Aalto University
School of Electrical Engineering

Device-Free activity recognition

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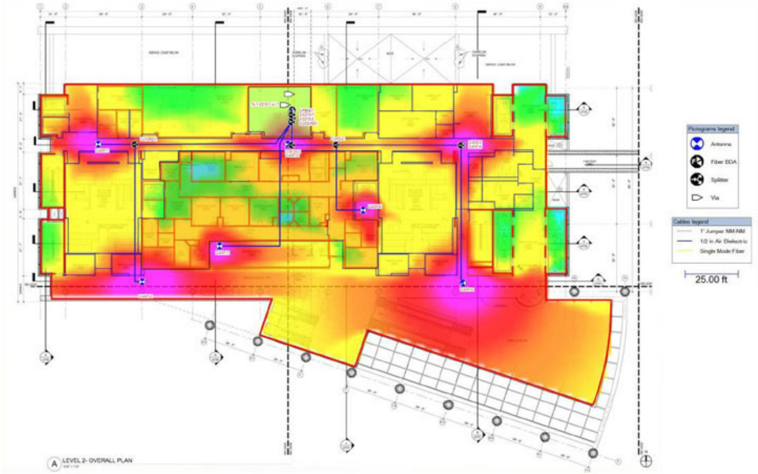
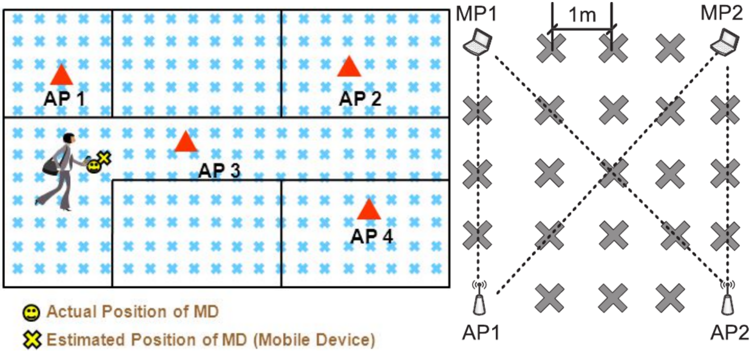
Bad Worishofen, 10.07.2017



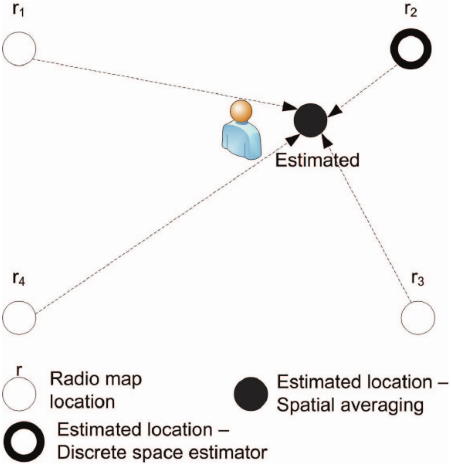
Pictograms legend
Antenna
Fiber BDA
Splitter
Via
Cables legend
1' Jumper NM-NM
1/2 in Air Dielectric
Single Mode Fiber
25.00 ft
LEVEL 2- OVERALL PLAN

WiFi Fingerprinting



Seifeldin et. al: Nuzzer: A Large-Scale Device-Free Passive Localization System for Wireless Environments, IEEE TMC 2013

Bong et. al: Reasonable Resolution of Fingerprint Wi-Fi Radio Map for Dense Map Interpolation, FRTA, 2014

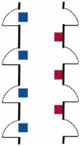


Seifeldin et. al: Nuzzer: A Large-Scale Device-Free Passive Localization System for Wireless Environments, IEEE TMC 2013

(a) Corridor
1.8m × 12m;

No equipment or obstructions

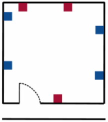
4 Transmitters and 3 receivers are placed on podiums at a height of 1.2m from the floor.



(b) Laboratory office
8.5m × 8m;

Furnished with multiple computer desks and chairs.

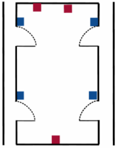
Transmitter and receiver are placed on desks with an approximate height of 0.8m from the floor.



(c) Conference room
9m × 14m;

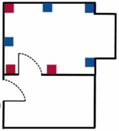
The environment contains tables, chairs, projector, etc.

4 Transmitters and 3 receivers are placed on stands at the walls in a height of 1.2m above the floor.

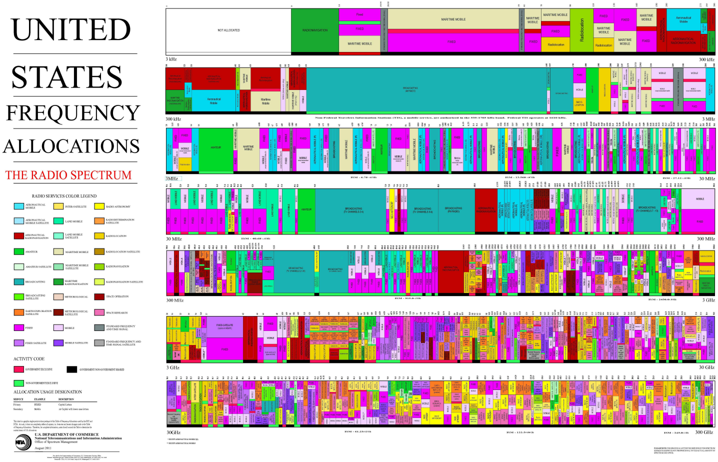


(d) Domestic home
11.6m × 7.2m;

Cluttered space with e.g. tables, chairs, television. Dominant non-LoS propagation.
4 Transmitters and 3 receiver in the living room are placed on stands in a height of 1.2m from the floor.

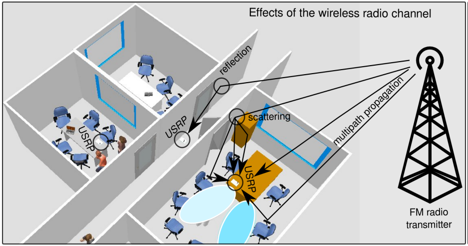


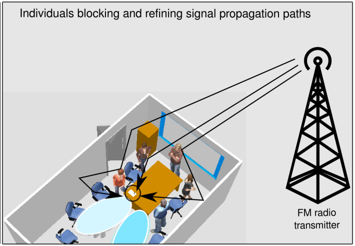
Acess point **Laptop**


UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
August 2011
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz

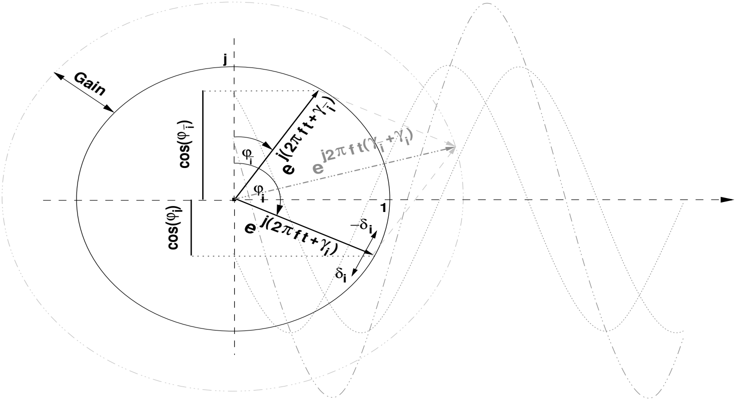
Exploiting the RF-channel for environmental preception

- Multi-path propagation
- Signal superimposition
- Scattering
- Signal Phase
- Reflection
- Blocking of signal paths
- Doppler Shift
- Fresnel effects

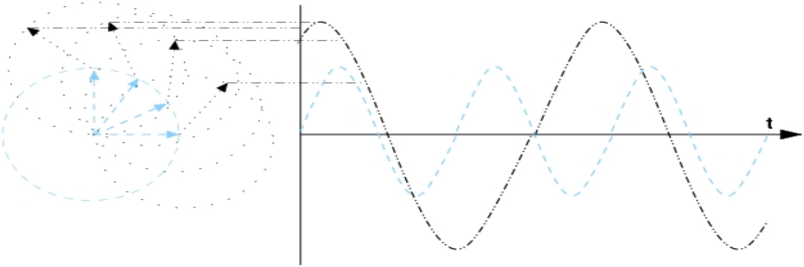




Aspects of the mobile radio channel



Aspects of the mobile radio channel



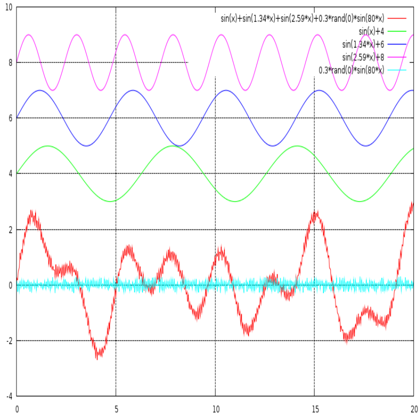
Superimposition of RF signals

- At a receiver, all incoming signals add up to one superimposed sum signal
- Constructive and destructive interference
- Normally: Heavily distorted sum signal

Aspects of the mobile radio channel

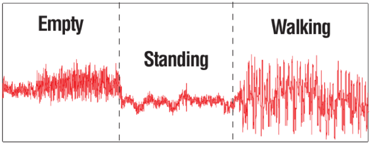
Superimposition of RF signals

- The wireless medium is a broadcast channel
- Multipath transmission
  - Reflection
  - Diffraction
  - Different path lengths
  - Signal components arrive at different times
- Interference

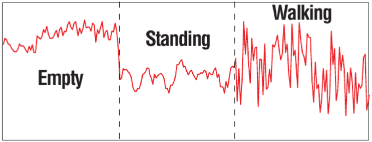


$$\zeta_{\text{sum}} = \sum_{i=1}^{\iota} \Re\left(e^{j(f_i t + \gamma_i)}\right)$$

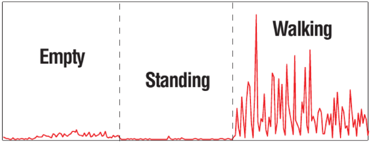
RF-based activity recognition



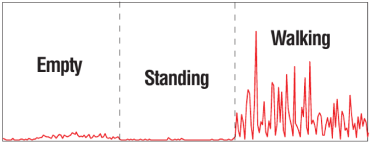
Raw



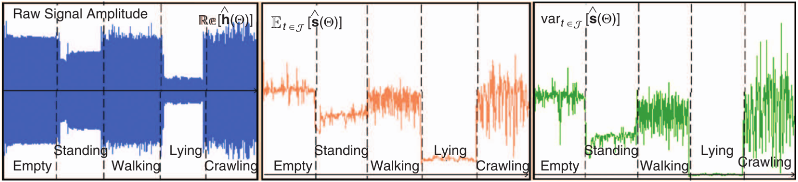
Mean



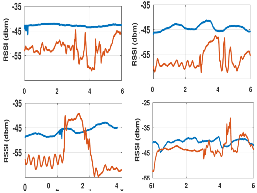
Variance

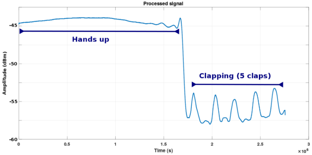


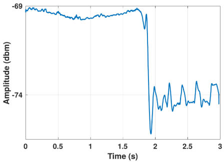
Energy

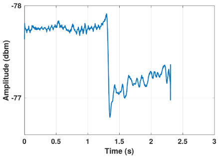


Angry, agitated driving









Time-domain signal strength fluctuation

- Recognition of environmental situation (presence, movement (speed))
- Non-intrusive
- Arbitrary antenna placement
- Pre-training possible
- Limited gesture recognition accuracy
- Noisy, information source

Device-Free recognition (DFL / DFAR)

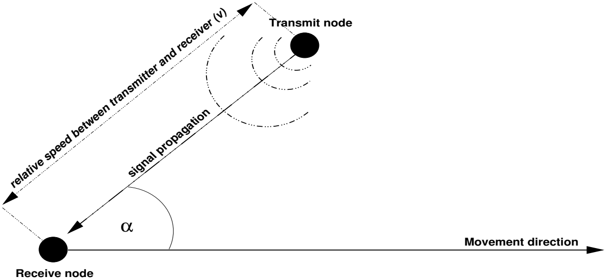
Time domain features – Situation awareness

Frequency domain features – Gesture recognition

Fresnel effects

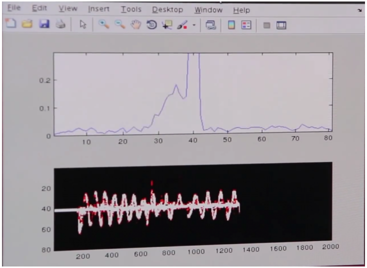
DFAR on COTS hardware

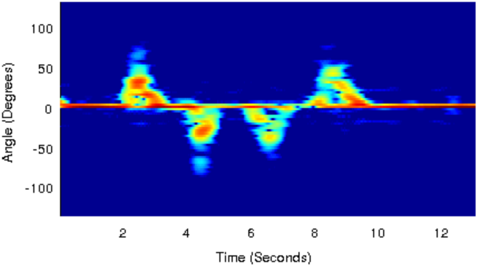
Aspects of the mobile radio channel



Doppler Shift

- Frequency of received and transmitted signal may differ
- Dependent on relative speed between transmitter and receiver
- $f_d = \frac{v}{\lambda} \cdot \cos(\alpha)$

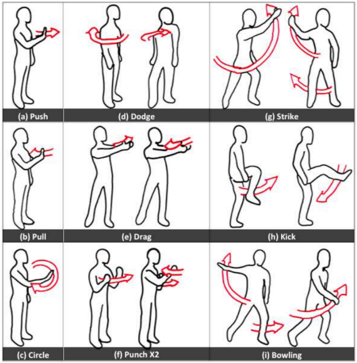


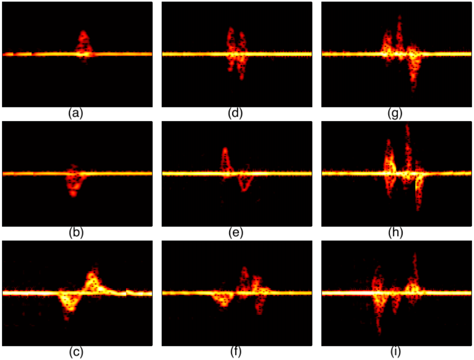


Whole-Home Gesture Recognition Using Wireless Signals, Q. Pu, S. Gupta, S. Gollakota, S. Patel, Mobicom'13

See Through Walls with Wi-Fi!, F Adib, D. Katabi, SIGCOMM'13

Micro doppler variations





See

Through Walls with Wi-Fi!, F Adib, D. Katabi, SIGCOMM'13

Micro doppler variations

- Recognition of fine-grained gestures
- Potentially directional recognition from multiple sources simultaneously
- Binary information (towards/away)
- Potentially also speed but noisy
- Accuracy dependent on direction of movement (towards Antenna)
- Requires non-standard hardware (e.g. software radios)

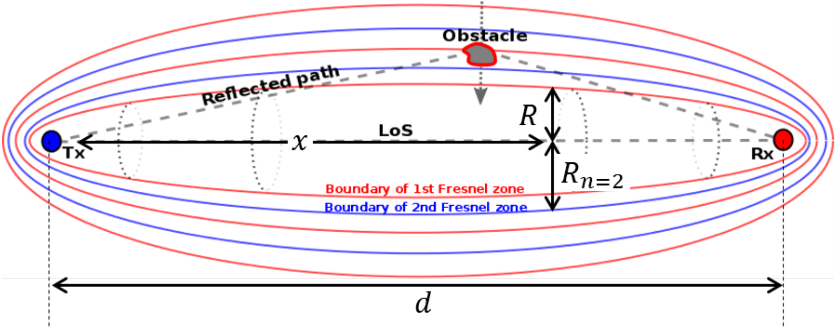
Device-Free recognition (DFL / DFAR)

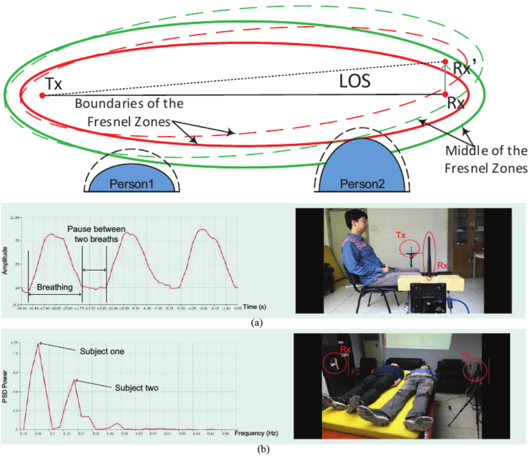
Time domain features – Situation awareness

Frequency domain features – Gesture recognition

Fresnel effects

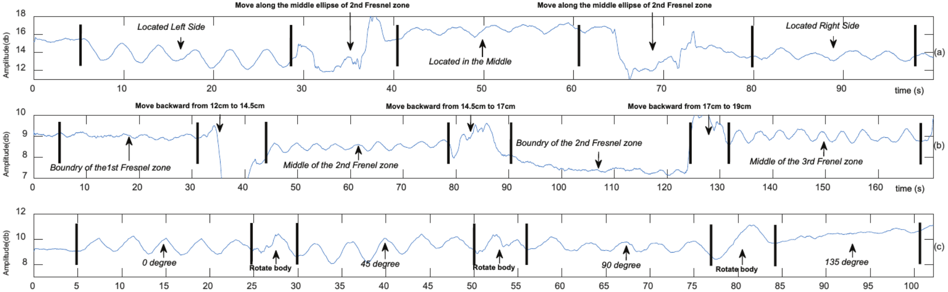
DFAR on COTS hardware


Obstacle
Reflected path
R
Tx
x
LoS
Rx
$R_{n=2}$
Boundary of 1st Fresnel zone
Boundary of 2nd Fresnel zone
d



Human Respiration Detection with Commodity WiFi Devices: Do User Location and Body Orientation Matter?, Wang et al., Ubicomp 2016

▪



Human Respiration Detection with Commodity WiFi Devices: Do User Location and Body Orientation Matter?, Wang et al., Ubicomp 2016

Fresnel effets for DFAR

- Fine-grained centimer-scale accuracy
- Fragile instrumentation requirements
- Requires non-standard hardware (e.g. software radios)

Device-Free recognition (DFL / DFAR)

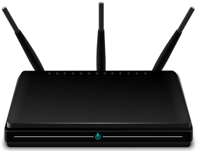
Time domain features – Situation awareness

Frequency domain features – Gesture recognition

Fresnel effects

DFAR on COTS hardware

Can we do this with standard hardware?

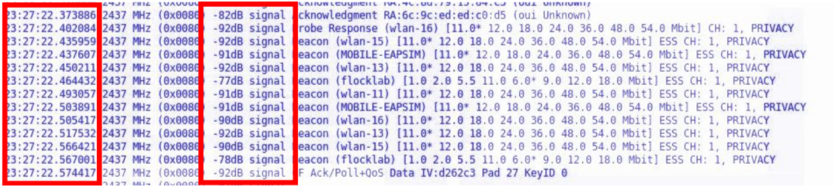


Measure signal strength on a phone

String	EXTRA_BSSID	The lookup key for a String giving the BSSID of the access point to which we are connected.
String	EXTRA_NETWORK_INFO	The lookup key for a `NetworkInfo` object associated with the Wi-Fi network.
String	EXTRA_NEW_RSSI	The lookup key for an `int` giving the new RSSI in dBm.
String	EXTRA_NEW_STATE	The lookup key for a `SupplicantState` describing the new state Retrieve with `getParcelableExtra(String)`.
String	EXTRA_PREVIOUS_WIFI_STATE	The previous Wi-Fi state

- Approx. 1 sample/sec

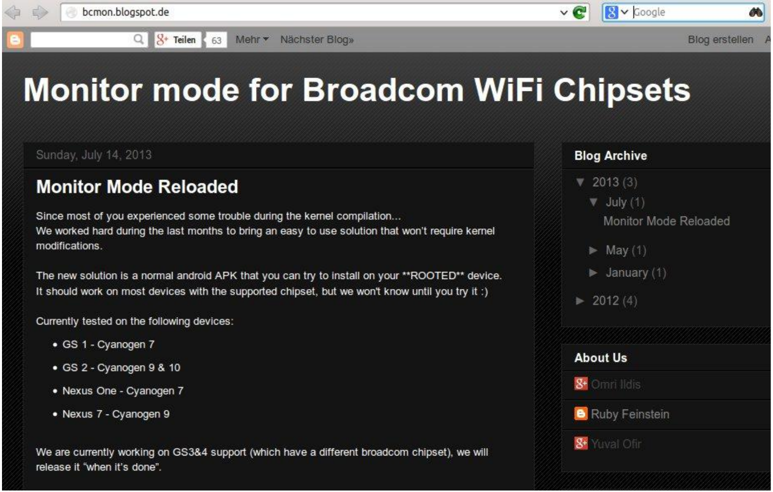
Measure signal strength on a phone



```
3:27:22.373886 2437 MHz (0x0080) -82dB signal cknowledgment RA:6c:9c:ed:ed:c0:d5 (oui Unknown)
3:27:22.402084 2437 MHz (0x0080) -92dB signal robe Response (wlan-16) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] CH: 1, PRIVACY
3:27:22.435959 2437 MHz (0x0080) -92dB signal eacon (wlan-15) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.437607 2437 MHz (0x0080) -91dB signal eacon (MOBILE-EAPSIM) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.450211 2437 MHz (0x0080) -92dB signal eacon (wlan-13) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.464432 2437 MHz (0x0080) -77dB signal eacon (flocklab) [1.0 2.0 5.5 11.0 6.0* 9.0 12.0 18.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.493057 2437 MHz (0x0080) -91dB signal eacon (wlan-11) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.503891 2437 MHz (0x0080) -91dB signal eacon (MOBILE-EAPSIM) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.505417 2437 MHz (0x0080) -90dB signal eacon (wlan-16) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.517532 2437 MHz (0x0080) -92dB signal eacon (wlan-13) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.566421 2437 MHz (0x0080) -90dB signal eacon (wlan-15) [11.0* 12.0 18.0 24.0 36.0 48.0 54.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.567001 2437 MHz (0x0080) -78dB signal eacon (flocklab) [1.0 2.0 5.5 11.0 6.0* 9.0 12.0 18.0 Mbit] ESS CH: 1, PRIVACY
3:27:22.574417 2437 MHz (0x0080) -92dB signal F 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

```
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
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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
```

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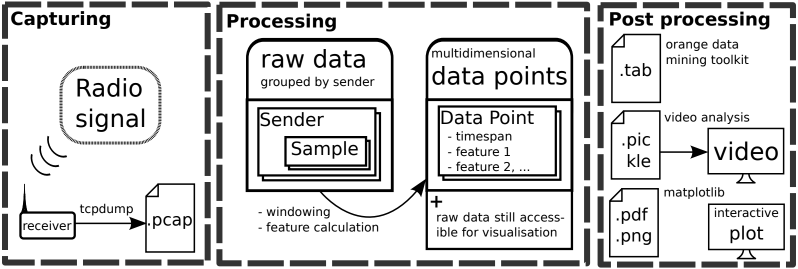
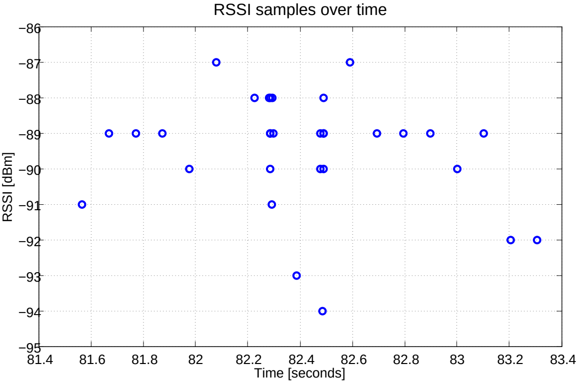
Measure signal strength on a phone



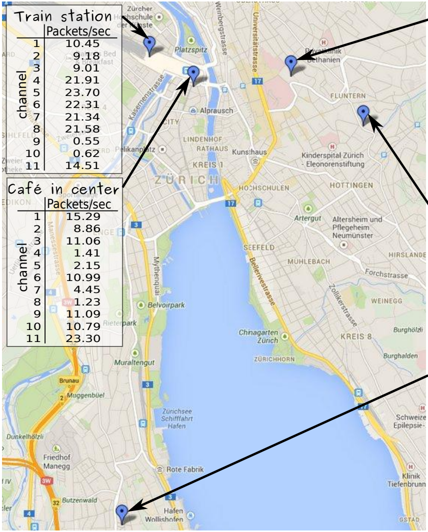
- http://www.stephansigg.de/DeviceFree/pcapTools.tar.gz

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	Packets/sec 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

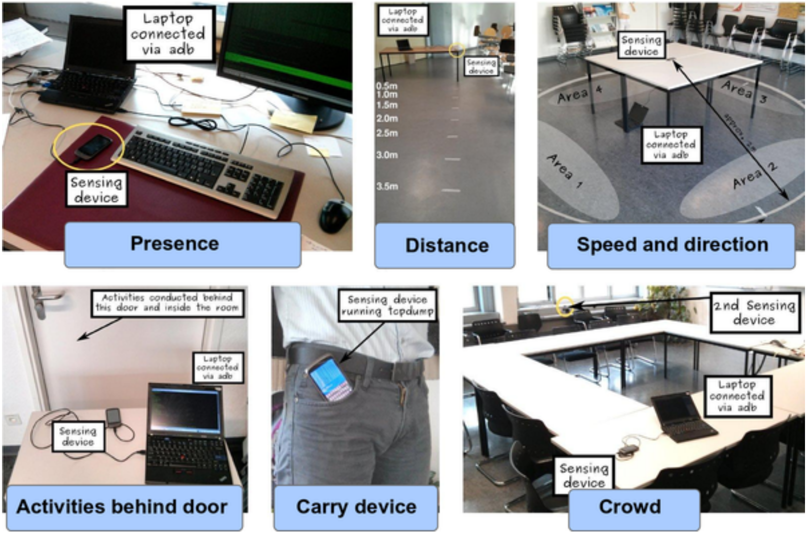
Dormitory

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

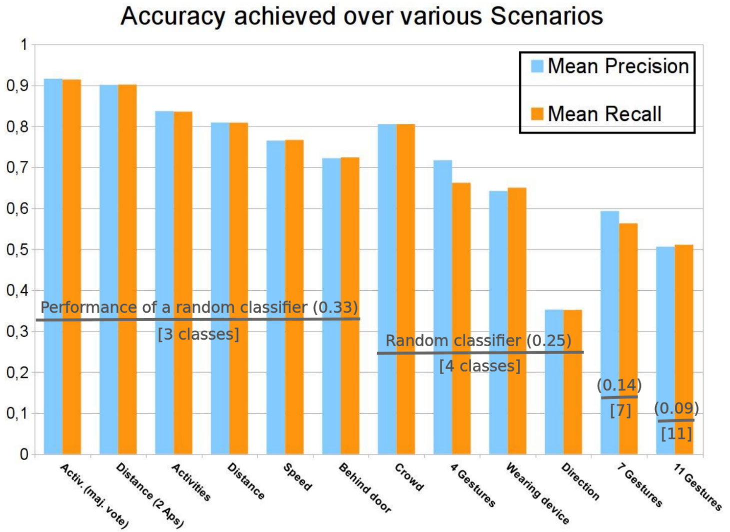
Suburban flat

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

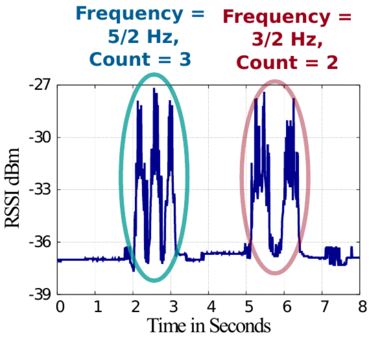
Case studies



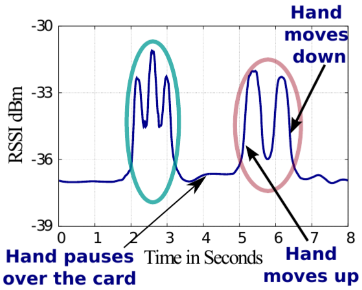
Results



Accuracy achieved over various Scenarios
Mean Precision
Mean Recall
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Performance of a random classifier (0.33)
[3 classes]
Random classifier (0.25)
[4 classes]
(0.14)
[7]
(0.09)
[11]
Activ. (maj. vote)
Distance (2 Aps)
Activities
Distance
Speed
Behind door
Crowd
4 Gestures
Wearing device
Direction
7 Gestures
11 Gestures

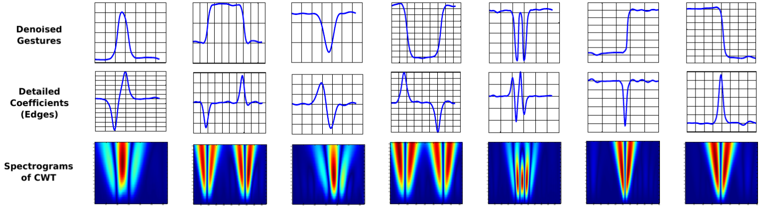


(a) Raw signal



(b) Denoised signal

Abdelnasser et. al: WiGest: A Ubiquitous WiFi-based Gesture Recognition System, INFOCOM, 2015



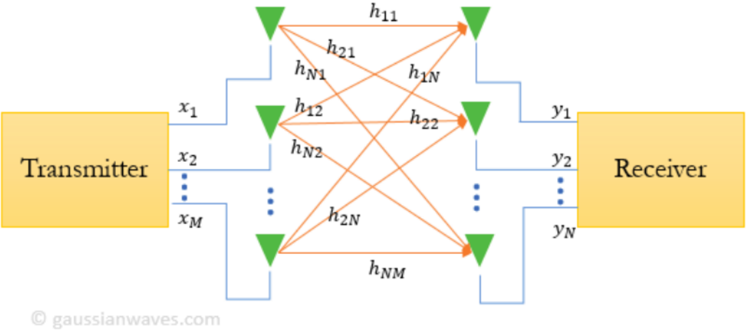
(a) Up-Down (b) Up-||-Down (c) Down-Up (d) Down-||-Up (e) Right-Left (f) Up (g) Down

Abdelnasser et. al: WiGest: A Ubiquitous WiFi-based Gesture Recognition System, INFOCOM, 2015

RSSI-based

- COTS hardware
- Ubiquitously available
- low accuracy
- dependent on environmental traffic situation

CSI-based DFAR



The received vector y is expressed in terms of the channel transmission matrix H, the input vector x and noise vector n as

$$y = Hx + n$$

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix} \quad \mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1M} \\ h_{21} & h_{22} & \cdots & h_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N1} & h_{N2} & \cdots & h_{NM} \end{bmatrix} \quad \mathbf{n} = \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_M \end{bmatrix}$$

802.11n – CSI

The CSI matrix

The MIMO control field in the 802.11n Management frame (used to manage the exchange of MIMO channel state or transmit beamforming feedback information) contains a CSI cotrol field in which the CSI matrix for all carriers is stored.

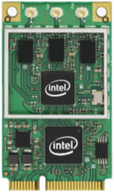
Example (3x3) – complex amplitude and phase:

$$\begin{bmatrix} 0.1-0.3j & -0.1+0.5j & -0.6j \\ 0.2-0.7j & -0.5+0.5j & 0.1-0.1j \\ 0.9 & 0.8+0.1j & 0.7-0.7j \end{bmatrix}$$

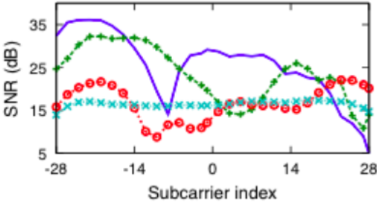
Open CSI tools

Atheros CSI tool http://pdcc.ntu.edu.sg/wands/Atheros/

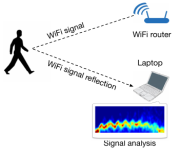
Intel 5300 tool https://dhalperi.github.io/linux-80211n-csitool/



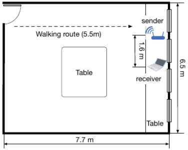
An Intel 5300 NIC



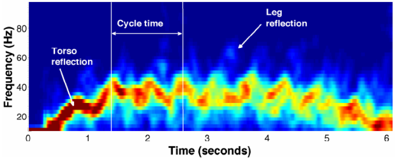
CSI-based gait recognition

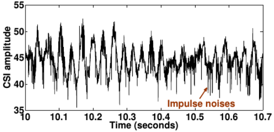


(a) Application scenario

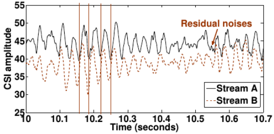


(b) Data collection environment

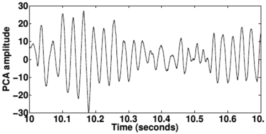




(a) Raw CSI waveforms (Stream A)



(b) CSI waveforms after low-pass filtering



(c) CSI waveforms after PCA denoising

Wang et. al: WiGest: Gait Recognition Using WiFi Signals, Ubicomp, 2016

CSI-based

- CSI phase fine-grained recognition of movement
- Available from COTS hardware
- Binary information
- Constant after change in distance conducted
- Recognition accuracy dependent on direction of movement wrt Rx antenna

Device-Free recognition (DFL / DFAR)

Time domain features – Situation awareness

Frequency domain features – Gesture recognition

Fresnel effects

DFAR on COTS hardware

Thank you!

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