RF-based DFAR and implicit ad-hoc usable security

Stephan Sigg

Aalto University, Communications and Networking

July 1, 2016

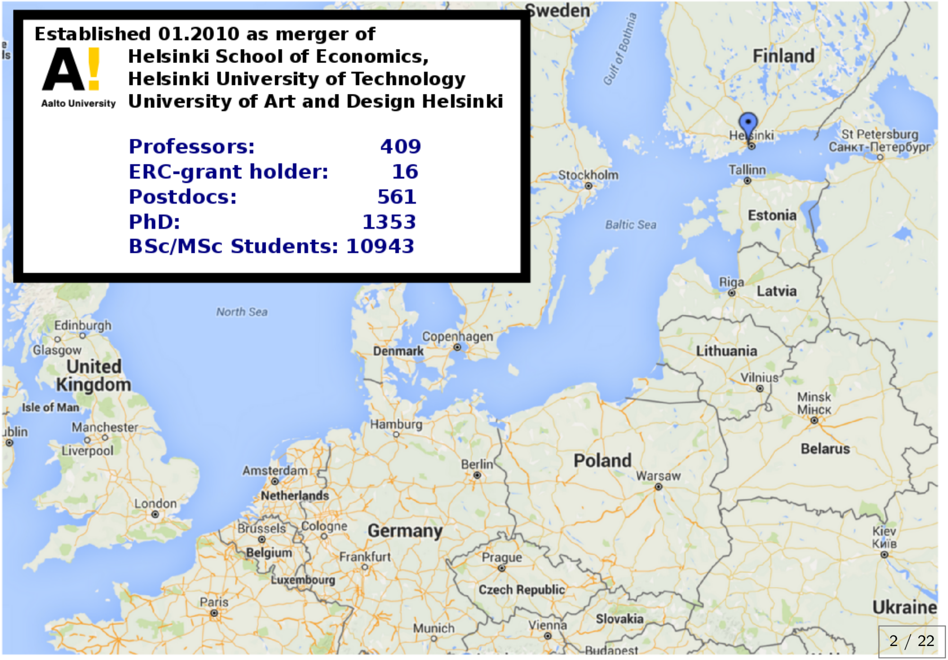

Sweden
Gulf of Bothnia
Norway
Finland
Helsinki
St Petersburg
Санкт-Петербург
Oslo
Stockholm
Tallinn
Estonia
Baltic Sea
Riga
Latvia
North Sea
Edinburgh
Glasgow
United Kingdom
Copenhagen
Denmark
Lithuania
Vilnius
Minsk
Минск
Isle of Man
Manchester
Liverpool
Hamburg
Belarus
Berlin
Poland
Warsaw
Amsterdam
Netherlands
London
Brussels
Cologne
Germany
Kiev
Київ
Belgium
Frankfurt
Prague
Luxembourg
Czech Republic
Paris
Slovakia
Ukraine
Munich
Vienna
Budapest

Established 01.2010 as merger of

Aalto University

Helsinki School of Economics,
Helsinki University of Technology
University of Art and Design Helsinki

Professors:	**409**
ERC-grant holder:	**16**
Postdocs:	**561**
PhD:	**1353**
BSc/MSc Students:	**10943**



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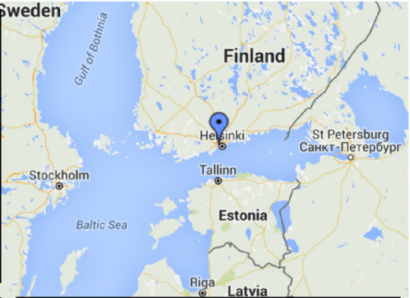
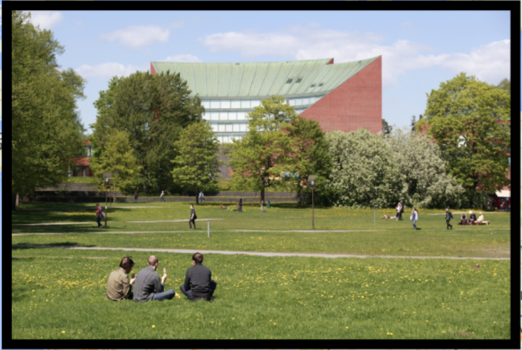
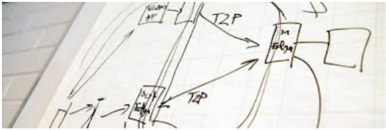




Comnet

- Personnel: ~115
- 11 + 2 Professors
- budget ~7.8 M€
  - ~ 60% external funding
- ~ 55 M.Sc thesis annually
- ~ 8 D.Sc thesis annually



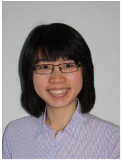
Comnet is a multi-disciplinary unit of research and higher education covering communications and networking technology, networking business and human aspects of communications. In its area, Comnet is the largest unit in Finland.

http://comnet.aalto.fi/en/

Aalto University
School of Electrical
Engineering

Comnet
6/8/16
2

Professors



Xiao Yu
Networking software and applications

Stephan Sigg
Ubiquitous computing

Antti Oulasvirta
Human-Computer Interaction
(User Interfaces)

Heikki Hämmäinen
Network Economics

Juuso Töyli
Network economics
Adjunct Prof.

Jarno Limnell
Cyber security
PoP

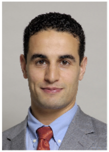
Patric Östergård
Information theory

Olav Tirkkonen
Communications theory

Riku Jäntti
Commuications Engineering
Head of department

Jyri Hämäläinen
Radio communications
Dean of ELEC

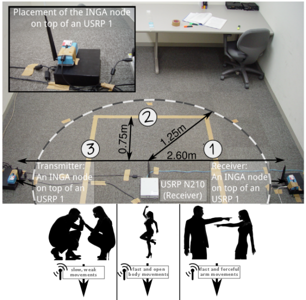
Raimo Kantola
Networking technology
Routing, trust, and privacy

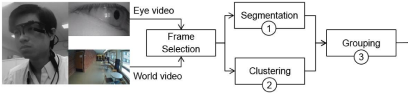


Tarik Taleb
Mobile Core Networks
Network Function Virtualization and Cloud Communications

Jukka Manner
Internet technologies
Transport

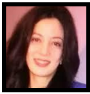
Ambient Intelligence





Stephan Sigg

Randomized Algorithms, Optimization, Usable security, Activity recognition, Machine learning, Pervasive Computing



Bahareh Gholampooryazdi

Signal processing, RF-based Device-free activity recognition

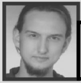
Le Ngu Nguyen

Usable Security, Activity recognition, Machine learning, Mobile applications

Muneeba Raja

Sentiment sensing, Device-Free RF-based Activity recognition, Pervasive Computing

Visitors



Dominik Schuermann

Security in DTN, Anonymity in decentralized networks, Authenticated Key Exchange Usable security

Arne Bruesch

Machine learning, Information systems, Ad-hoc secure device pairing, Inertial sensors

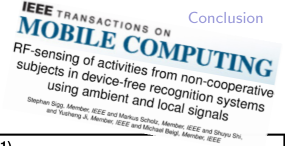
Project:

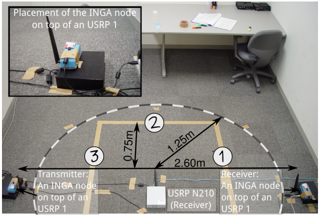
RF-based device-free activity recognition

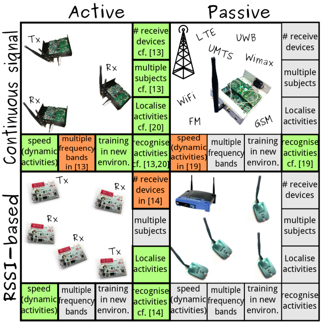
RF-based activity recognition

Sensewaves Video

RF-based device-free activity recognition







Active SDR-based DFAR (USRP1)

Frequency: 900MHz (RFX900 board), Vert900 Antenna), 4dBi antenna gain
Signal: Sine signal, continuously modulated onto the carrier
Sample rate: 80 Hz

Passive SDR-based DFAR (USRP N210)

Frequency: 82.5MHz (WBX board), Vert900 Antenna, 4dBi antenna gain
Signal: Environmental FM radio captured from a nearby radio station
Sample rate: 64Hz

Active RSSI-based DFAR (INGA wsn nodes, v1.4)

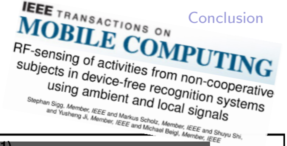
Frequency: 2.4GHz IEEE802.15.4, PCB High Gain-Antenna
Signal: RSSI samples from packets transmitted between nodes
Sample rate: Transmission of 100 packets per second

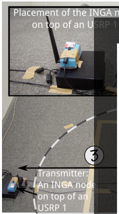
Accelerometer-based activity recognition (Iphone 4)

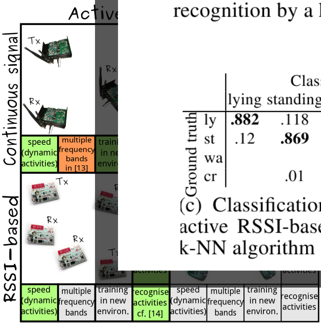
Signal: 3-axis accelerometer
Sample rate: 40 Hz

Walking standing Crawling
Lying empty

RF-based device-free activity recognition







Active SDR-based DFAR (USRP1)

Frequency: 900MHz (RFX900 board), Vert900 Antenna), 4dBi antenna gain

nna gain

io station

des

ling

Ground truth	lying	standing	walking	crawling
ly	**.976**	.024		
st		**1.0**		
wa			**.955**	.045
cr			.253	**.748**

(a) Classification accuracy for accelerometer-based activity recognition by a k-NN

Ground truth	lying	standing	walking	crawling
ly	**.904**	.096		
st	.096	**.898**	.006	
wa		.013	**.962**	.025
cr		.038	.212	**.75**

(b) Classification accuracy for active SDR-based DFAR by a k-NN algorithm

Ground truth	lying	standing	walking	crawling
ly	**.882**	.118		
st	.12	**.869**	.007	.004
wa			**.953**	.047
cr		.01	.439	**.551**

(c) Classification accuracy for active RSSI-based DFAR by a k-NN algorithm

Ground truth	lying	standing	walking	crawling
ly	**1.0**			
st	.056	**.98**	.022	
wa	.023		**.874**	.102
cr	.044		.144	**.811**

(d) Classification accuracy for passive SDR-based DFAR by a k-NN algorithm

Features

Assume that $\mid \mathcal{W}_t \mid$ samples s_i are taken on the signal strenth of an incoming signal for a window $\mathcal{W}_t = s_1^t, \dots, s_{|\mathcal{W}_t|}^t$

Mean signal strength

The mean signal strength over a window of measurements represents static characteristic changes in the received signal strength.

It provides means to distinguish a standing person as well as her approximate location.

$$\text{Mean}(\mathcal{W}_t) = \frac{\sum_{s_i \in \mathcal{W}_t} s_i}{\mid \mathcal{W}_t \mid}$$

Mean difference between subsequent maxima

When the maximum peaks within a sample window are of similar magnitude, this indicates low activity in an environment or static activities. The opposite might be found with dynamic activities

$$\mathcal{W}_{\max}(\mathcal{W}_t) = \{s_i \mid s_i \in \mathcal{W}_t, s_{i-1} < s_i \wedge s_i > s_{i+1}\}$$

$$a(\mathcal{W}_t) = \sum_{\substack{\forall s_i, s_j \in \mathcal{W}_{\max}(\mathcal{W}_t); \\ i<j; \\ \nexists s_k \text{ with} i<k<j}} \frac{\mid s_i - s_j \mid}{\mid \mathcal{W}_{\max}(\mathcal{W}_t) \mid}$$

Variance of the signal's strength

The variance of the signal strength represents the volatility of the received signal.

It can provide some estimation on changes in a receiver's proximity such as movement of individuals

$$\text{Var}(\mathcal{W}_t) = \sqrt{\frac{\sum_{s_i \in \mathcal{W}_t} (s_i - \text{Mean}(\mathcal{W}_t))^2}{\mid \mathcal{W}_t \mid}}$$

Count of zero crossings

The count of zero crossings over a sample interval is a measure of the fluctuation in a received signal's strength.

It can be leveraged in order to estimate the count of individuals or movement in proximity of a receiver.

$$g(s_i) = \begin{cases} 0 & \text{if } \text{sgn}(s_{i-1}) = \text{sgn}(s_i) \\ 1 & \text{else} \end{cases}$$

$$\text{ZeroCross}(\mathcal{W}_t) = \sum_{s_i \in \mathcal{W}_t} g(s_i)$$

Signal peaks within 10% of a maximum

Reflections at nearby or remote objects impact the signal strength at a receive antenna. When all peaks are of the similar magnitude, this is an indication that movement is farther away.

This feature can indicate near-far relations and activity of individuals.

$$h(s_i) = \begin{cases} 1 & \text{if } s_i \geq \max(s_1, \dots, s_{|\mathcal{W}|}) \cdot 0.9 \\ 0 & \text{else} \end{cases}$$

$$\max_{0.9}(\mathcal{W}_t) = \sum_{s_i \in \mathcal{W}_t} h(s_i)$$

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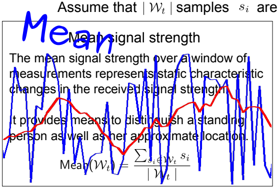

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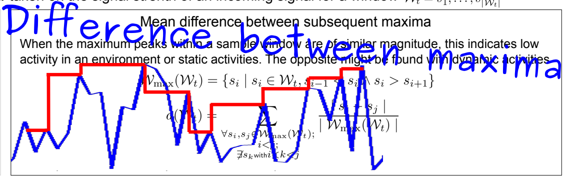

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$$\max_{0.9}(\mathcal{W}_t) = \sum_{s_i \in \mathcal{W}_t} h(s_i)$$

Mean

Difference between maxima

Variance

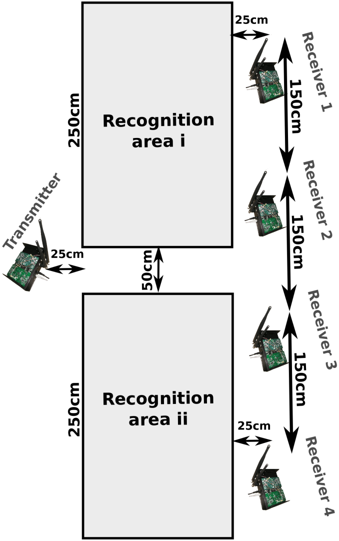
Zero crossings

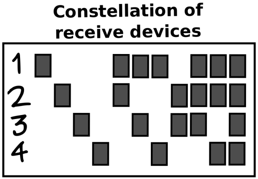
Signal peaks

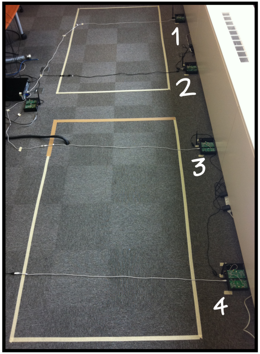
Recognition of multiple activities simultaneously

standing
walking
crawling
lying
empty

5x5=25



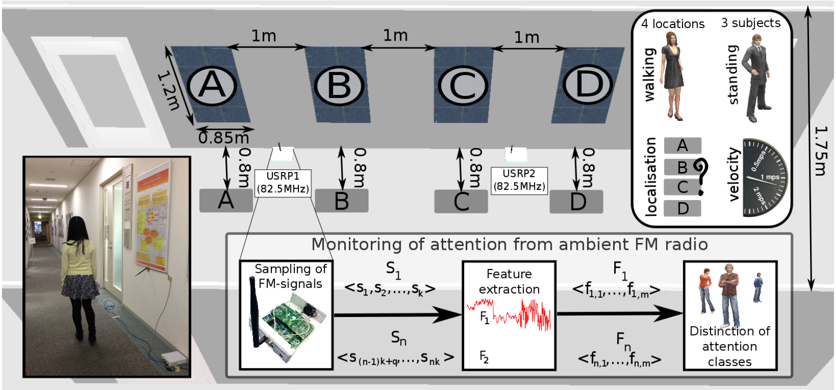




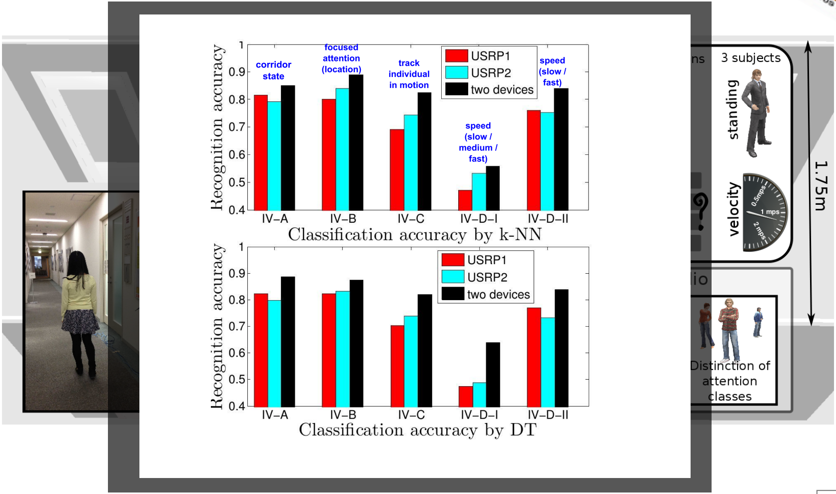
	Constellation of receive devices						
	1,2	1,3	1,4	2,3	1,2,3	1,2,4	1,2,3,4
CA	.697	.749	.726	.730	.787	.754	.838
IS	1.49	1.64	1.57	1.57	1.7	1.65	1.86
Brier	.421	.355	.388	.390	.318	.343	.229
AUC	.930	.946	.939	.928	.958	.960	.980

Table 5: Overall performance of the k-NN classifier

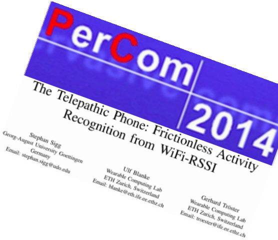
Monitoring attention from RF

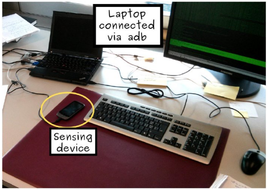


Monitoring attention from RF

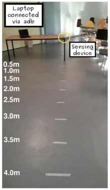


Situation and gestures from passive RSSI-based DFAR

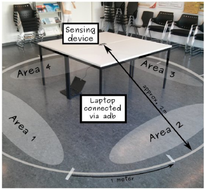




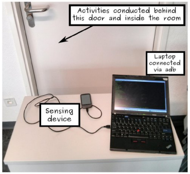
(a) Office environment at ETH



(b) Lecture room at TU-BS

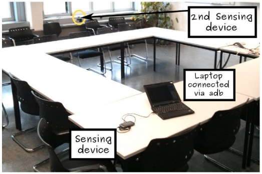


(c) Scenario for the distinction of walking speed

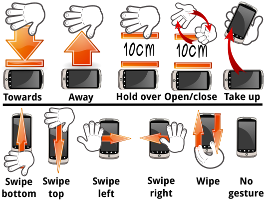


(d) Activities conducted behind a closed door

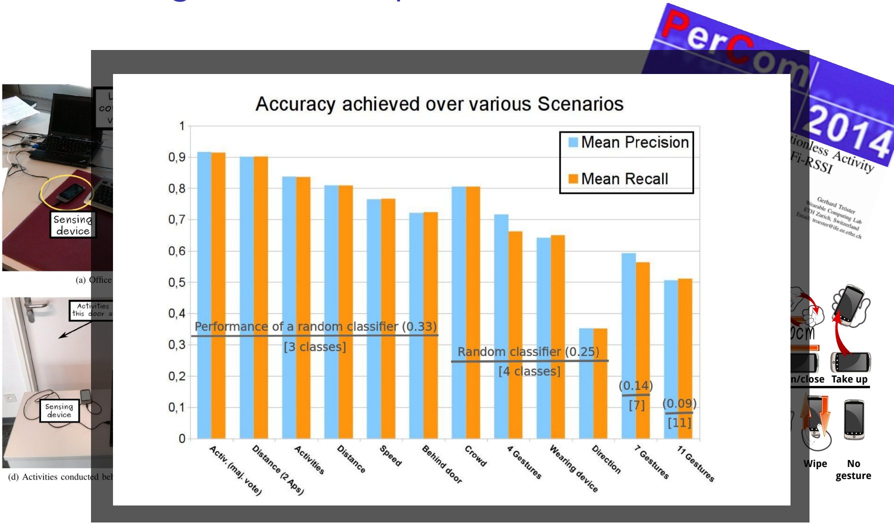
(e) Sensing device inside pocket



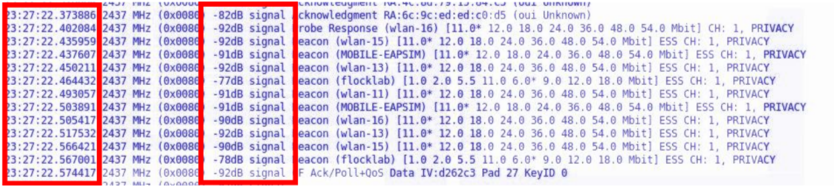
(f) Meeting room at ETH



Situation and gestures from passive RSSI-based DFAR



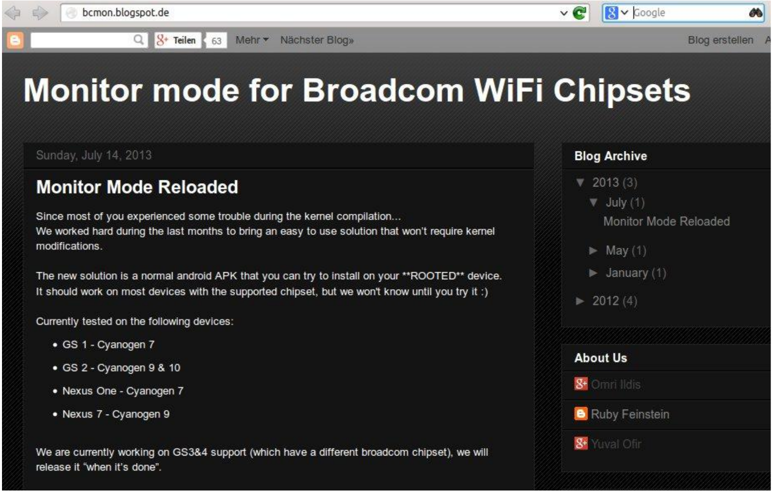
Measure signal strength on a phone



```
23:27:22.373886 2437 MHz (0x0080) -82dB signal Acknowledgment RA:6c:9c:ed:ed:c0:d5 (oui Unknown)
23:27:22.402084 2437 MHz (0x0080) -92dB signal Probe Response (wlan-16) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] CH: 1, PRIVACY
23:27:22.435959 2437 MHz (0x0080) -92dB signal Beacon (wlan-15) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.437607 2437 MHz (0x0080) -91dB signal Beacon (MOBILE-EAPSIM) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.450211 2437 MHz (0x0080) -92dB signal Beacon (wlan-13) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.464432 2437 MHz (0x0080) -77dB signal Beacon (flocklab) [1.0 2.0 5.5 11.0 6.0* 9.0 12.0 18.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.493057 2437 MHz (0x0080) -91dB signal Beacon (wlan-11) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.503891 2437 MHz (0x0080) -91dB signal Beacon (MOBILE-EAPSIM) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.505417 2437 MHz (0x0080) -90dB signal Beacon (wlan-16) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.517532 2437 MHz (0x0080) -92dB signal Beacon (wlan-13) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.566421 2437 MHz (0x0080) -90dB signal Beacon (wlan-15) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.567001 2437 MHz (0x0080) -78dB signal Beacon (flocklab) [1.0 2.0 5.5 11.0 6.0* 9.0 12.0 18.0 Mbit] ESS CH: 1, PRIVACY
23:27:22.574417 2437 MHz (0x0080) -92dB signal CF Ack/Poll+QoS Data IV:d262c3 Pad 27 KeyID 0
```

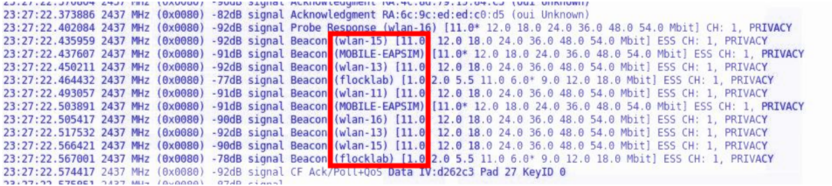
- How to obtain this data on a phone?
  - root access ✓
  - Firmware does not support such access

Measure signal strength on a phone



Ildis, Ofir, Feinstein: Wardriving from your pocket, RECon 2013

Measure signal strength on a phone



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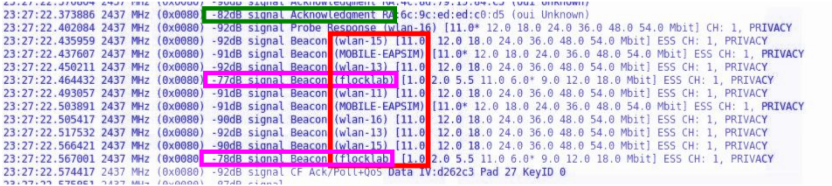
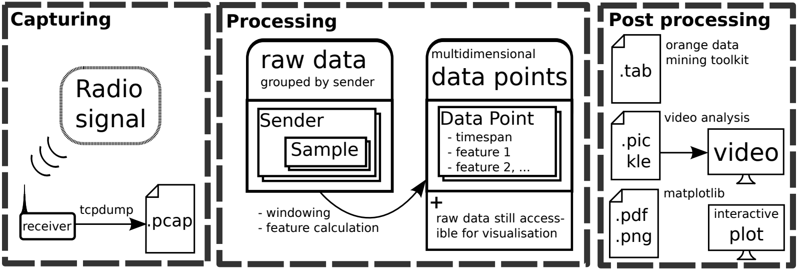
23:27:22.574417 2437 MHz (0x0080) -92dB signal CF Ack/Poll+QoS Data IV:d262c3 Pad 27 KeyID 0
```

Measure signal strength on a phone

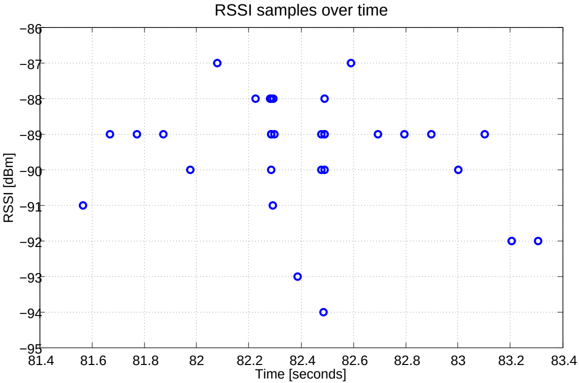


Measure signal strength on a phone



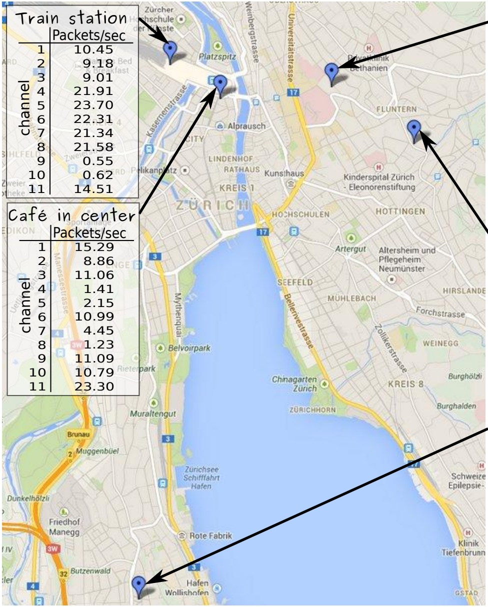
- http://www.stephansigg.de/DeviceFree/pcapTools.tar.gz

Sampled RSSI over time



- Only use simple time-domain features
- Pre-processing?

Which sample rate can we expect?



Train station

channel	Packets/sec
1	10.45
2	9.18
3	9.01
4	21.91
5	23.70
6	22.31
7	21.34
8	21.58
9	0.55
10	0.62
11	14.51

Café in center

channel	Packets/sec
1	15.29
2	8.86
3	11.06
4	1.41
5	2.15
6	10.99
7	4.45
8	1.23
9	11.09
10	10.79
11	23.30

University (ETH)

channel	Packets/sec	
	ground	*3rd fl.*
1	34.06	14.88
2	0.61	5.02
3	4.45	0.19
4	0.10	0.04
5	53.97	192.29
6	0.14	0.04
7	0.28	0.03
8	0.11	0.07
9	26.46	2.88
10	0.06	0.09
11	0.05	0.02

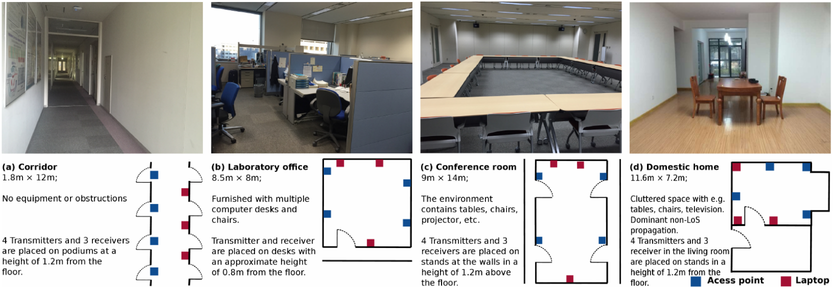
Dormitory

channel	Packets/sec
1	10.28
2	10.03
3	12.13
4	9.92
5	9.30
6	1.77
7	0.09
8	0.19
9	6.92
10	0.47
11	0.36

Suburban flat

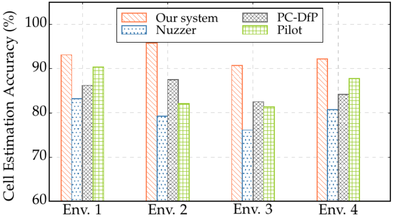
channel	Packets/sec
1	0.85
2	0.35
3	0.32
4	0.20
5	0.85
6	3.10
7	2.59
8	11.85
9	4.46
10	2.05
11	9.61

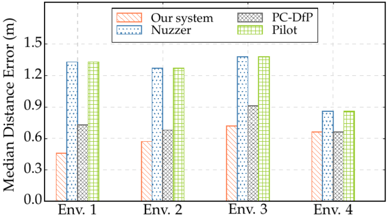
Modelling CSI vectors via multivariate gaussian distribution



We model the amplitude of every CSI reading at location 'y' to approximately follow a multivariate Gaussian Distribution. Location is then predicted via the maximum likelihood estimate.

Modelling CSI vectors via multivariate gaussian distribution



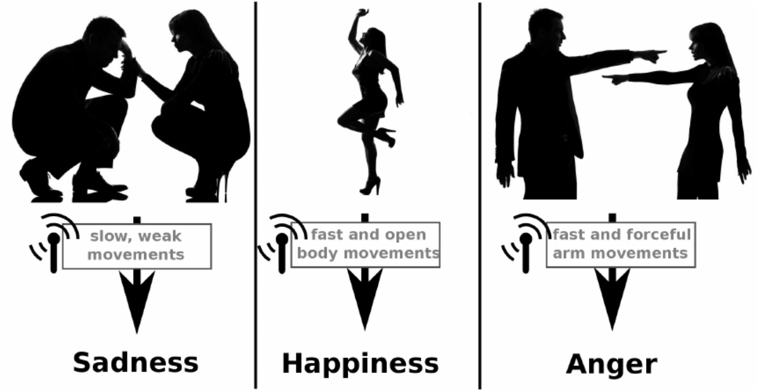


We model the amplitude of every CSI reading at location 'y' to approximately follow a multivariate Gaussian Distribution. Location is then predicted via the maximum likelihood estimate.

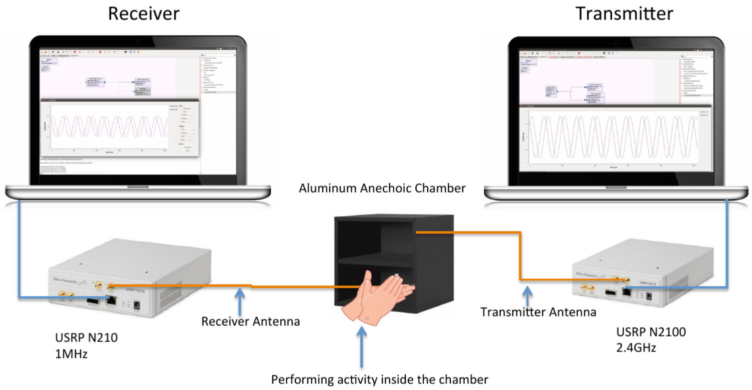
Nuzzer: Seifeldin, Saeed, Kosba, El-keyi, Youssef. Nuzzer: A large-scale device-free passive localization system for wireless environments. IEEE Transactions on Mobile Computing, 2013.
Pilot: Xiao, Wu, Yi, Wang, Ni. Pilot: Passive device-free indoor localization using channel state information. ICDCS, 2013.

PC-DfP: Xu, Firner, Zhang, Howard, Li, Lin. Improving rf- based device-free passive localization in cluttered indoor environments through probabilistic classification

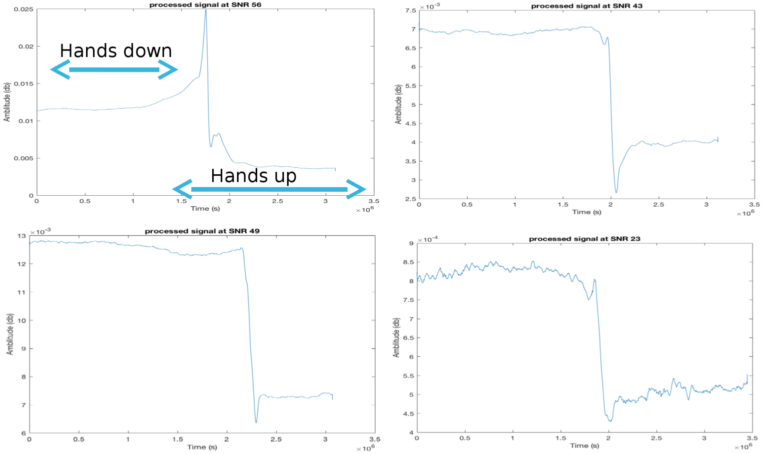
Emotion recognition from RF



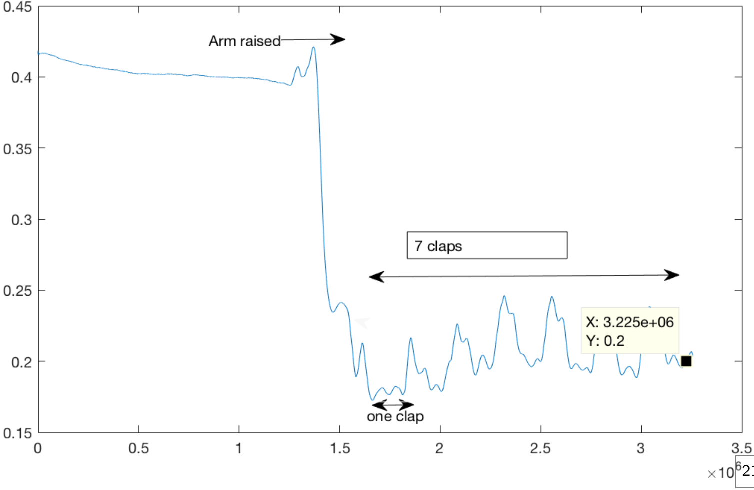
Emotion recognition from RF



Emotion recognition from RF



Emotion recognition from RF



Thank you!

Stephan Sigg
stephan.sigg@aalto.fi