Geo-Regioning in Rich Multipath Environment

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Outline

• Introduction and motivation
• Measurement campaign
• A first Geo-Regioning algorithm
• Performance results
• Conclusions
Geo-Regioning Principle

- **Objective**: Perform rough localization by means of received signature
- RX receives **signatures** which are determined by multipath components of propagation channel ("Footprints" of the propagation channel)
- **Assumption**:
  - Signature is almost unique for fixed TX/RX positions
  - Signatures originating from the same region have some characteristic similarities
- RX algorithm extracts similarities to detect region (Geo-regioning algorithm)
- Region size may be several cubic decimeters to meters

Requires rich multipath → **UWB specific technique**
Promises of the Geo-Regioning approach

- Not based on propagation times
  - Lower temporal accuracy required (internal clocks at TX/RX)
  - No global time reference (as in TOA)
  - No time-synchronized protocol (medium access) at TX required (as for RTOF)
- Only one RX (position) sufficient (no triangulation)
- All signal processing at RX (TX must only enable CIR estimation at RX (implemented anyway))
  → technique for heterogeneous network
- Appropriate in LOS and NLOS situations
- Appropriate in static environment, also with mobile nodes

Can be used in combination with standard localization techniques
Requirements for Geo-Regioning

- CIR / signature estimation at RX
- Reference transmitters for data-aided approach
- Performance depends on environment, (rich) multipath required
- Region size (localization accuracy) determined by environment, coverage with references and algorithm
Measurement Scenario

- **Cellar room** of building ETF at ETH Zurich
- The room has a size of about **7.4m x 45m** and the height is about **6m**
- Only a part of the room was used for TX positions
- Many **products** of various stature and material stored in the room
- **Full of metallic objects** as, e.g., large metallic shelves, heating pipes and metal cores
- Hardly any continuously wave blocking objects as, e.g., walls or cabinets, which may be a significant difference
- 22 regions
  - 1800 SISO links per region
Measurement Results
(Average) Power Delay Profiles (1)

- LOS (R03) and NLOS (R18) can easily be distinguished

Note: Alignment of Signatures is very important
(Average) Power Delay Profiles (2)

- Regions located symmetrically look very similar (e.g. R17, R19)

→ Are the differences in the APDP significant?
A first Regioning algorithm

- Requirements for feasibility
  - Signatures from the same region must have significant similarities
  - Signatures from different regions must have significant differences
- Fulfillment of requirements is a channel characteristic → measurements
- A Regioning algorithm must detect both together
  - Proposal of an initial algorithm
  - Uses a priori knowledge of the APDPs for Maximum Likelihood decision (data-aided approach)
  - Evaluate performance with measured data
- Shows principle feasibility
APDP based ML approach (Data-Aided)

- Use the APDP of the regions to achieve a simplified channel model for each region
  - assume the amplitudes zero-mean Gaussian distributed and statistically independent
  - the variance of the Gaussian distribution is given by the corresponding APDP value
  - for region A:

\[
\sigma_A^2(k) \approx APDP_A(k) = \frac{1}{N_A} \sum_{n=1}^{N_A} y_n^2(k)
\]

\[
p(x(k) | A) = \frac{1}{\sqrt{2\pi \sigma_A(k)}} \cdot \exp \left( - \frac{x^2(k)}{2\sigma_A^2(k)} \right)
\]
ML detector with a priori APDP

- ML detector to decide between two hypothesis (regions) A and B:

\[ p(\bar{x} \mid A) > \frac{H_A}{H_B} < p(\bar{x} \mid B) \]

\[ \prod_k p(x(k) \mid A) > \frac{H_A}{H_B} < \prod_k p(x(k) \mid A) \]

\[ \frac{\sum_k x^2(k)}{2\sigma^2_B(k)} - \frac{x^2(k)}{2\sigma^2_A(k)} > \frac{H_A}{H_B} < \sum_k \ln \sigma_A(k) - \ln \sigma_B(k) \]

\[ \frac{\sum_k x^2(k) \left[ \sigma^2_A(k) - \sigma^2_B(k) \right]}{\sigma^2_B(k)\sigma^2_A(k)} - \sum_k \ln \frac{\sigma^2_A(k)}{\sigma^2_B(k)} > \frac{H_A}{H_B} < 0 \]
Pairwise Error Probability Performance

\[ \sigma^2_A(k) = \sigma^2_A(k) + \sigma^2_n \]

\[ \sum_{k=1}^{K} x^2(k) \frac{\sigma^2_A(k) - \sigma^2_B(k)}{\sigma^2_A(k) \sigma^2_B(k)} \geq \sum_{k=1}^{K} \frac{\sigma^2_A(k)}{\sigma^2_B(k)} \ln \frac{\sigma^2_A(k)}{\sigma^2_B(k)} \]

\[ \text{SNR} = \frac{1}{\sigma^2_n} \cdot \frac{1}{N_A + N_B} \sum_{m=1}^{N_A+N_B} \sum_{k=1}^{K} |h_m(k)|^2 \]

- All regions achieve \( P_2(e) < 10^{-2} \)
- Direct neighbor regions perform worse
- Required SNR is not unrealistic for channel estimation
- Also with normalized energy reasonable performance
Impact of Bandwidth

- Same set of measurements used for evaluation
- Bandwidth varies from 3GHz (3-6GHz) to 20MHz (3.00-3.02GHz)
- Performance increases with bandwidth
- Bandwidth > 200MHz required to achieve $P_2(e) < 10^{-2}$
Number of relevant taps

- For single tap \((K=1)\) performance increases with ratio of variances

\[
\alpha(k) := \max \left\{ \frac{\sigma_A^2(k)}{\sigma_B^2(k)}, \frac{\sigma_B^2(k)}{\sigma_A^2(k)} \right\}
\]

\[
P_2(e) = \frac{1}{2} + \frac{1}{2} \left[ \text{erf} \left( \sqrt{\frac{\alpha \cdot \ln \alpha}{2(\alpha - 1)}} \right) - \text{erf} \left( \sqrt{\frac{\ln \alpha}{2(\alpha - 1)}} \right) \right]
\]

- Selection of \(K\) taps with maximum ratio
- Performance increases with number of taps
Conclusions & Outlook

• Principle feasibility of Geo-Regioning shown
• Regions can be separated by the signatures for $B > 200\text{MHz}$ \(\Rightarrow\) UWB technique
• With APDP knowledge, ML is simple and performance good
• Also for NLOS regions good performance
• Future work
  – Framework to analyze impact of parameters as spatial and temporal sampling, alignment, region size, …
  – Multiple Antenna Signatures
  – Other approaches
  – Non data aided