Model Needs for High-accuracy Positioning in Multipath Channels

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High-accuracy Positioning

Manufacturing

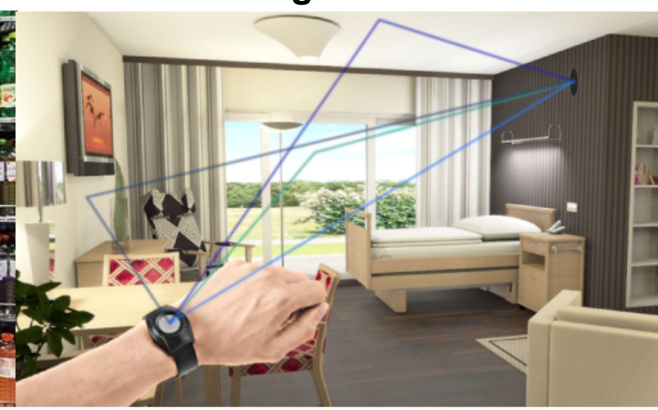
Retail

Autonomous Driving

Logistics

Smart Labeling

Assisted Living



Objectives:
Positioning and navigation; activity recognition; control

Requirements:
Accuracy (5 – 20 cm);
Reliability (90 – 100%)

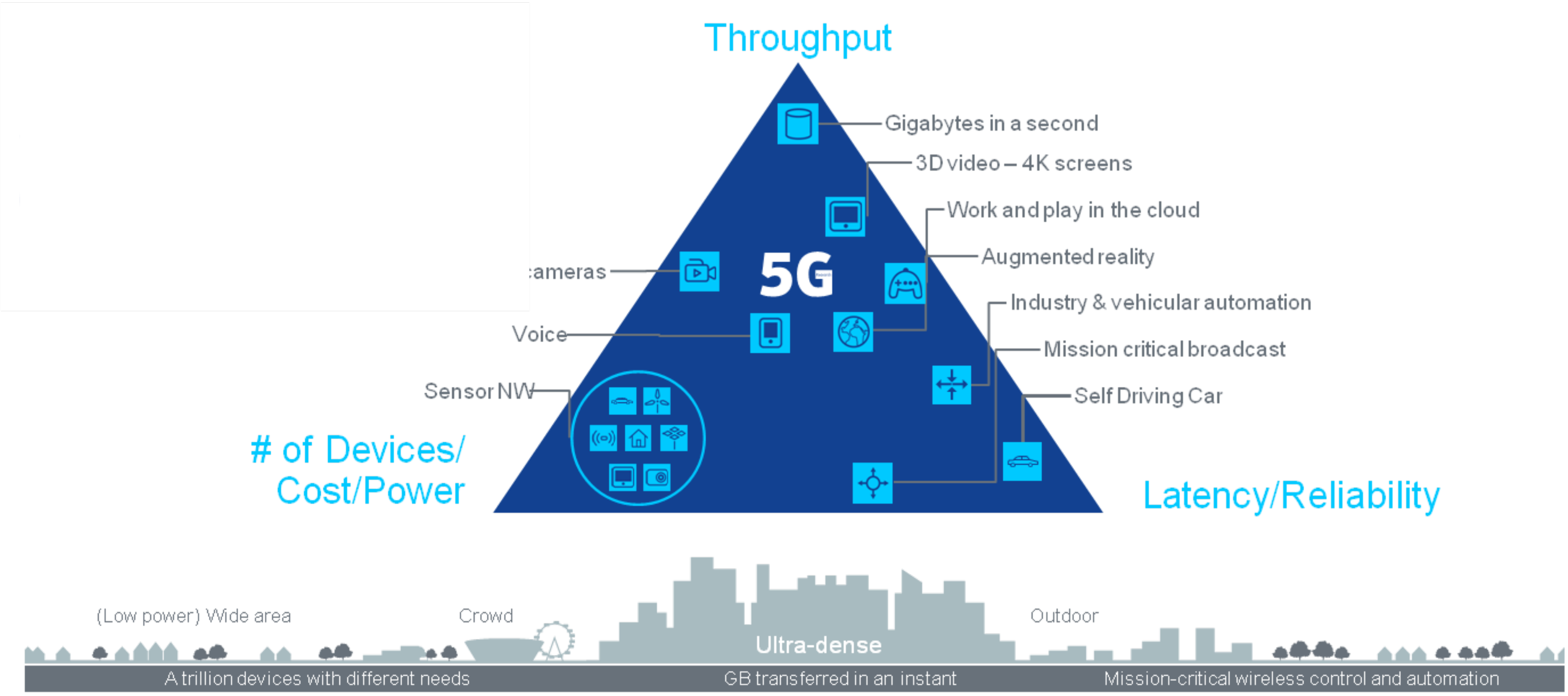
Challenges:
Heterogeneity: scenarios and technologies; multipath

Fotos: Ubisense, SES-imagotag GmbH, brighamyen.com, Witrisal, Jungheinrich, slashgear.com

5G Networks:

higher capacity, lower latency, ultra-dense deployment

Diversity of services, use cases and (extreme) requirements

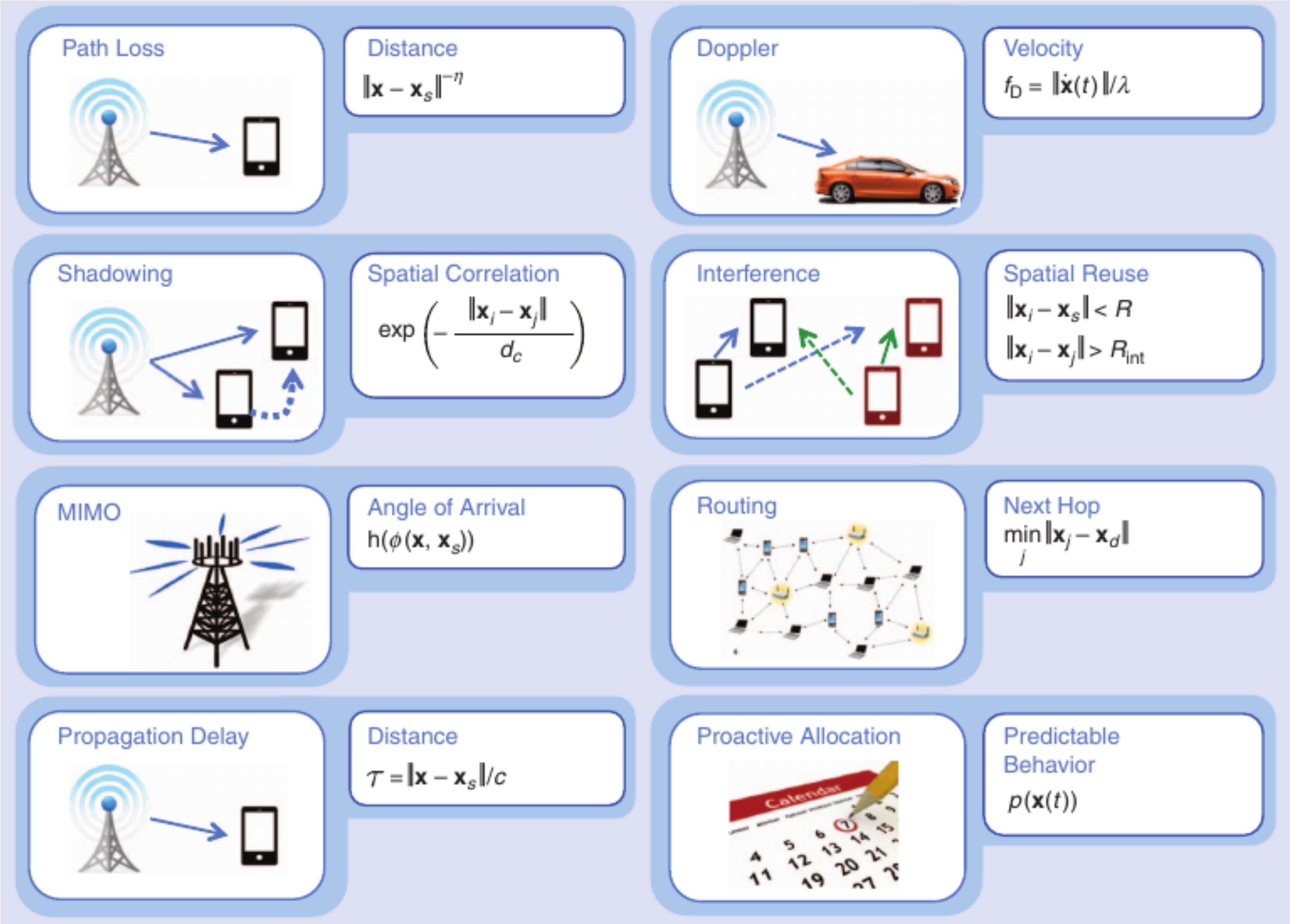


- **5G technologies:** mm-wave; massive MIMO; small cells; D2D

[Nokia Networks, “5G Use Cases and Requirements”, White Paper, 2014]

Location-awareness:

many system parameters depend on the position



[Di Taranto et al., "Location-Aware Communications for 5G Networks",
IEEE Signal Proc. Mag., Nov. 2014]

Outline

- Introduction – need for localization in 5G systems
- Model theory
- Examples of modeling needs in localization
  1. Cooperative Localization
  2. Ranging in Dense Multipath Channels
  3. Multipath-assisted Indoor Navigation and Tracking (MINT)
- Conclusions

General Definition of the Term "Model"

*A model of a **system** is a **representation** (of the considered system) created for a particular **purpose**.*

Three questions should be considered:

- **Purpose:** Why do we need the model – what should it be used for?
- **Scope:** What is the system considered?
- **Representation:** How is the system represented?

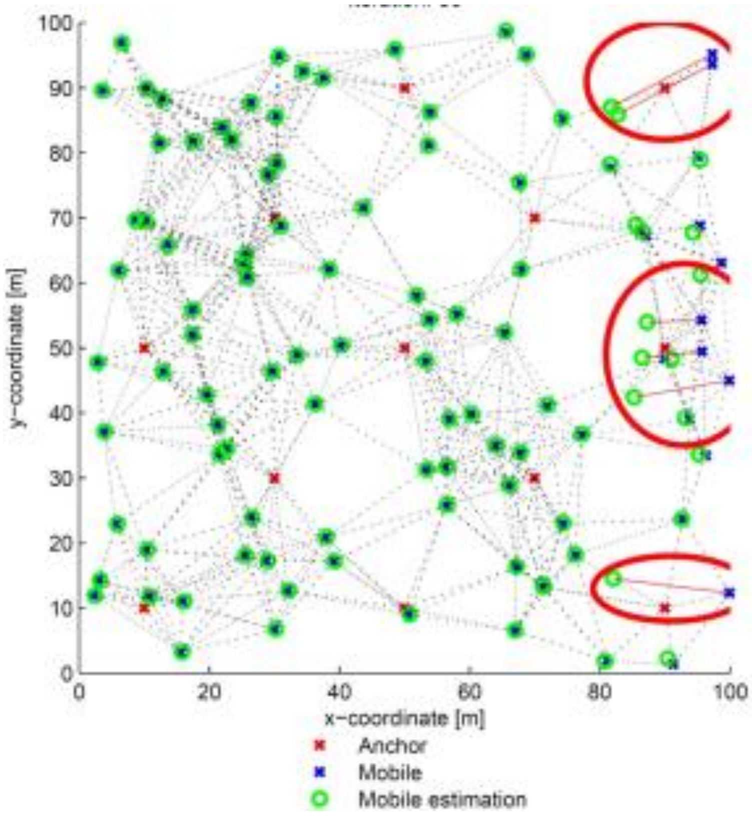
The **purpose** dominates the two others and should be considered first.

Different purposes lead to different models! What are the needs for channel models in localization?

Example 1:
Derivation and Testing of Cooperative Localization Algorithms

Example 1: Cooperative Localization

- D2D communication enables cooperative localization
- Each link provide relative position information via observables such as link presence, RSS, ToA, or DoA.
- Most methods rely on a two-step procedure:
    1. Ranging (DoA estimation)
    2. Localization (+ tracking)
- The localizaton problem may be solved in a distributed fashion e.g by message passing algorithms.



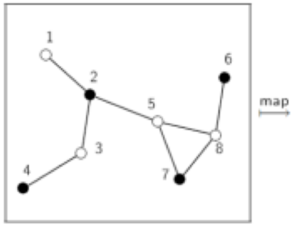
Example 1: Cooperative Localization

- Distributed algorithms are derived based on stochastic models for
  - Connectivity, i.e. network,
  - range error, i.e.

$$d_{r,t} = ||\, x_r - x_t || + \epsilon_{r,t},$$

where the error $\epsilon_{r,t}$ is random.

- Algorithms are tested with many Monte Carlo runs over network configurations and range errors.



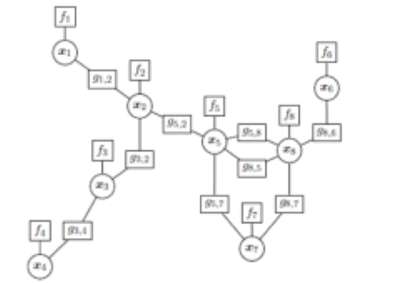
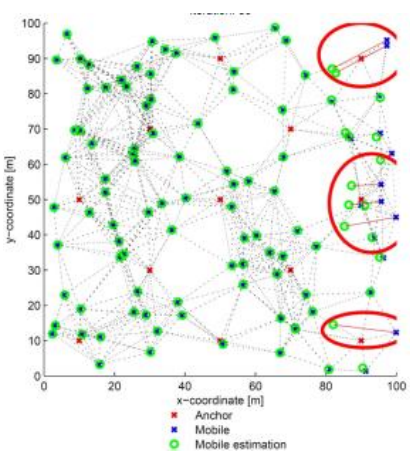


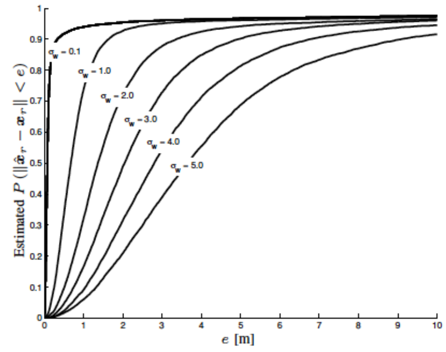
Figure 2: Factor graph corresponding to the WSN topology in Figure 1.

Factors

$$f_v(\boldsymbol{x}_v) = f_v = p_v(\boldsymbol{x}_v)$$

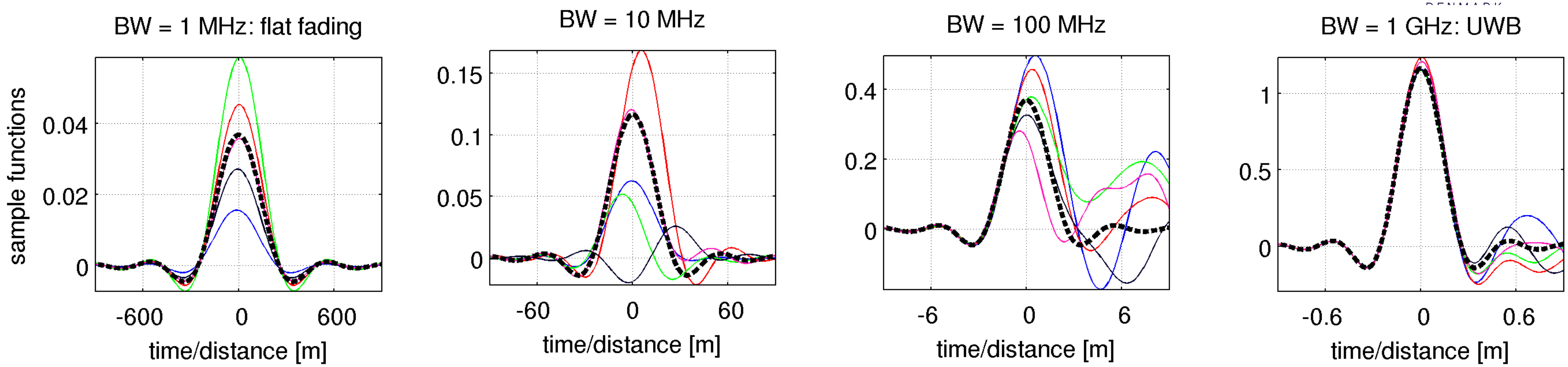
$$g_{r,t}(\boldsymbol{x}_r, \boldsymbol{x}_t) = g_{r,t} = p(d_{r,t} \,|\, \boldsymbol{x}_r, \boldsymbol{x}_t)$$



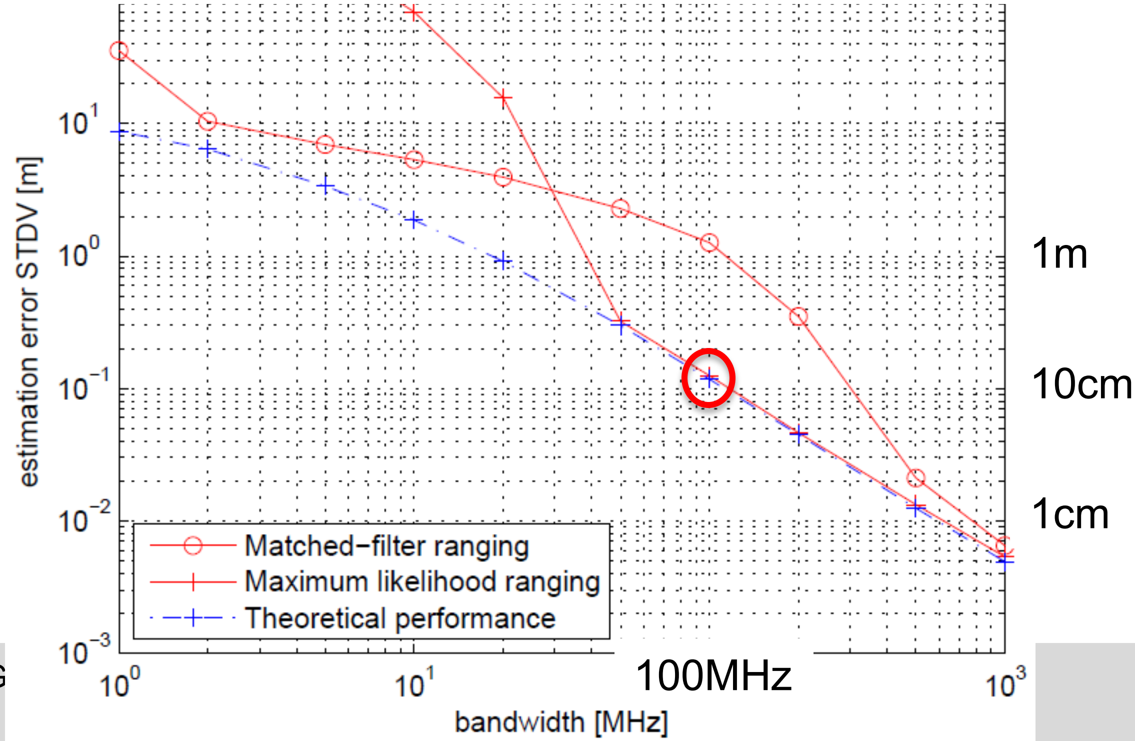


Example 2: Derivation of CRLB for ranging in dense multipath

Influence of bandwidth – *time-of-flight ranging*



- LOS in dense multipath
  - scaling of bandwidth = scaling of time resolution
- Multipath:
  - amplitude fading
  - pulse distortion
- Ranging performance
  - **theoretical limit**



Modeling the dense multipath

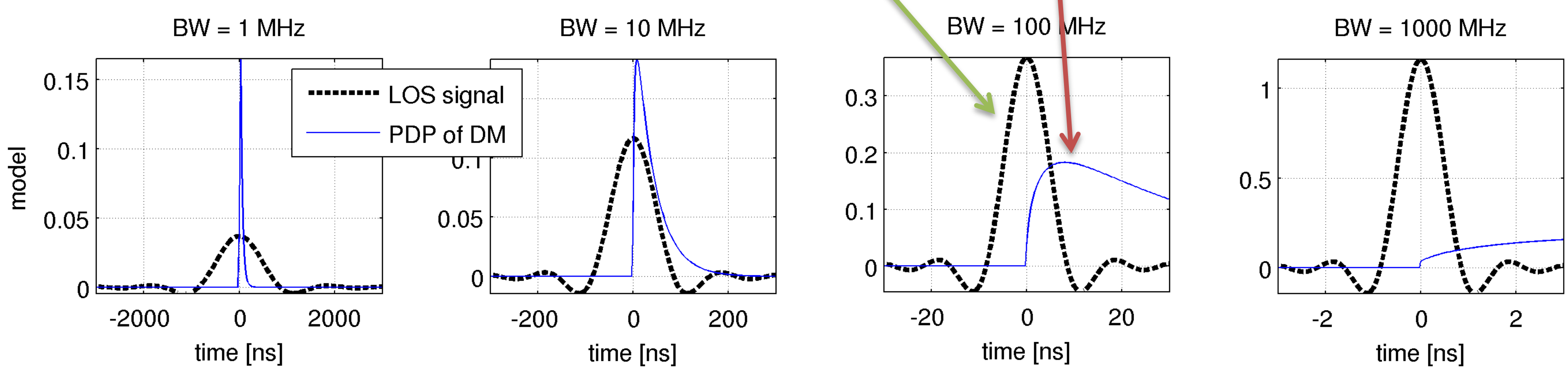
to derive the theoretical limit (CRLB)

Received signal from anchor j located at $\mathbf{p}^{(j)}$: ($s(t)$: TX signal)

$$r^{(j)}(t) = \underbrace{\alpha^{(j)} s(t - \tau^{(j)})}_{\text{useful signal}} + \underbrace{(s * \nu^{(j)})(t)}_{\text{interference}} + \underbrace{w(t)}_{\text{noise}}$$

$$\tau^{(j)} = \frac{1}{c}\|\mathbf{p} - \mathbf{p}^{(j)}\|$$

$$\mathrm{E}\{\nu(\tau)\nu^*(u)\} = S_\nu(\tau)\delta(\tau - u)$$



[Witrisal et al. "Bandwidth Scaling and Diversity Gain for Ranging and Positioning in Dense Multipath Channels," IEEE Wireless Commun. Lett., 2016.]

Ranging error bound and SINR

shows the *bandwidth scaling in dense multipath*

bandwidth

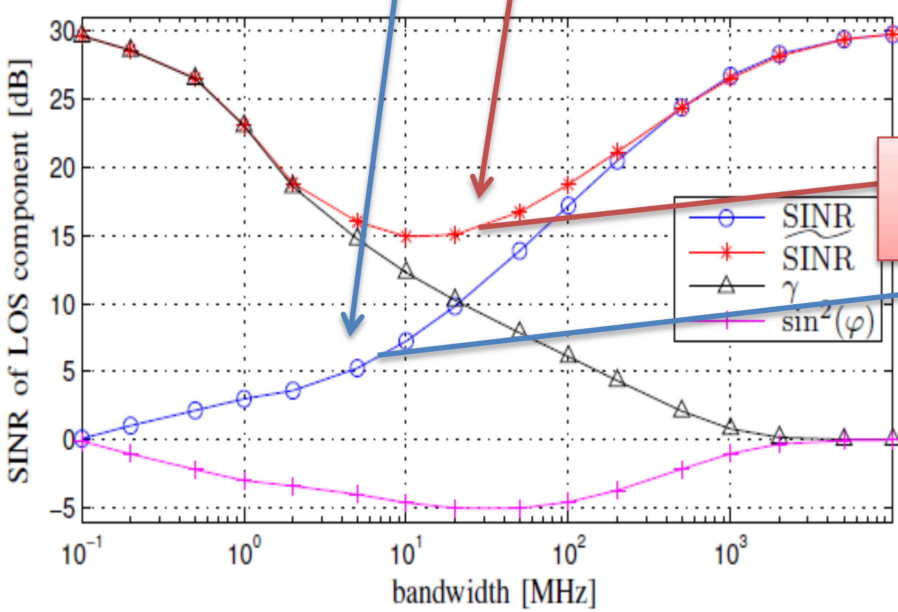
CRLB in AWGN

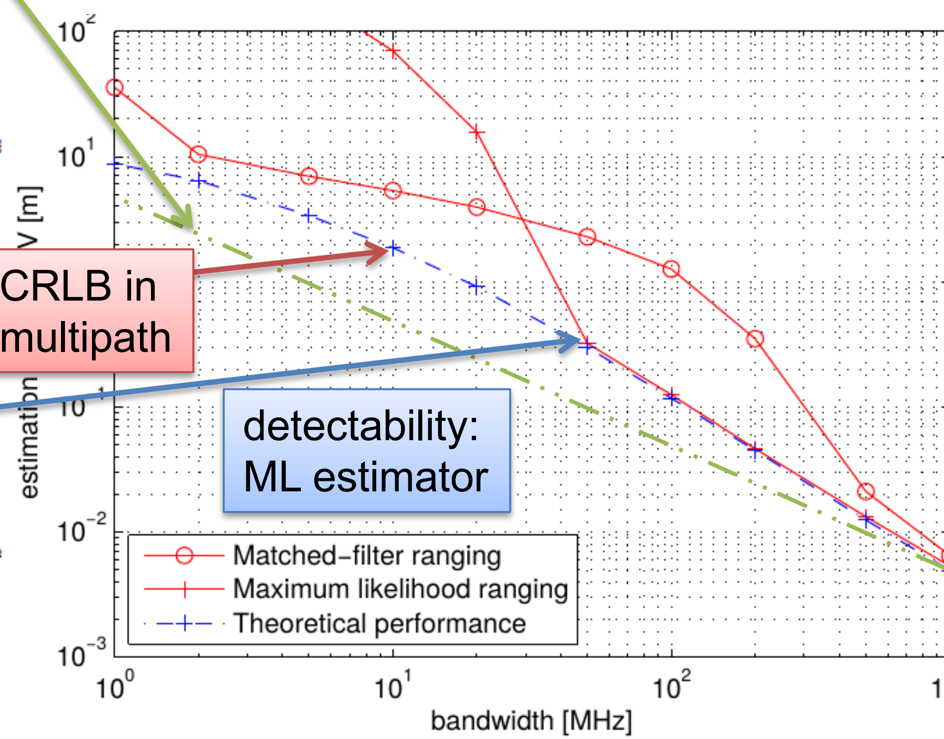
$$\mathrm{var}\{\hat{\tau}\} \geq \left(8\pi^2\beta^2\widetilde{\mathrm{SINR}}\right)^{-1}$$

$$\widetilde{\mathrm{SINR}} = \gamma \mathrm{SINR} \sin^2(\varphi)$$

Parameters

- *SNR = 30 dB*
- K_{LOS} = 1 … LOS-to-DM-power



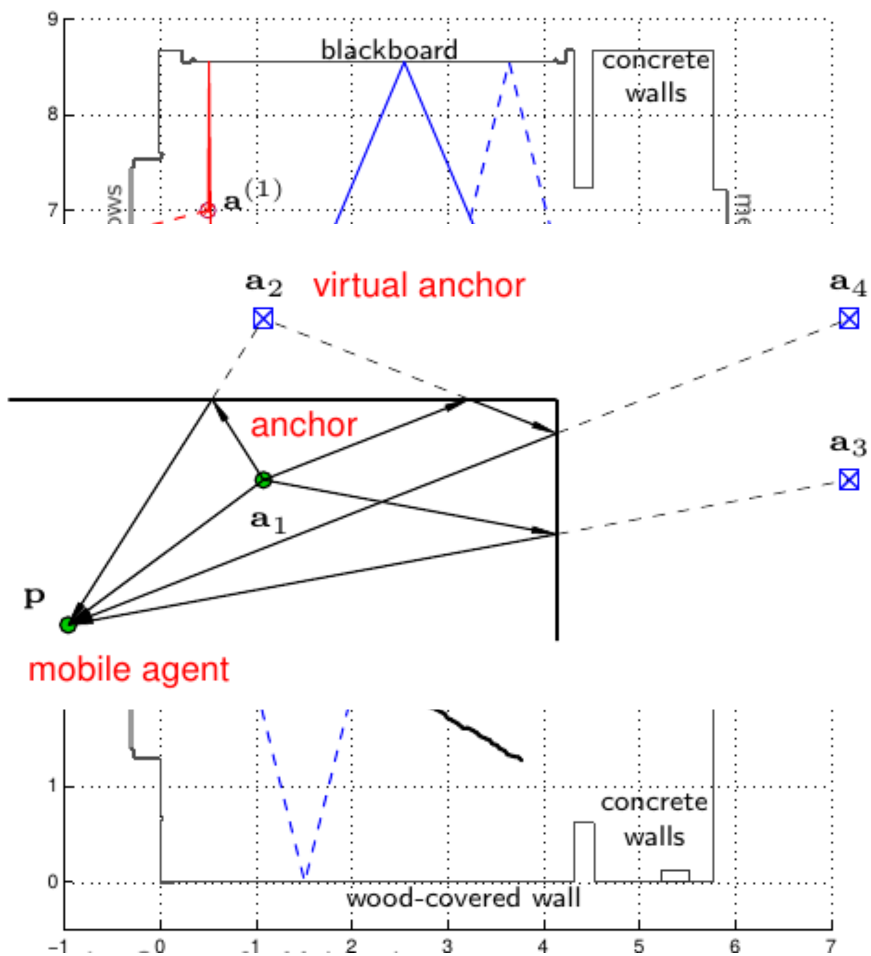


[Witrisal et al. "Bandwidth Scaling and Diversity Gain for Ranging and Positioning in Dense Multipath Channels," IEEE Wireless Commun. Lett., 2016.]

Example 3: Multipath-assisted Indoor Navigation and Tracking (MINT)

Multipath-assisted Indoor Navigation and Tracking (MINT) – *concept and geometric model*

- **Idea:**
  - exploit range/position information from *reflected* multipath
- **Benefits:**
  - less anchor nodes;
  - more redundancy, i.e. robustness in NLOS;
  - higher accuracy
- **Geometric model**:
  - *virtual anchors (VAs)* (mirror sources)



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

Signal Model

(Geometry-based stochastic channel model - GSCM)

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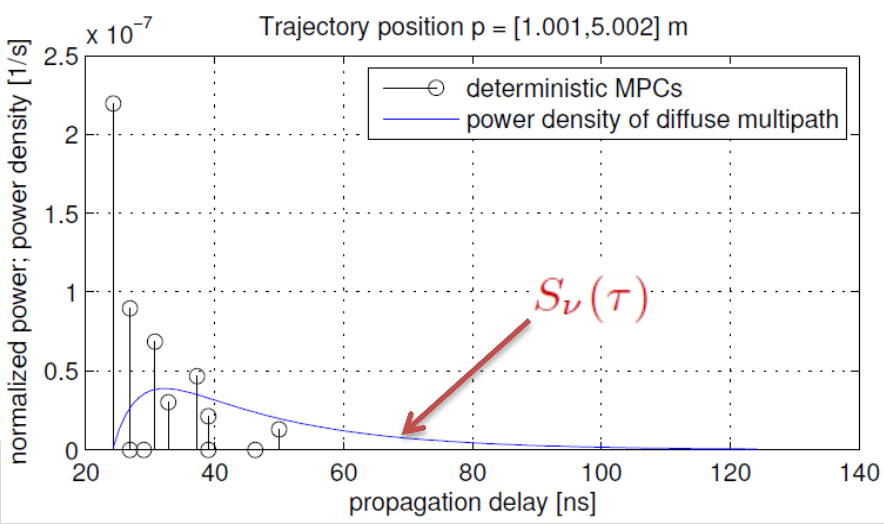
- Received signal: ($s(t)$: TX signal)

$$r(t) = \underbrace{\sum_{k=1}^{K} \alpha_k s(t-\tau_k)}_{\text{useful signal}} + \underbrace{\int_{-\infty}^{\infty} s(\lambda)\nu(t-\lambda)d\lambda}_{\text{interference}} + \underbrace{w(t)}_{\text{noise}}$$

  - *K* **deterministic** multipath components
    - Anchor (LOS), virtual anchors (NLOS), deterministic scatterers
  - **Diffuse** multipath *v*(*t*)
    - PDP $S_\nu(\tau)$
- **MPCs** characterized by

$$\mathrm{SINR}_k := \frac{|\alpha_k|^2}{N_0 + T_s S_\nu(\tau_k)}$$



Validation of the signal model – *derived environment map for **location-aware** MINT*

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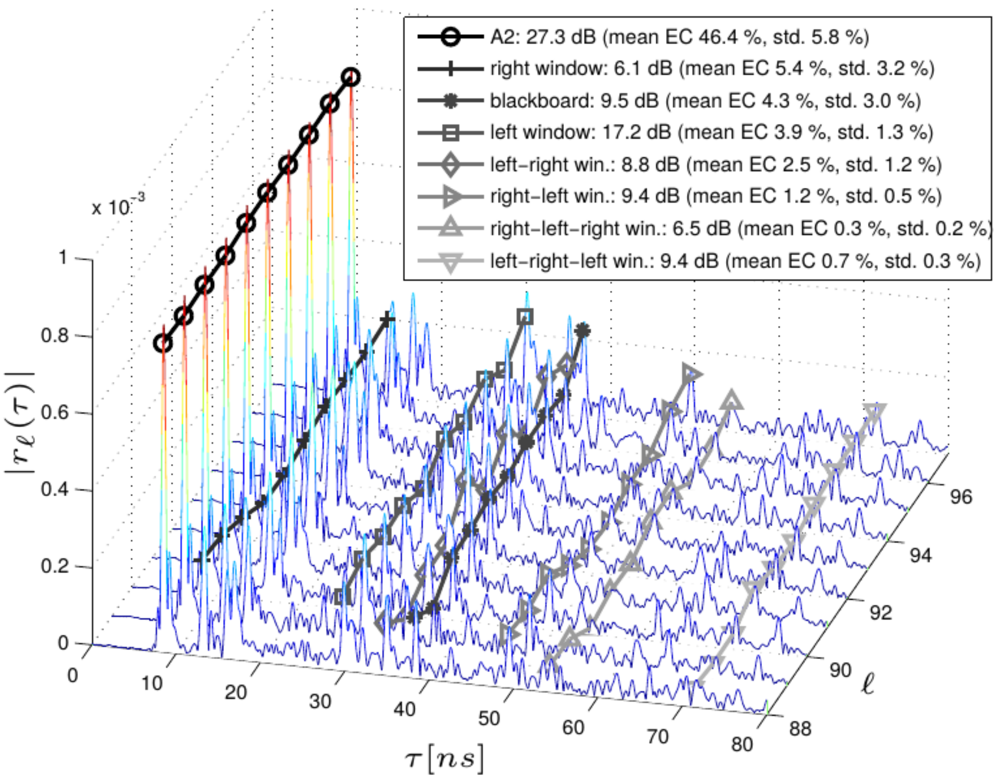
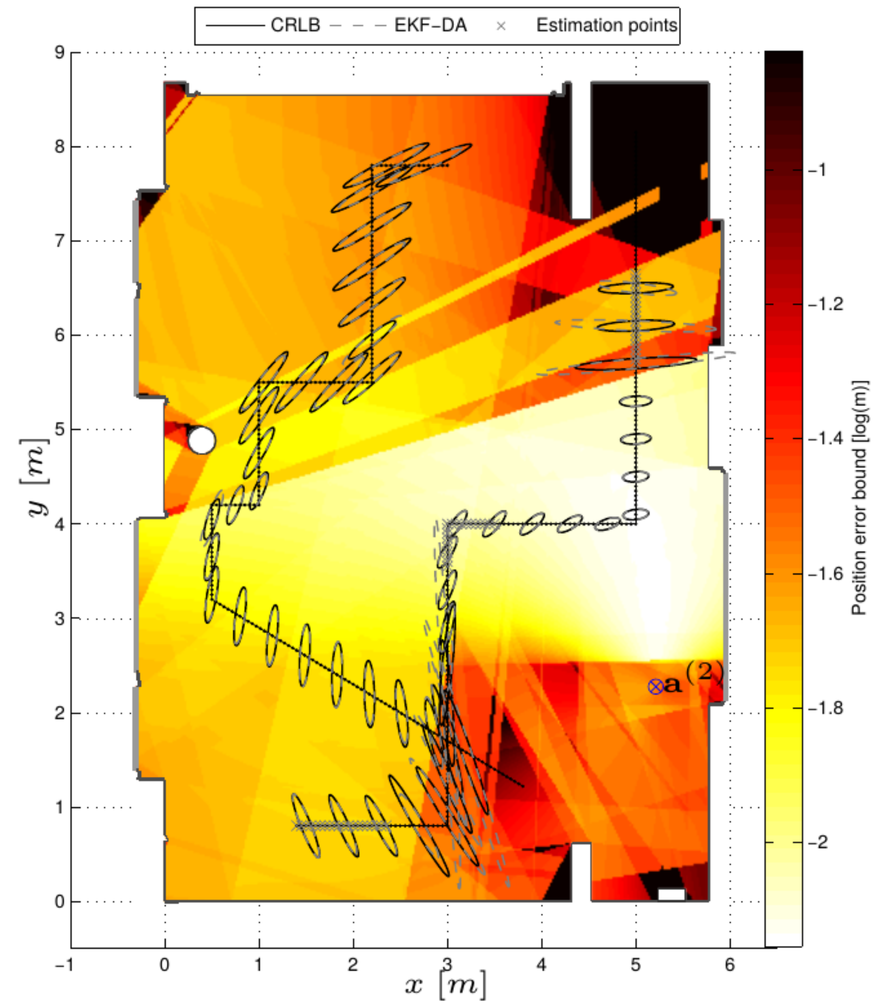


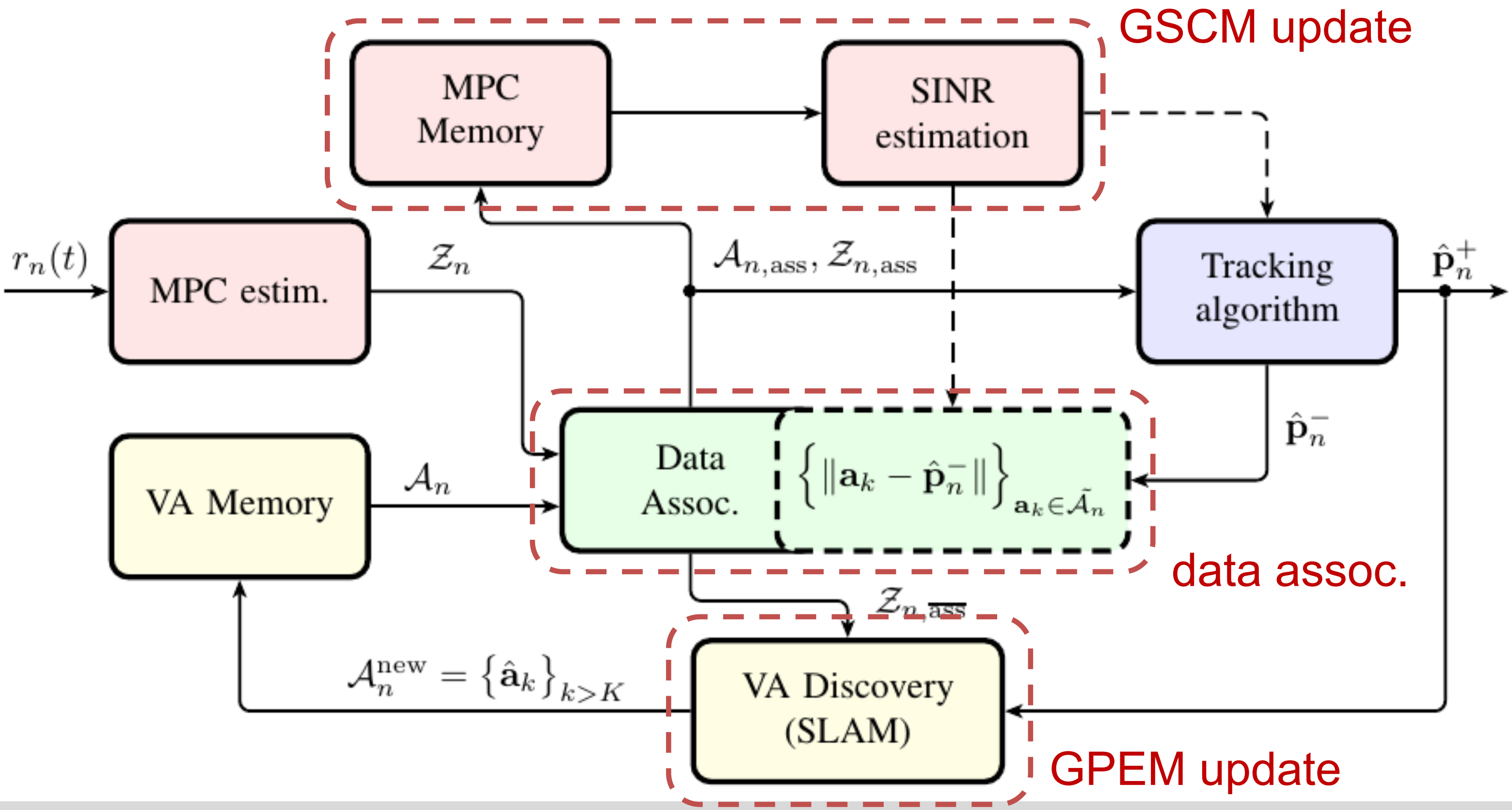
SINR estimation, BW 2 GHz, $f_c = 7$ GHz,
Anchor 2, traj. 2



[Meissner, Witrisal, "Analysis of Position-Related Information […]," EUCAP 2012.]
[Meissner, "Multipath-Assisted Indoor Positioning," Ph.D. Thesis, TU Graz, 2014.]

Tracking algorithms exploiting multipath

- (1) *data association* of multipath ranges and *state-space tracking*
- (2) *ranging uncertainty* is estimated from multipath amplitudes
- (3) a SLAM-style algorithm is used to *discover new VAs*



[Meissner, et al., "UWB for Robust Indoor Tracking: […]," IEEE Wireless C. Lett., 2014.]
[Witrisal, et al., "High-Accuracy Localization […]," IEEE Signal Proc. Mag., March 2016.]

Channel Models in Localization

- The **characteristics of the radio channel** have a direct impact on the **performance of localization** systems!

Purposes identified from the examples:

- **Analytical tool** for derivation of localization algorithms and performance bounds
  - Analyticaly tractability. Interpretability of parameters. Simplicity.
- **Link-level simulation** for test of parameter estimation methods
  - Accurate representation of specular and diffuse MPCs
  - Simulation complexity
- **System-level simulation** for positioning and location-aware networks
  - Accurate representation of time-varying MPC (e.g. beamforming)
  - Heterogenity; site-specific models of the propagation environment
  - Multi-link aspects
  - Simulation complexity

Conclusions

- Channel models are embedded deeply in localization algorithms!

- Needs for radio channel models in localization and communications systems overlap but differ!
  - Location-aware wireless networks: Exploiting the geometric dependency of channel parameters. A way of the future?

- At present, localization algorithms are tested by use of measurement data: costly and hindering comparison of different algorithms.
  - Wanted: common/standardized simulation models for testing and comparing localization algorithms via Monte Carlo simulations.

- Discussion has started in IRACON to include requirements of localization in the next “COST channel model”.