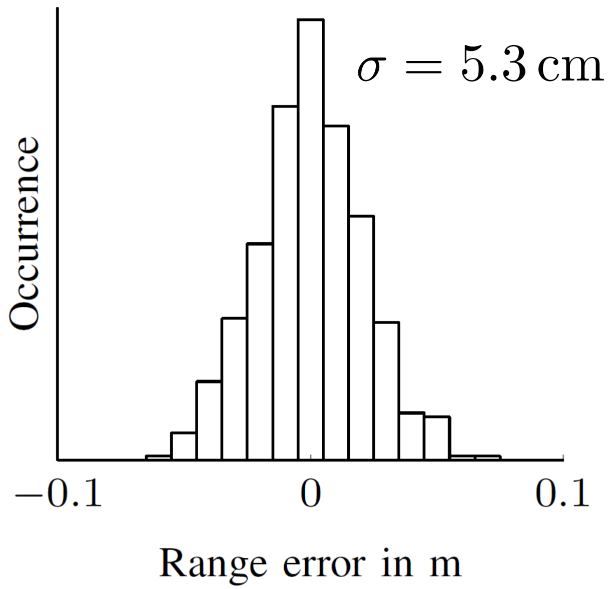


Analysis of the DecaWave DW1000 (2)

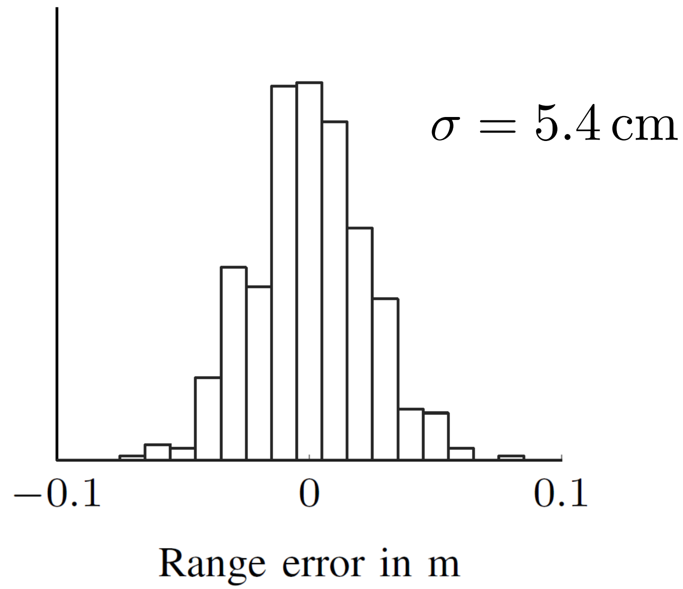
Synchronization accuracy between nodes

- Nodes synchronize each other by exchanging timestamps
- Employ timestamps for ranging $c\,t_{\mathrm{DW}}$

IEEE 802.15.4 Channel 2
(4 GHz, BW: 500 MHz)



Channel 4
(4 GHz, BW: 900 MHz)



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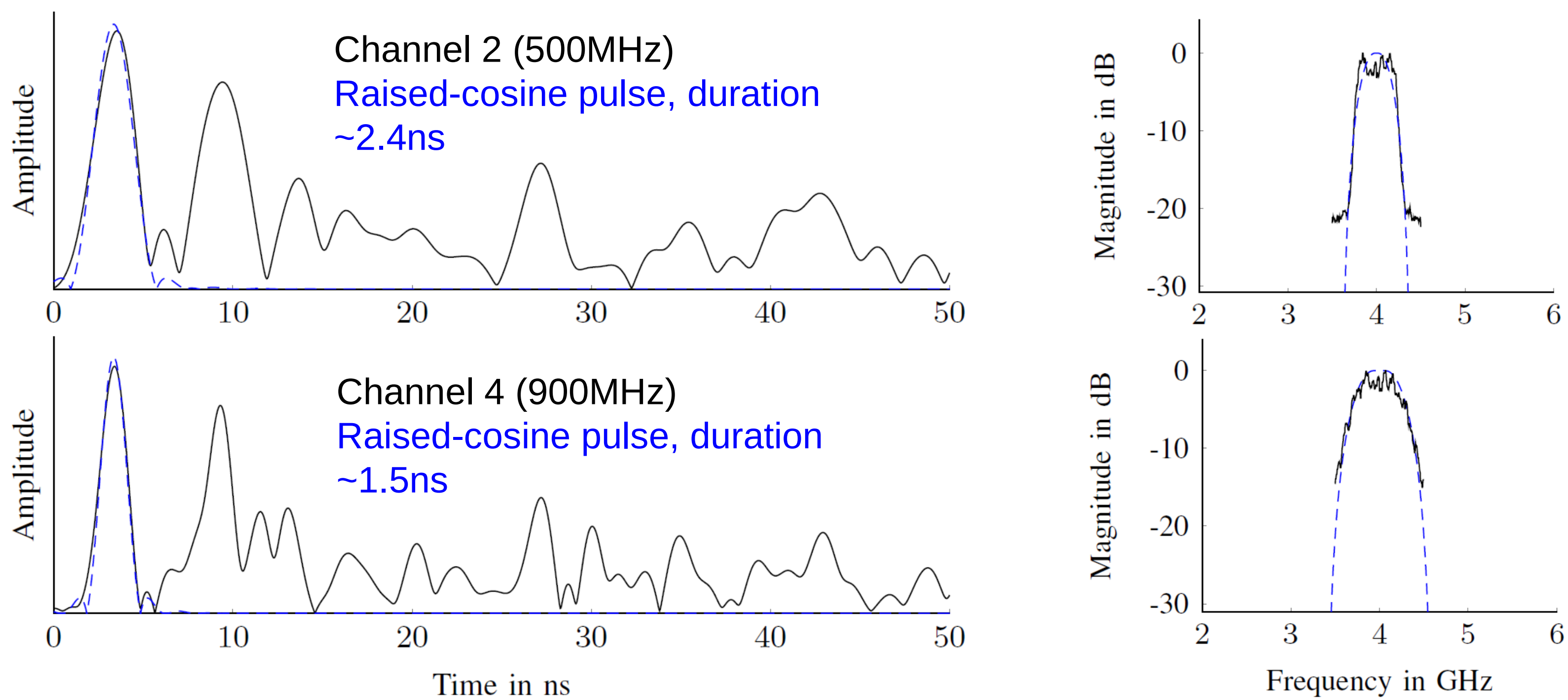
Analysis of the DecaWave DW1000 (3)

Analysis of pulse shape of measured signal by DW1000

- Pulse shape $s(t)$ not standardized
- Depends on RF-filters, antenna transfer function
- Approximation as raised-cosine pulse



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Comparison with laboratory equipment IlmSense Channel Sounder

Evaluation of

- The ability to resolve multipath components (MPCs)
- The impact of clock synchronization

Reliability of MPCs

- Signal-to-interference-plus-noise ratio SINR of selected MPCs
- SINR relates MPC path energy to interfering diffuse multipath and AWGN

Comparison with laboratory equipment

SINR values in dB

Aligned according to (a) DW1000 $r_{(a)}(t) = r(t - t_{\mathrm{LOS}} + t_{\mathrm{DW}})$

or (b) *true* range $r_{(b)}(t) = r(t - t_{\mathrm{LOS}} + \|\mathbf{p} - \mathbf{a}\|/c)$

MPC	DecaWave DW1000				Channel Sounder		Avg. distance
	Channel 2		Channel 4				
	a)	b)	a)	b)	$T_\mathrm{p} = 2.4\,\mathrm{ns}$	$T_\mathrm{p} = 1.5\,\mathrm{ns}$	
LOS	19.6	19.9	21.5	22.4	21.9	23.3	3.3 m
plaster board east	3.2	3.7	−2.7	−2.2	−0.2	4.6	4.4 m
plaster board west	−4.1	−2.3	*nan*	*nan*	−0.7	−2.7	9.5 m
white board	8.6	8.6	11.5	11.8	9.9	13.2	4.9 m
window	7.0	8.3	5.8	6.7	1.8	3.3	10.5 m

- DW1000 and Channel Sounder reach similar levels
- Synchronization accuracy can be neglected $(\sigma = 5\,\mathrm{cm} \ll 45\,\mathrm{cm} = cT_\mathrm{p})$
- LOS reaches high values due to temporal isolation
- White board and window are still promising for positioning

Single-anchor indoor positioning

DW1000 measures range between nodes t_{DW} and CIR $\mathbf{r}$

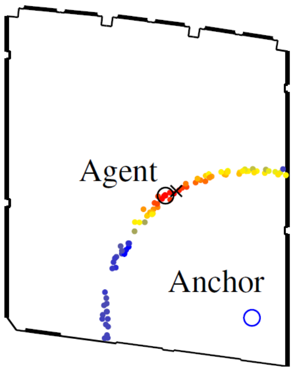
AWGN model $\mathbf{r} = \sum_k \alpha_k \mathbf{s}(\tau_k) + \mathbf{w} = \mathbf{S}(\boldsymbol{\tau})\boldsymbol{\alpha} + \mathbf{w}$

Log likelihood $\ln p(\mathbf{r}|\boldsymbol{\alpha}, \boldsymbol{\tau}) \propto -\|\mathbf{r} - \mathbf{S}(\boldsymbol{\tau})\boldsymbol{\alpha}\|^2$

Using geometric floorplan model $\hat{\mathbf{p}} = \mathrm{argmax}_{\mathbf{p} \in \mathcal{P}} p(\mathbf{r}|\mathbf{p})$

Monte Carlo sampling on a circle around the anchor $\mathbf{a}$

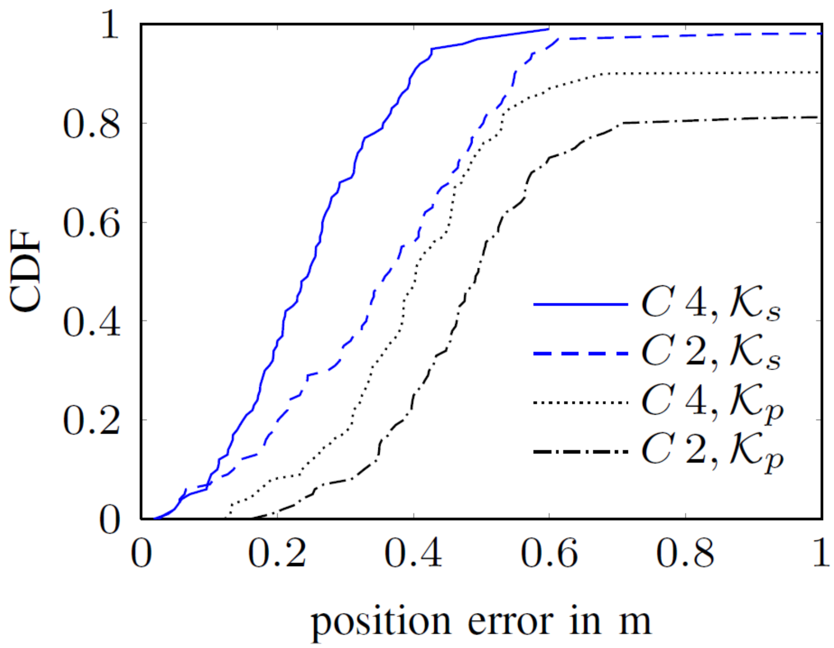
$$d^{(i)} \sim \mathcal{N}(c t_{\mathrm{DW}}, \sigma^2)$$
$$\phi^{(i)} \sim \mathcal{U}(0, \pi)$$
$$\mathbf{p}^{(i)} = [d^{(i)} \cos(\phi^{(i)}), d^{(i)} \sin(\phi^{(i)})]^T + \mathbf{a}$$



Positioning performance

Position estimation at 100 different positions

Channel 4 (900 MHz) outperforms Channel 2 (500 MHz)



Consider MPCs from floorplan

Consider MPCs with high SINR

- Improves robustness

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Summary

Reflected signals can be approximated by raised-cosine pulse

Synchronization errors are neglectable

Achieved SINR values are comparable to measurement equipment

Reflected MPCs can be used for positioning

- Demonstration of single-anchor positioning using capabilities of the DW1000
- Higher bandwidth increases accuracy
- Data and implementation are provided online

http://www2.spsc.tugraz.at/people/s0773094/dw