Multiuser Positioning

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DLR: www.dlr.de/kn

WHERE2 Project: www.ict-where2.eu

Motivation: Indoor Navigation

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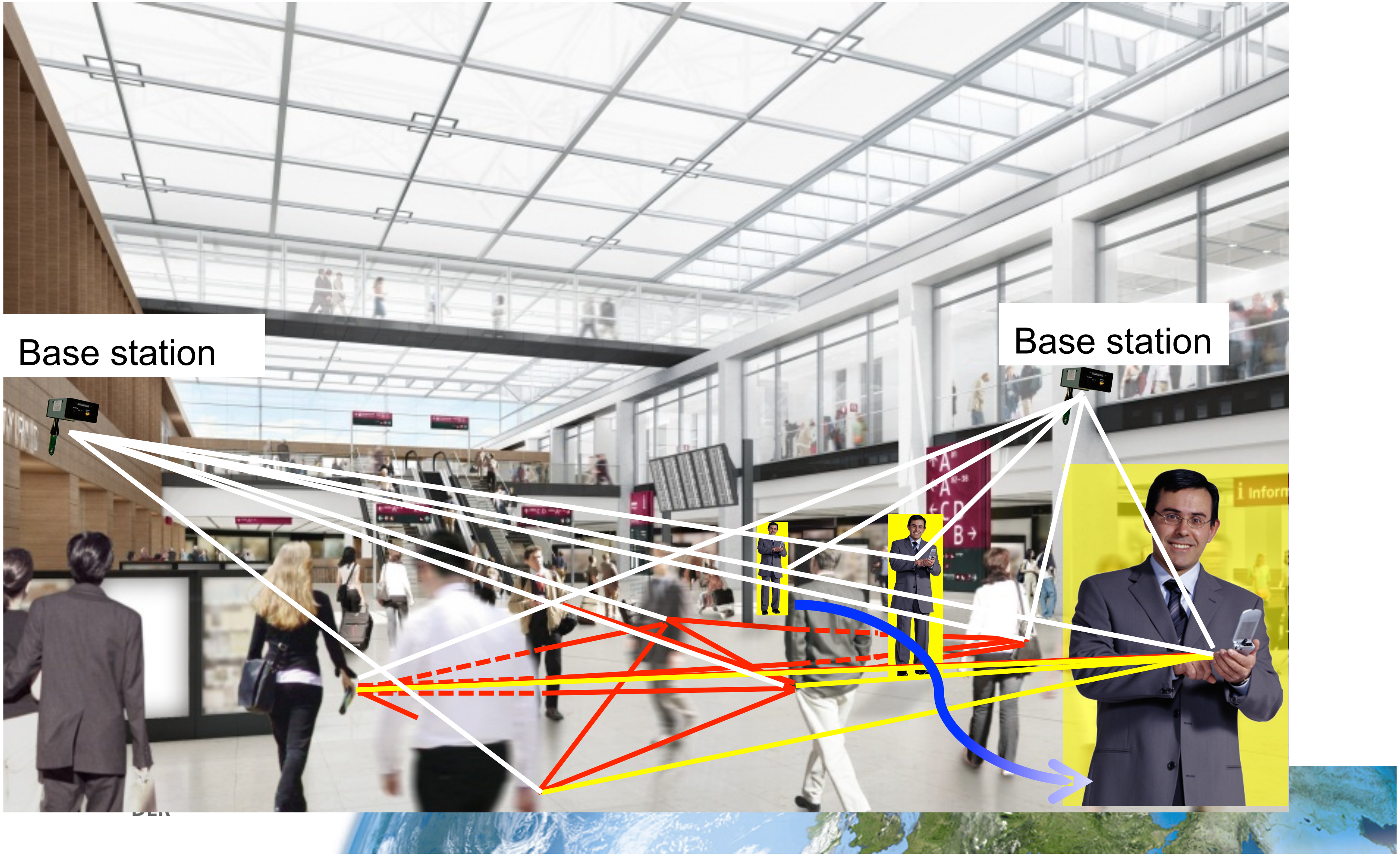
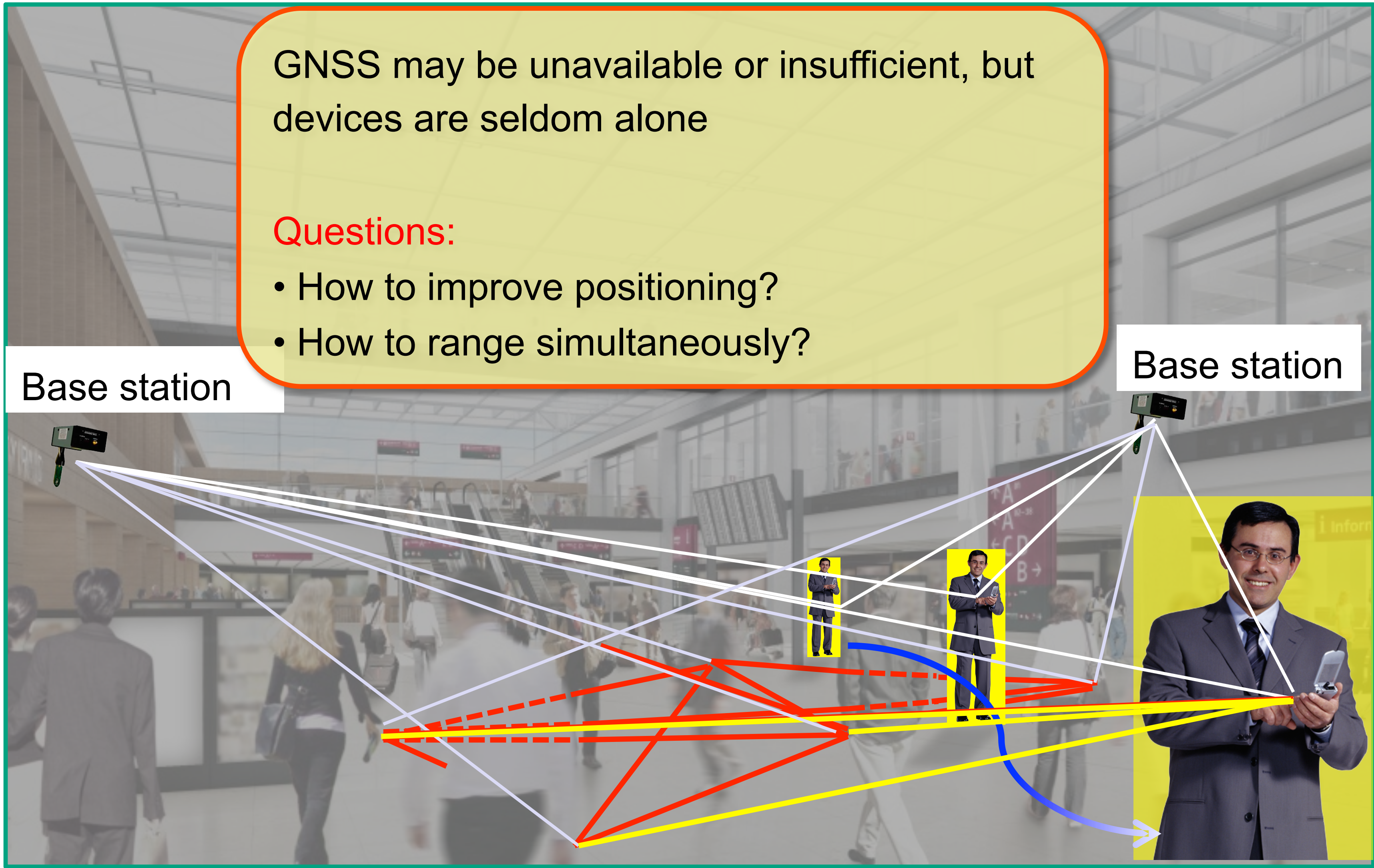


Motivation: Indoor Navigation

GNSS may be unavailable or insufficient, but devices are seldom alone

Questions:

- How to improve positioning?
- How to range simultaneously?



Outline

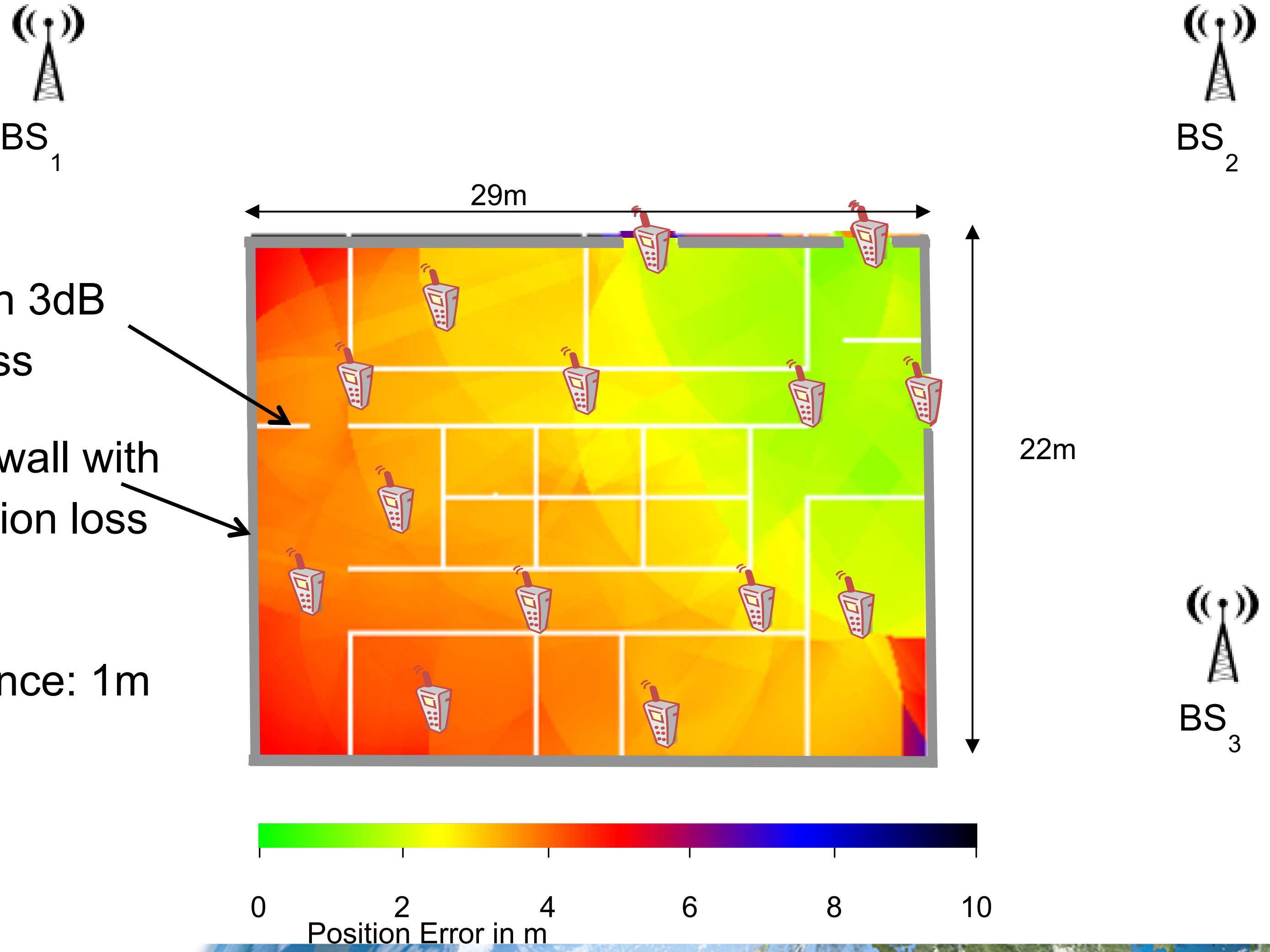
- Motivation
- **Cooperative positioning and related work**
- Multicarrier Ranging and Positioning Cramer-Rao Lower Bound
- Multiuser positioning concept
- Measurement evaluation
- Conclusions & Outlook

Cooperative Positioning: Deep Indoors

Office wall with 3dB penetration loss

Core building wall with 10dB penetration loss

Ranging variance: 1m



Related Work

Multicarrier Ranging (Luise et al. [2009])

Coop. Pos. with link selection in WSN (Wymeersch et al. [2012])

Communication Standards – Device-2-Device:

- WiFi-direct (Android [today])
- LTE-direct (R12 discussion)

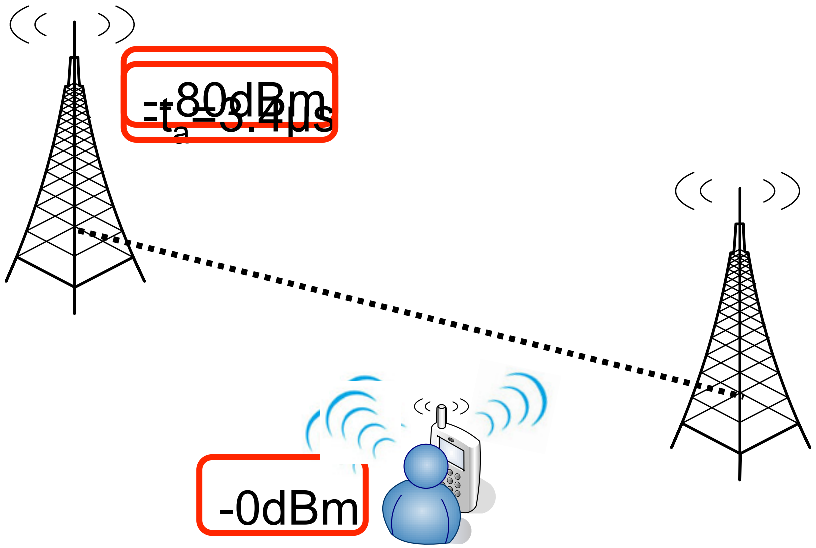
- **Resource Allocation in Coop. Pos.**
- **Multiuser D2D Ranging**

Ranging →Measuring the Wireless Channel

- **Received Signal Strength (RSS)**
  - Corrupted by the propagation effects
- **Time of Arrival (TOA)**
  - Requires synchronization between transmitter and receiver

$$p = \alpha - 10\beta \log(d)$$

$$t_a = t_d + \frac{d}{c}$$



Cramér-Rao Lower Bound (CRLB) for Ranging and Positioning with Multicarrier Signals

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System Model

- Distance between cooperating node and node of interest 1:

$$d = \|\boldsymbol{x}_1 - \boldsymbol{x}\| = \sqrt{(x_1 - x)^2 + (y_1 - y)^2}$$

- OFDM Signal: $s(t) = \frac{1}{\sqrt{N}} \sum_{n=-N/2}^{N/2} S_n e^{j2\pi n f_{sc} t}$

- Received signal under line-of-sight conditions (single slope path loss model):

$$r(t) = a_0 \left(\frac{d}{d_0}\right)^{-\gamma/2} s\left(t - \frac{d}{c_0}\right) + z(t)$$

- S_n is the n'th signal sample of the transmitted multicarrier signal
- n subcarrier index
- f_{SC} subcarrier spacing
- N number of subcarriers
- γ attenuation / path loss exponent (γ = 2 for free space)
- a_0 path loss at the reference distance d_0
- z Gaussian thermal noise
- c_0 speed of light

Joint CRLB TOA and Received Signal Strength

- CRLB(TOA) = $\sigma^2 / \frac{f_{SC}^2}{2 f_c^2 d^2} \sum_{n=-N/2}^{N/2} n^2 |S(n)|^2$
- CRLB(RSS) = $\sigma^2 / \frac{c_0^2}{8 \pi^2 f_c^2 d^4} \sum_{n=-N/2}^{N/2} |S(n)|^2 (f_{SC}^2 (N+1))$
- CRLB(RSS,TOA) = $\sigma^2 / \frac{c_0^2}{8 \pi^2 f_c^2 d^4} \sum_{n=-N/2}^{N/2} |S(n)|^2 + \frac{f_{SC}^2}{2 f_c^2 d^2} \sum_{n=-N/2}^{N/2} n^2 |S(n)|^2$

- **Subcarrier index**
- **Signal power**
- Bandwidth
- f_C : Carrier frequency

→ **Signal power**

- f_C : Carrier frequency used to include free space path loss

Ranging Bounds for TOA and RSS – Path Loss Integrated

$$J_{TOA} = \frac{2a^2}{\sigma^2}\left(\frac{d}{d_0}\right)^{-\gamma} \frac{4\pi^2 f_{SC}^2}{c^2} \sum_{n=-\frac{N-1}{2}}^{\frac{N-1}{2}} \ldots$$

Fisher Information Matrix

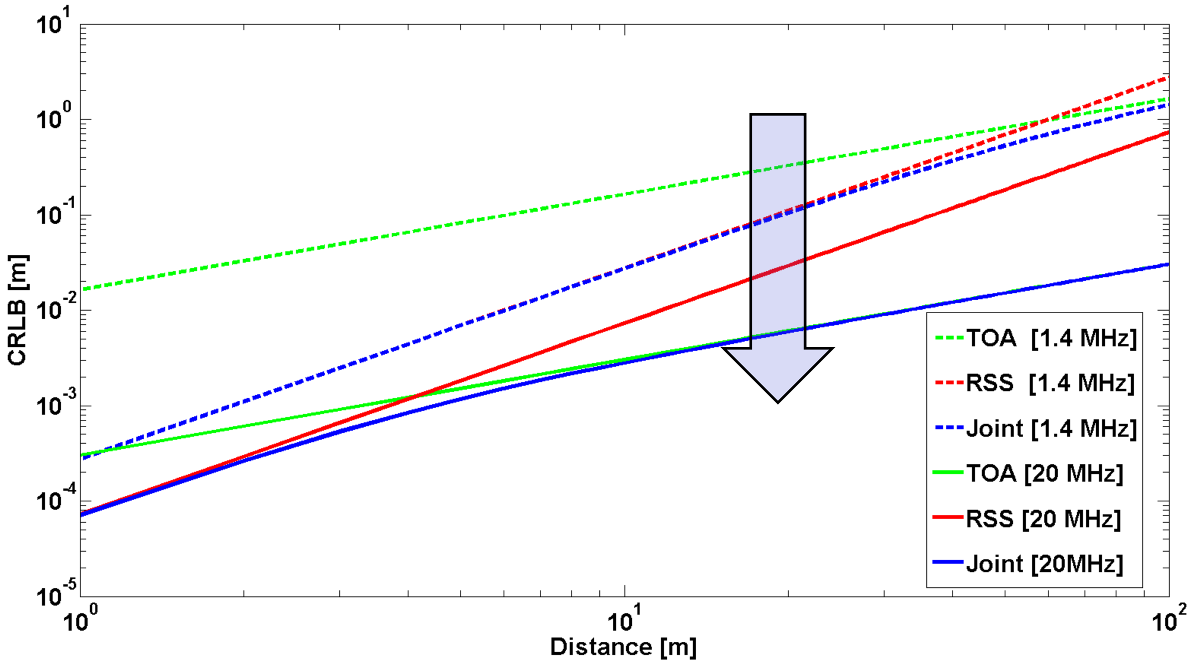
$$J_{RSS} = \frac{2a^2}{\sigma^2}\left(\frac{d}{d_0}\right)^{-\gamma} \frac{\gamma^2}{4d^2} \sum_{n=-\frac{N-1}{2}}^{\frac{N-1}{2}} S[n]^{\ldots}$$

$$J_{Joint} = J_{TOA} + J_{RSS}$$

$$\mathrm{CRLB}_{\mathrm{Joint}} = 1/J_{Joint}$$

Cramer-Rao Lower Bound

Bandwidth affects Ranging CRLB



Different bandwidths:

- **More bandwidth reduces CRLB**

- Parameters:
- $P\downarrow 0 = -30\ dBm/subcarrier$
- $f\downarrow SC = 15\ kHz$
- AWGN channel

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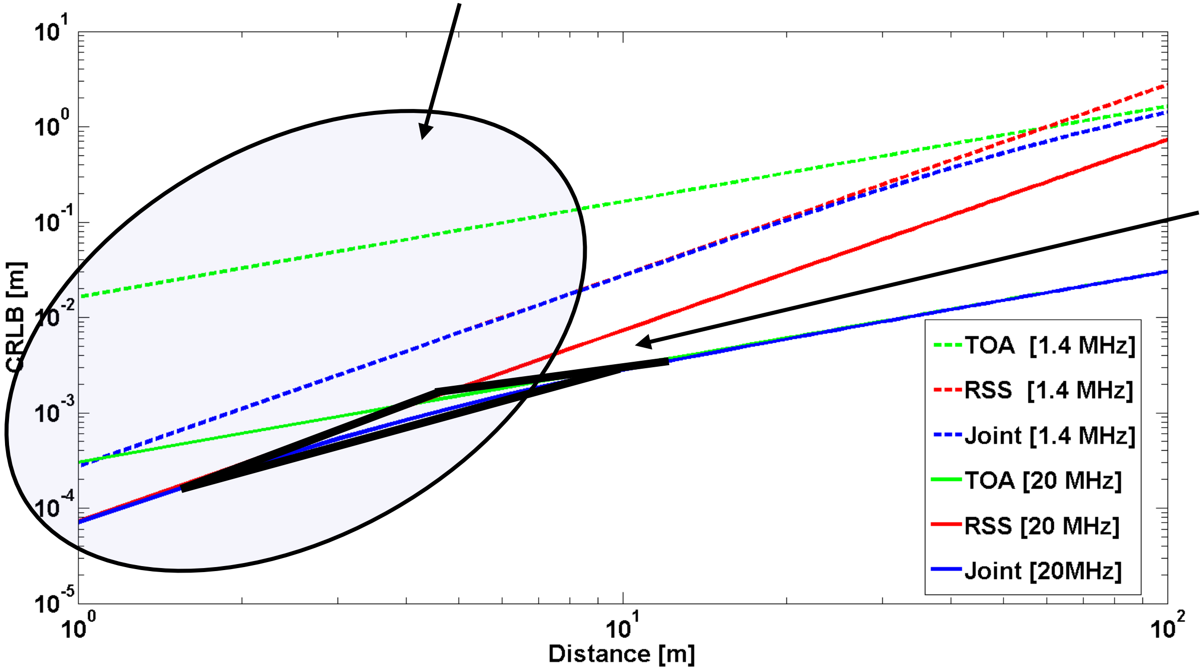
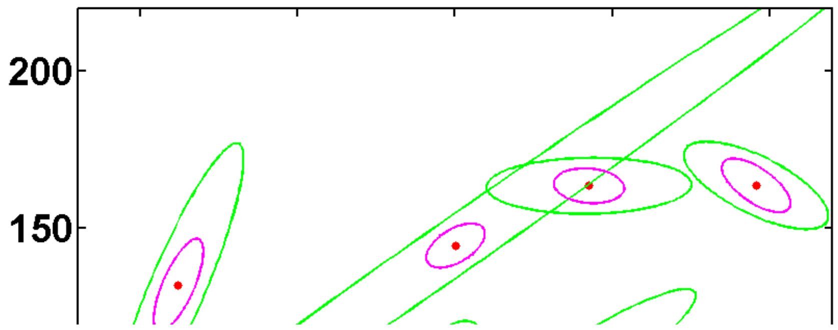
Different Zones of the CRLB

Shorter distances favor RSS estimator → cooperative links!



Triangular zone: Jointly RSS plus TOA – here for 20MHz

CRLB Positioning Bound

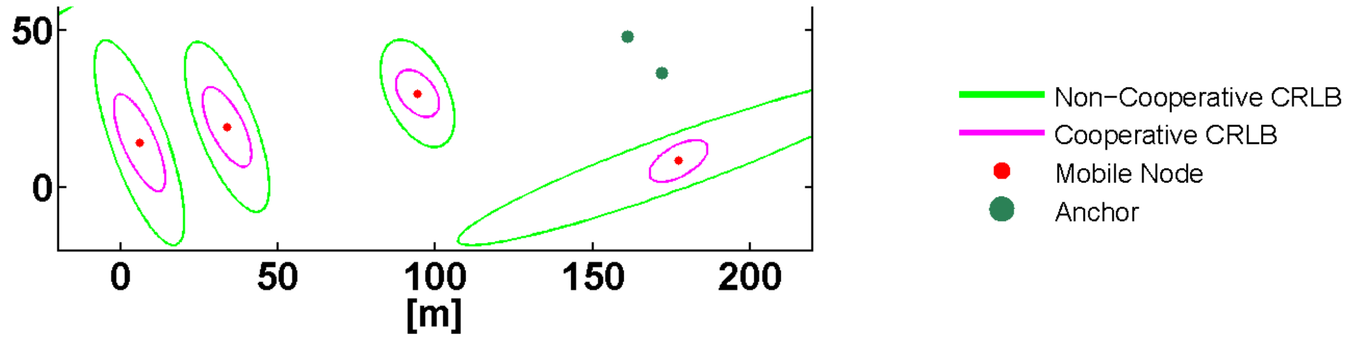


Important aspects:

- Ranging performance
- Geometric constellation

- Mobility and limited ranging increases uncertainty

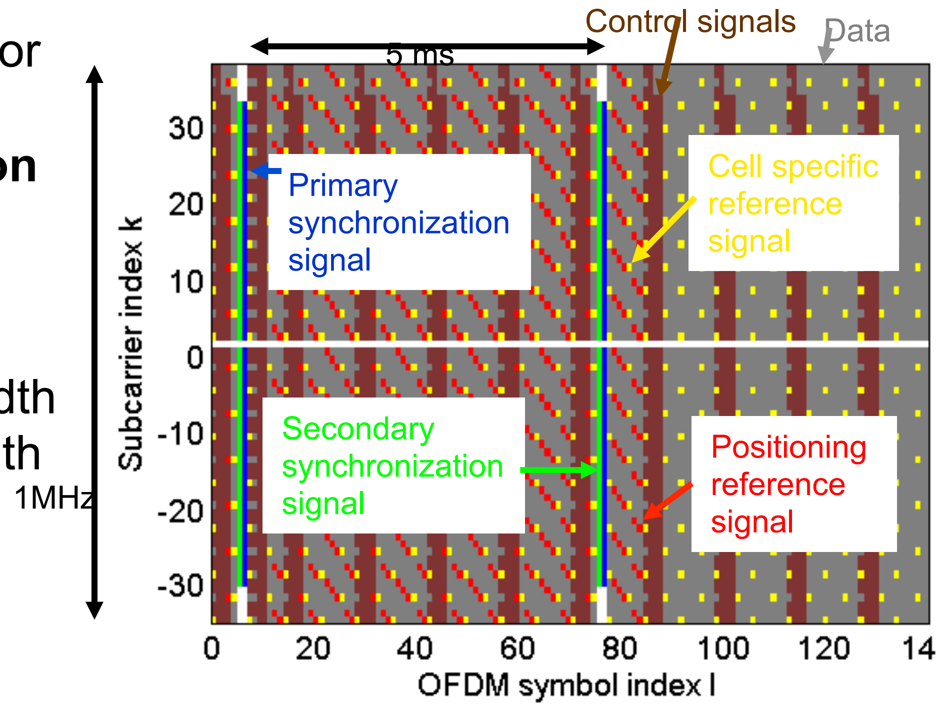
- Simultaneous ranging possible?



DOI10.1002/ett.2572 - Raulefs, Zhang, Mensing: “Bound-based spectrum allocation for cooperative positioning”

LTE Frame Structure

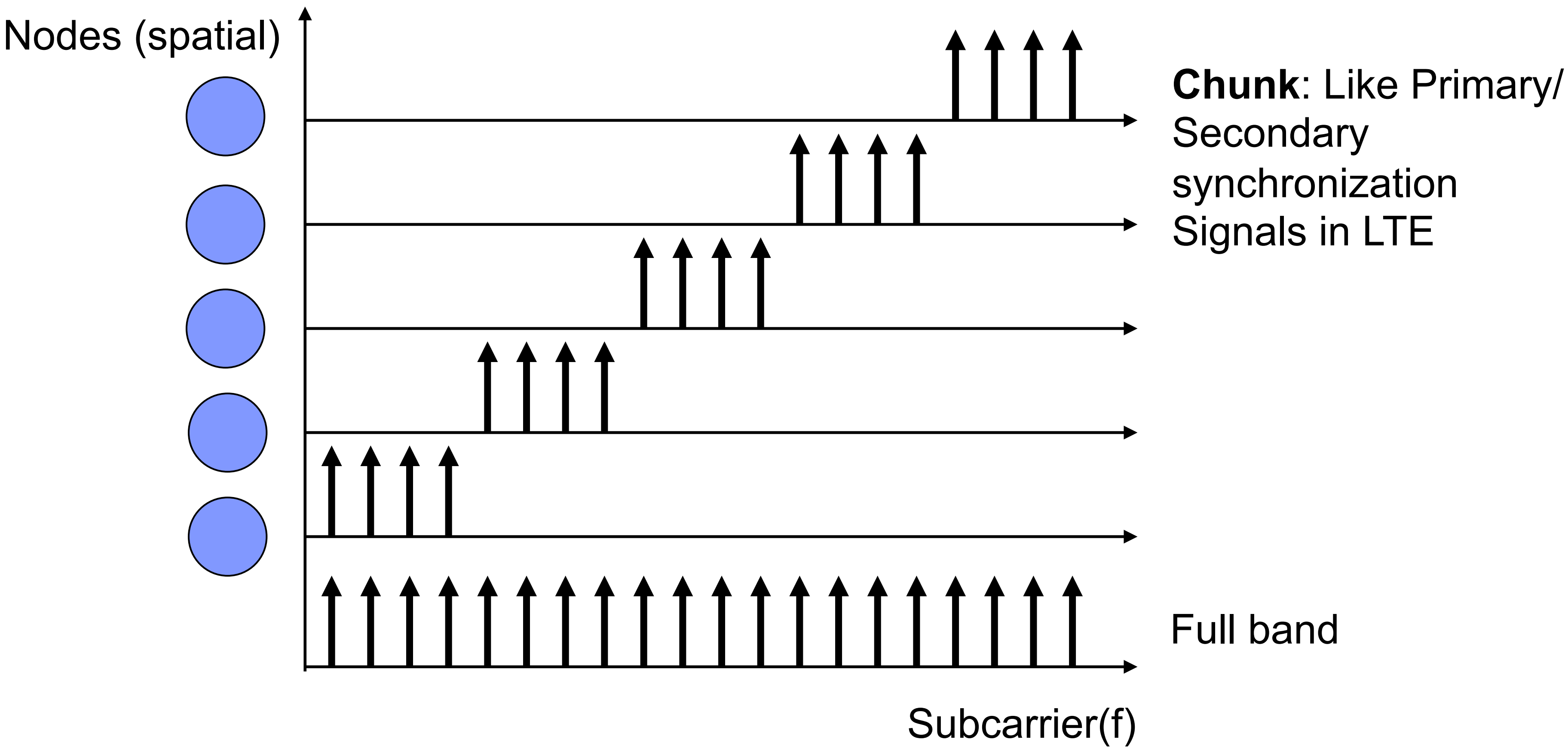
- Todays multicarrier based cellular communication systems, such as LTE, use for synchronization and positioning:
  - Primary and Secondary **synchronization signal**
    → **Chunk** of signals (low bandwidth)
  - **Positioning Reference Signals (PRS)** are scattered over the available bandwidth
    → **Grid** of reference signals (scale with communication load)



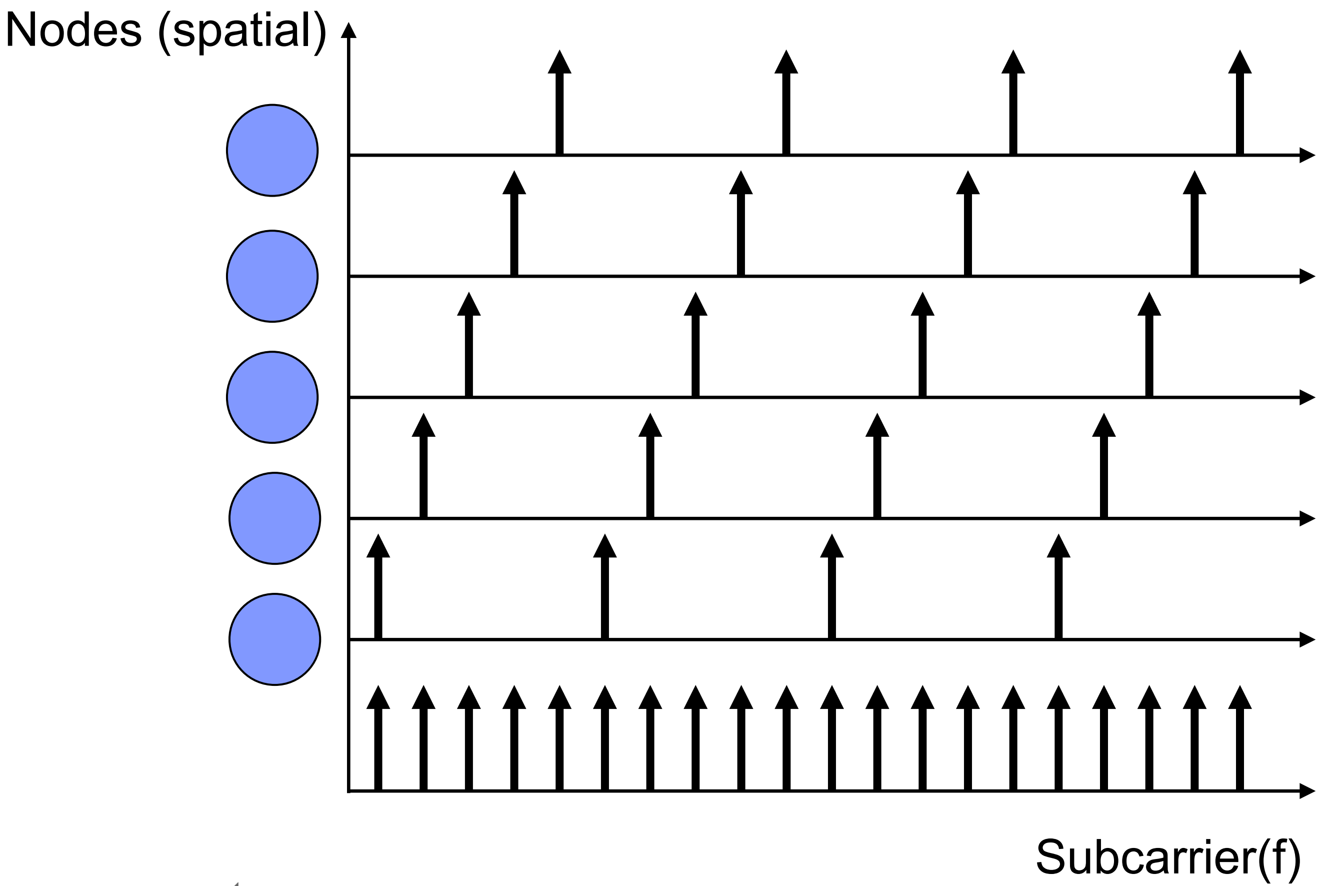
LTE frame structure (10 subframes)

- Can we apply such a scheme to range simultaneously multiple users?
- What is the impact on the CRLB bound in case only limited subcarriers are used?

Multiuser Ranging - Sharing: Spectrum Allocation 1. Chunks



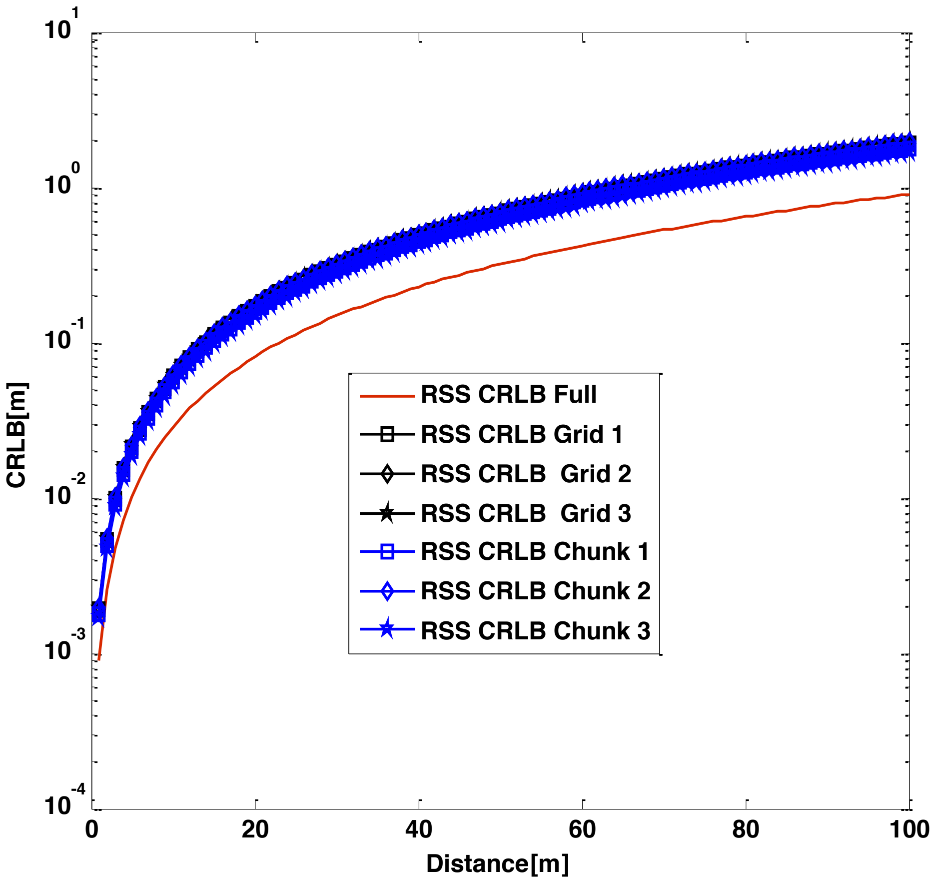
Multiuser Ranging - Sharing: Spectrum Allocation
2. Grid



Grid: Like Positioning Reference Signals (PRS) in LTE

Full band

RSS CRLB with Block Fading Channel



- Block Fading Channel
- **Grid** and **Chunk** scheme perform **similar**
- **Full band** uses **more** signal **power**
- **Channel is known!**

- 1540 subcarriers (grid: every 77th or chunk: 77 subcarriers)

Received Signal Strength Ranging

- Using **distance dependent path loss model** to determine distance

$P(d)=a_0 \ (d_0/d)^{-\gamma}$

- If link budget (TX power, antenna gains, path loss, etc.) is known

→ distance estimation possible

Indoors:

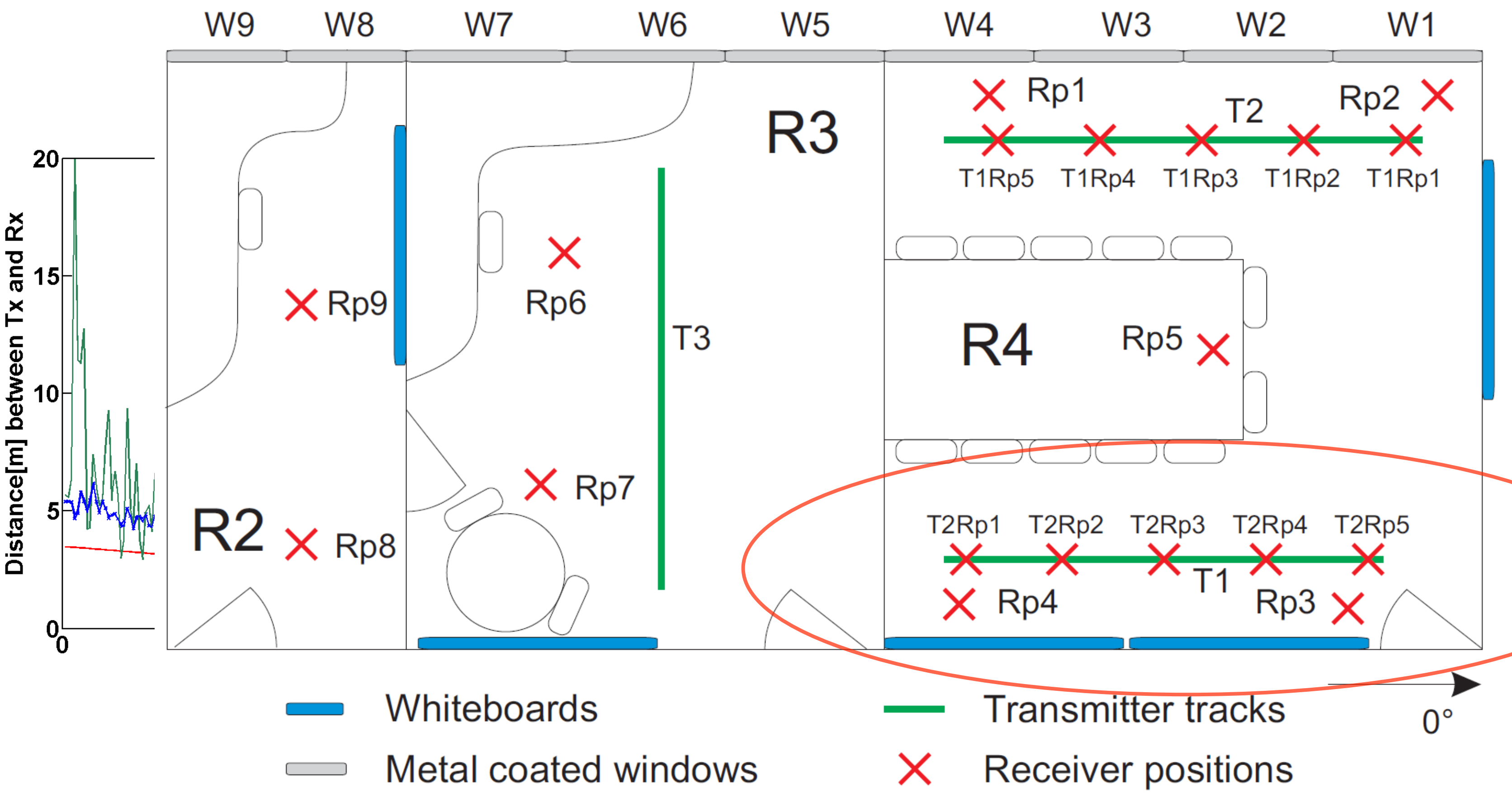
- LoS condition between devices is reasonable
- Short ranges → RSS-CRLB outperforms TOA-CRLB

P_0 : Averaged received power at distance d_0

d: Distance in m

$\gamma=1.13$ Environmental path-loss exponent (determined by measurement campaign)

Received Signal Strength Ranging: Channel Snapshot



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20MHz
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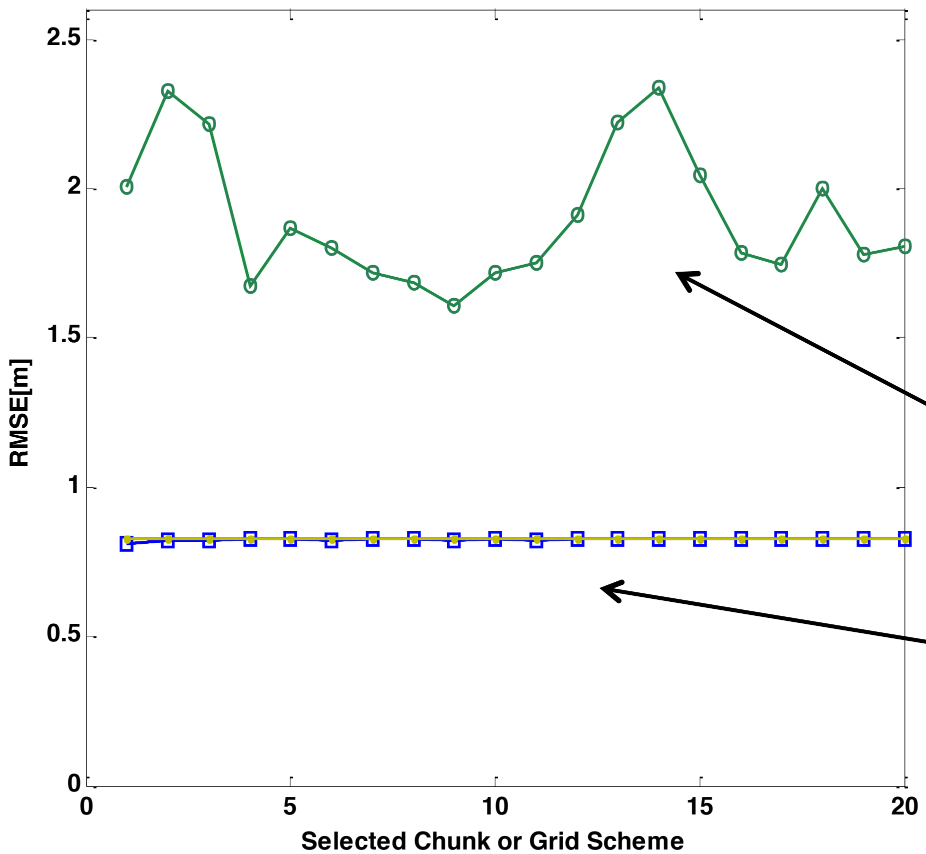
Received Signal Strength Ranging with Real Data



Path loss for single slope model:

$P(d)=a_0 (d_0/d)^{-\gamma}, \gamma=1.13$

120MHz channel bandwidth (1 track)

Chunk: Mismatch compared to the derived path loss model

Grid and **full band** approach fits fairly well (same performance as full band)

Conclusions

- **Cooperative positioning** improves performance significantly (esp. indoors)
- Received signal strength (**RSS**) is a simple **non-synchronous** scheme **ranging scheme**
- **Multiuser positioning** concept:
    - Frequency division **multiple access**
    - Benefits for **grid** vs. chunk scheme to represent the **broadband path loss model**

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