Comparison of Different Vector Distance Measure Calculation Variants for Indoor Location Fingerprinting

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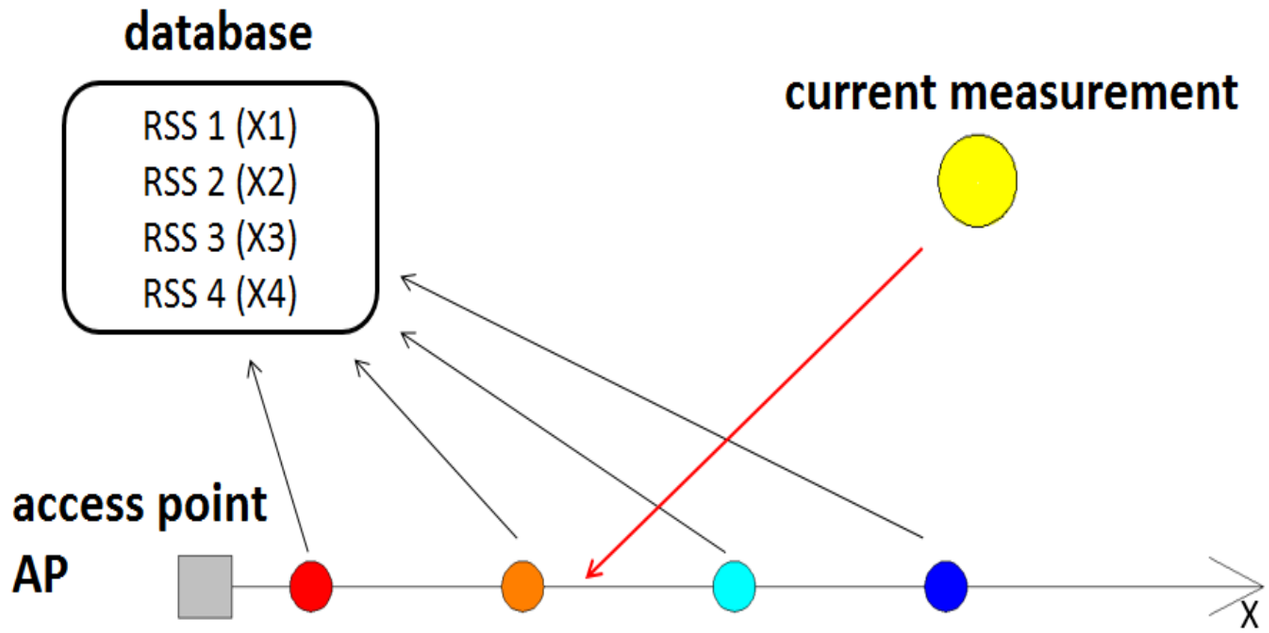
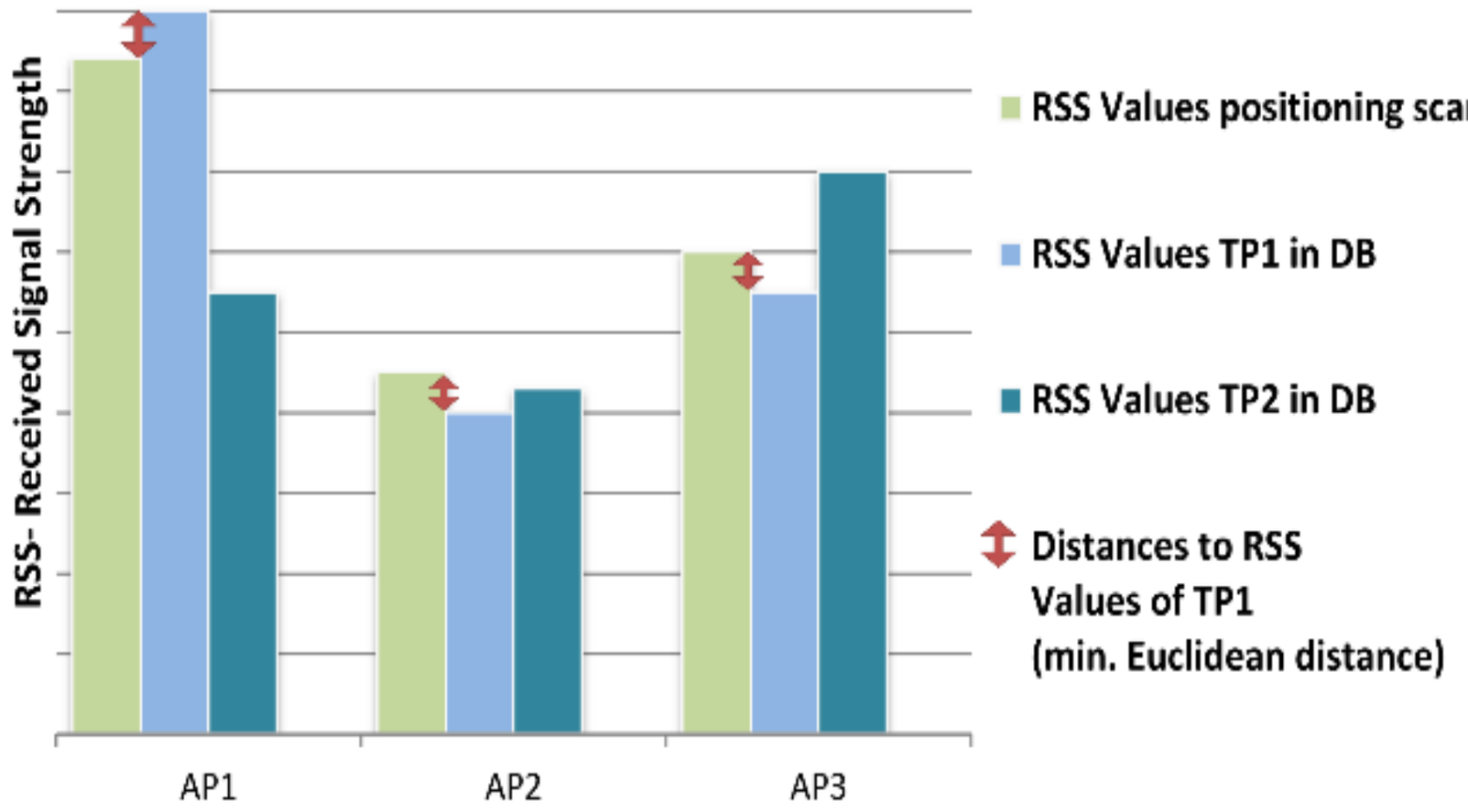
Wi-Fi Positioning

- Signal-of-Opportunity
- Use of already available infrastructure

- IEEE-802.11 standard in 2,4 GHz band
- Compatible devices
- Received Signal Strength RSS
- Location fingerprinting



Fingerprinting Matching Approaches



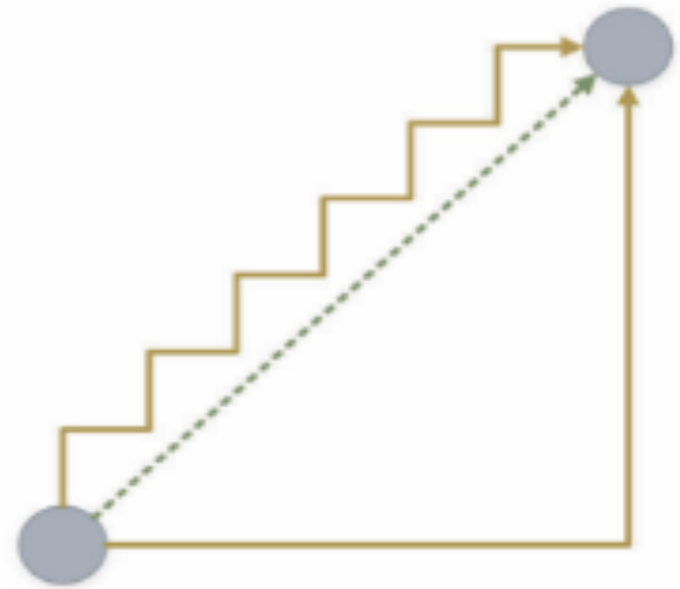
Allocation of RSS scans in the positioning phase to the training fingerprinting database DB

Universial Minkowski Vector Distance VD

$$L\downarrow q = \sqrt{q}\&\sum p=1\uparrow P\blacksquare |s\downarrow t,p - s\downarrow r,p |\uparrow q$$

where
$s\downarrow t,p$ is the $RSS\downarrow p$ of the fingerprint $TP\downarrow t$ measured in the positioning phase on the test point to be positioned,
$s\downarrow r,p$ the $RSS\downarrow p$ of the fingerprint $RP\downarrow r$ measured in the training phase on the reference point,
q the norm parameter and
$L\downarrow q$ is the norm q between two points

Manhattan and Euclidean VD



$q = 1$: $L\downarrow 1 = \sum p=1 \uparrow P \blacksquare |s\downarrow t,p - s\downarrow r,p|$

$q = 2$: $L\downarrow 2 = \sqrt{\sum p=1 \uparrow P \blacksquare |s\downarrow t,p - s\downarrow r,p|\uparrow 2}$

Chebyshev VD

$q=\infty$: $L\downarrow \infty = \max\nolimits_{\top} p\ |s\downarrow t,p - s\downarrow r,p|$

Canberra VD

$$d\downarrow Can = \sum p=1\uparrow P \frac{|s\downarrow t,p - s\downarrow r,p|}{|s\downarrow t,p| + |s\downarrow r,p|}$$

Cosine VD

$$d\downarrow Cos = 1 - \sum p=1\uparrow P s\downarrow t,p \cdot s\downarrow r,p \; / \sqrt{\sum p=1\uparrow P s\downarrow t,p\uparrow 2} \cdot \sqrt{\sum p=1\uparrow P s\downarrow r,p\uparrow 2}$$

Sorensen VD

$$d\downarrow Sor = \sum p=1\uparrow P |s\downarrow t,p - s\downarrow r,p| \; / \sum p=1\uparrow P (s\downarrow t,p + s\downarrow r,p)$$

Hellinger VD

$$d\downarrow Hel = 1/\sqrt{2} \cdot \| \sqrt{s\downarrow t} - \sqrt{s\downarrow r} \|$$

Chi-square VD

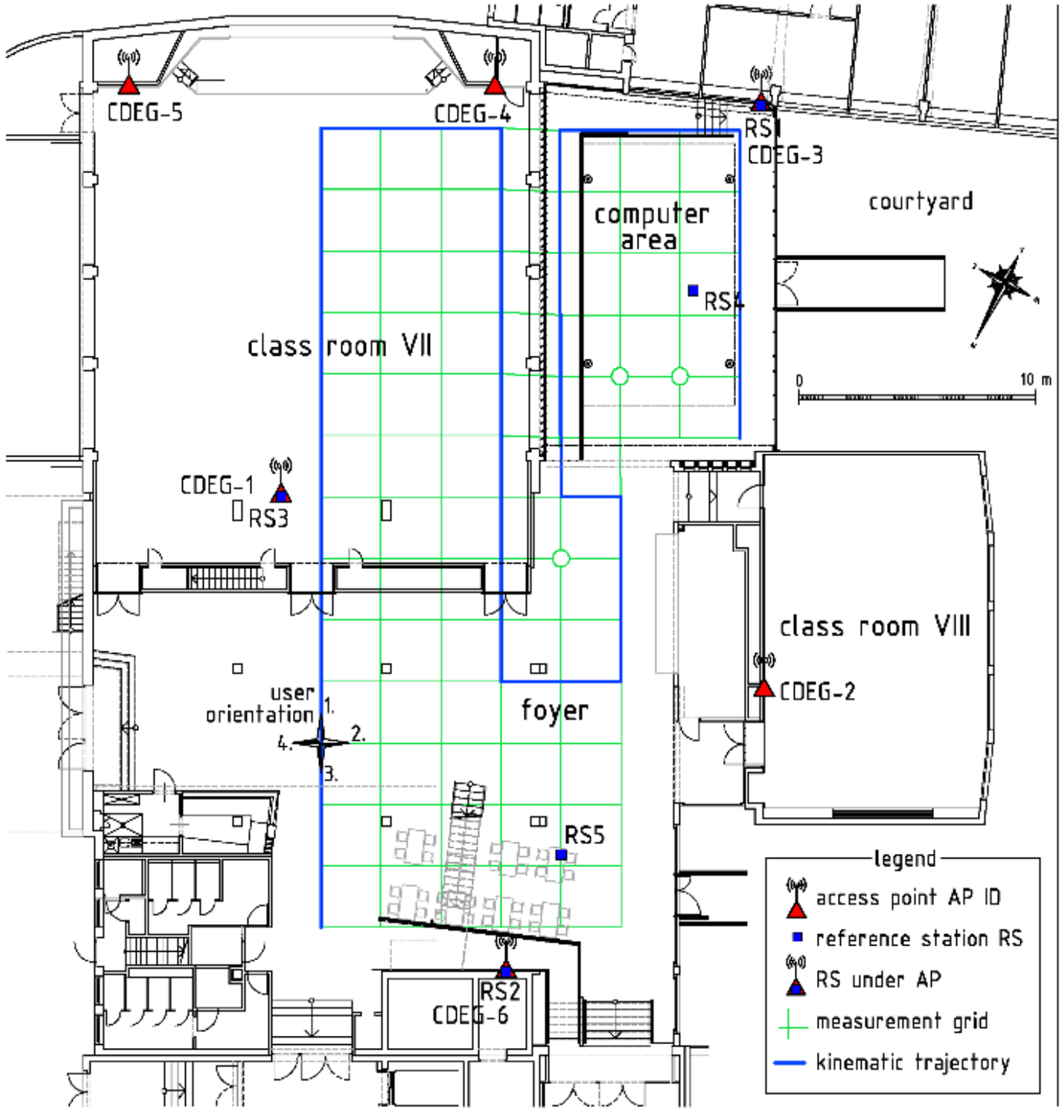
$$d\downarrow Chi = \sum p=1\uparrow P (s\downarrow t,p - \rho\downarrow p)\uparrow 2 / \rho\downarrow p$$

Jeffrey VD

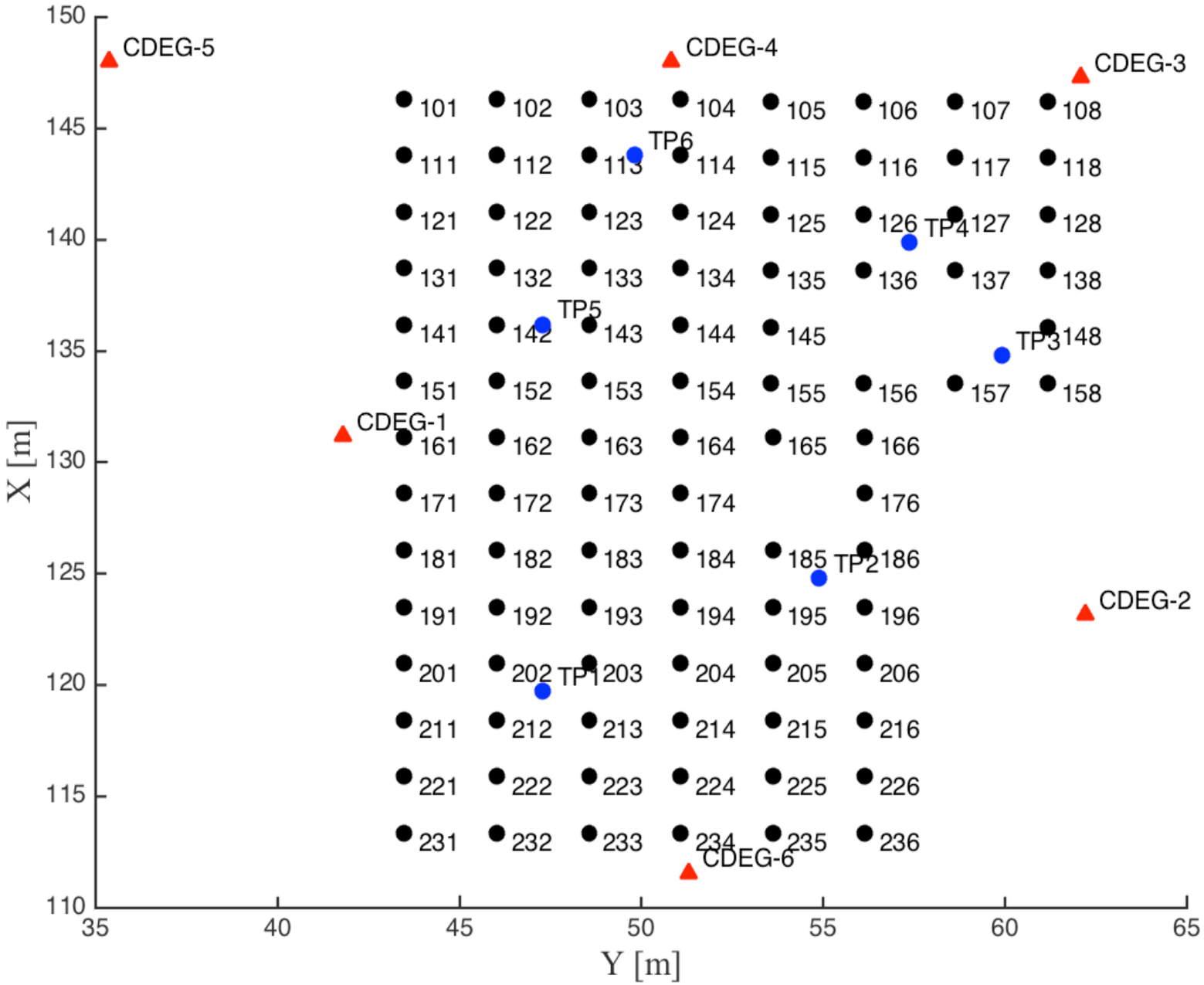
$$d\downarrow Jef = \sum p=1\uparrow P (s\downarrow t,p \cdot \log\downarrow 10 (s\downarrow t,p / \rho\downarrow p) + s\downarrow r,p \cdot \log\downarrow 10 (s\downarrow r,p / \rho\downarrow p))$$

Experiments

- 93 grid reference points
- 6 Access points
- 4 orientations



Indoor Test Site

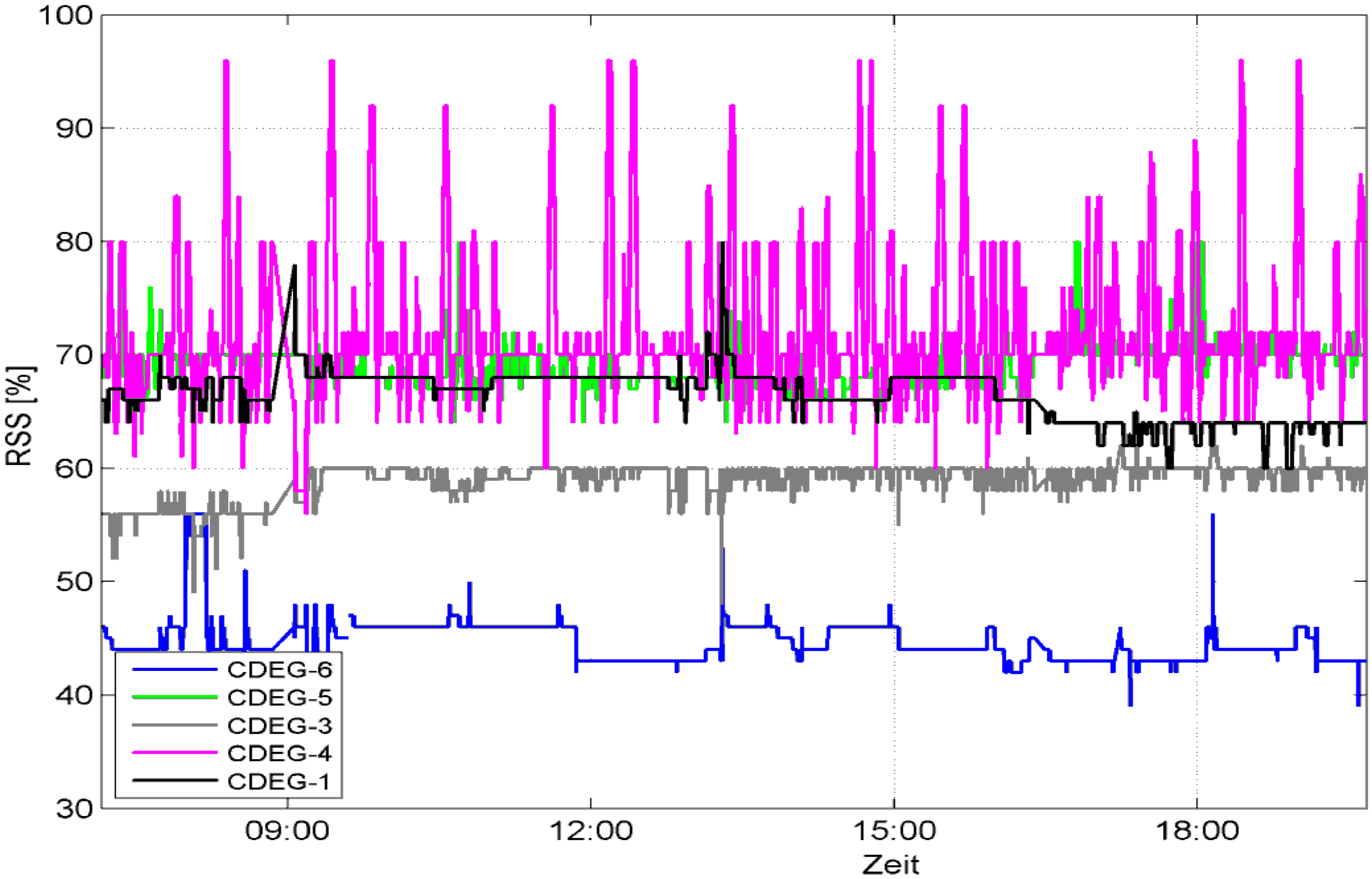


Distribution of reference points RPs (black dots), test points TPs (blue dots) and Access Points APs (red triangles)

4 Multiple-SSID Networks

SSID	Characteristics
eduroam	Network for students, staff and participants of this international network
tunet	Network for students and staff as well as visiting scholars and conference participants. The network is encrypted.
tunetguest	Alternative for network tunet, not encrypted.
wlanipsec	Network only for staff of TU Wien while using a VPN (Virtual Private Network) connection.

Long-time RSS Observations



DEs in [m] in the four different SSID networks and in total for the different VDs

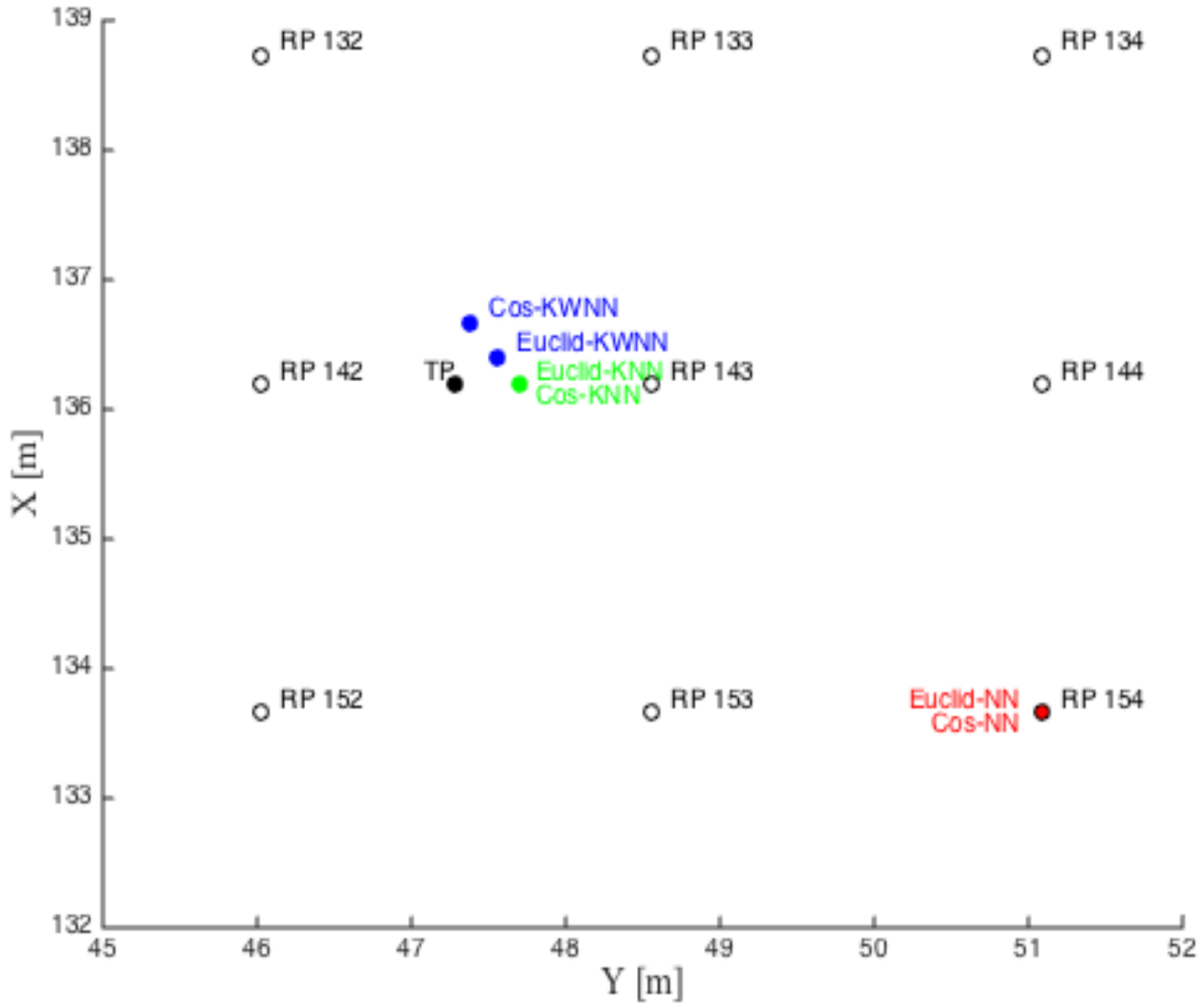
$$DE(TP\downarrow t)=\sqrt{(x\downarrow t-x\downarrow t)\uparrow 2+(y\downarrow t-y\downarrow t)\uparrow 2}$$

		eduroam		tunet		tunetguest		wlanipsec		total	
		min	max	min	max	min	max	min	max	min	max
Man-hattan	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.27	6.83	1.27	5.38
	KNN	0.60	2.99	0.95	4.67	0.60	7.20	0.60	4.67	0.60	4.67
	KWNN	0.55	3.01	1.16	4.87	0.71	7.83	0.63	4.79	0.66	4.72
Eucli-dean	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	5.49	0.42	5.49
	KWNN	0.35	2.57	0.32	3.49	1.59	7.73	0.33	5.48	0.31	5.18
Cheby-shev	NN	1.27	6.46	1.27	4.57	1.27	8.96	1.79	6.46	1.79	6.34
	KNN	0.60	4.67	0.42	3.90	1.34	4.35	2.15	7.20	0.42	5.56
	KWNN	0.73	4.69	0.34	3.72	1.39	4.72	2.13	7.654	0.35	5.57
Can-berra	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.27	6.83	1.27	5.38
	KNN	0.95	2.99	0.95	4.67	0.60	7.20	0.60	4.67	0.60	4.67
	KWNN	0.54	3.03	1.11	4.921	0.72	7.76	0.62	4.82	0.68	4.70
Cosine	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.79	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	5.49	0.42	5.49	0.60	5.87
	KWNN	0.43	2.68	0.59	3.02	1.30	4.01	0.29	5.48	0.82	5.62
Soren-sen	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.27	6.83	1.27	5.38
	KNN	0.60	2.99	0.95	4.67	0.60	7.20	0.60	4.67	0.60	4.67
	KWNN	0.55	3.01	1.16	4.87	0.71	7.83	0.63	4.80	0.67	4.72
Hell-inger	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	7.20	0.42	2.99
	KWNN	0.35	2.59	0.30	3.55	1.61	7.67	0.32	7.76	0.30	3.08
Chi-square	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	7.20	0.42	2.99
	KWNN	0.43	2.72	0.53	3.21	1.43	8.16	0.27	8.33	0.42	3.17
Jeffrey	NN	1.27	5.38	1.27	5.38	1.27	5.38	1.79	6.46	1.27	4.57
	KNN	0.42	2.46	0.42	3.90	1.74	7.20	0.42	7.20	0.42	2.99
	KWNN	0.43	2.72	0.53	3.21	1.43	8.16	0.27	8.33	0.42	3.17

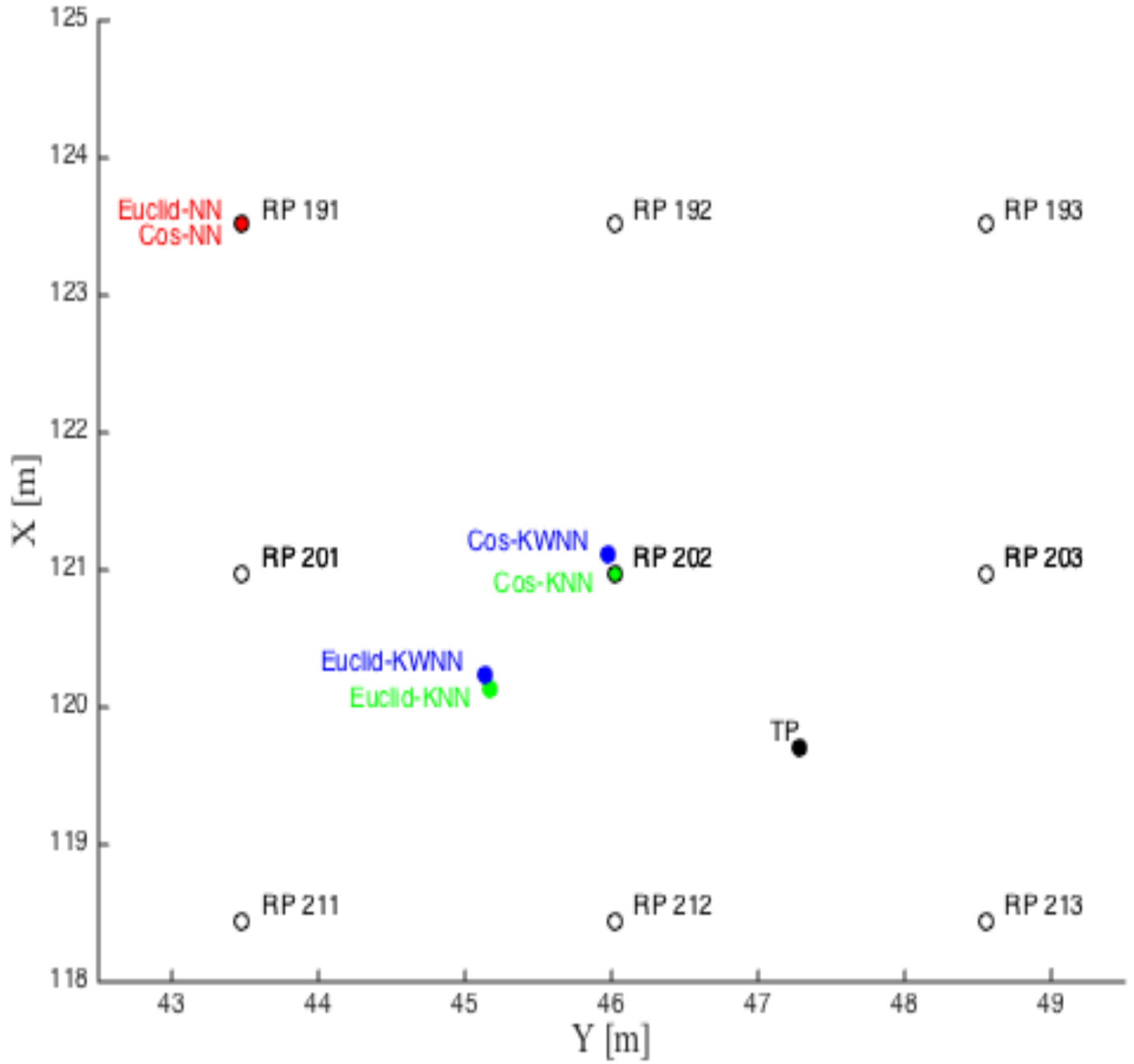
MDEs in [m] in the SSID network eduroam of all six TPs for the different VDs

$$MDE(l) = 1/T \cdot \sum_{t=1}^{T} DE(TP_t)$$

		TP 1	TP 2	TP 3	TP 4	TP 5	TP 6
Man-hattan	NN	5.38	1.79	4.01	1.79	4.60	1.27
	KNN	2.99	2.15	2.46	0.60	1.52	0.95
	KWNN	3.01	2.21	2.56	0.61	1.07	0.55
Eucli-dean	NN	5.40	1.79	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.21	2.19	2.57	0.63	0.35	0.58
Cheby-shev	NN	1.79	4.01	6.46	1.79	4.57	1.27
	KNN	3.64	2.15	4.67	0.60	2.83	0.95
	KWNN	3.55	2.22	4.69	0.76	2.58	0.73
Can-berra	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.99	2.15	2.46	1.79	1.52	0.95
	KWNN	3.03	2.22	2.62	1.76	1.11	0.55
Cosine	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	1.79	2.15	2.46	0.60	0.42	0.95
	KWNN	1.91	2.25	2.68	0.65	0.48	0.43
Soren-sen	NN	5.40	1.79	4.01	1.79	4.57	1.27
	KNN	2.99	2.15	2.46	0.60	1.52	0.95
	KWNN	3.01	2.21	2.56	0.61	1.07	0.55
Hell-inger	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.22	2.22	2.59	0.64	0.35	0.57
Chi-square	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.30	2.30	2.72	0.68	0.44	0.43
Jeffrey	NN	5.38	4.01	4.01	1.79	4.57	1.27
	KNN	2.15	2.15	2.46	0.60	0.42	0.95
	KWNN	2.30	2.30	2.72	0.68	0.44	0.43



Comparison of resulting positions with the NN, KNN and KWNN matching approach on test point TP 5



Comparison of resulting positions with the NN, KNN and KWNN matching approach on test point TP 1

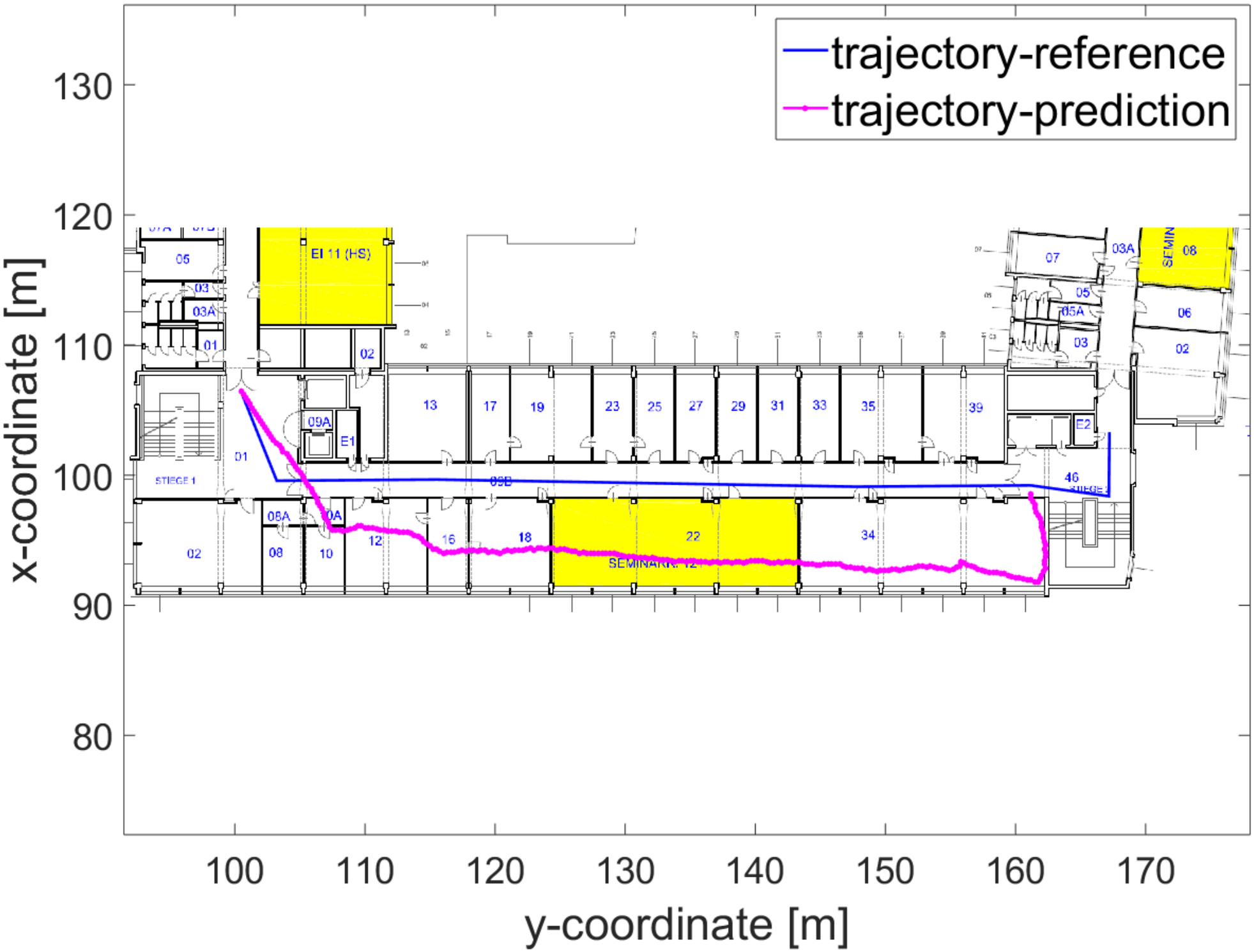
Discussion

- Results of 9 VDs do not show significant differences
- Selection depends on the surrounding environment and the present interference conditions
- The use of the most commonly employed Euclidean VD is suitable
- Only one network of **multiple-SSIDs should be selected**
- Averaging over all networks is not recommended
- KNN and KWNN have better performance than the NN matching approach

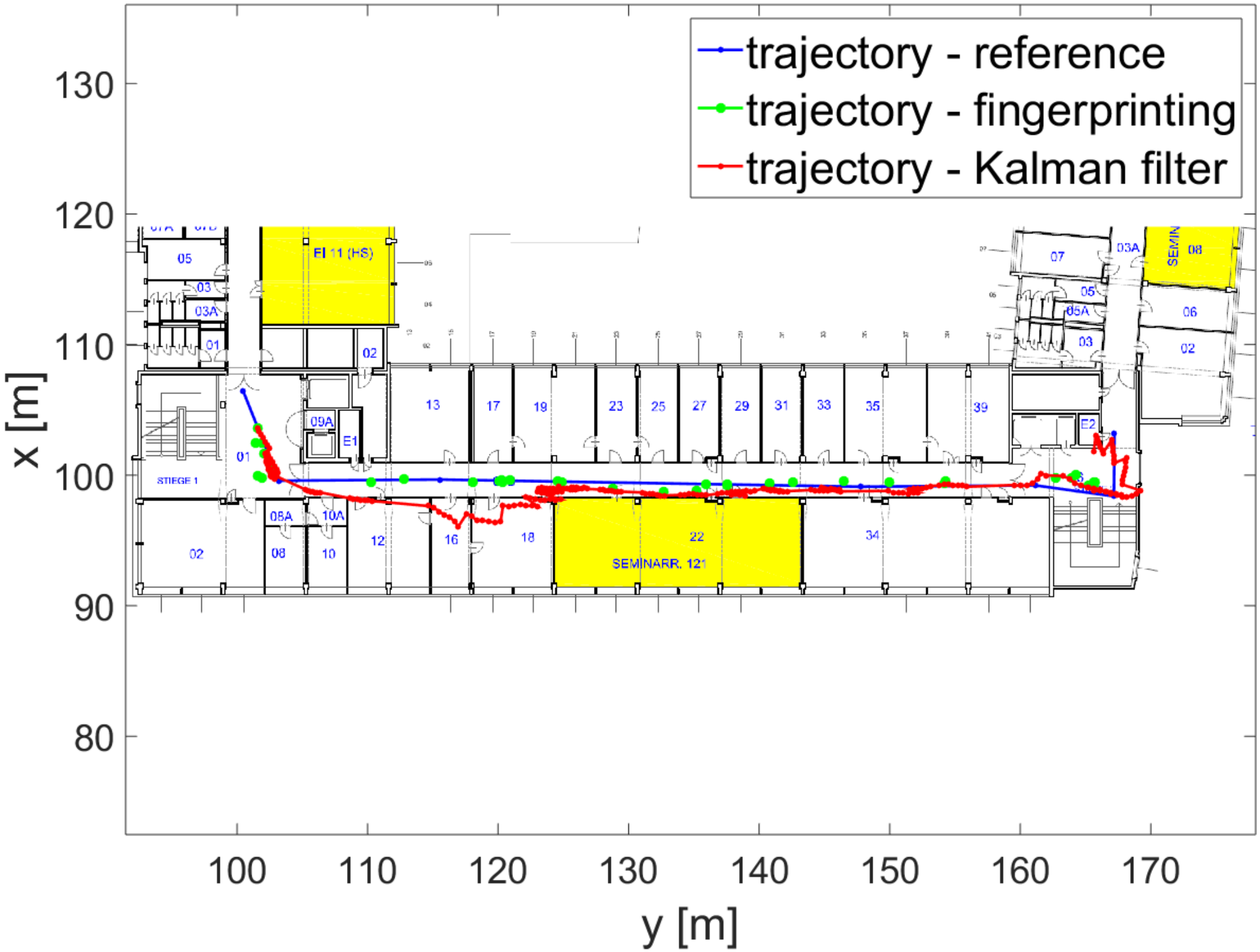
Conclusions and Future Work

- Current investigations are focused on the additional integration of continuous long-time measurements to consider temporal and spatial RSS signal variations
- A performance increase is the additional use of the compass data from the smartphone sensors and an orientation dependent fingerprinting DB
- Investigation of probabilistic approaches such as the Mahalanobis VD
- Combination of Wi-Fi positioning with fingerprinting using present ambient geomagnetic fields yields to positioning accuracies of around 0.5 m
- Integration with the inertial sensors embedded in the smartphone for dead reckoning
- 3D environments with barometric pressure sensor augmentation

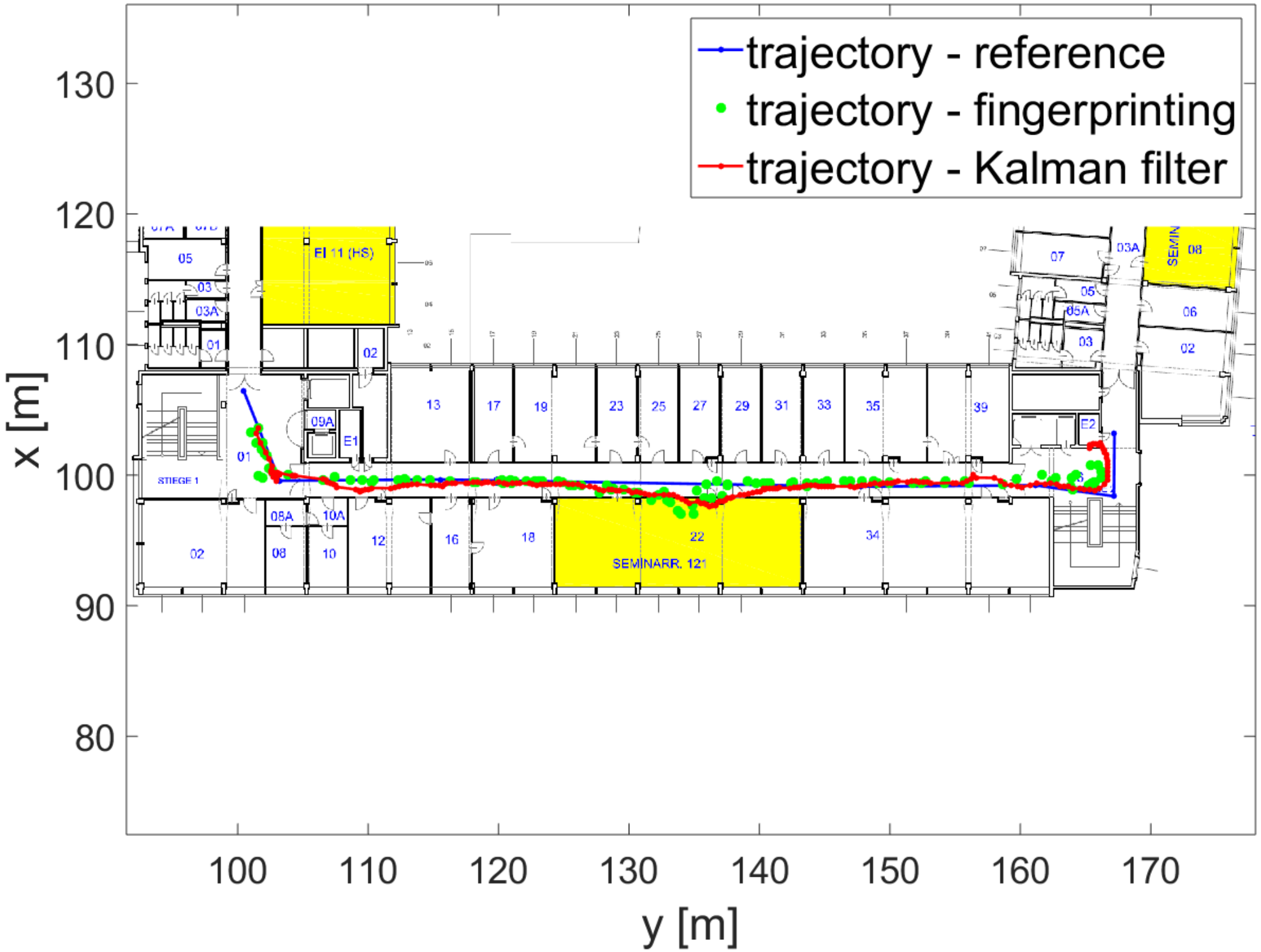
Kinematic Measurements



Kinematic Measurements



Kinematic Measurements



Kinematic Measurements

Mean lateral deviation	Fingerprinting method	
	Wi-Fi	Mag + Wi-Fi
Trajectory 1	0.72m	0.47m
Trajectory 2	1.34m	0.47m
Trajectory 3	2.00m	0.98m