Aalto University
School of Electrical
Engineering

Maintenance-free, distributed sensing – Challenges and algorithms

Stephan Sigg

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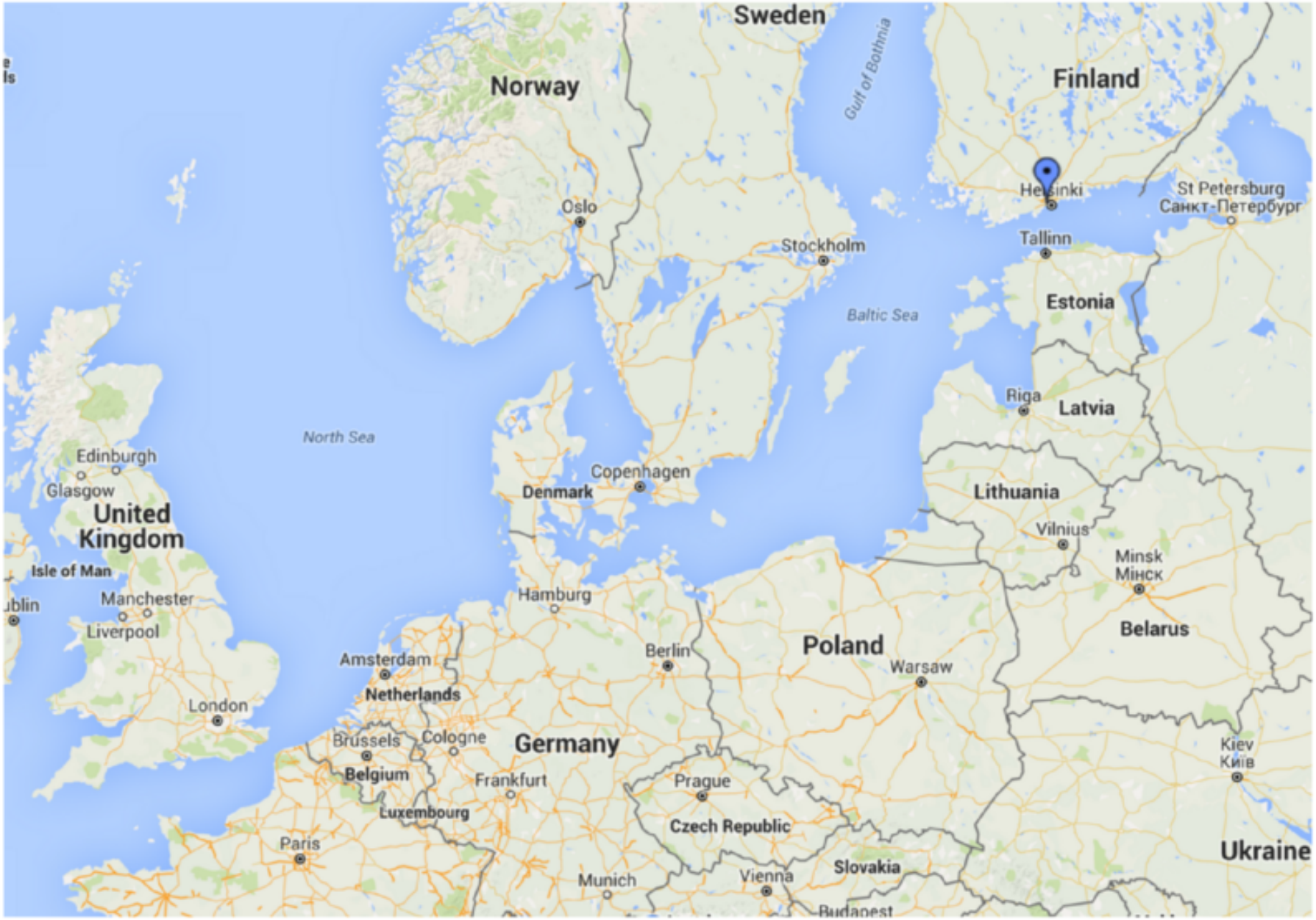
Siremti Workshop, 13.03.2017


Sweden
Norway
Gulf of Bothnia
Finland
Helsinki
St Petersburg
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Oslo
Stockholm
Tallinn
Estonia
Baltic Sea
Riga
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North Sea
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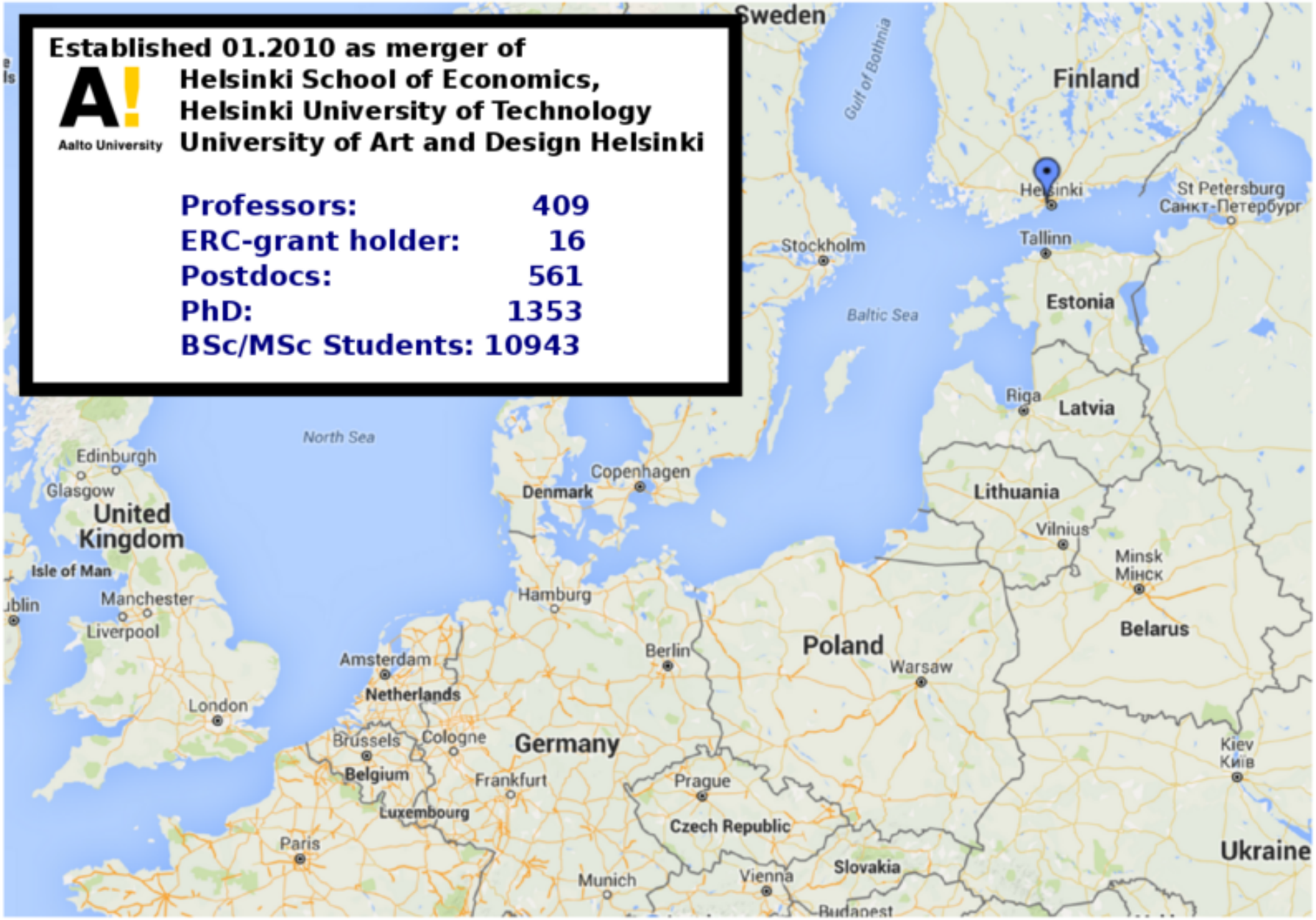
Established 01.2010 as merger of

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

Aalto University

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



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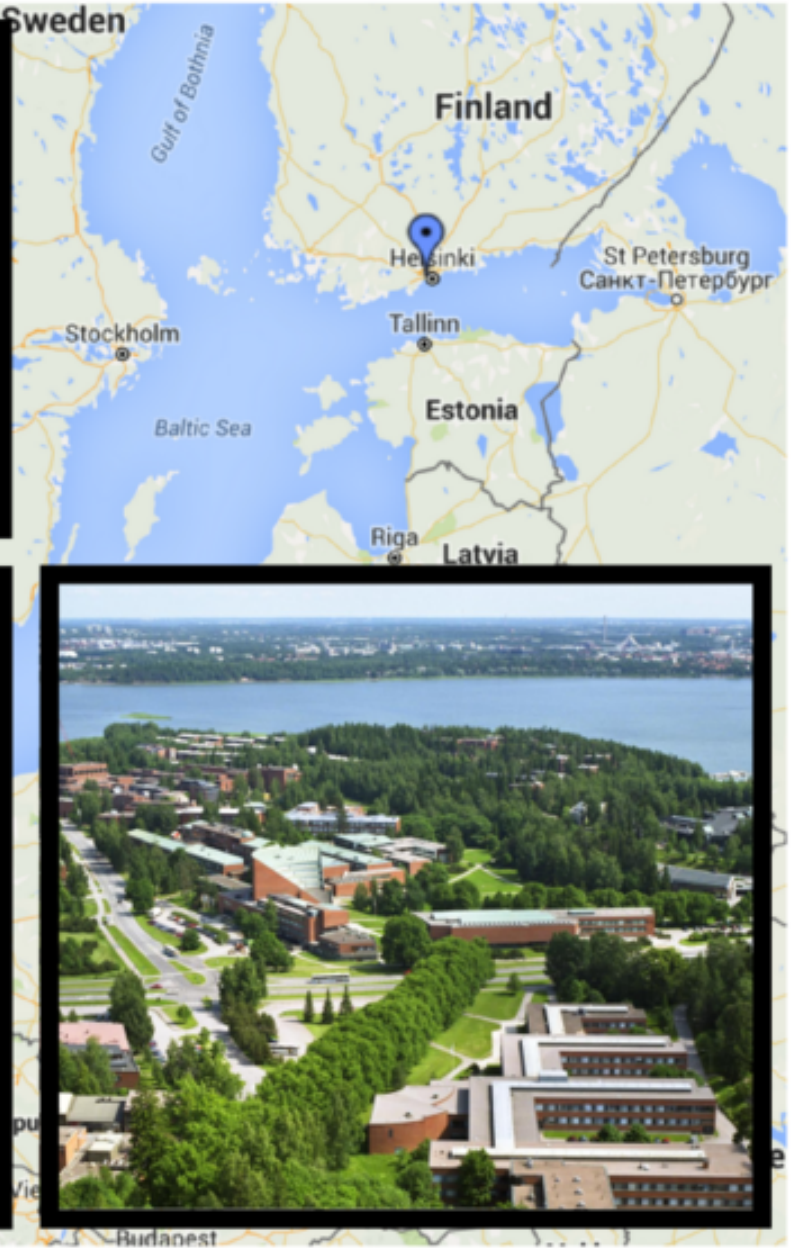
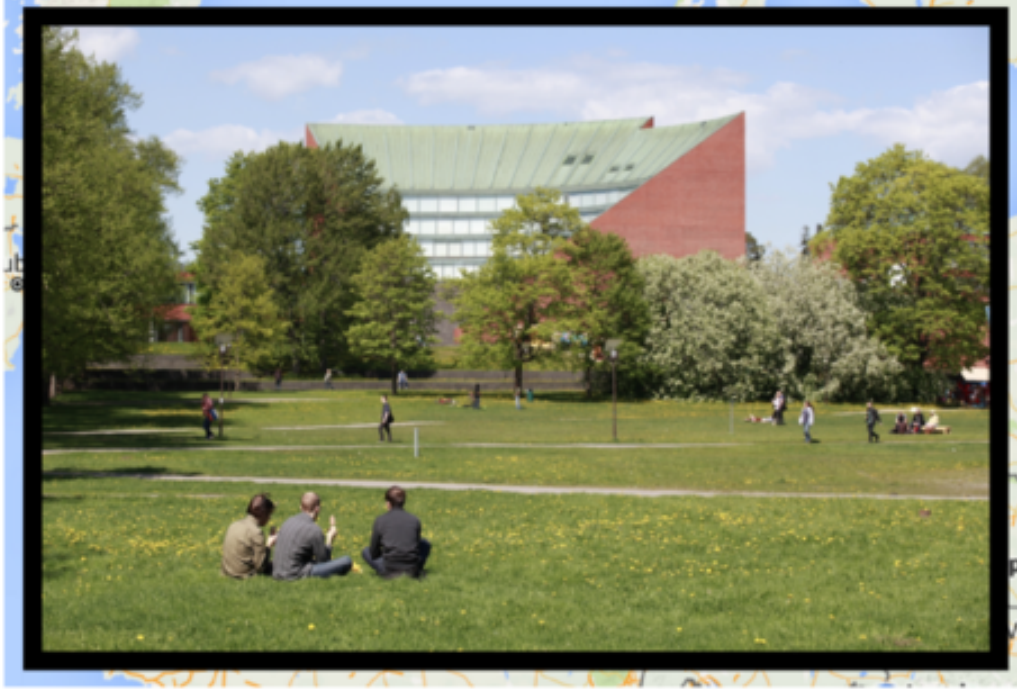




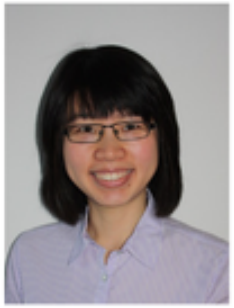
Comnet

- 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/

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

Group members and recent related research

- RF-based activity recognition

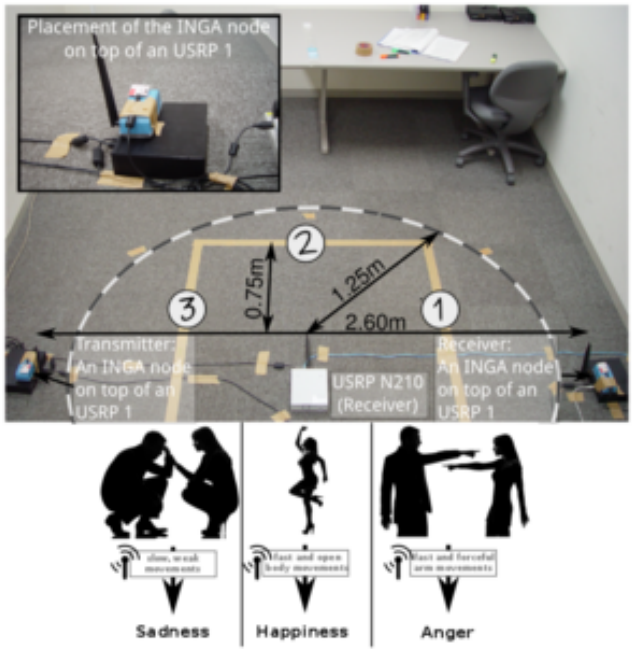
Maintenance-free, intelligent distributed sensing

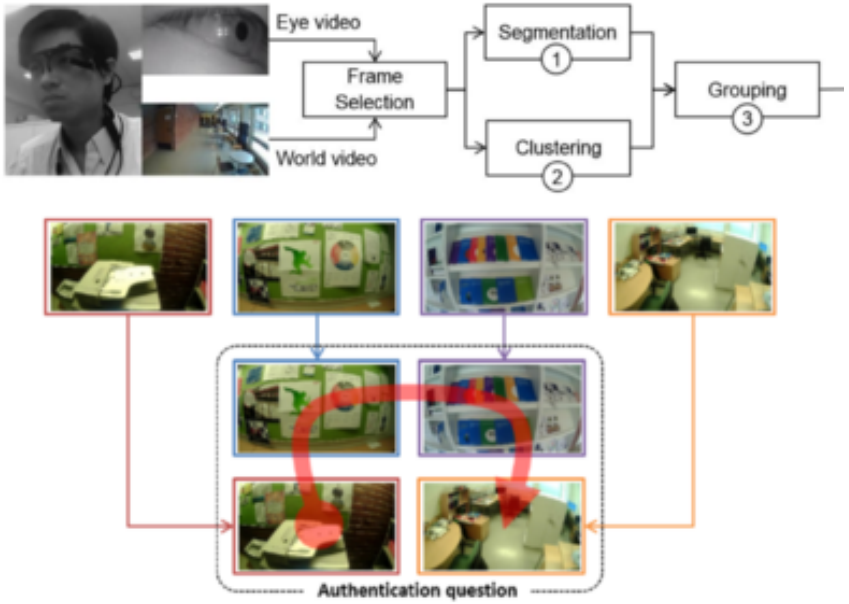
Sensor graphs for distributed mathematical operation

- Probabilistic superimposed mathematical operations
- Artificial neural computation from implicit channel inputs

Conclusion

ambient intelligence





Stephan Sigg

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

Le Ngu Nguyen

Usable Security, Activity recognition, Machine learning, Mobile applications

Bahareh Gholampooryazdi

Signal processing, RF-based Device-free activity recognition

Muneeba Raja

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

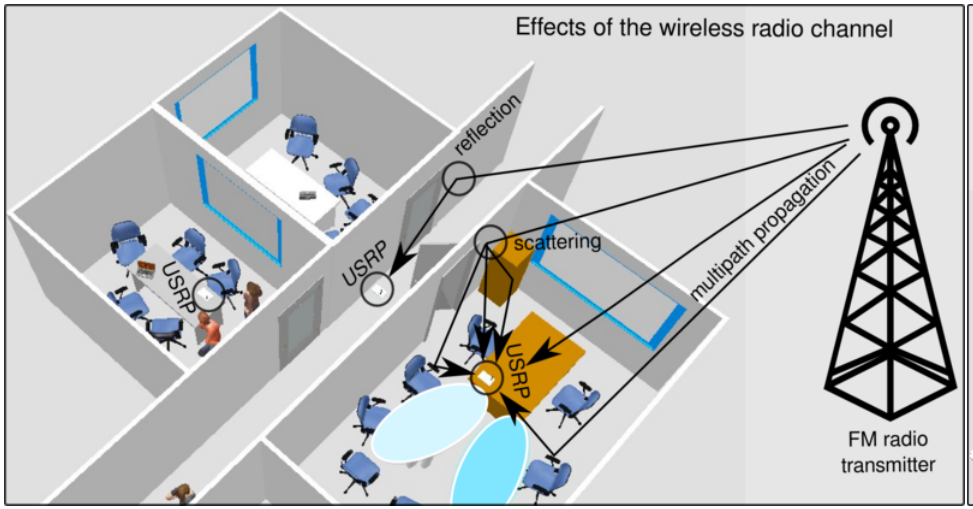
Visitors

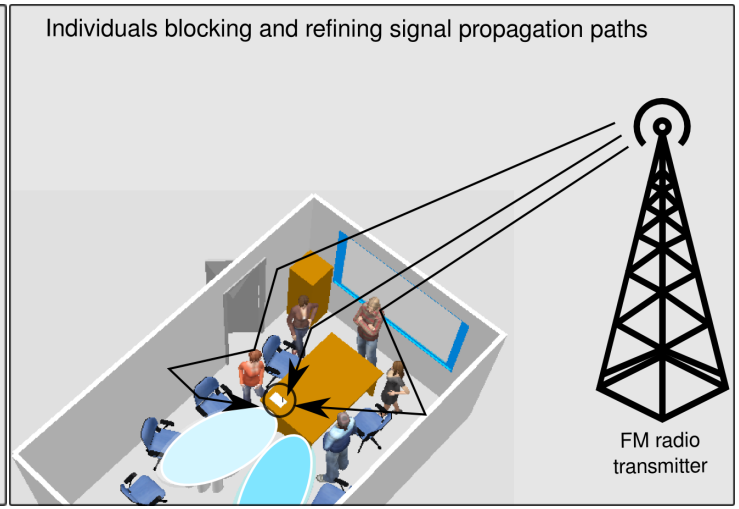
Takuya Maekawa

Wearable/Ubiquitous Sensing
Activity Recognition
Lifelogging
Web Contents Engineering

Exploiting the RF-channel for environmental preception

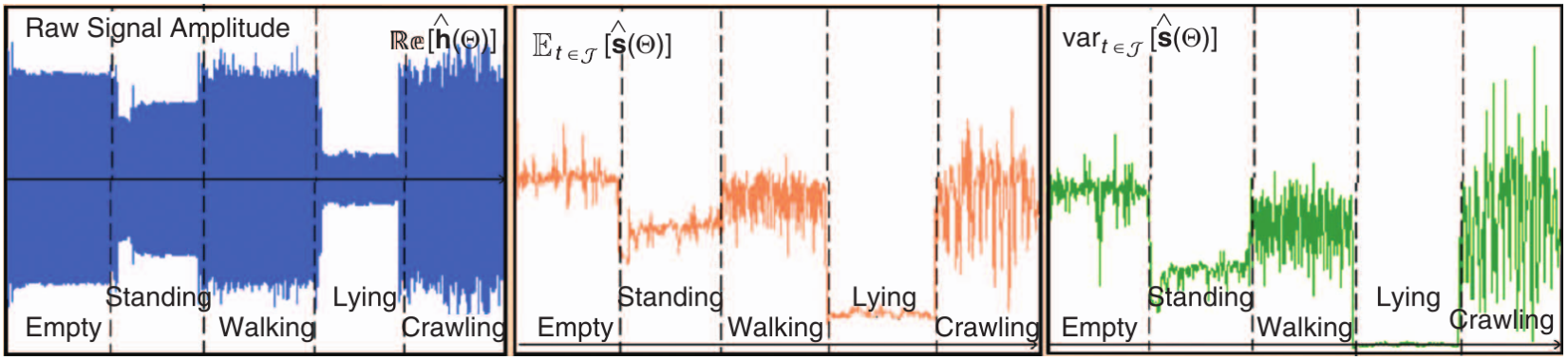
- Multi-path propagation
- Signal superimposition
- Scattering
- Signal Phase
- Reflection
- Blocking of signal paths
- Doppler Shift
- Fresnel effects



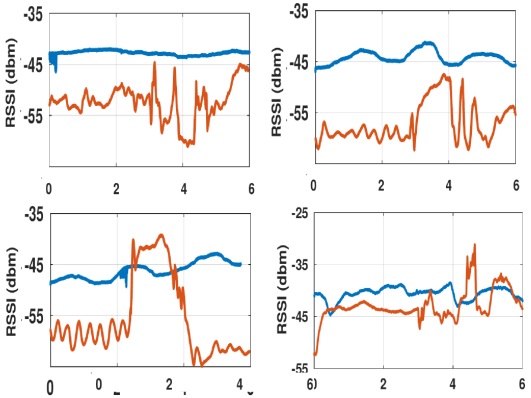


RF-based activity recognition

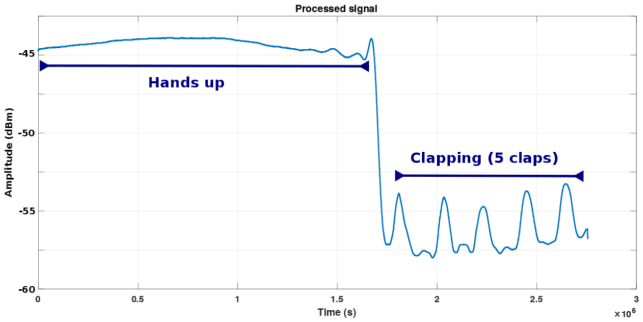
Sensewaves Video

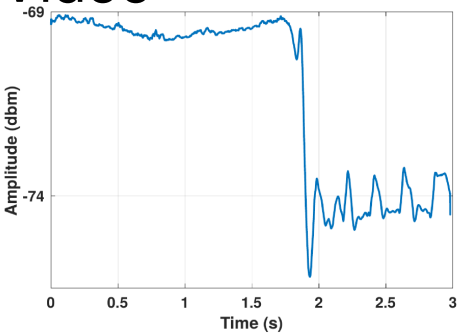


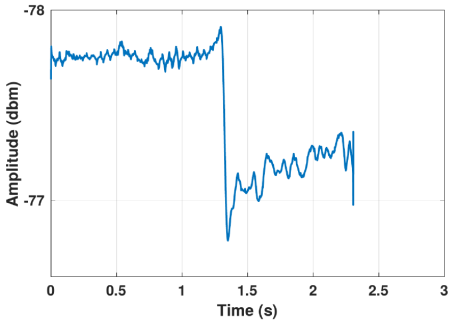
Angry, agitated driving



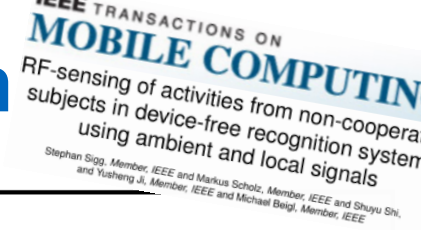
– Video –

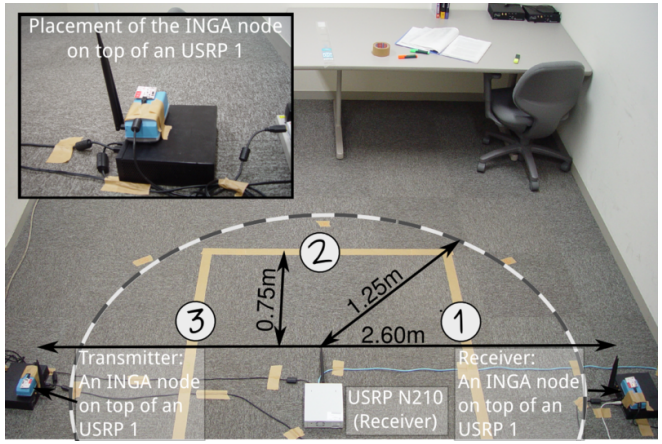


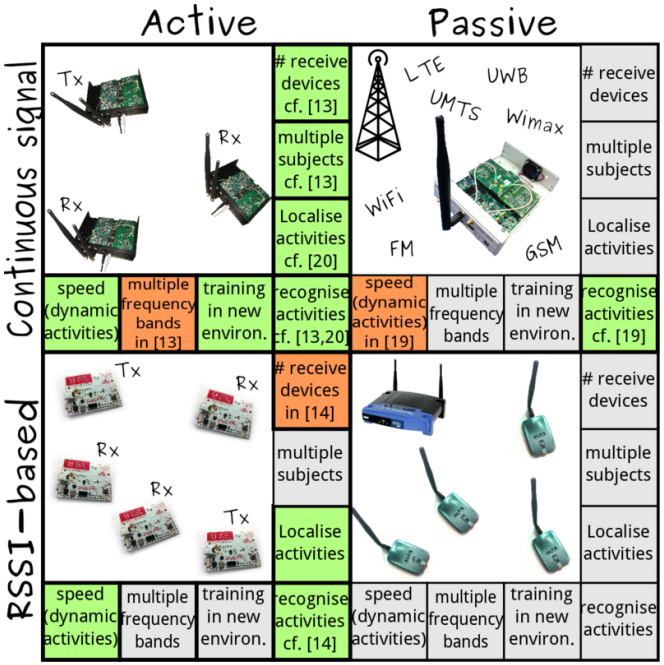


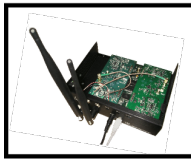


RF-based device-free activity recognition









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)

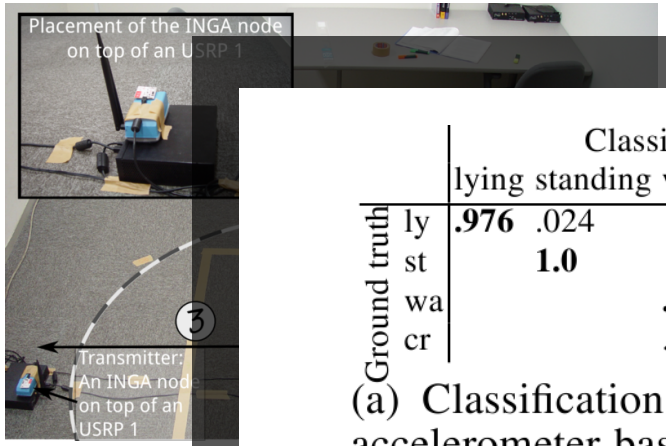
Frequency: 2.4GHz IEEE802.15.4, PCB High Gain-Antenna
Signal: RSSI samples from packets transmitted between nodes
Sample rate: Transmission of 100 packets per second

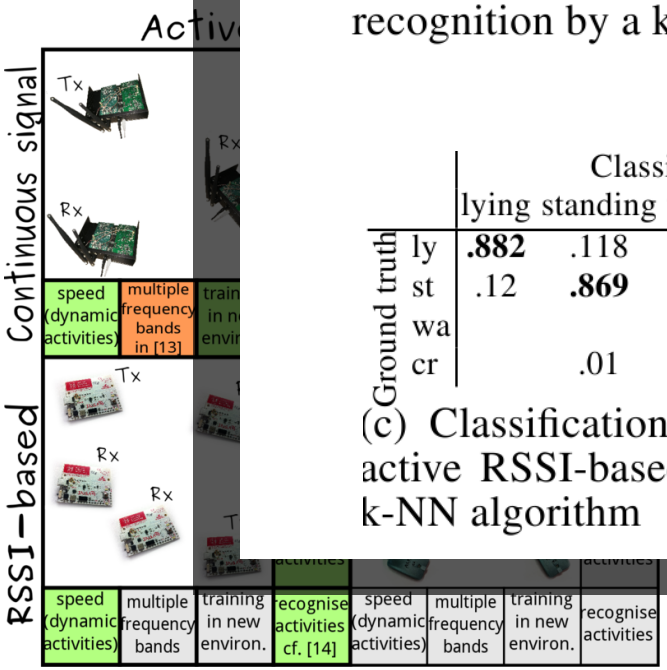
Accelerometer-based activity recognition (Iphone 4)

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

Ground truth \ Classification	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 \ Classification	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

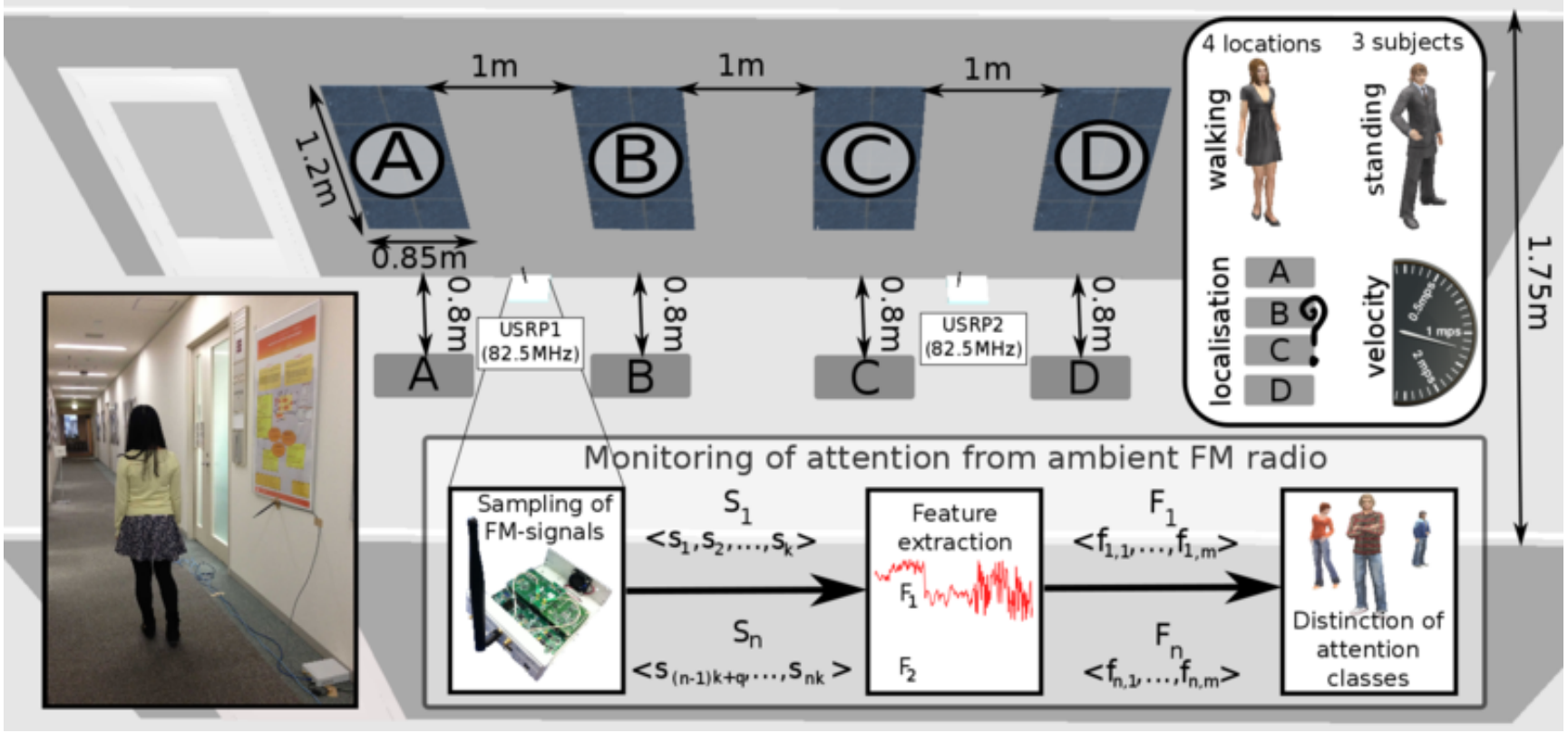
Ground truth \ Classification	lying	standing	walking	crawling
ly	**.882**	.118		
st	.12	**.869**	.007	.004
wa			**.953**	.047
cr		.01	.439	**.551**

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

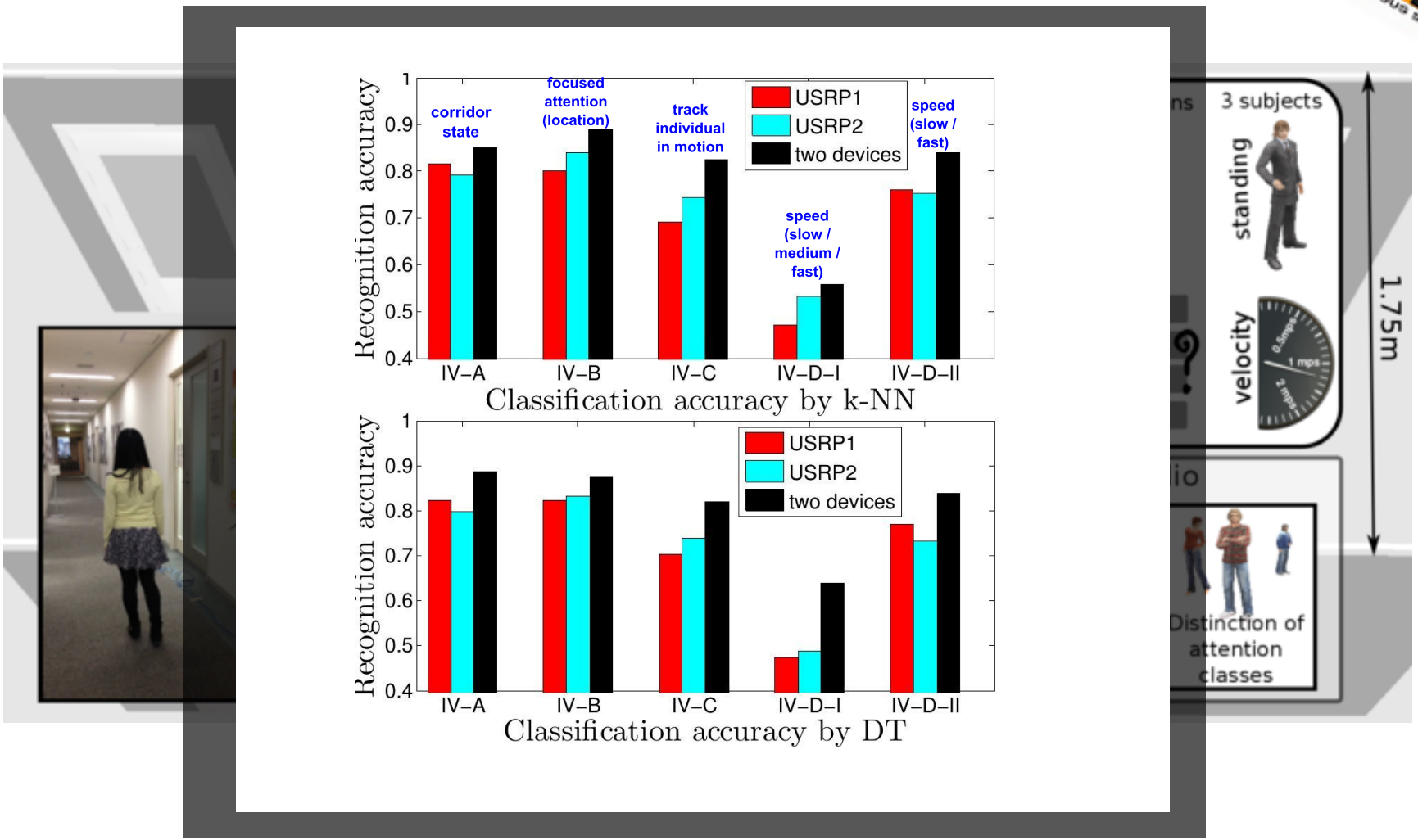
Ground truth \ Classification	lying	standing	walking	crawling
ly	**1.0**			
st	.056	**.98**	.022	
wa	.023		**.874**	.102
cr	.044		.144	**.811**

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

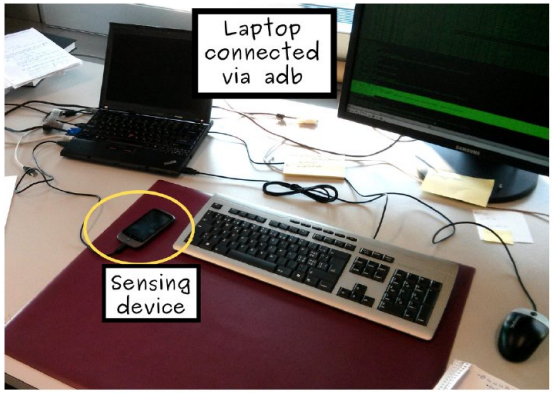
Monitoring attention from RF



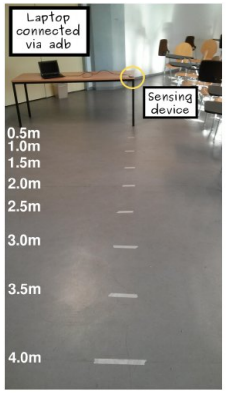
Monitoring attention from RF



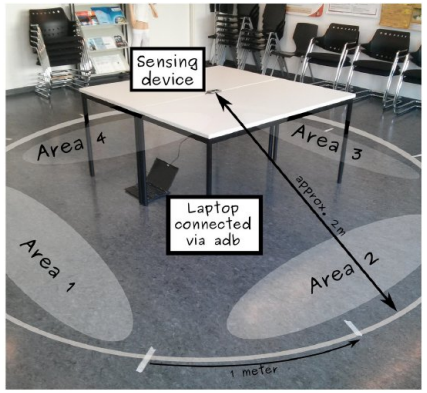
Situation and gestures from passive RSSI-based DFAR



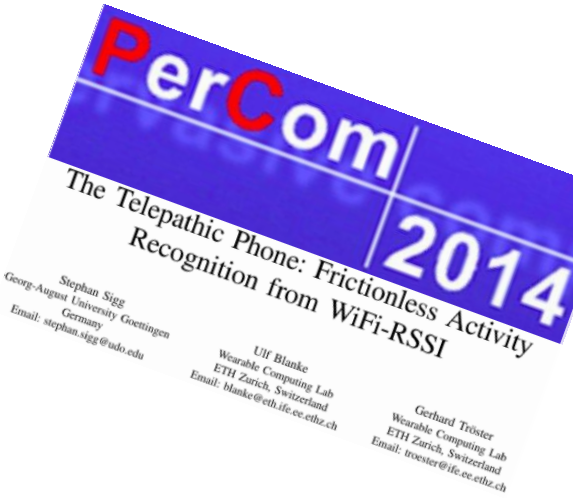
(a) Office environment at ETH

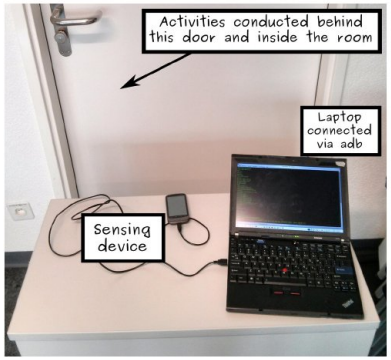


(b) Lecture room at TU-BS



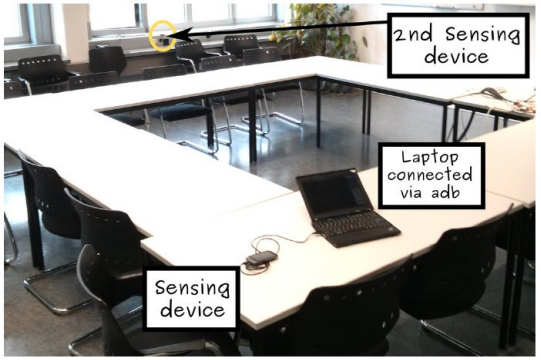
(c) Scenario for the distinction of walking speed



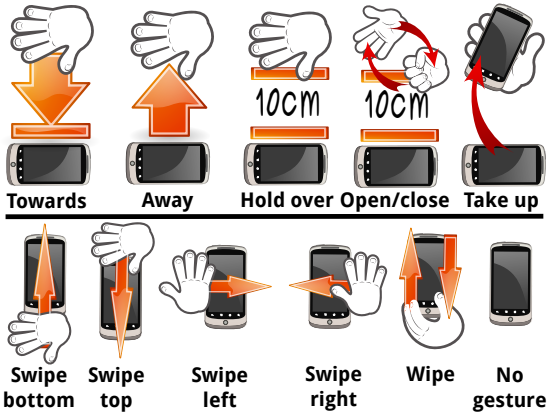


(d) Activities conducted behind a closed door

(e) Sensing device inside pocket

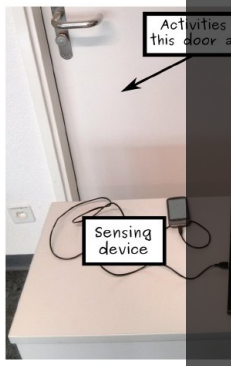


(f) Meeting room at ETH

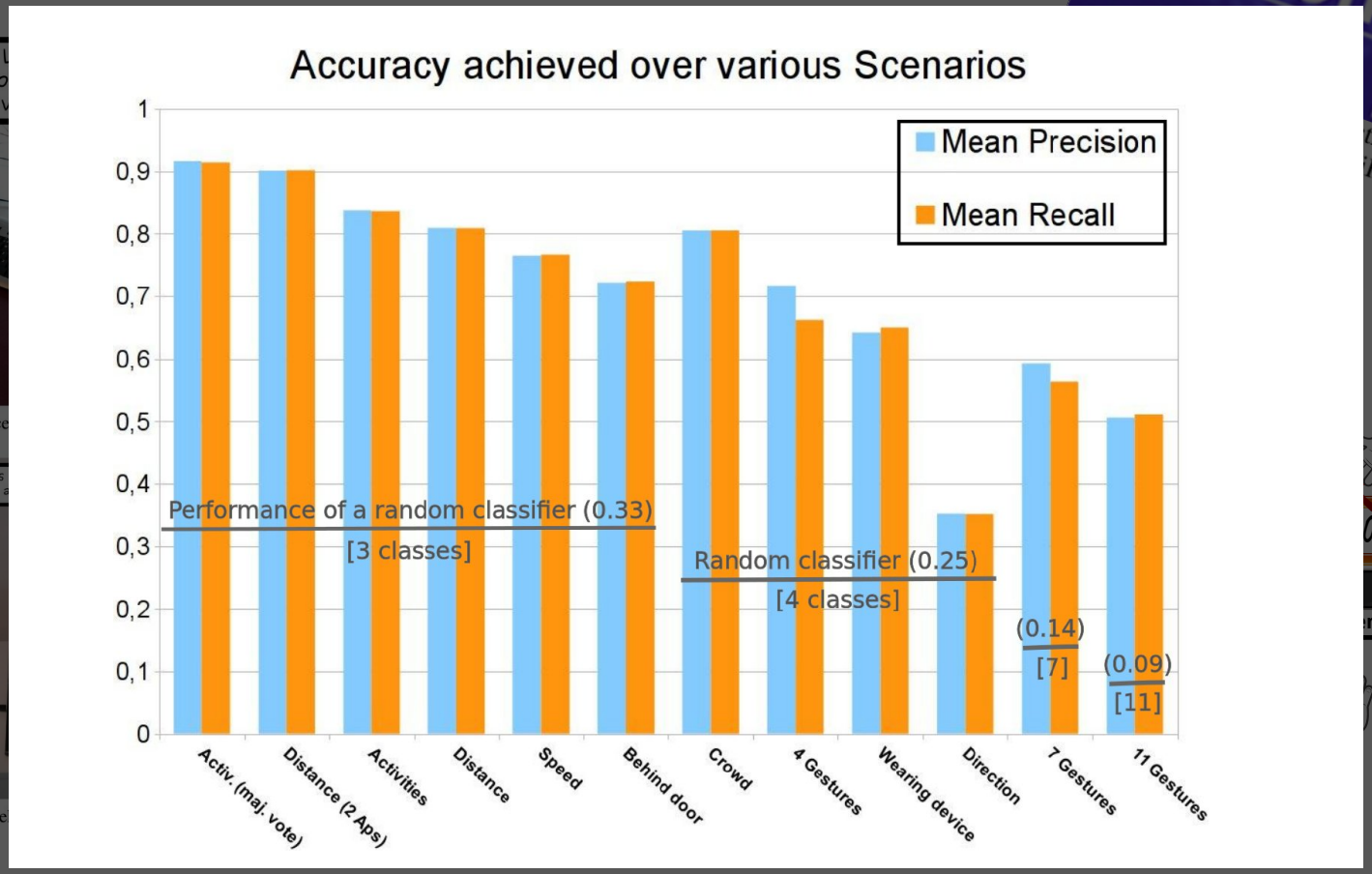


Situation and gestures from passive RSSI-based DFAR

(a) Office



(d) Activities conducted be



Group members and recent related research

- RF-based activity recognition

Maintenance-free, intelligent distributed sensing

Sensor graphs for distributed mathematical operation

- Probabilistic superimposed mathematical operations
- Artificial neural computation from implicit channel inputs

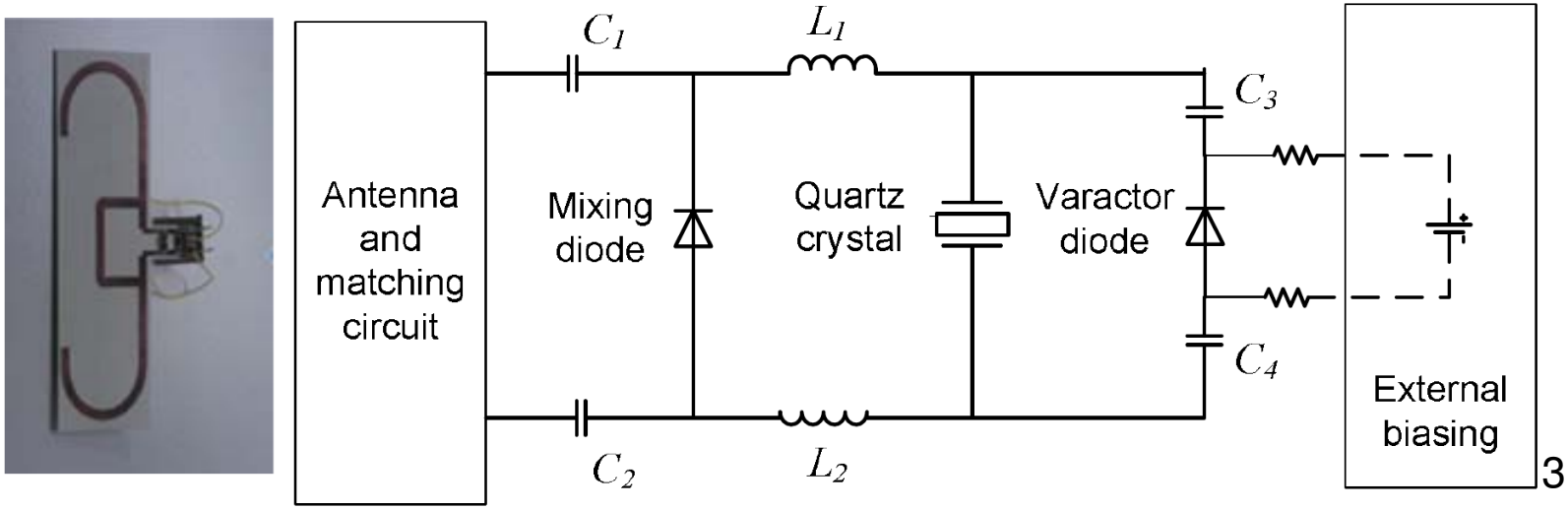
Conclusion

Energy-harvesting from Ambient RF noise

Efficiency: DC-conversion possible at about 70% efficiency[1]

7cm·7cm rectenna : transmissions at 0.2Hz for 3.4ms each[2]

0.5m^2 rectenna : RF-activity at 20Hz for 300μs each

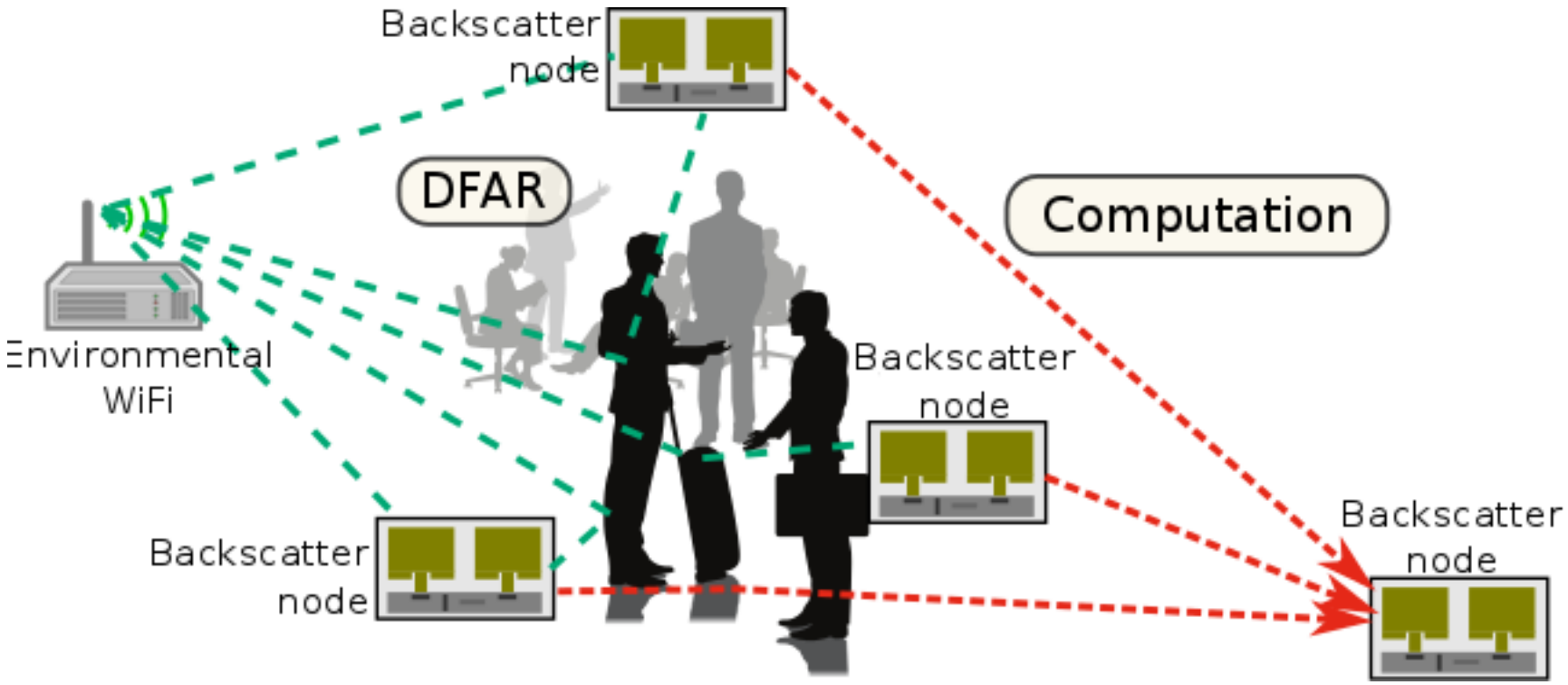


[1] Doan et al. 'Design and Fabrication of Rectifying Antenna Circuit for Wireless Power Transmission System Operating At ISM Band.' International Journal of Electrical and Computer Engineering, 2016

[2] Nishimoto et al. 'Prototype implementation of ambient RF energy harvesting wireless sensor networks.' IEEE Sensors, 2010.

[3] Song et al. 'On the use of the intermodulation communication towards zero power sensor nodes.' EuMC 2013

Maintenance-free intelligent distributed sensing



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Calculation during transmission on the channel

Envisioned paradigm shift in mobile computing

Parasitic operation Communication comes virtually for free

Miniaturisation Processing and storage capabilities limited

(passive, parasitic, backscatter)

Calculation during transmission on the channel

Envisioned paradigm shift in mobile computing

Parasitic operation Communication comes virtually for free

Miniaturisation Processing and storage capabilities limited

(passive, parasitic, backscatter)

Potential: Trade processing load for communication load

- Shift computation towards the wireless communication channel

Calculation during transmission on the channel

Envisioned paradigm shift in mobile computing

Parasitic operation Communication comes virtually for free

Miniaturisation Processing and storage capabilities limited

(passive, parasitic, backscatter)

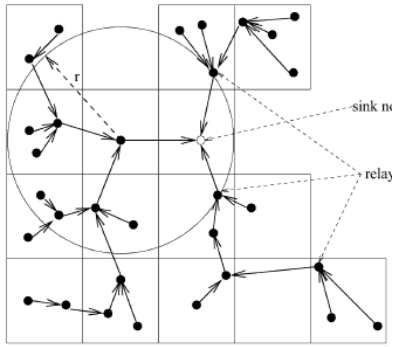
Potential: Trade processing load for communication load

- Shift computation towards the wireless communication channel
- Computation below computational complexity possible?

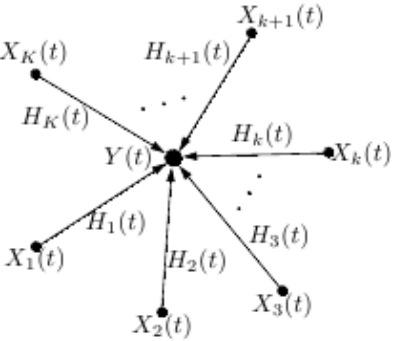
Calculation during transmission on the channel

Motivation: Computation during transmission[a]

- Max. rate to compute & communicate functions
- Mention: Collisions might contain information



[a] A. Giridhar and P. Kumar, Toward a theory of in-network computation in wireless sensor networks, IEEE Comm. Mag., vol. 44, no 4, pp. 98-107, april 2006



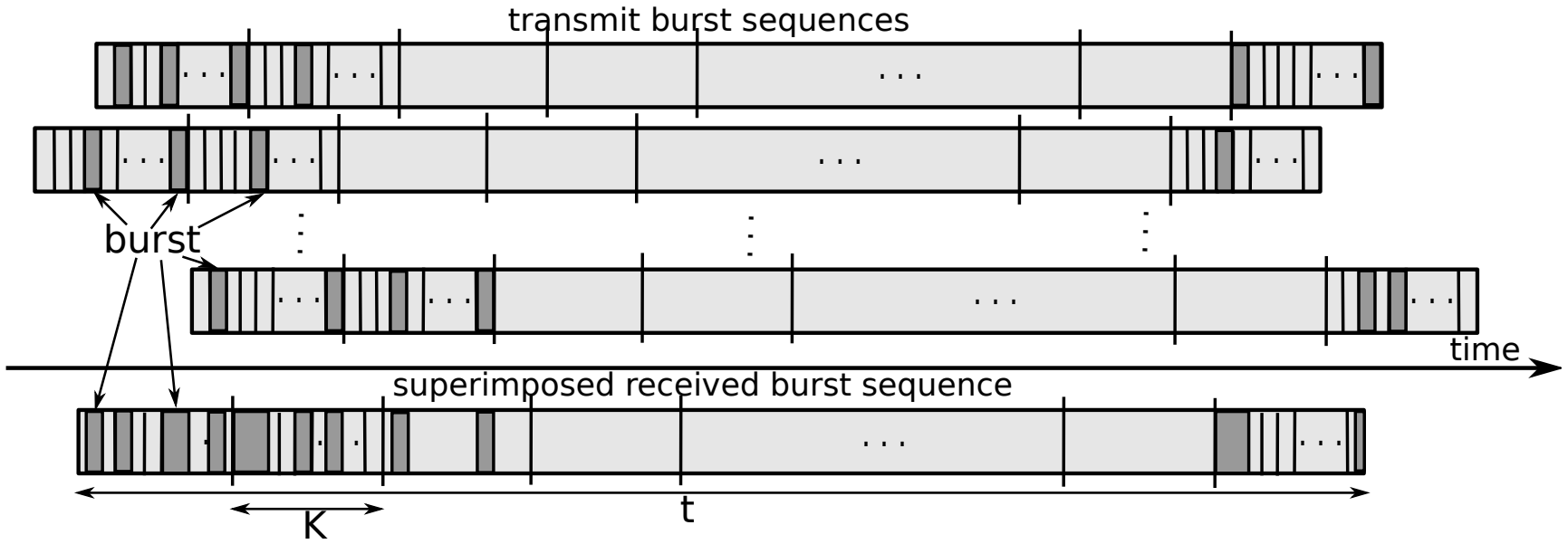
Calculation of by means of post- and pre-processing[a]

- Requires accurate channel state information
- Requires identical absolute transmit power

[a] M. Goldenbaum, S. Stanczak, and M. Kaliszan, On function computation via wireless sensor multipl channels, IEEE Wireless Communications and Networking Conf., 2009

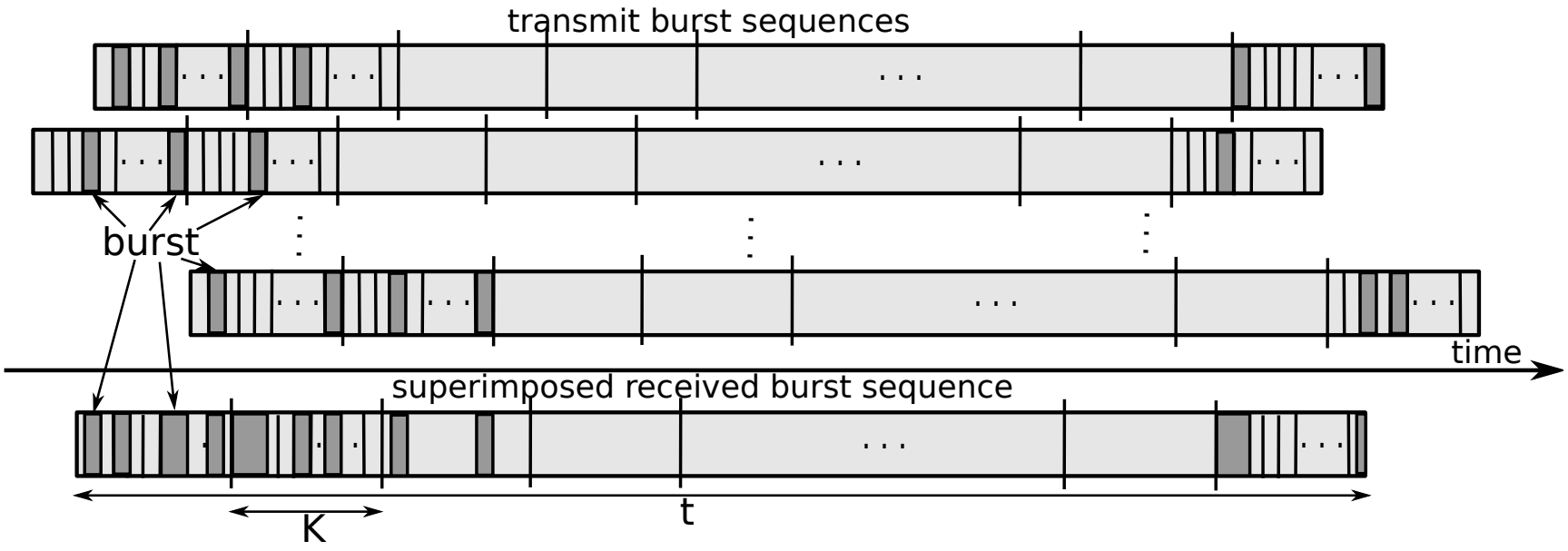
Calculation during transmission on the channel

Utilising Poisson-distributed burst-sequences



Calculation during transmission on the channel

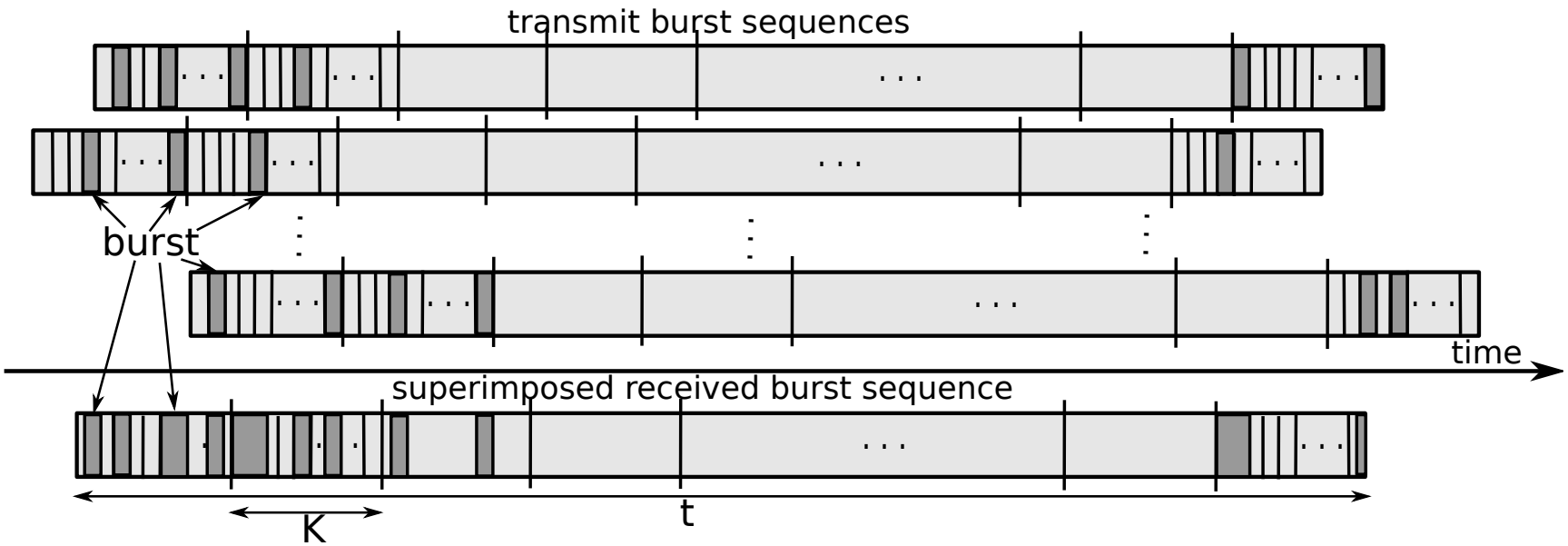
Utilising Poisson-distributed burst-sequences



Basic operations Addition, subtraction, division and multiplication at the time of wireless data transmission via Poisson-distributed burst-sequences

Calculation during transmission on the channel

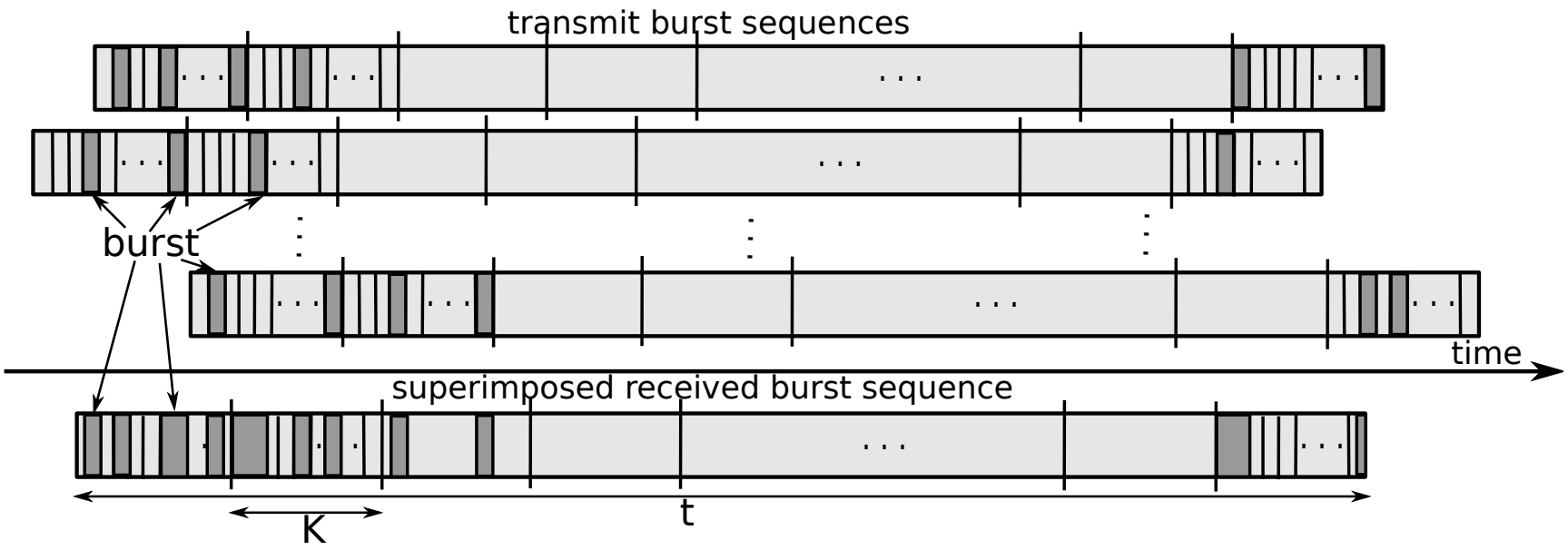
Utilising Poisson-distributed burst-sequences



Addition Adding Poisson processes i with mean μ_i will result in a Poisson process with mean $\sum_{i=1}^{n} \mu_i$.

Calculation during transmission on the channel

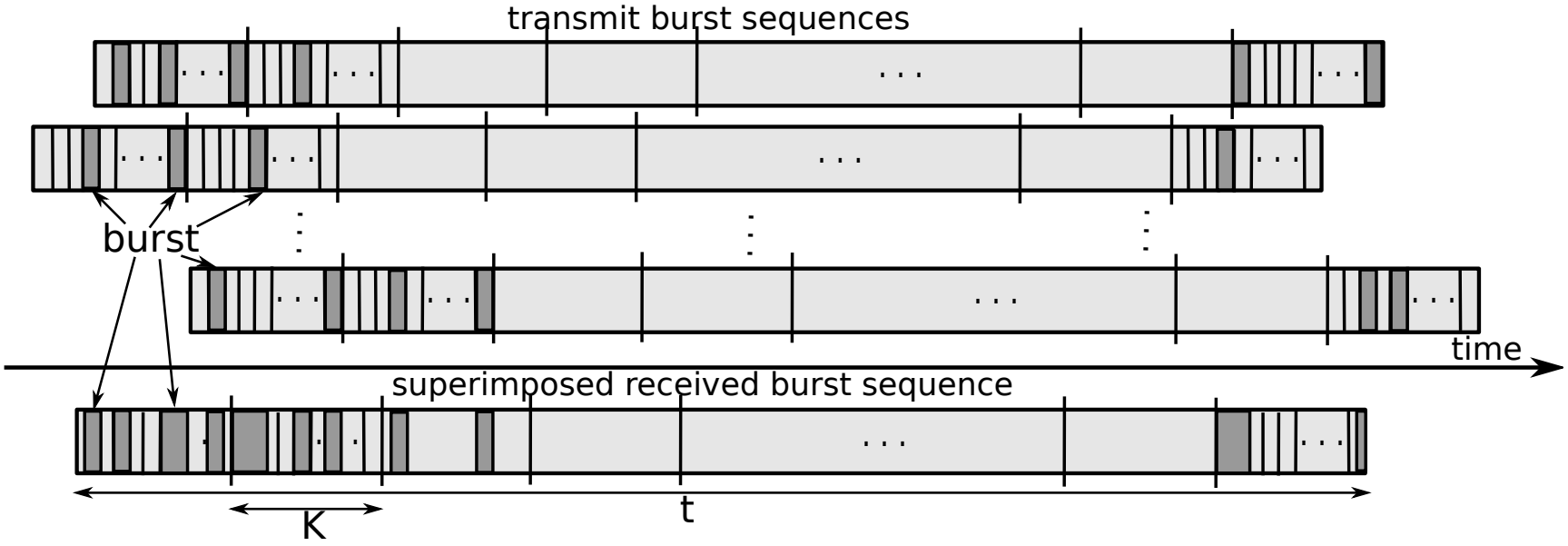
Utilising Poisson-distributed burst-sequences



Multiplication Applying logarithm laws allows multiplication

Calculation during transmission on the channel

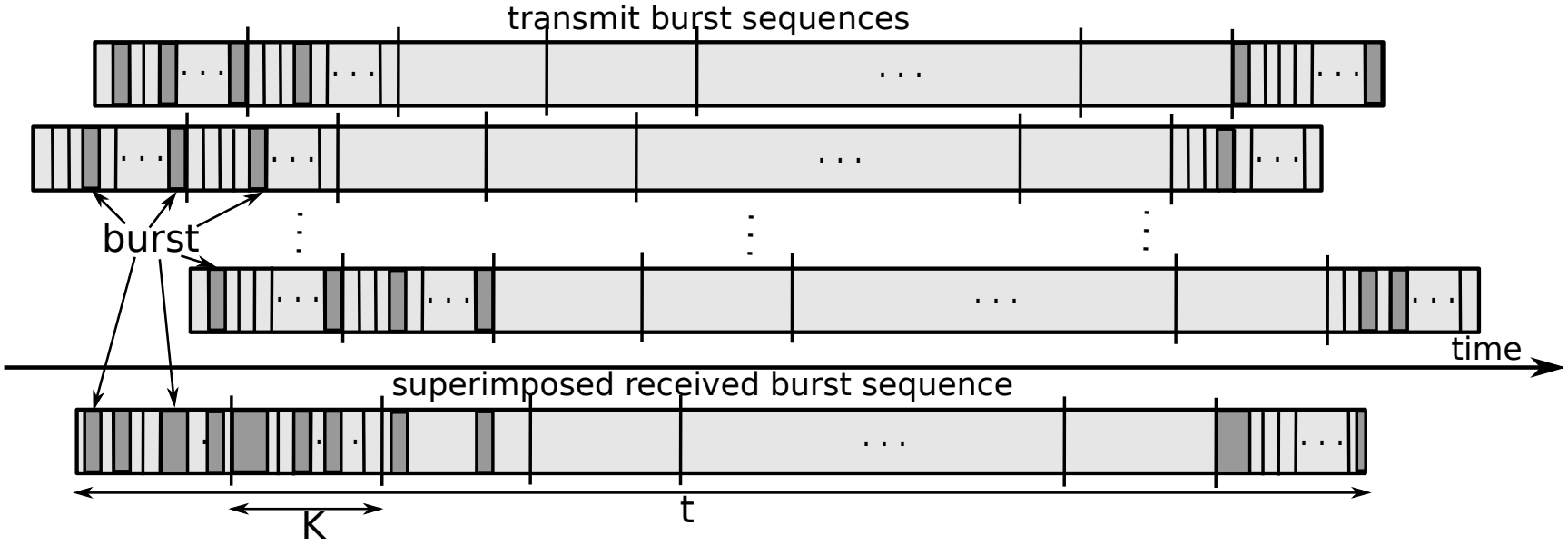
Utilising Poisson-distributed burst-sequences



Division From two nodes, one transmits the Numerator and one the Denominator (fraction)

Calculation during transmission on the channel

Utilising Poisson-distributed burst-sequences



Subtraction Combining division with logarithm laws allows subtraction (two nodes only)

Calculation during transmission on the channel

Errors for calculating during transmission on the wireless channel

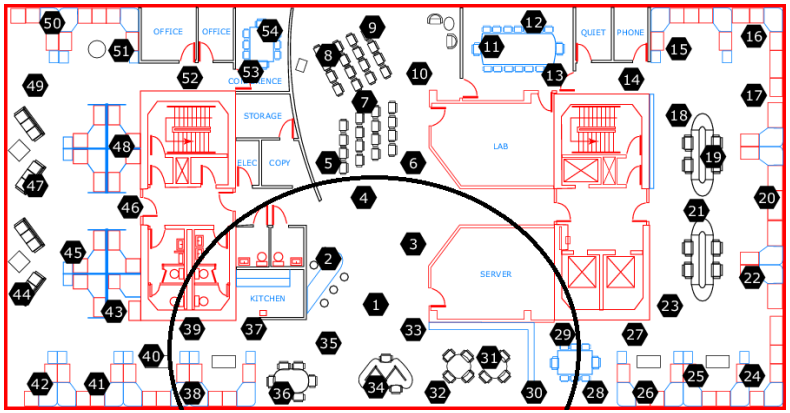
$t = 10^6$; $\kappa = 10^3$	10 nodes	20 nodes	30 nodes	40 nodes	50 nodes
mean err	.0322	.0466	.0609	.051	.0719
std-dev.	.0232	.0368	.0536	.0336	.0438
max N_i	9	14	18.5	26	31
median T	2653.5	5161.5	7393	101816	124179

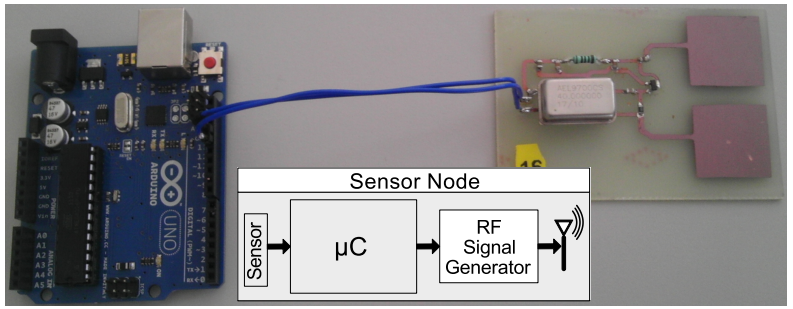
$t = 10^7$; $\kappa = 10^3$	10 nodes	20 nodes	30 nodes	40 nodes	50 nodes
mean err	.0049	.0176	.0402	.0475	.0781
std-dev.	.0062	.0127	.0233	.0292	.0405
max N_i	12	18	23	27	31
median T	25708.5	52617.5	78502	101381	114348

$t = 10^7$; $\kappa = 10^2$	10 nodes	20 nodes	30 nodes	40 nodes	50 nodes
mean err	.0190	.1337	.2619	.4903	.6597
std-dev.	.0107	.0358	.0591	.0708	.1129
max N_i	9.5	16	19	24	27
median T	24165	50037	71686.5	96829	114383

Calculation during transmission on the channel

Case study to compare the calculation accuracy

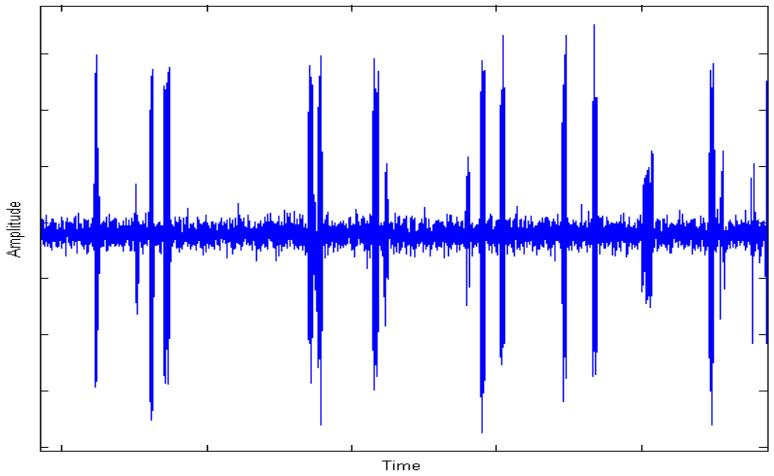


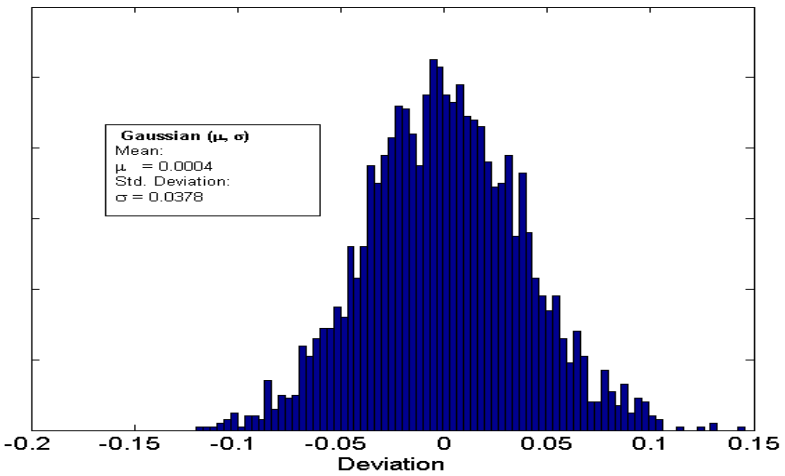


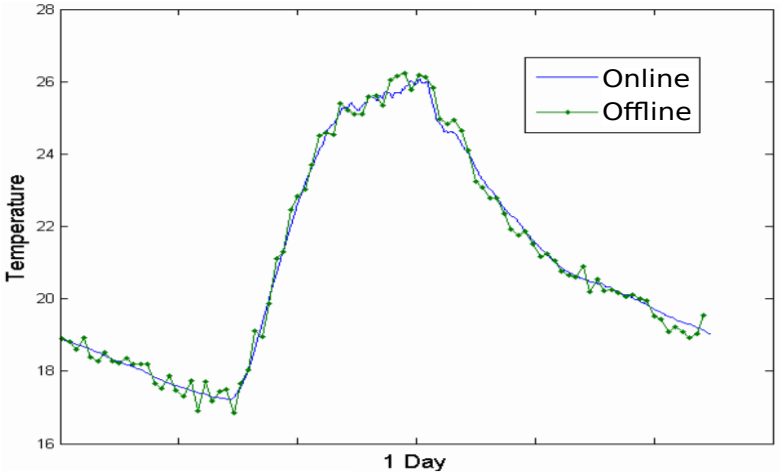
- Utilise data from the Intel Berkeley laboratory network (here: temperature)[4]
- Transmission of data by simple sensor nodes

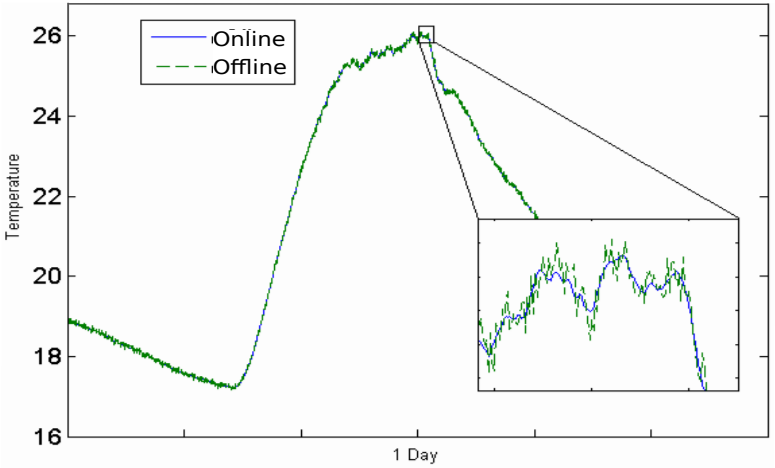
[4] http://db.csail.mit.edu/labdata/labdata.html

Calculation during transmission on the channel





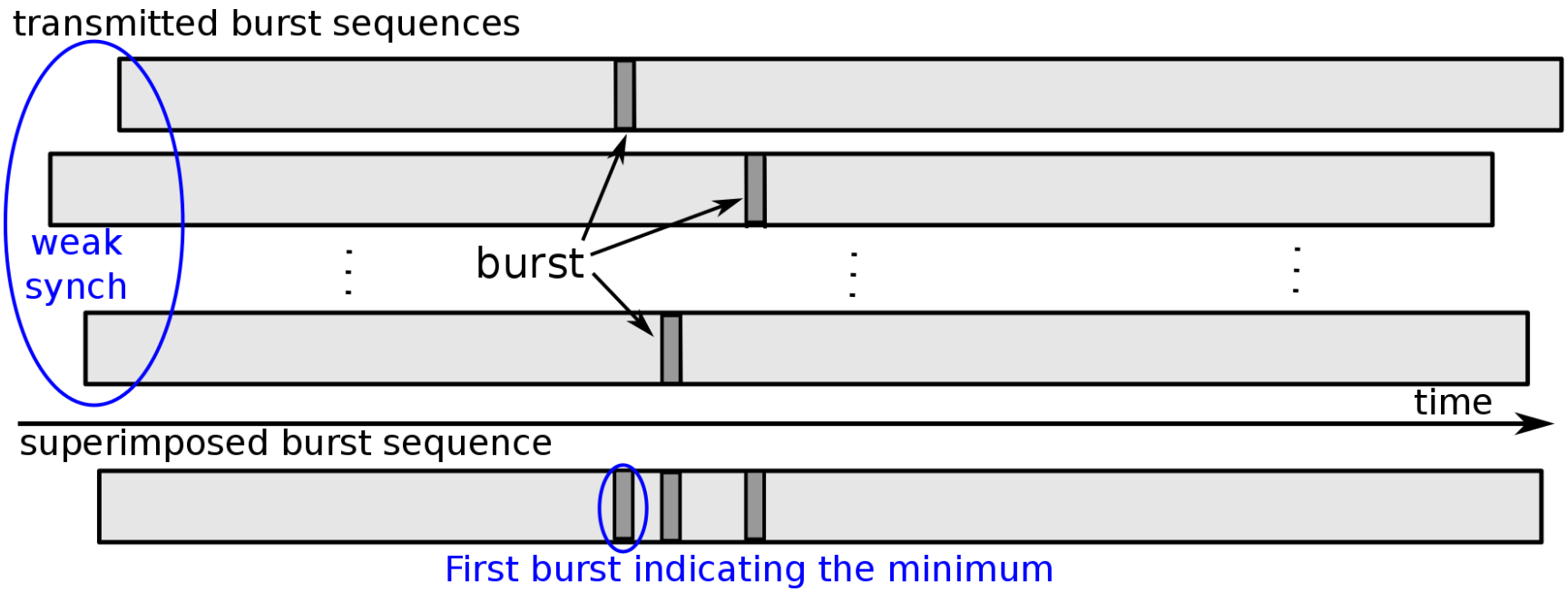




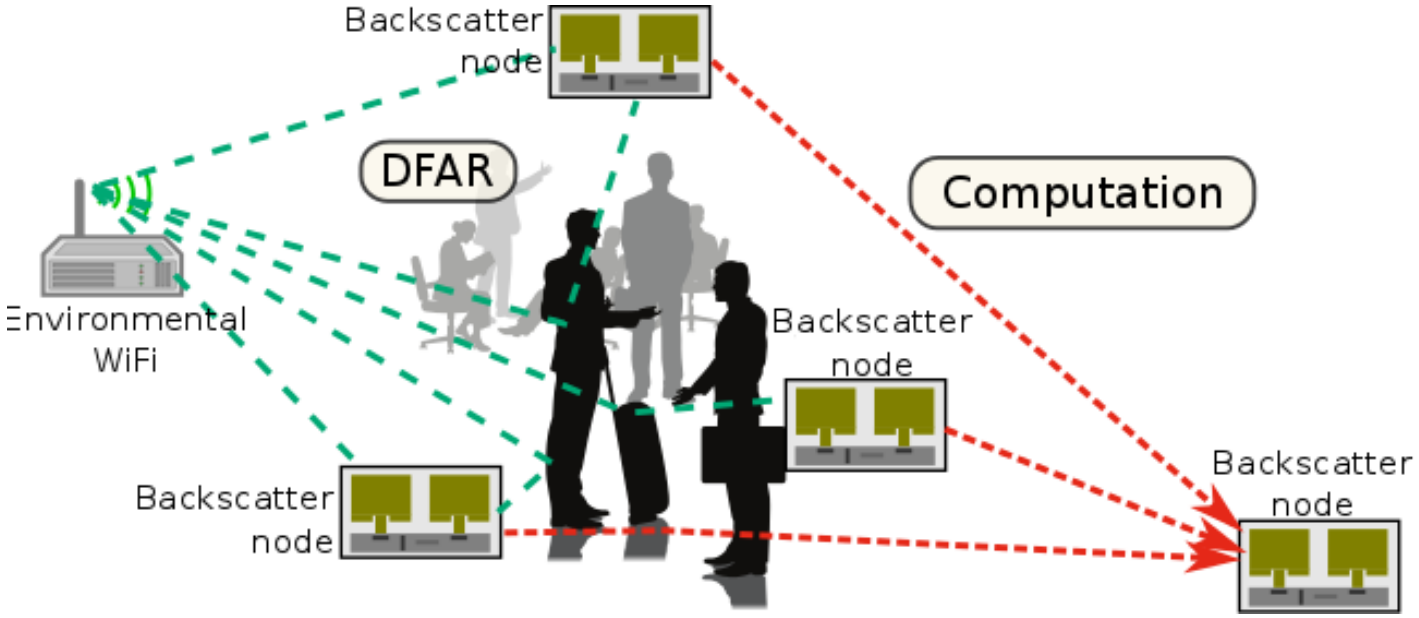
Further mathematical operations

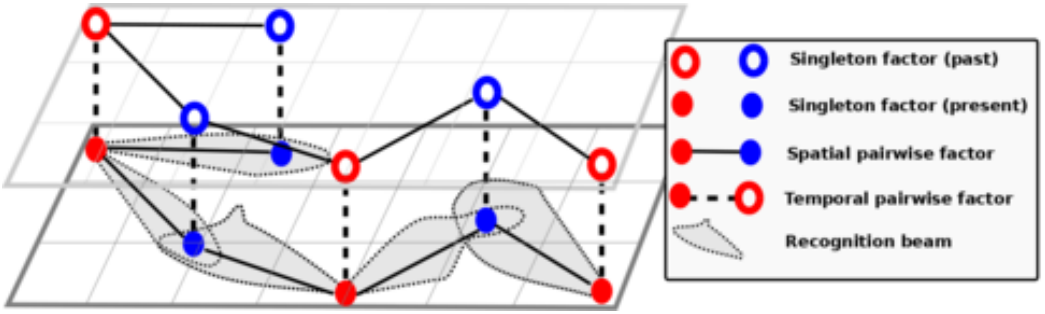
Utilising the mean of the minimum of a convolution

- Exploiting the CDF of the minimum of a distribution, further operations are possible
  - $\sqrt{n}$
  - d^n
  - ...



Environmental perception with CRFs





Joint probability distribution:

$$P(Q_{:,j-1}, Q_{:,j}) = \frac{1}{Z} \prod_{i=1}^{n} \phi_i^S(q_{i,j-1}) \prod_{i=1}^{n} \phi_i^S(q_{i,j}) \prod_{(a,b)\in E} \phi_{a,b}^{SP}(q_{a,j}, q_{b,j}) \prod_{i=1}^{n} \phi_i^{TP}(q_{i,j-1}, q_{i,j})$$

Group members and recent related research

- RF-based activity recognition

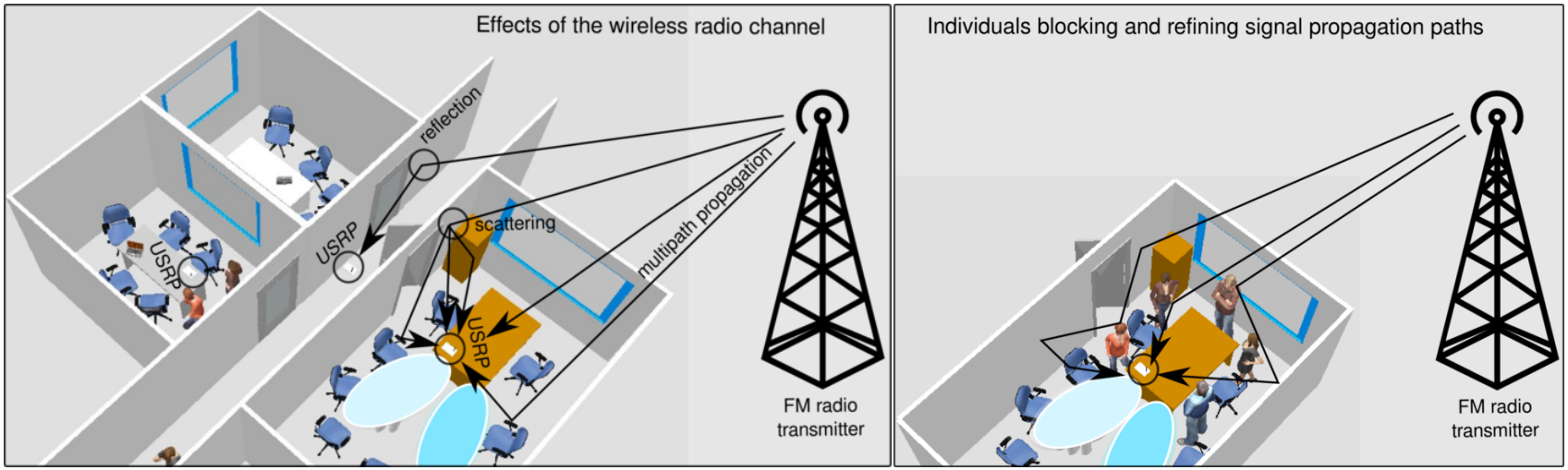
Maintenance-free, intelligent distributed sensing

Sensor graphs for distributed mathematical operation

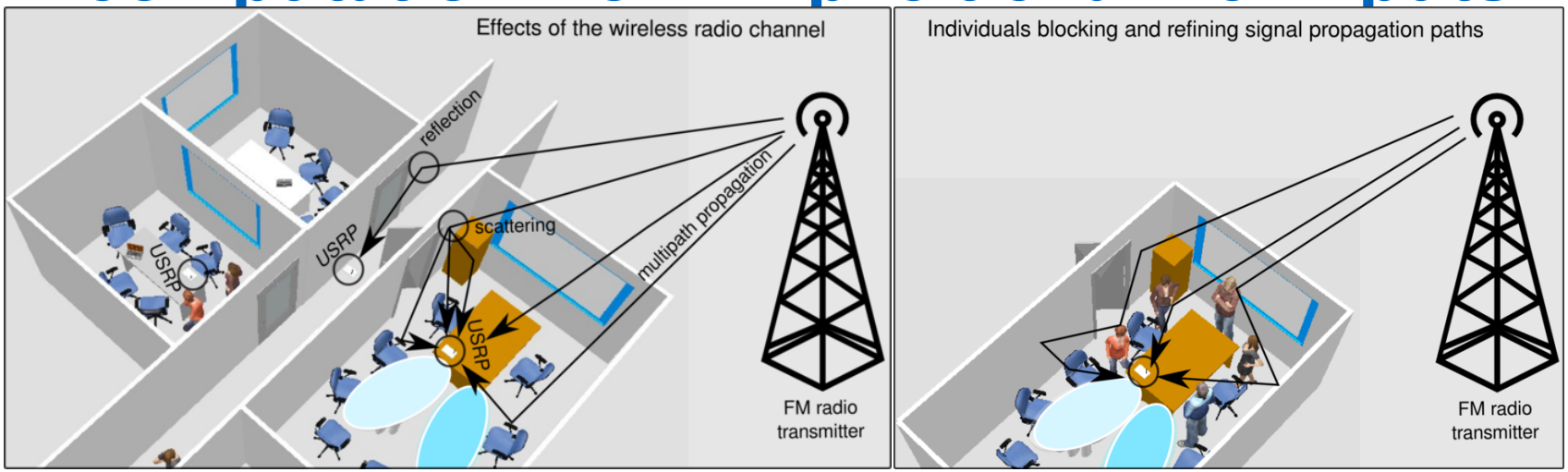
- Probabilistic superimposed mathematical operations
- Artificial neural computation from implicit channel inputs

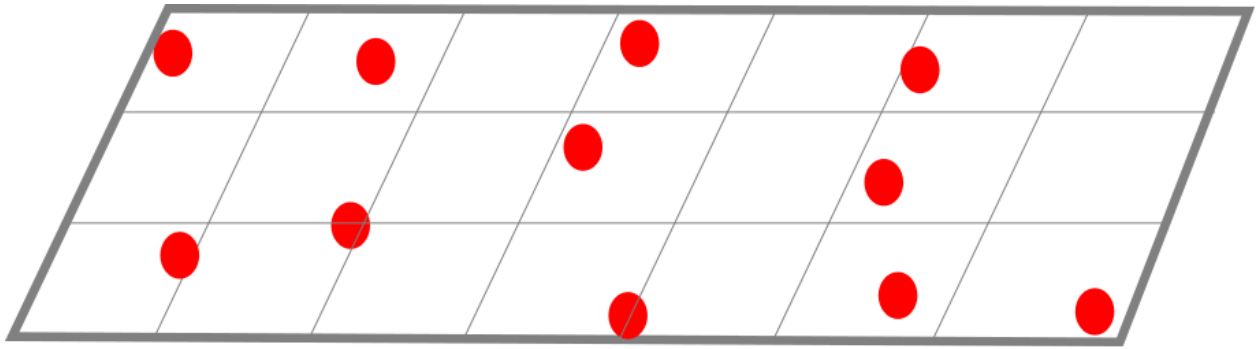
Conclusion

ANN computation from implicit channel inputs

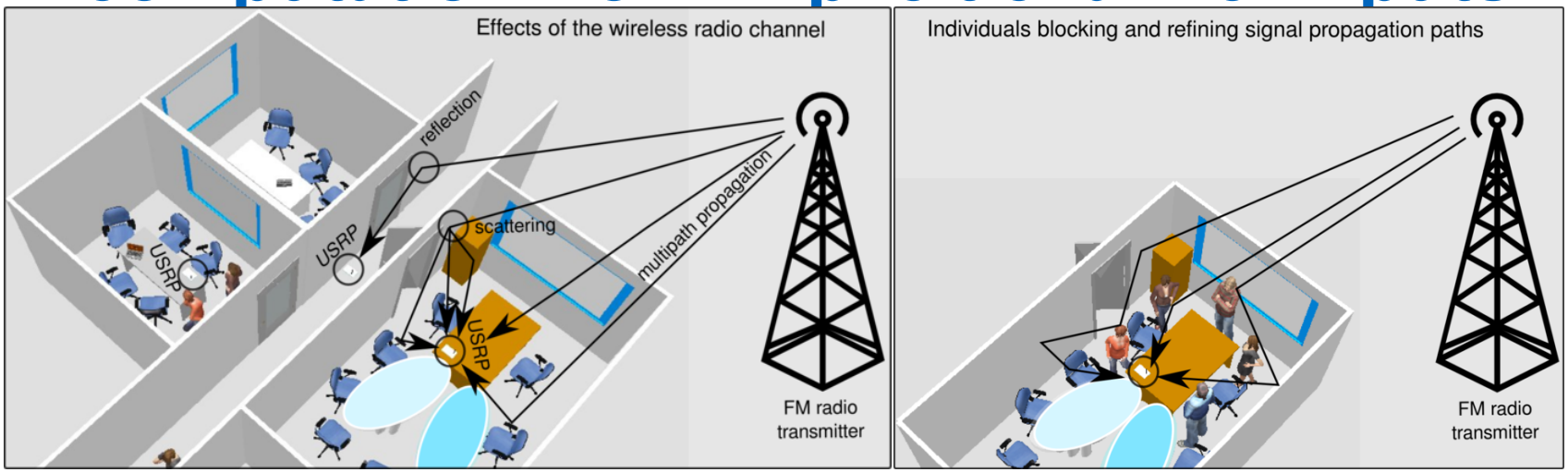


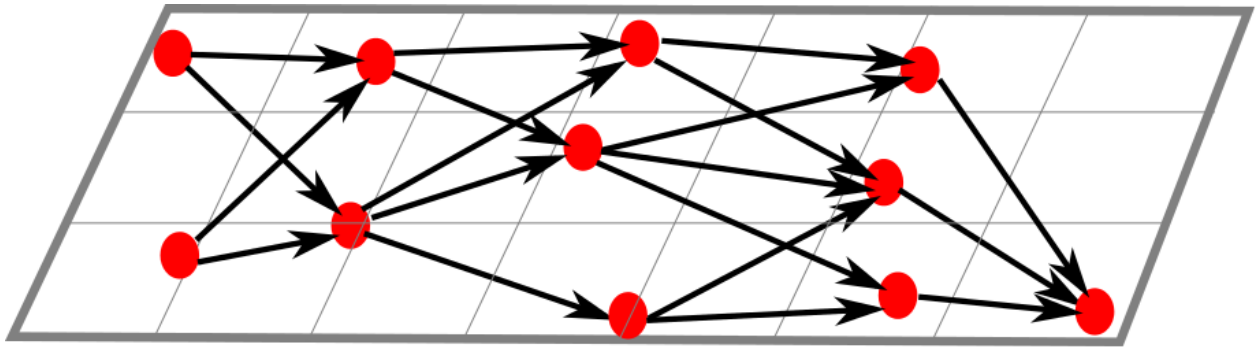
ANN computation from implicit channel inputs



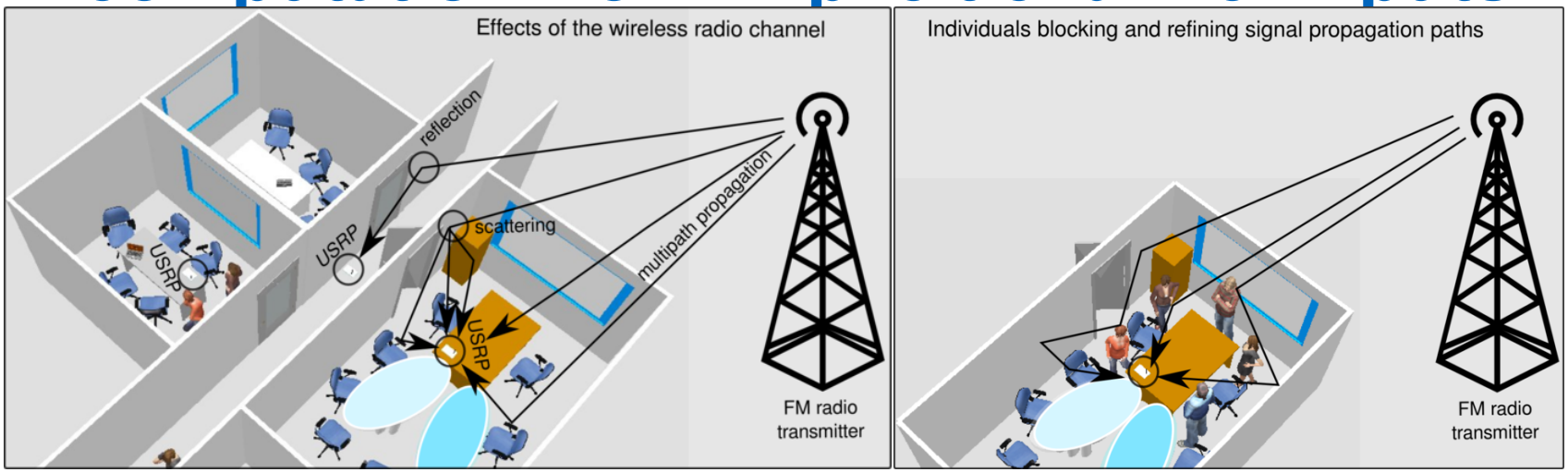


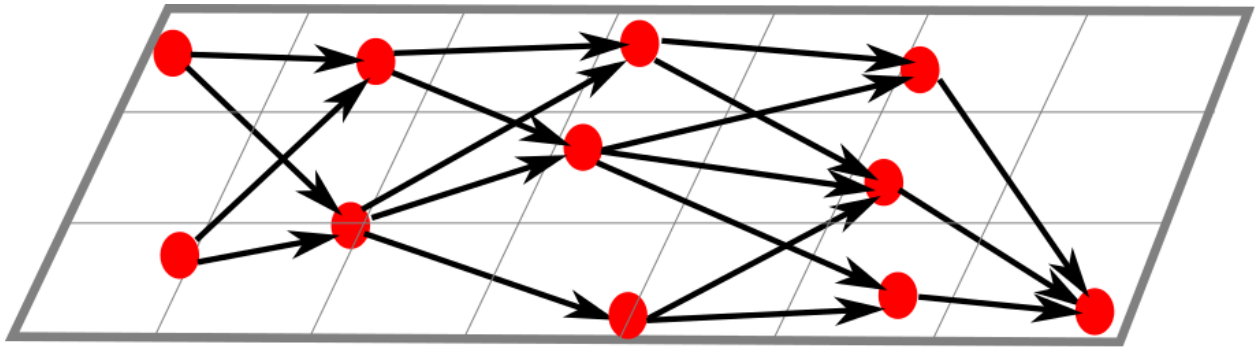
ANN computation from implicit channel inputs





ANN computation from implicit channel inputs





$$h_k(\vec{x}, \vec{w}) = f_{\text{act}}^{(3)} \left(\sum_{j=1}^{D_2} w_{jk}^{(2)} f_{\text{act}}^{(2)} \left(\sum_{i=1}^{D_1} w_{ij}^{(1)} x_i + w_{0j}^{(1)} \right) + w_{0k}^{(2)} \right)$$

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Maintenance-free intelligent distributed sensing