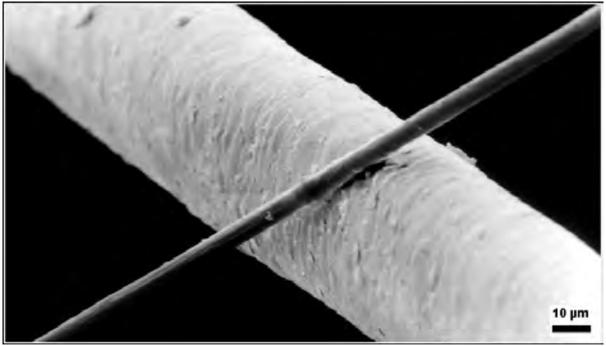
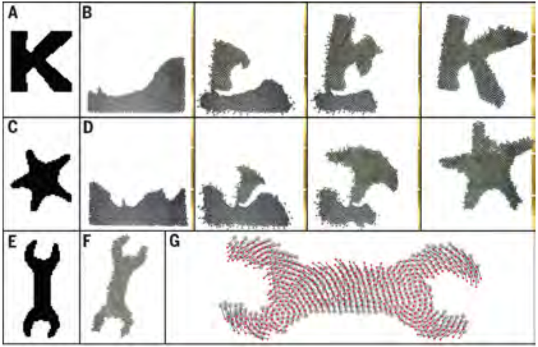
“

In-body imaging tech achieves 100microns resolution.
Leaky blood vessel inroads are only a few in diameter. [6]

”



src: Wikipedia [3]



src: Science , 2014 [7]

Really Dense Networks of Things

Georgios Exarchakos, ECO, TU/e
Assistant professor, Smart Networks

Credits: Tim v.d. Lee, ECO, TU/e
PhD Candidate, Smart Network Resourcing

October 10, 2018

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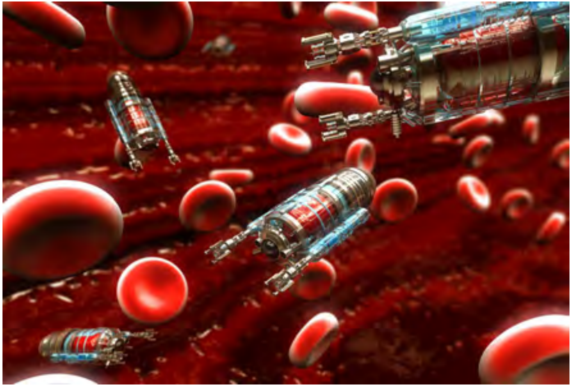
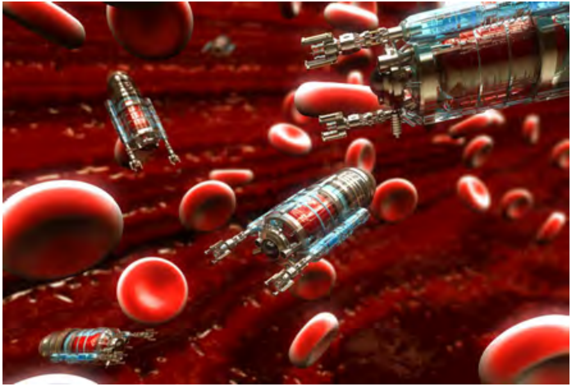
Future Networks inside Living Organisms



src:Boston Children's Hospital, Harvard Medical School [2]

- Miniaturization
- Communication microrobot-to-x
- Continuous coordination
- Navigation
- Privacy
- Info/robot retrieval
- Single-task operation

Future Networks **inside** Living Organisms



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Future Networks inside Living Organisms

Challenges

- microrobot-to-x
- Continuous coordination
- Privacy
- Info/robot retrieval
- Single-task operation

Requirements

- Really dense $> 10^5/m^3$
- THz communications
- Small power budget
- Collective intelligence
- Simple processing
- One-off microrobot-to-I

Resources

- time
- frequency
- wavelength
- transmit power
- links
- energy
- computation
- memory
- ...

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Future Networks ~~inside~~ as Living Organisms

Requirements

- Really dense $> 10^5/\mathrm{m}^3$
- Collective intelligence
- Simple processing
- One-off device-to-I

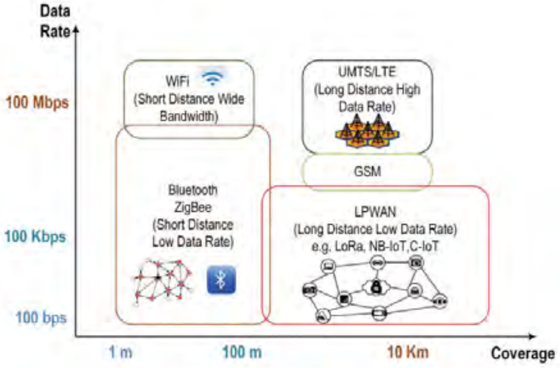
Idea

Wireless Neural Network

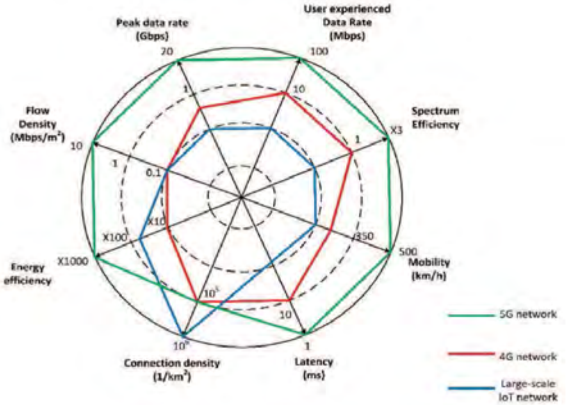
Intuition

- Attach semantics on links and wireless resources
- Teach them and build a physical wireless learning machine

Wireless device density



src: IEEE Access [1]



src: IEEE Access [1]

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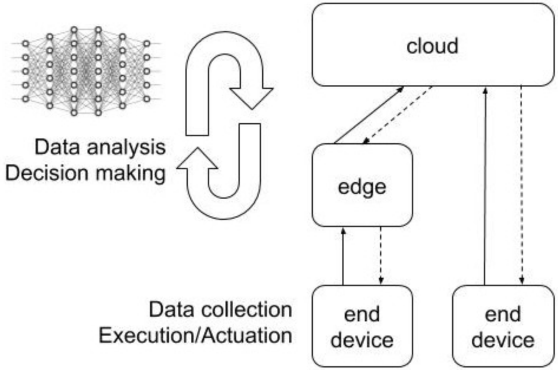
Collective intelligence

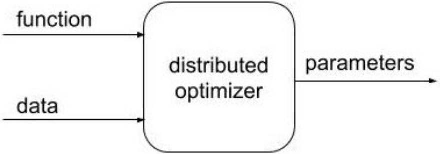


Hierarchical Intelligence

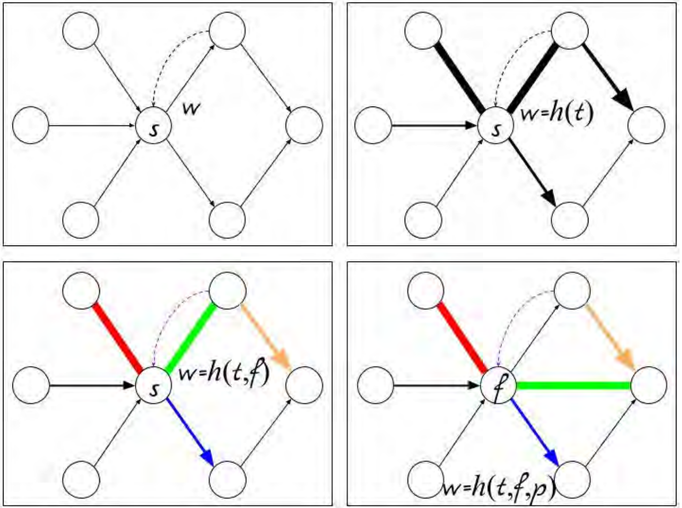
- ✗ highly dense end devices
- ✗ device-to-infrastructure
- ✗ spontaneous intelligence
- ✗ energy waste
- ✓ highly intelligent & ultra-low latency

Collective intelligence

Swarm Intelligence



Wireless Meshes as Neural Networks



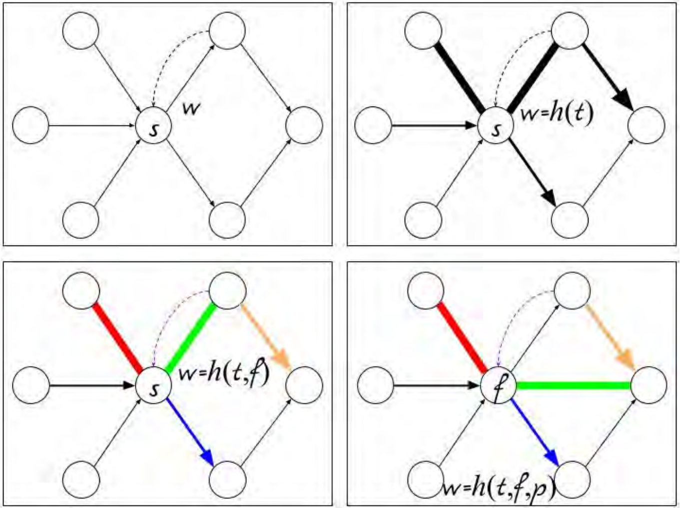
Basics

- link weight as *f.* of wireless resources
- feedback to adapt weights $\rightarrow$ adapt resource allocation function

Feedback & Resourcing

- Delayed delivery at output neuron
- High local Tx retries with unhappy output neuron
- ...

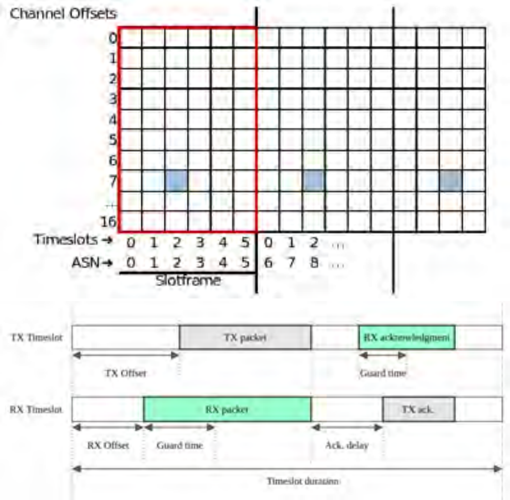
Wireless Meshes as Neural Networks



Challenges

- Feedback mechanisms
- Feedback → resources mapping
- Inherent instability
- Multi-tenancy applications
- Deployment

Learning reliability



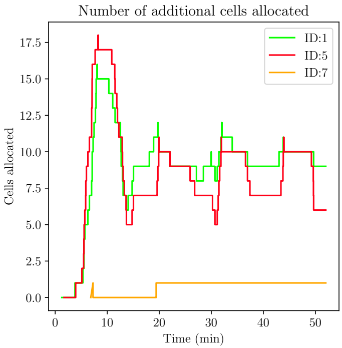
Goal

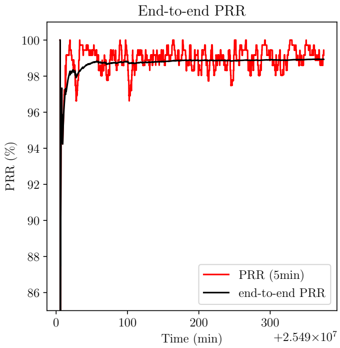
- keep reliability high and stable
- local-only coordination
- small duty cycle
- assumed always happy output neuron

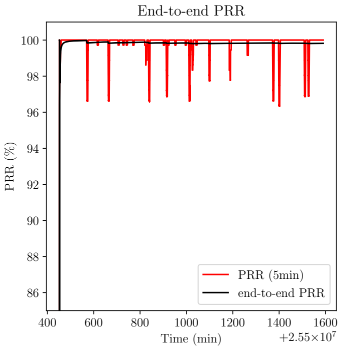
Method

- Continuous swarm coordination & local feedback
- Time dependent resource release
- Resource utility based reward

Learning reliability







Learning reliability

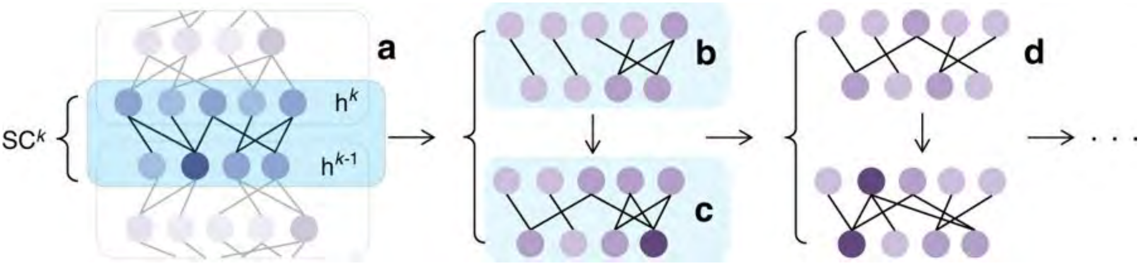
More predictable links for more stable wireless neural networks

Simple · Distributed · Energy efficient

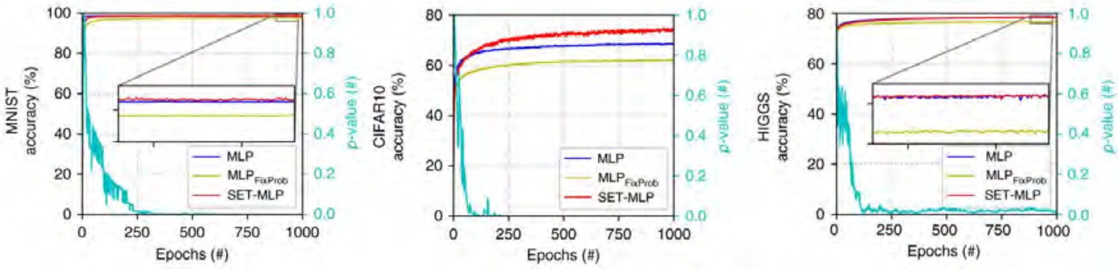
Energy Efficient Learning [5]

Dimensionality reduction of ANNs

- Wireless networks are inherently non fully connected
- ANNs are predominantly fully connected



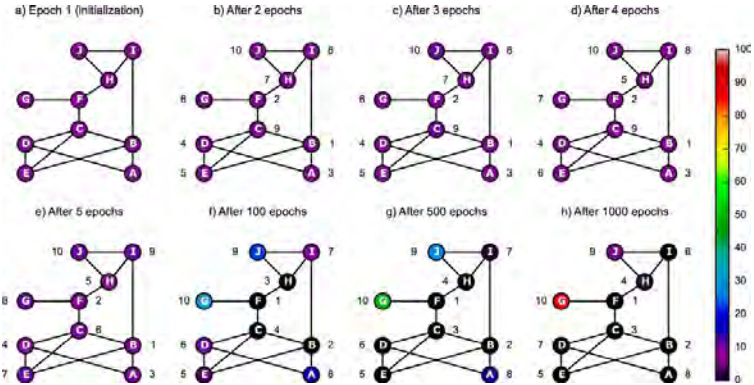
Energy Efficient Learning [5]



Conclusions

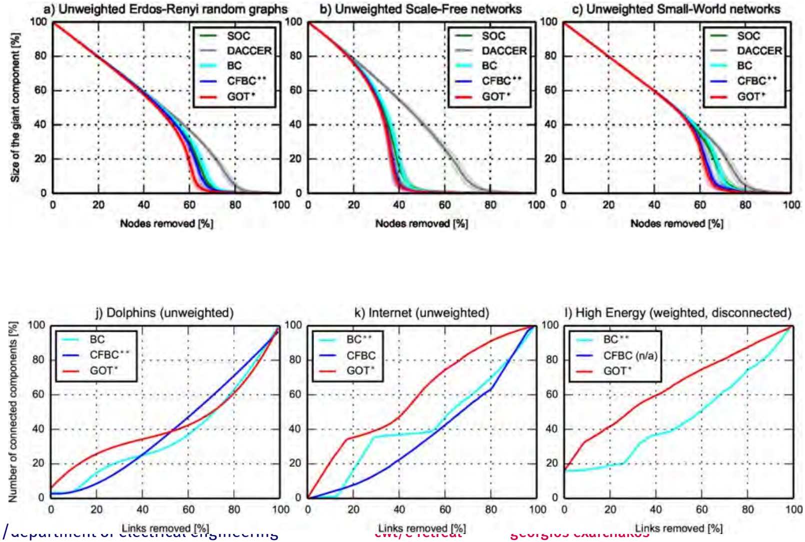
- Random rewiring could reduce training efforts while maintaining performance
- Current computation machines unfit for sparse matrix multiplications

Multi-tenancy of neural networks [4]



- One wireless mesh - many WNNs
- Restrict knowledge leakages
- Detect influencers
- Control transmit power
- Allocate links according to needs per WNN

Multi-tenancy of neural networks [4]



- fast detection of influencial nodes
- fast network fragmentation

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Messages

density is in the eyes of the beholder

we need in-built intelligence on the pipes, not solely on endpoints

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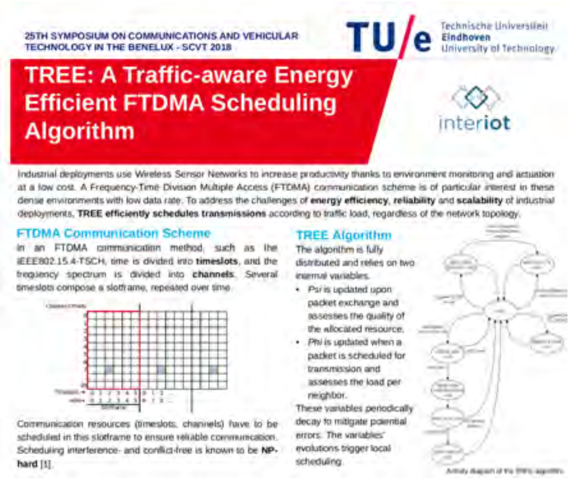
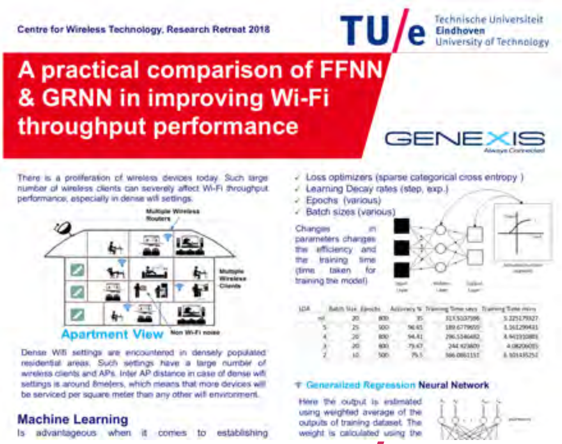
Q&A





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References I

[1] M. Chen et al. "Narrow Band Internet of Things". In: *IEEE Access* 5 (2017), pp. 20557–20577.

[2] *Medical millibots for less-invasive surgeries moving out of proof-of-concept studies.* Healthinnovations. May 28, 2015. URL: https://health-innovations.org (visited on 10/07/2018).

[3] *Micrometre.* In: *Wikipedia.* Sept. 30, 2018.

[4] Decebal Constantin Mocanu, Georgios Exarchakos, and Antonio Liotta. "Decentralized dynamic understanding of hidden relations in complex networks". In: *Scientific Reports* 8.1 (Jan. 25, 2018), p. 1571.

[5] Decebal Constantin Mocanu et al. "Scalable training of artificial neural networks with adaptive sparse connectivity inspired by network science". In: *Nature Communications* 9.1 (June 19, 2018), p. 2383.

[6] Stephen Ornes. "Inner Workings: Medical microrobots have potential in surgery, therapy, imaging, and diagnostics". In: *Proceedings of the National Academy of Sciences* 114.47 (Nov. 21, 2017), pp. 12356–12358.

[7] Michael Rubenstein, Alejandro Cornejo, and Radhika Nagpal. "Programmable self-assembly in a thousand-robot swarm". In: *Science* 345.6198 (Aug. 15, 2014), pp. 795–799.