UNIVERSITÄT BERN

ACM SIGCOMM Software Radio Implementation Forum (SRIF) 2014

SDR-based Passive Indoor Localization System for GSM

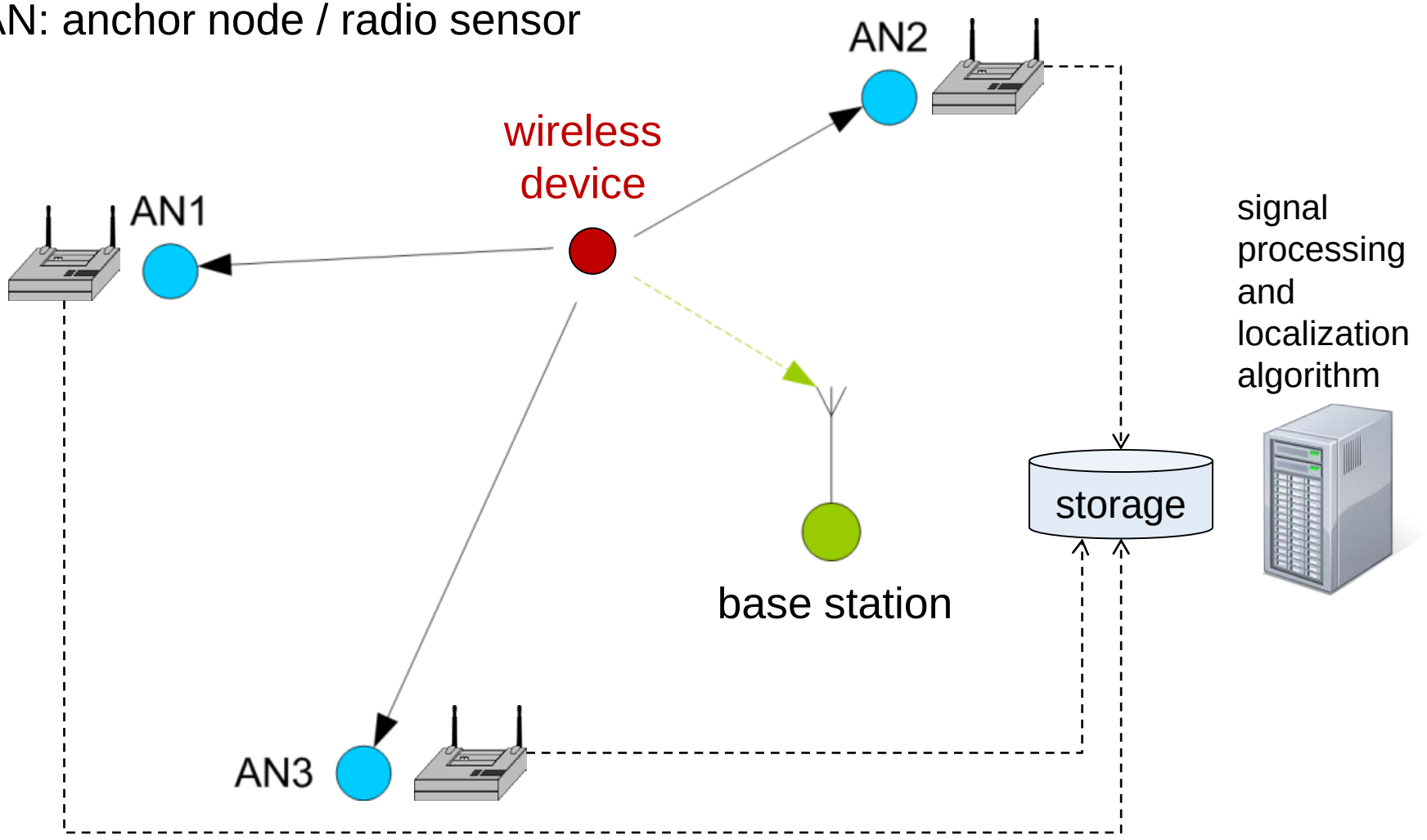
Islam Alyafawi, Desislava Dimitrova, Torsten Braun
Universität Bern
braun@iam.unibe.ch, cds.unibe.ch

Passive Localization of Wireless Devices

- System can
  - overhear radio (e.g., GSM, WiFi) signals,
  - process them to retrieve user identity, and
  - locate user based on the signal properties.
- System components based on software-defined radio
  - Radio signal acquisition
  - Signal property retrieval, e.g., timestamps, power levels
  - Message parsing, e.g., identifiers
  - Localization algorithms
- Applications
  - Analysis of customer behaviour in shopping centres / amusement parks
  - Analysis of number of people and movements in public areas

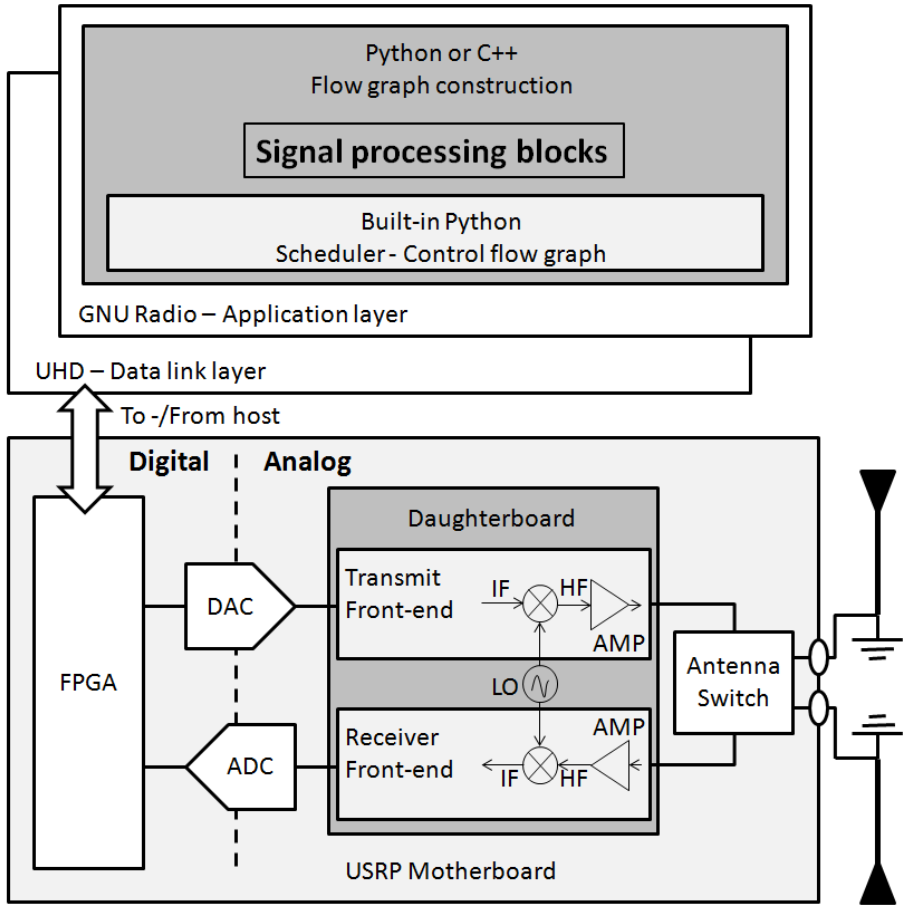
Passive Localisation System

AN: anchor node / radio sensor

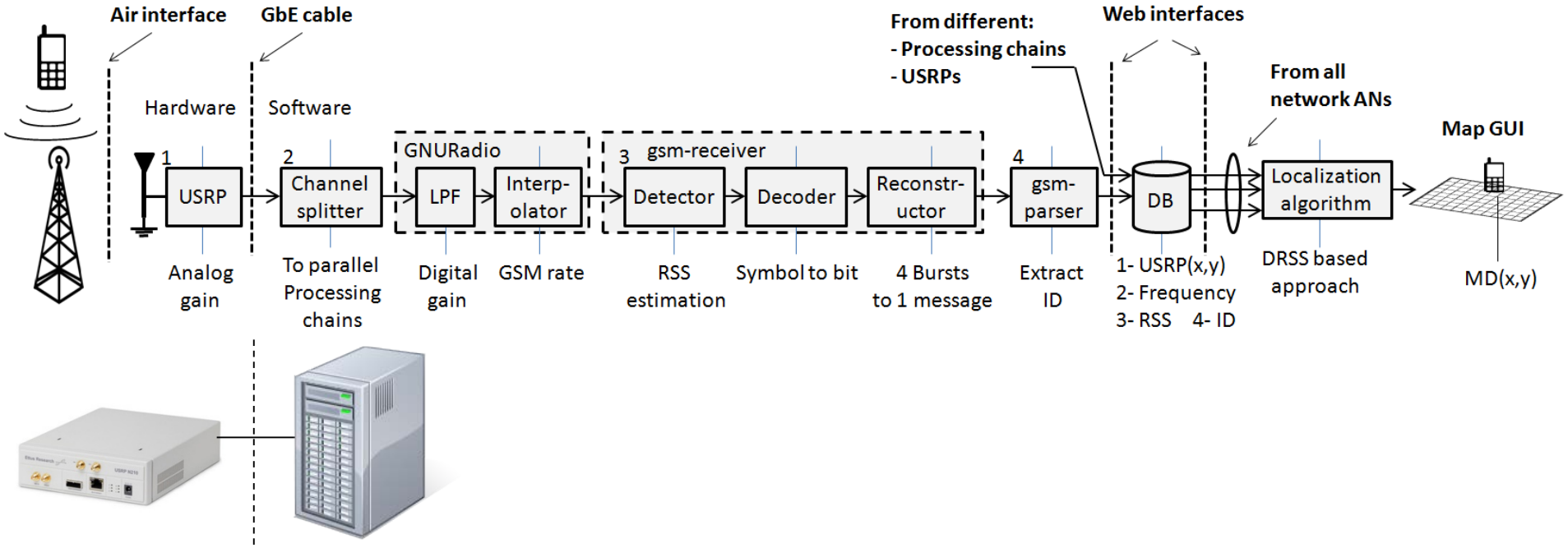


Universal Software Radio Peripheral

- USRP hardware is controlled by open source USRP Hardware Driver, which translates instructions between FPGA hardware and signal processing software
- GNUradio applications
  - Airprobe intercepts GSM downlink messages.
  - OpenBTS implements base station protocol stack up to layer 3.

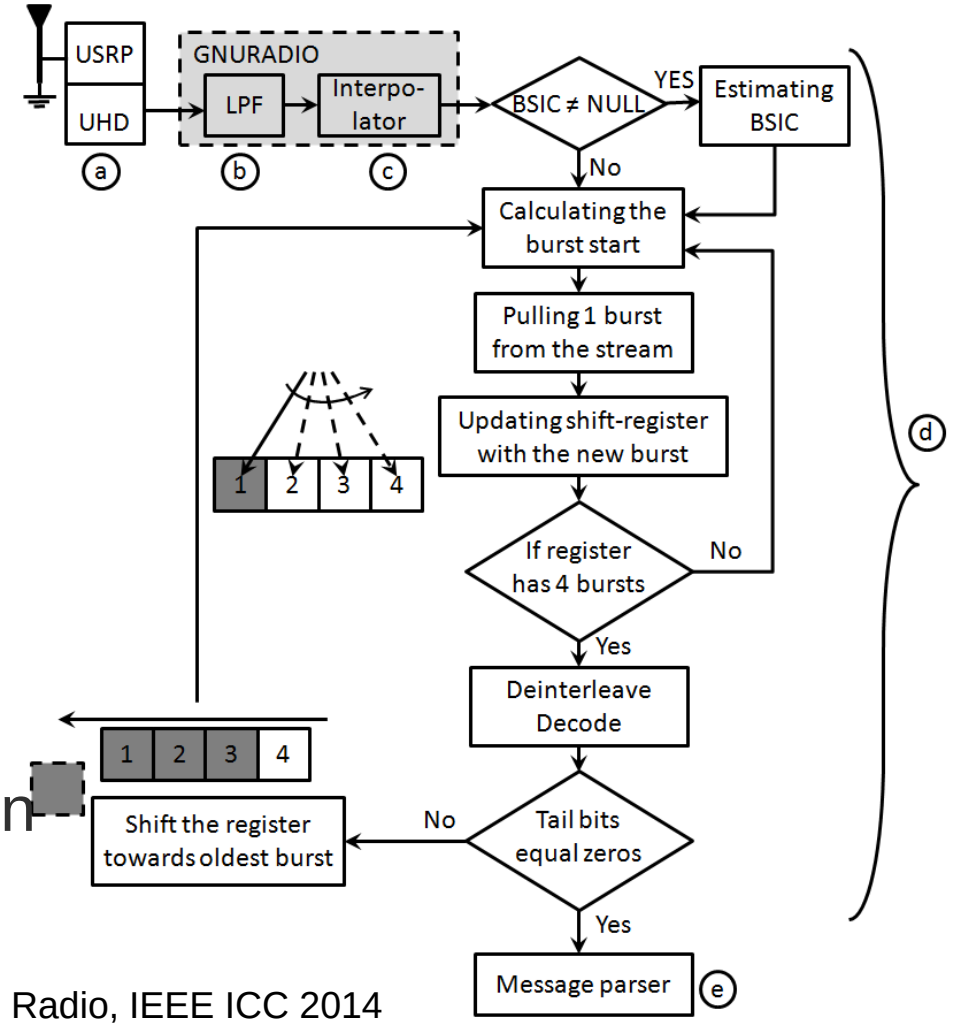


System Implementation



GSM Message Capturing

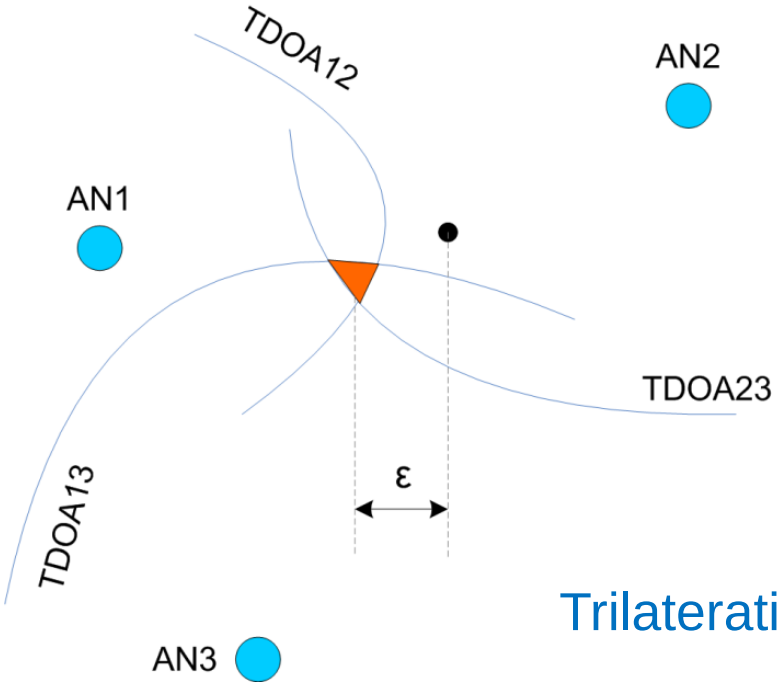
a. Sample capturing
b. GNUradio
   low pass filter
c. Interpolator
d. Time synchronization
   - Training sequence discovery
   - Normal burst detection
   - Message reconstruction
e. Message parsing



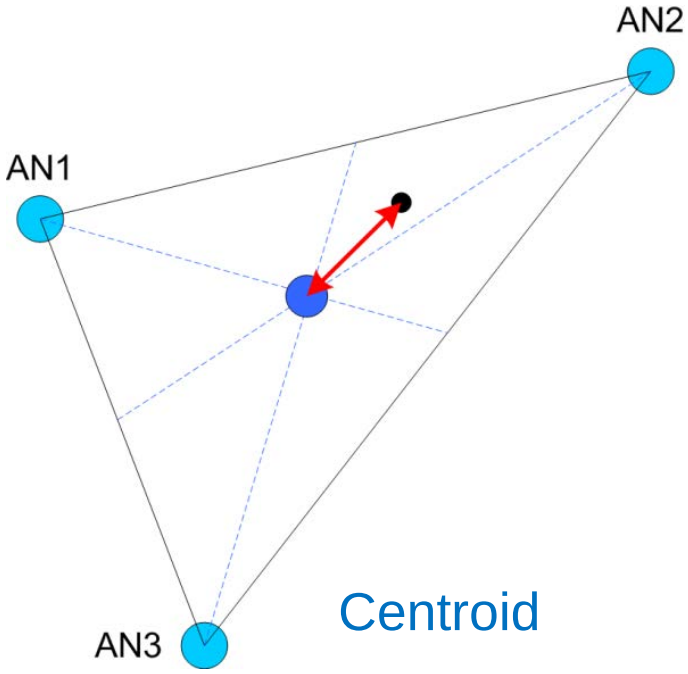
Alyafawi et al.: Real-Time Passive Capturing of the GSM Radio, IEEE ICC 2014

Localization Algorithms

- Range-based positioning using Time/Angle (Difference) of Arrival, Received Signal Strength (RSSI) and multi-lateration
- Finger-printing
- Proximity-based positioning, e.g., Centroid

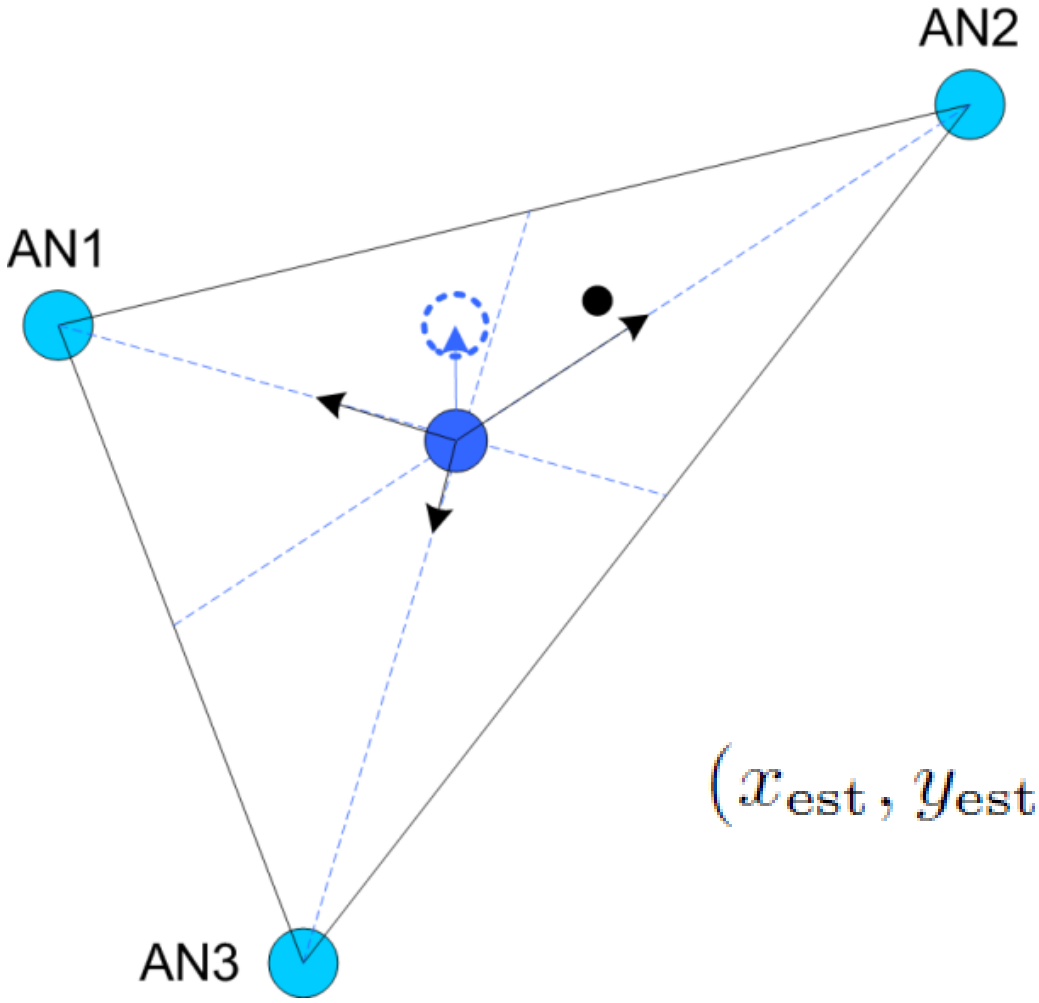


Trilateration



Centroid

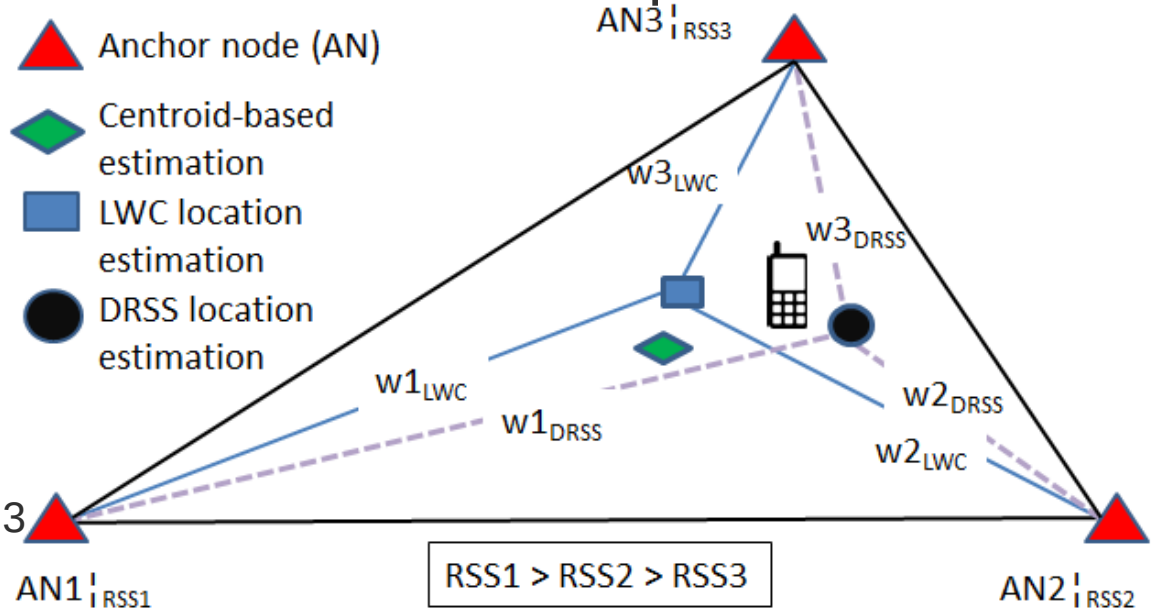
Linear Weighted Centroid (LWC)



$$(x_{\text{est}}, y_{\text{est}}) = \left(\frac{\sum_{i=1}^{N_C} w_i * (x_i, y_i)}{\sum_{i=1}^{N_C} w_i} \right)$$

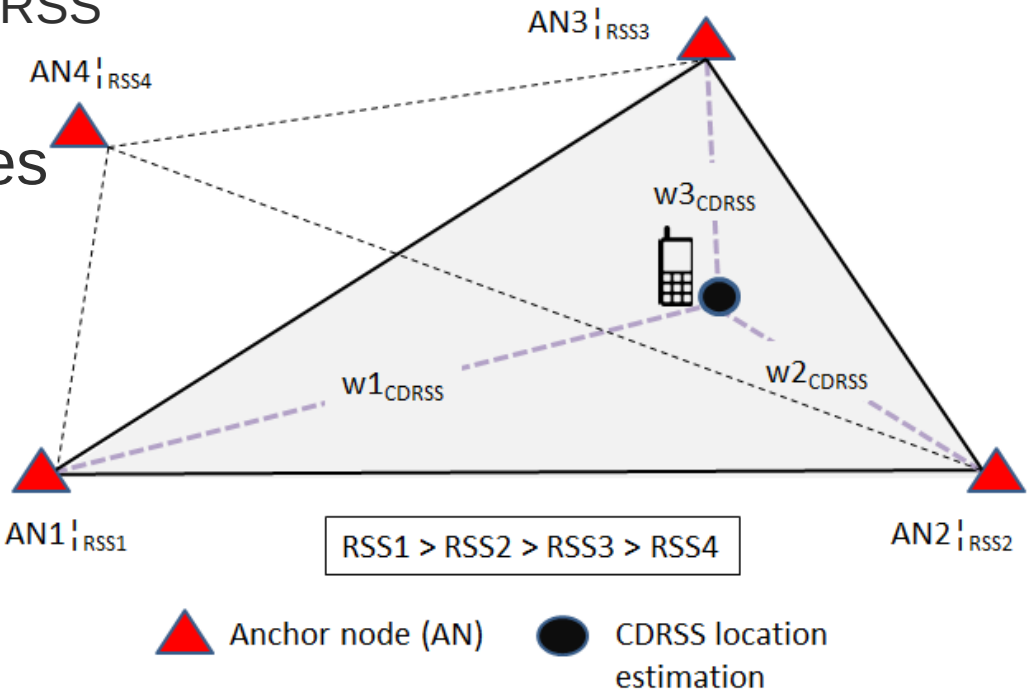
Differential RSS

- $RSS = P_r(d) = A - 10\,\alpha \log\left(\frac{d}{d_0}\right) - \psi$
- $DRSS_{ij} = RSS_i - RSS_j = P_r(d_i) - P_r(d_j) = 10\,\alpha \log\left(\frac{d_j}{d_i}\right) - \psi_{ij}$
- Select 3 ANs with largest RSS values
- Calculate DRSS values between each AN pair
  - X = $RSS_1 - RSS_2$
  - Y = $RSS_1 - RSS_3$
  - Z = $RSS_2 - RSS_3$
- Q_1 = Y/X
- Q_2 = Z/X
- Q_3 = Z/Y
- $\omega_1:\omega_2:\omega_3 = Q_1:Q_2:Q_3$
- $\omega_1+\omega_2+\omega_3 = 1$



Combined Differential RSS (CDRSS)

1. Form all possible K triangles
2. Calculate weights $\omega_{ik,DRSS}$
   - i = 1,2,3
   - k = 1..K for all K triangles
3. Calculate weights $\omega_{i,CDRSS}$ for the 3 ANs with highest RSS



$$w_{i_{\mathrm{CDRSS}}} = \frac{1}{\mathrm{K}} \sum_{k=1}^{\mathrm{K}} w_{ik_{\mathrm{DRSS}}} \quad \text{for } i = 1,2,3$$

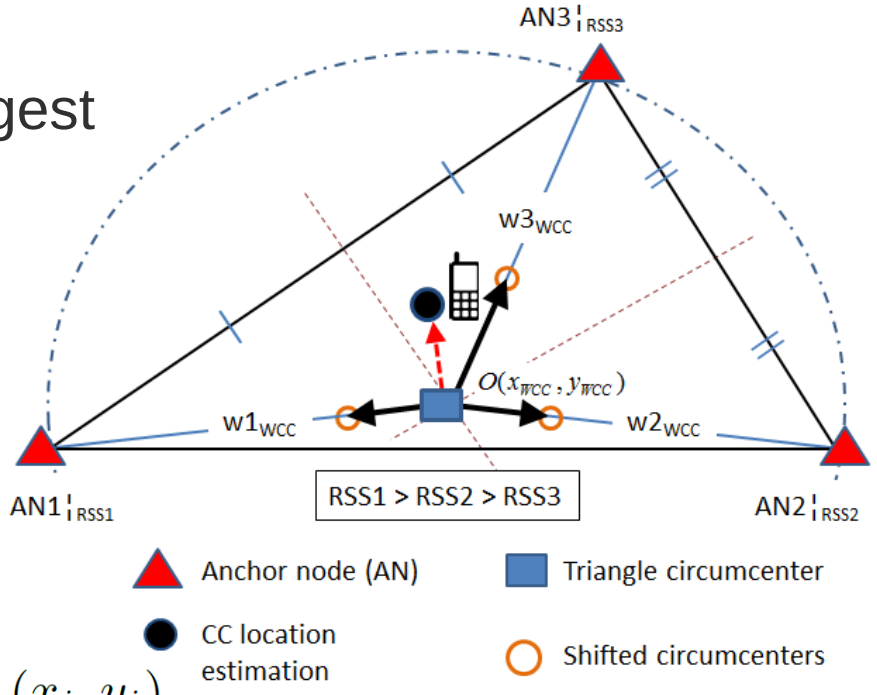
Weighted Circumcenter (WCC)

1. Form triangle using 3 ANs with largest RSS values
2. Calculate circumcenter
3. Calculate DRSS values
   - $X = RSS_1 - RSS_2$
   - $Y = RSS_1 - RSS_3$
   - $Z = RSS_2 - RSS_3$
   - $h_1 = X/Y$, $h_2 = X/Z$, $h_3 = Y/Z$
4. Move circumcenter point to each AN:

$$(x_i', y_i') = h_i * O(x_{wcc}, y_{wcc}) + (1 - h_i) * (x_i, y_i)$$

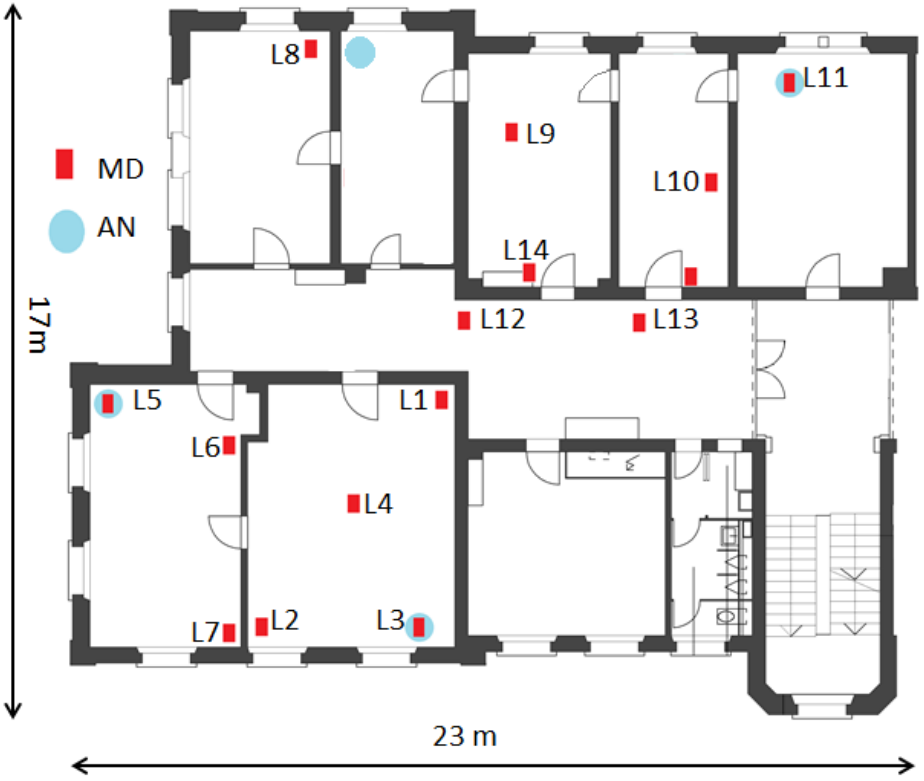
5. Calculate AN weights $\omega_{i,WCC}$ using differential RSS for new triangle
6. Estimate coordinates of mobile device

$$(x_{\text{est}}, y_{\text{est}}) = \left(\frac{\sum_{i=1}^{3} w_{i_{WCC}} * (x_i', y_i')}{\sum_{i=1}^{3} w_{i_{WCC}}} \right)$$

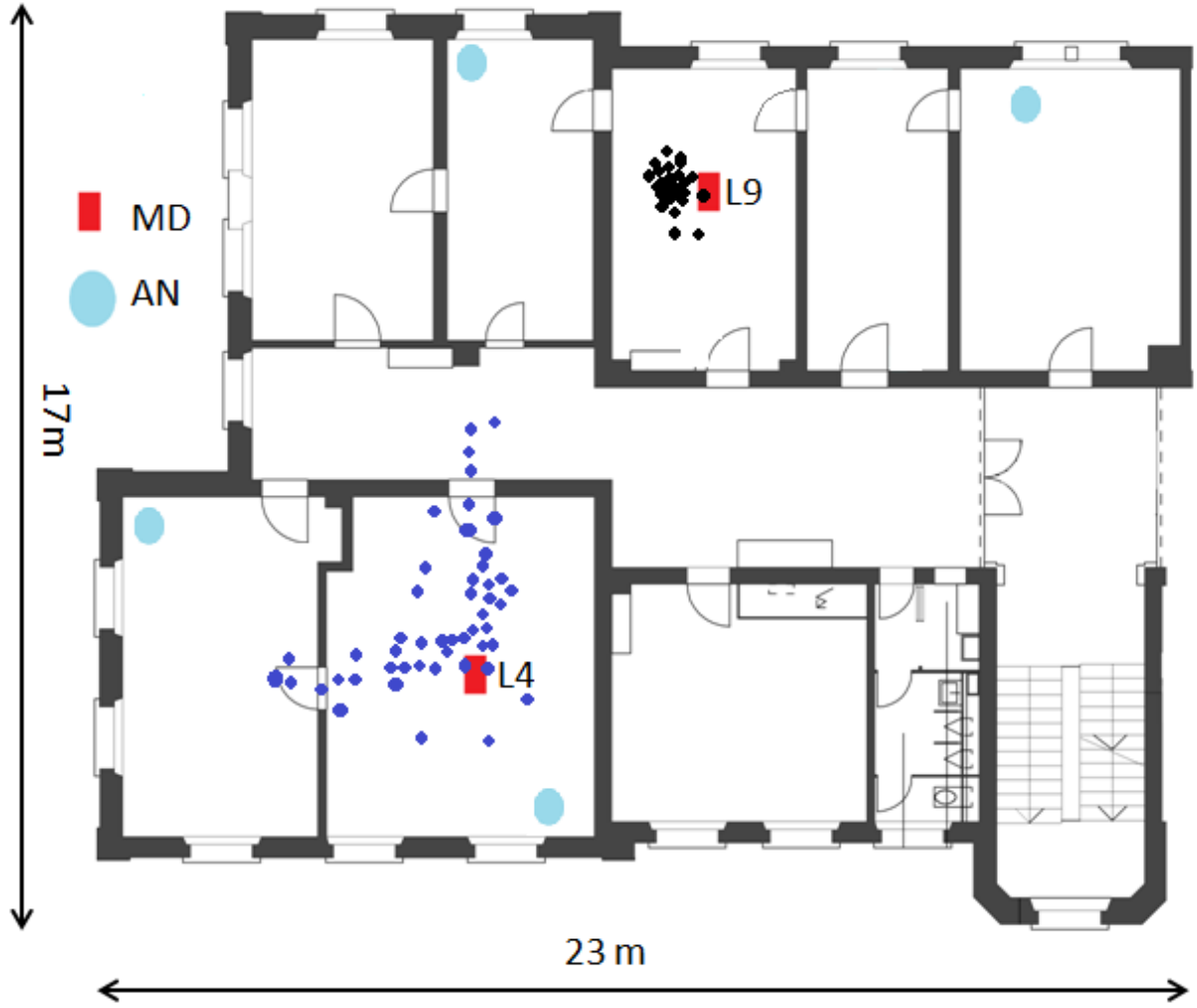


Localization Performance

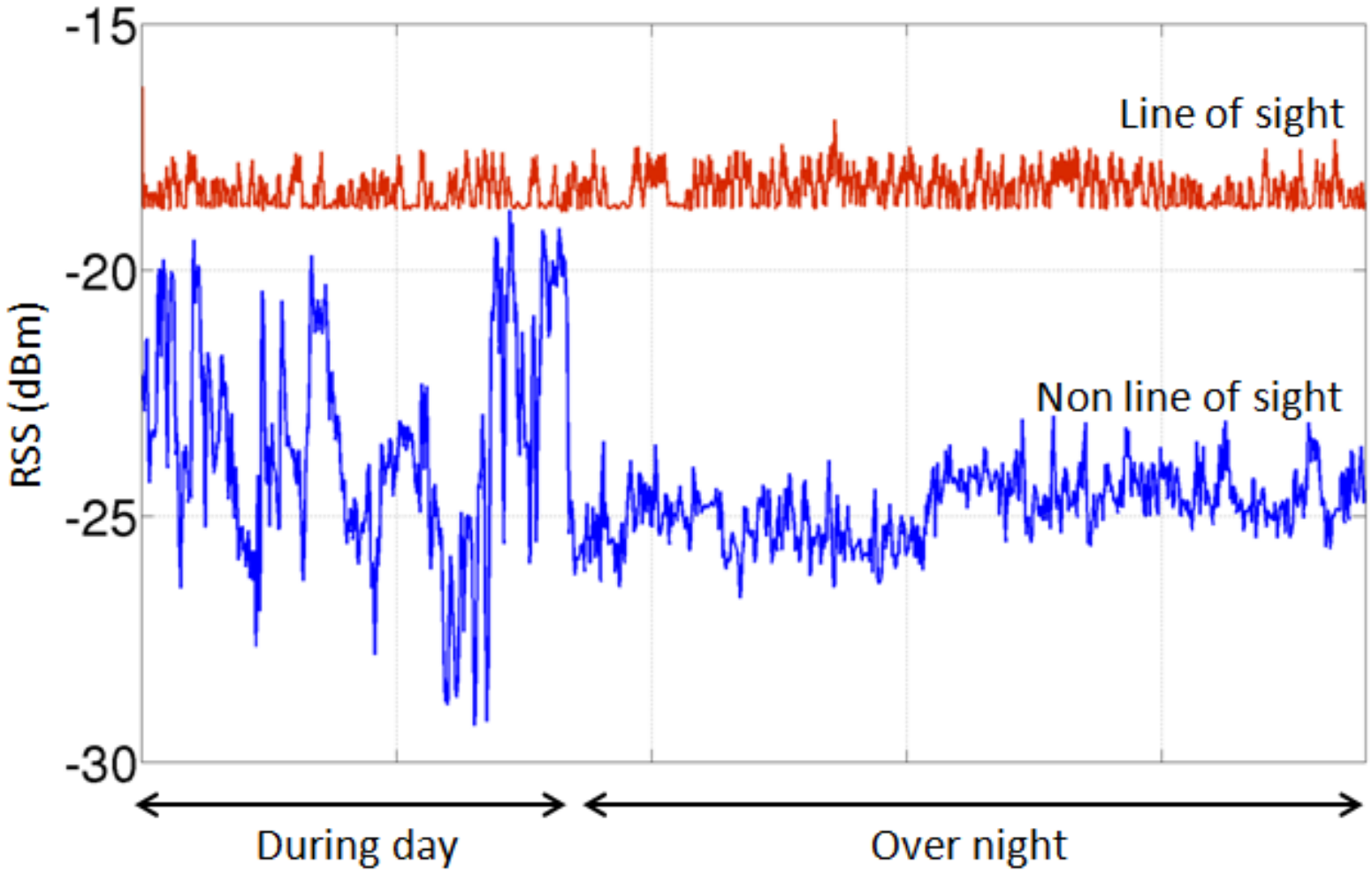
MD Location	LWC		CDRSS		WCC	
	μ	σ	μ	σ	μ	σ
L1	3.36	0.28	2.52	0.93	2.72	1.18
L2	6.45	0.09	4.47	0.20	3.19	0.02
L3	6.68	0.21	4.21	0.91	4.38	0.87
L4	3.76	0.08	2.68	1.49	2.14	1.46
L5	5.17	0.12	3.67	0.19	1.83	0.21
L6	1.94	0.76	0.74	0.17	1.02	0.48
L7	6.52	0.19	4.88	0.77	3.54	1.29
L8	8.42	0.20	4.50	0.19	3.67	1.18
L9	4.52	0.10	1.15	0.11	0.97	0.13
L10	5.91	0.11	3.67	0.20	2.01	0.51
L11	6.37	0.27	4.85	0.11	3.10	0.40
L12	2.25	1.15	2.17	1.54	2.00	2.65
L13	4.58	0.83	2.50	0.41	1.25	1.01
L14	0.57	0.06	2.95	1.01	2.32	1.89
Average	4.75	0.31	3.21	0.54	2.43	0.90



Impact of Open/Closed Doors



RSS of (Non-)Line-of-Sight Signals



Summary and Outlook

- SDR systems allow new opportunities for signal processing
- Positioning based on proximity-based localization algorithms (CDRSS and WCC) outperform LWC
- Promising results but challenges remain,
  main challenge: multi-path mitigation

Thanks for your attention !

> braun@iam.unibe.ch
> cds.unibe.ch