Aalto University
School of Electrical Engineering

Challenges and tools for maintenance-free, intelligent distributed sensing

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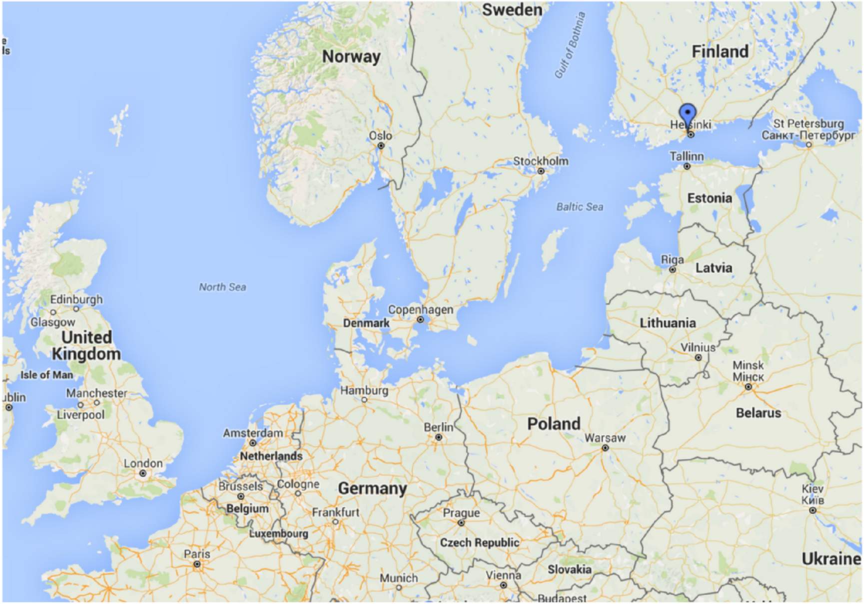
CiNet, 22.02.2017



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Oslo
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Baltic Sea
Riga
Latvia
North Sea
Edinburgh
Glasgow
United Kingdom
Copenhagen
Denmark
Lithuania
Vilnius
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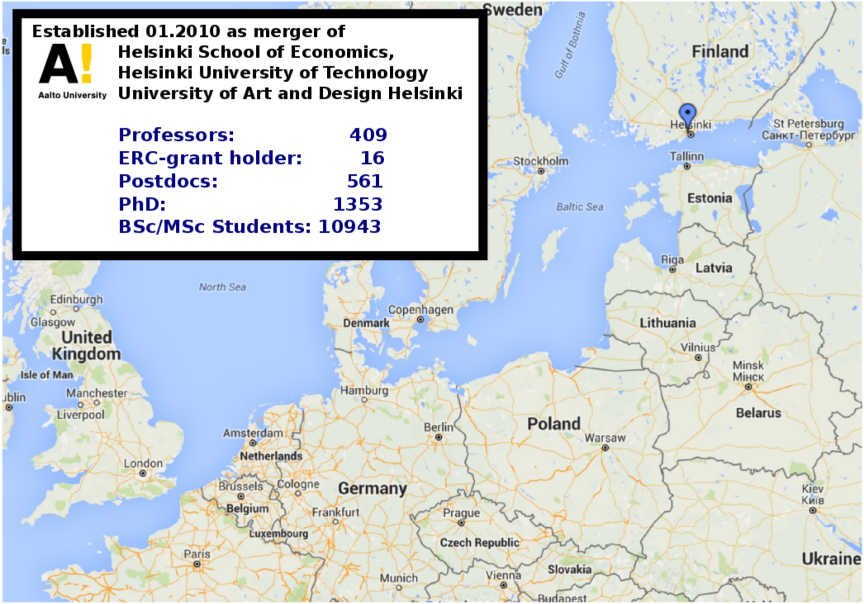
Established 01.2010 as merger of

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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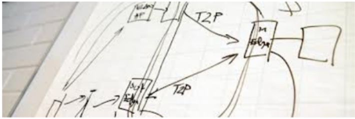
Comnet

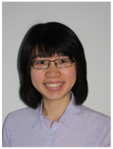
- Personnel: ~115
- 11 + 2 Professors
- budget ~7.8 M€
  ~ 60% external funding
- ~ 55 M.Sc thesis annually
- ~ 8 D.Sc thesis annually



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/

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

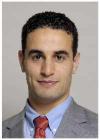
Patric Östergård
Information theory

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

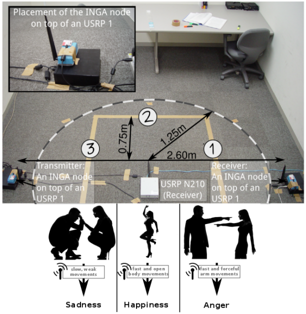
Sensor graphs for distributed mathematical operation

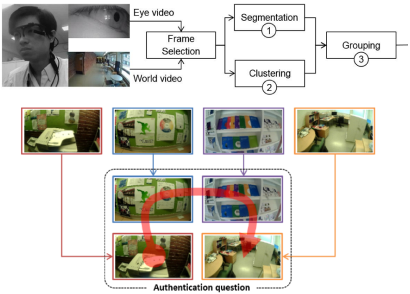
Neuron-inspired communication between distributed nodes

Probabilistic superimposed mathematical operations

Artificial neural computation from implicit channel inputs

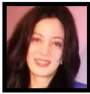
Conclusion





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

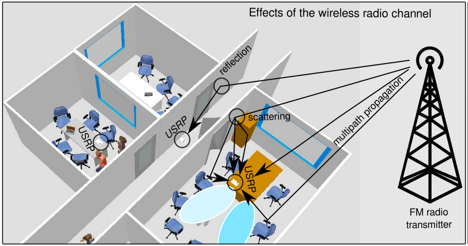
Visitors

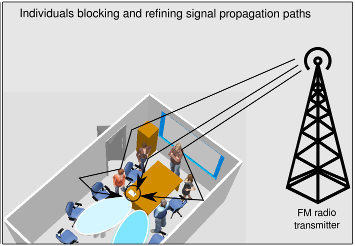
Takuya Maekawa

Wearable/Ubiquitous Sensing
Activity Recognition
Lifelogging
Web Contents Engineering

Exploiting the RF-channel for environmental preception

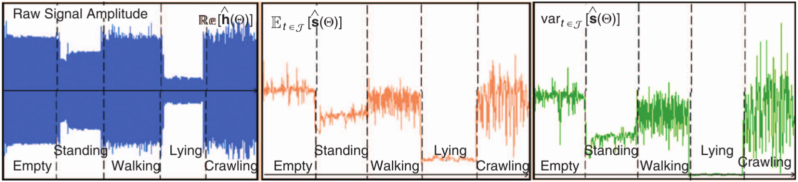
- Multi-path propagation
- Signal superimposition
- Scattering
- Signal Phase
- Reflection
- Blocking of signal paths
- Doppler Shift
- Fresnel effects



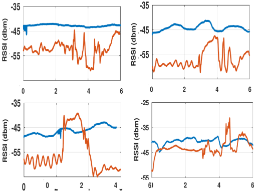


RF-based activity recognition

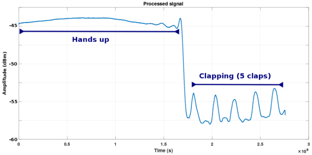
Sensewaves Video

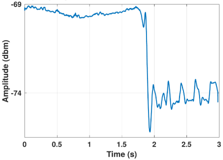


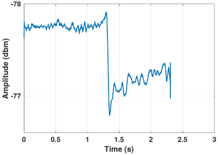
Angry, agitated driving



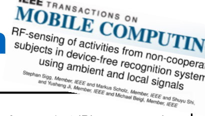
– Video –

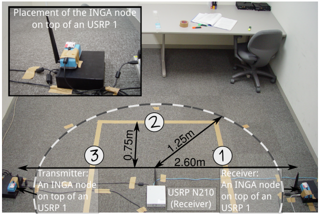


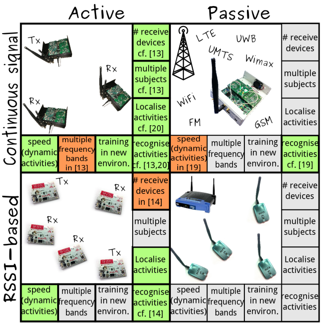


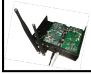


RF-based device-free activity recognition









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

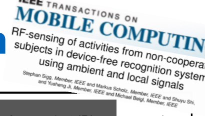
Passive SDR-based DFAR (USRP N210)
Frequency: 82.5MHz (WBX board), Vert900 Antenna, 4dBi antenna gain
Signal: Environmental FM radio captured from a nearby radio station
Sample rate: 64Hz

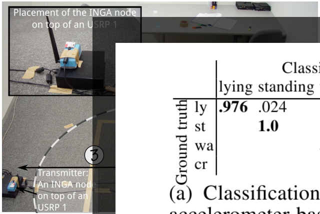
Active RSSI-based DFAR (INGA wsn nodes, v1.4)
Frequency: 2.4GHz IEEE802.15.4, PCB High Gain-Antenna
Signal: RSSI samples from packets transmitted between nodes
Sample rate: Transmission of 100 packets per second

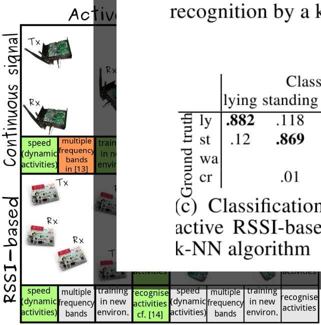
Accelerometer-based activity recognition (Iphone 4)
Signal: 3-axis accelerometer
Sample rate: 40 Hz

Walking Lying standing empty Crawling

RF-based device-free activity recognition







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

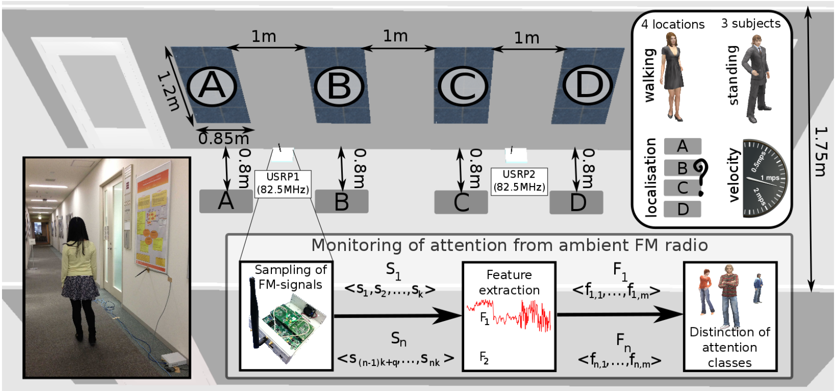
Ground truth	lying	standing	walking	crawling
ly	**.882**	.118		
st	.12	**.869**	.007	.004
wa			**.953**	.047
cr		.01	.439	**.551**

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

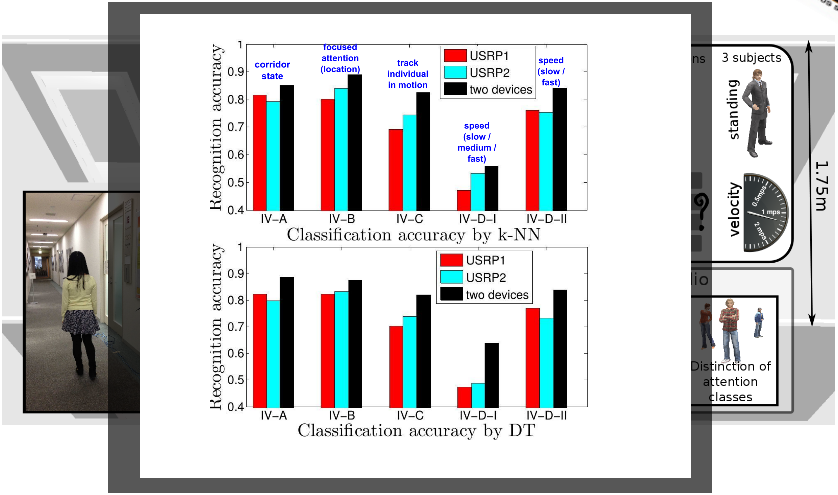
Ground truth	lying	standing	walking	crawling
ly	**1.0**			
st	.056	**.98**	.022	
wa	.023		**.874**	.102
cr	.044		.144	**.811**

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

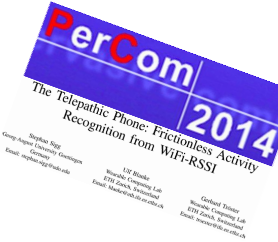
Monitoring attention from RF

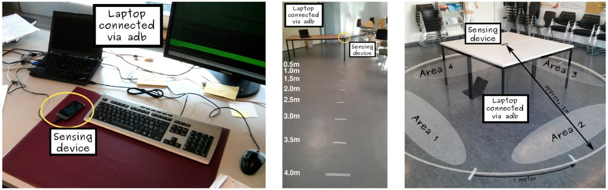


Monitoring attention from RF

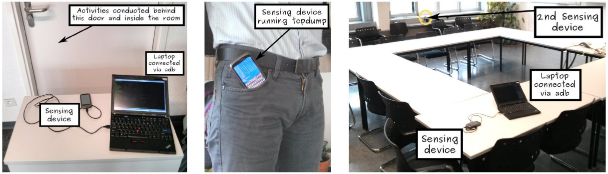


Situation and gestures from passive RSSI-based DFAR

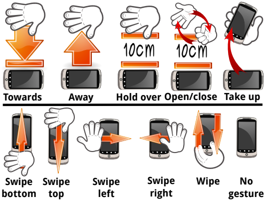




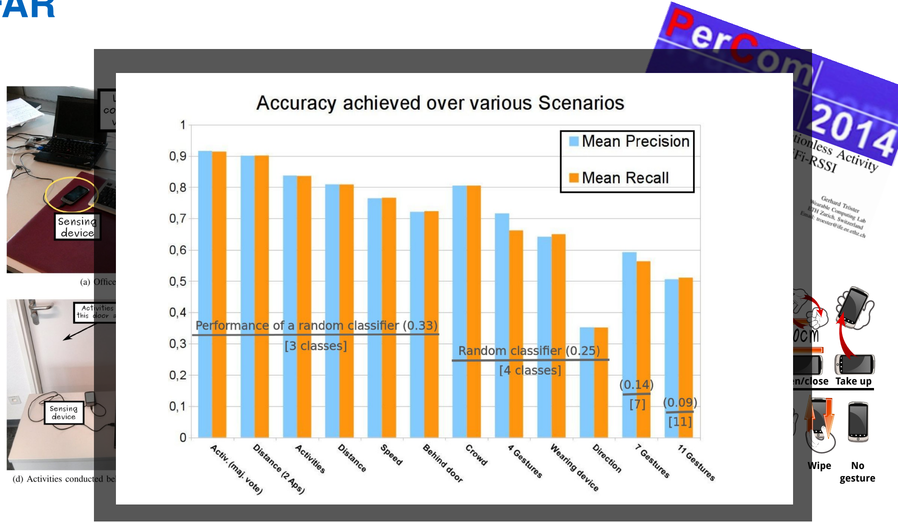
(a) Office environment at ETH (b) Lecture room at TU-BS (c) Scenario for the distinction of walking speed



(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



Group members and recent related research

- RF-based activity recognition

Maintenance-free, intelligent distributed sensing

Sensor graphs for distributed mathematical operation

- Neuron-inspired communication between distributed nodes
- Probabilistic superimposed mathematical operations
- Artificial neural computation from implicit channel inputs

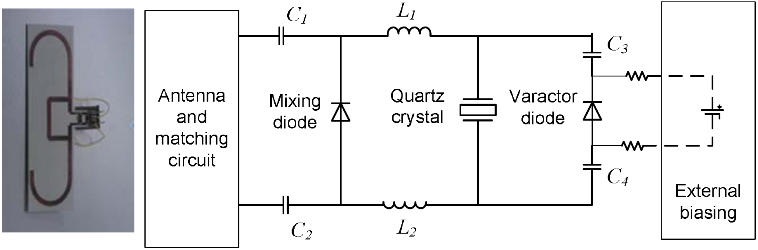
Conclusion

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



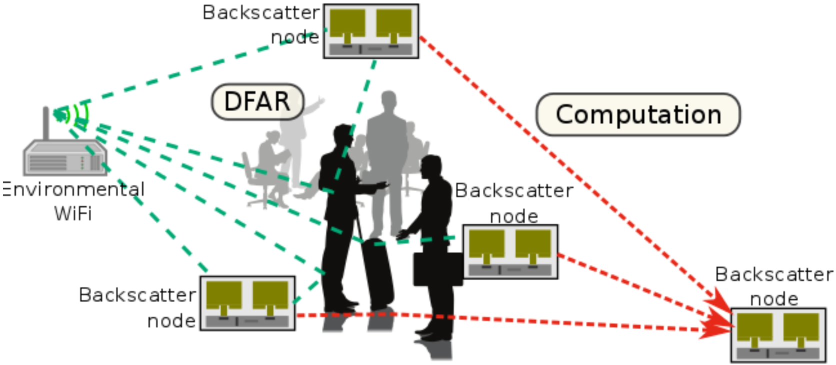
3

[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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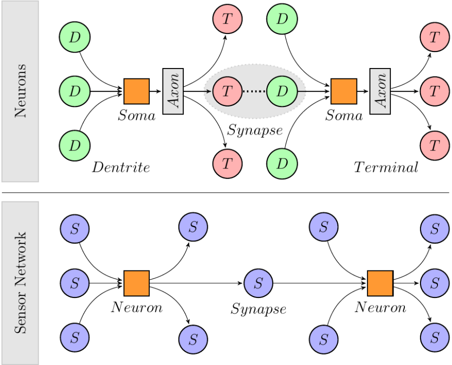
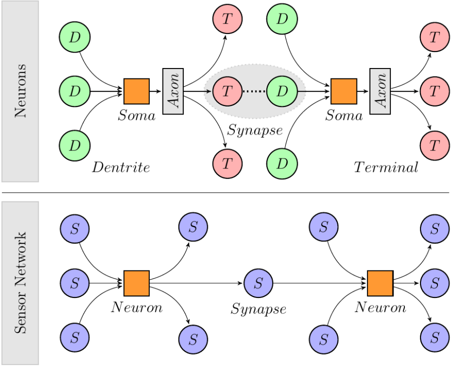
Neural communication for sensor networks



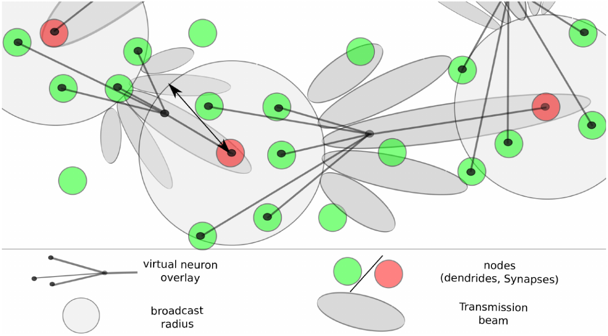
Neural communication for sensor networks



Problem

- Communication in sensor networks is omnidirectional
- In neural networks, the missing of edges is vital for the network's computational power

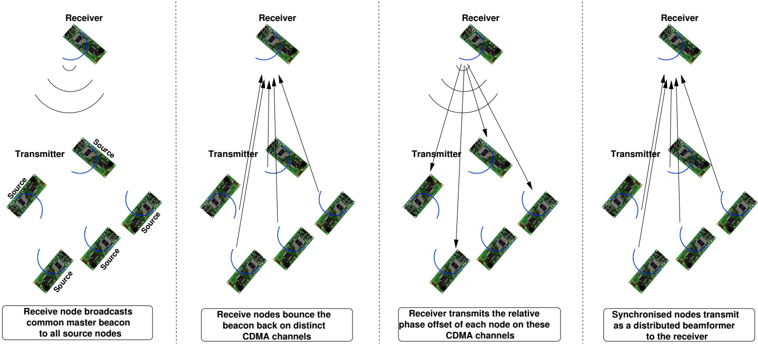
Neural communication for sensor networks



Proposal

- Transmit beamforming to establish dedicated links

Example closed-loop carrier synchronization

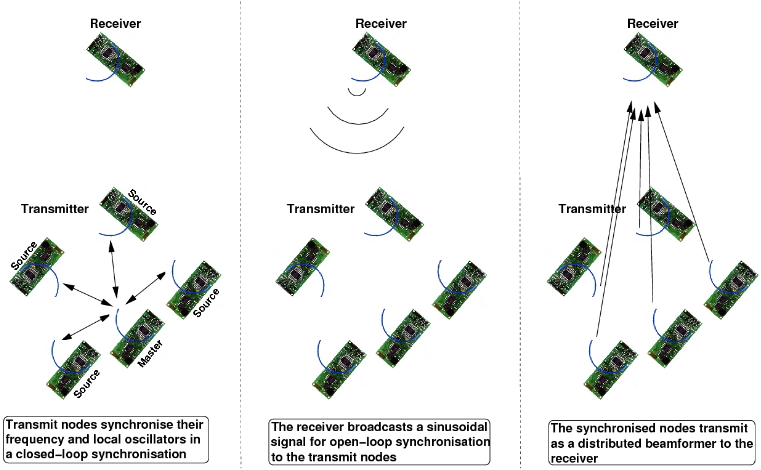


[4]

- Too computationally expensive for parasitic operation

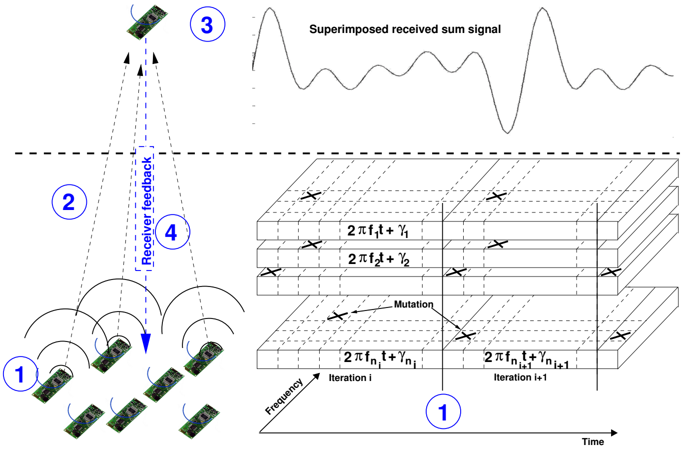
[4] Y. Tu and G. Pottie, *Coherent Cooperative Transmission from Multiple Adjacent Antennas to a Distant Stationary Antenna Through AWGN Channels*, Proceedings of the IEEE VTC, 2002

Example open-loop carrier synchronization



- Too computationally expensive for parasitic operation

Feedback-based open-loop carrier synchron.



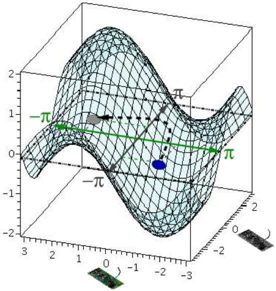
[5], [6]

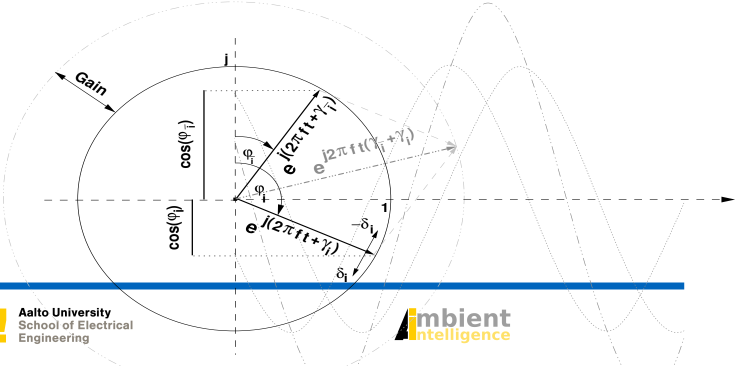
[5] R. Mudumbai, G. Barriac and U. Madhow, *On the feasibility of distributed beamforming in wireless networks*, IEEE Transactions on Wireless Communications, 2007

[6] Sigg, El Masri and Beigl, A sharp asymptotic bound for feedback based closed-loop distributed adaptive beamforming in wireless sensor networks, IEEE Transactions on Mobile Computing, 2013

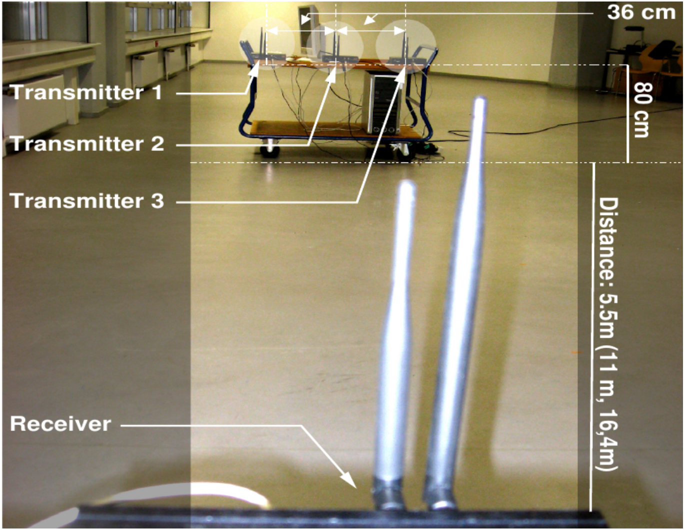
Feedback-based open-loop carrier synchronizat.

- Weak multimodal fitness function
- Single local=global optimum

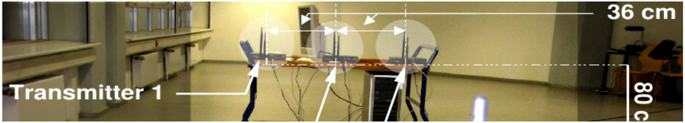


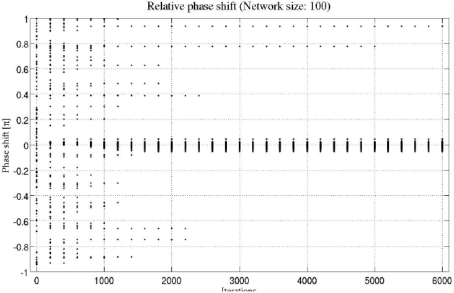


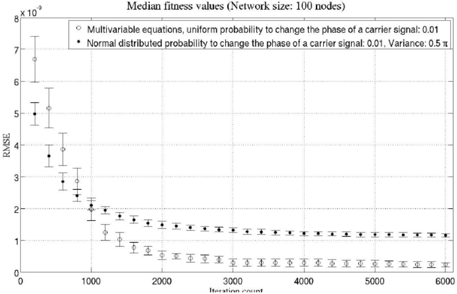
Feedback-based open-loop carrier synchron.

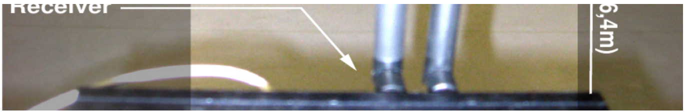


Feedback-based open-loop carrier synchron.

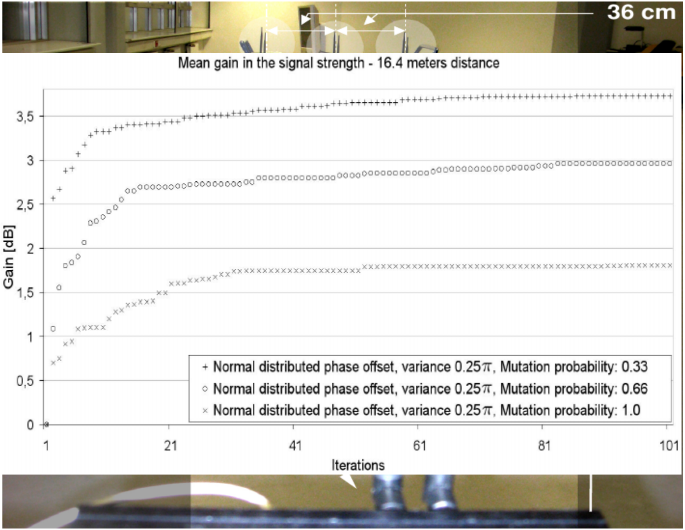


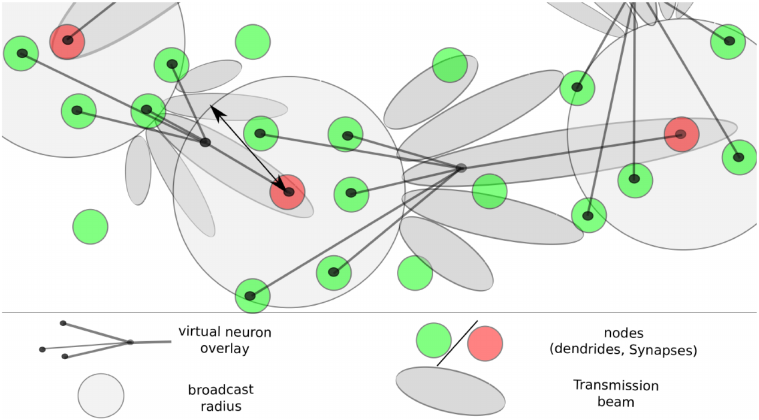






Feedback-based open-loop carrier synchron.




virtual neuron overlay
broadcast radius
nodes (dendrides, Synapses)
Transmission beam

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Conclusion

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

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(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)

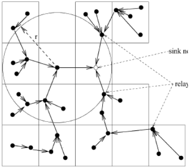
Potential: Trade processing load for communication load

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

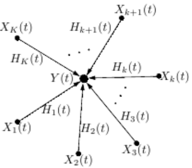
Calculation during transmission on the channel

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



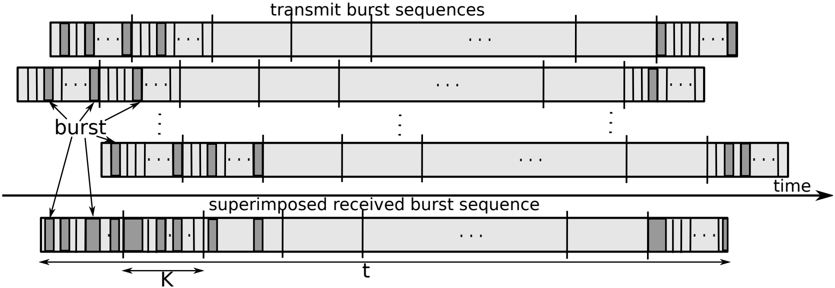
Calculation of by means of post- and pre-processing[a]

- 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

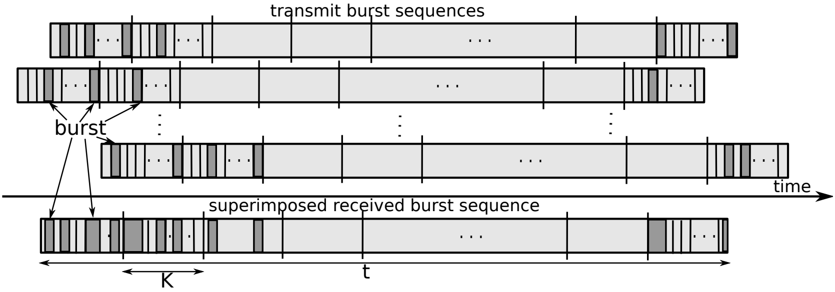
Calculation during transmission on the channel

Utilising Poisson-distributed burst-sequences



Calculation during transmission on the channel

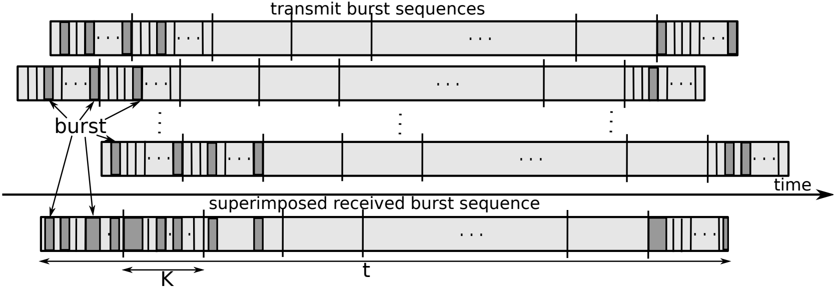
Utilising Poisson-distributed burst-sequences



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

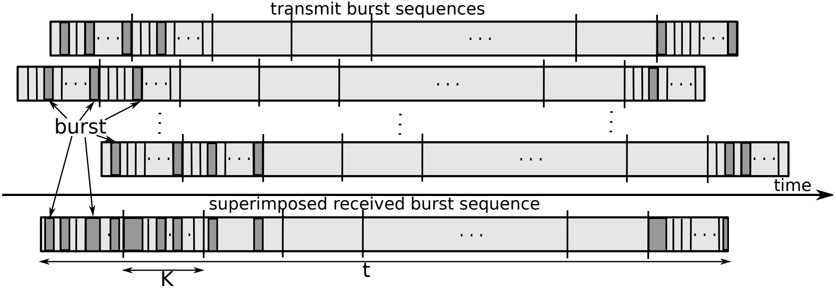
Utilising Poisson-distributed burst-sequences



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

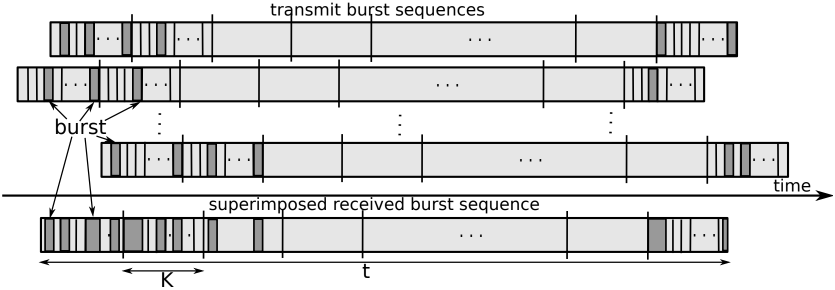
Utilising Poisson-distributed burst-sequences



Multiplication Applying logarithm laws allows multiplication

Calculation during transmission on the channel

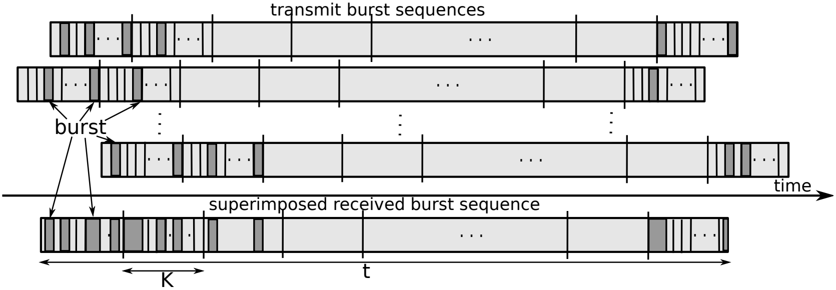
Utilising Poisson-distributed burst-sequences



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

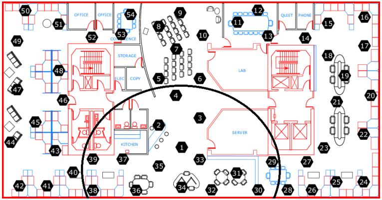
$t = 10^6; \kappa = 10^3$	10 nodes	20 nodes	30 nodes	40 nodes	50 nodes
mean err	.0322	.0466	.0609	.051	.0719
std-dev.	.0232	.0368	.0536	.0336	.0438
max N_i	9	14	18.5	26	31
median T	2653.5	5161.5	7393	101816	124179

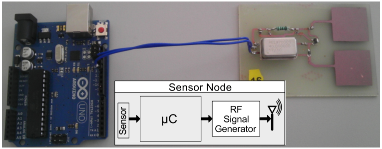
$t = 10^7; \kappa = 10^3$	10 nodes	20 nodes	30 nodes	40 nodes	50 nodes
mean err	.0049	.0176	.0402	.0475	.0781
std-dev.	.0062	.0127	.0233	.0292	.0405
max N_i	12	18	23	27	31
median T	25708.5	52617.5	78502	101381	114348

$t = 10^7; \kappa = 10^2$	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)[7]
- Transmission of data by simple sensor nodes

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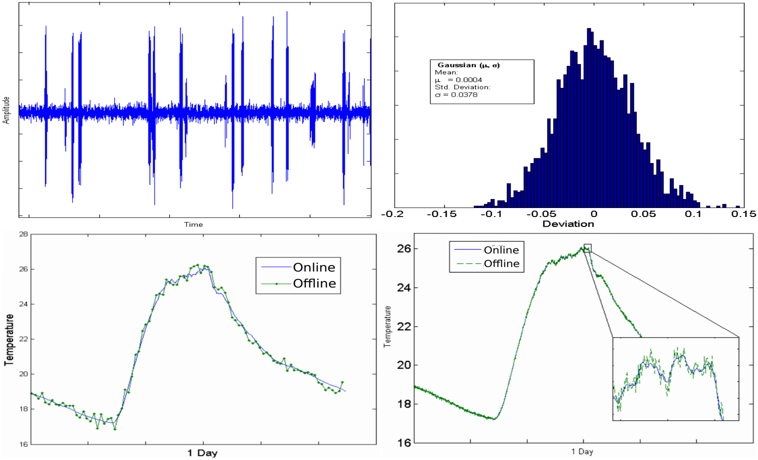
[7] http://db.csail.mit.edu/labdata/labdata.html

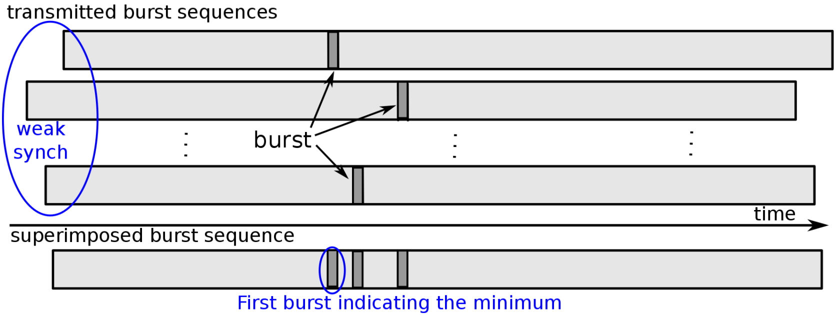
Calculation during transmission on the channel



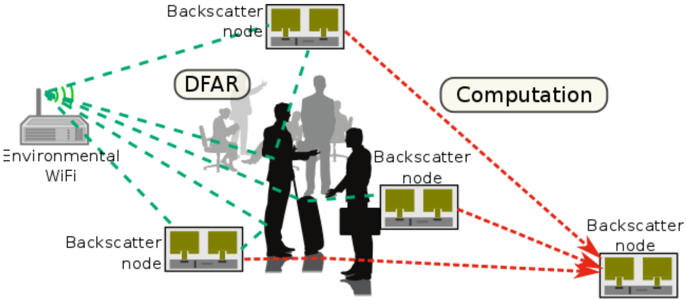
Further mathematical operations

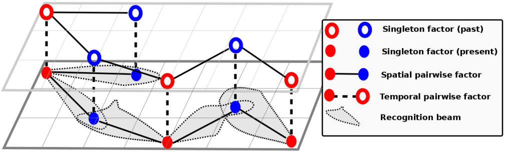
Utilising the mean of the minimum of a convolution

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



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

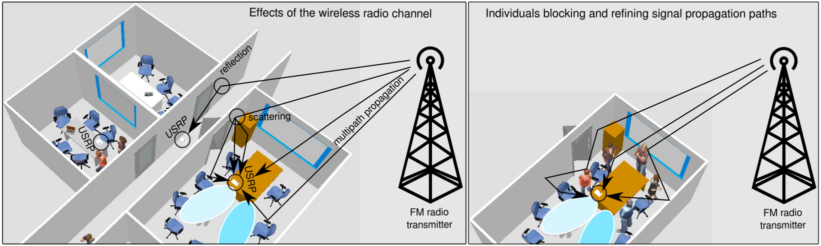
Maintenance-free, intelligent distributed sensing

Sensor graphs for distributed mathematical operation

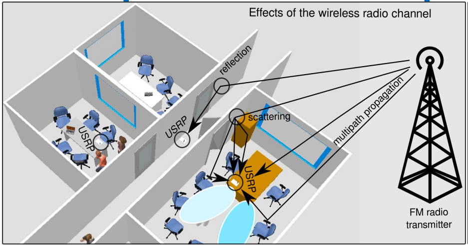
- Neuron-inspired communication between distributed nodes
- Probabilistic superimposed mathematical operations
- Artificial neural computation from implicit channel inputs

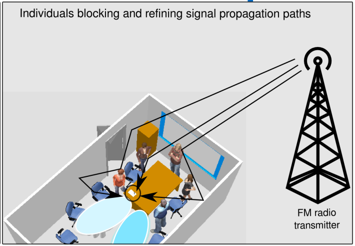
Conclusion

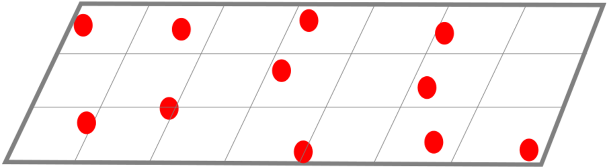
ANN computation from implicit channel inputs



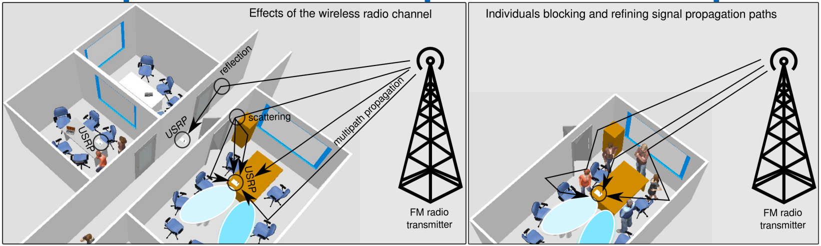
ANN computation from implicit channel inputs

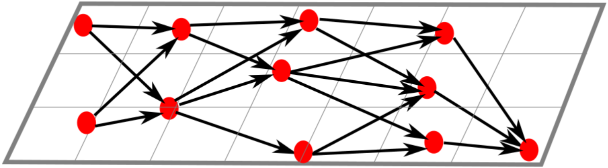




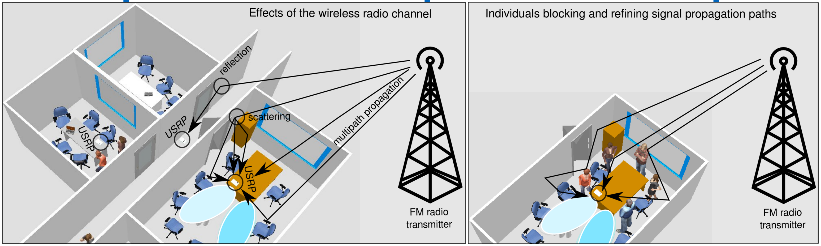


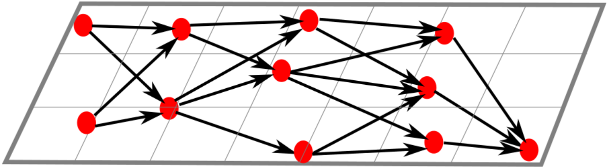
ANN computation from implicit channel inputs





ANN computation from implicit channel inputs





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

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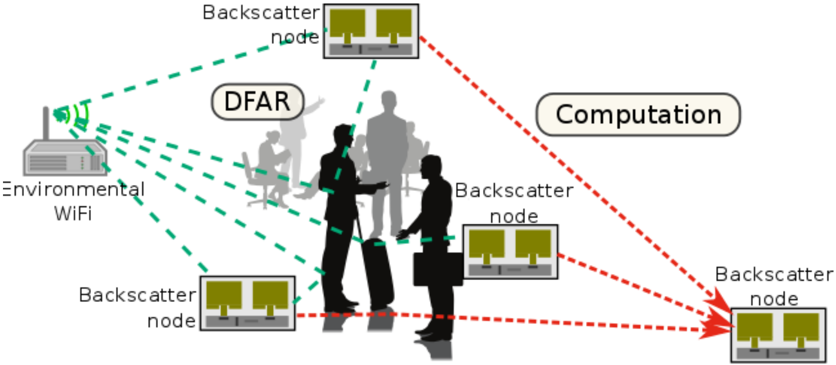
Maintenance-free intelligent distributed sensing



Thank you!

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