

# Farewell to deterministic networks

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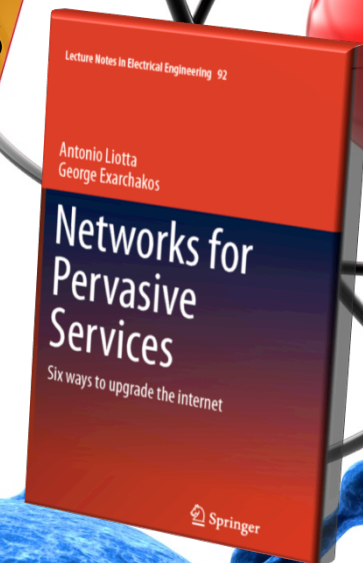


**TU/e** [http://bit.ly/autonomic\\_networks](http://bit.ly/autonomic_networks)

 <http://nl.linkedin.com/in/liotta>

 [https://twitter.com/#!/a\\_liotta](https://twitter.com/#!/a_liotta)

 [www.slideshare.net/ucaclio](http://www.slideshare.net/ucaclio)



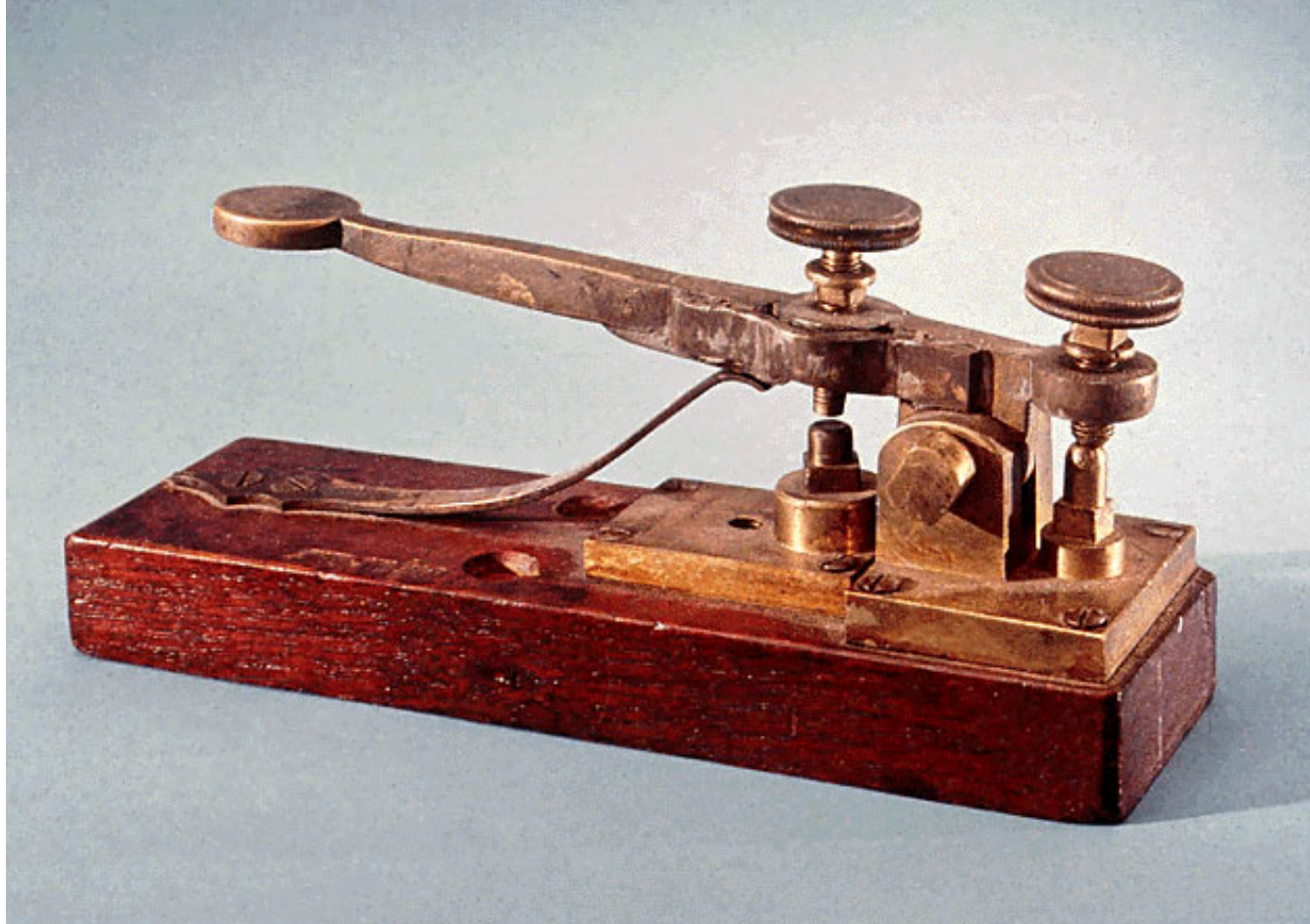
***NexTech Symposium***

***27 September 2012, Barcelona, Spain***

# Three questions about networks

- How have we come to build 'deterministic' networks?
- Can we really connect 1 trillion 'things' by 2020?
- What's the anatomy of a smart network?

# Advances in communication networks: What was the first 'deterministic' network?



The Telegraph (William Cooke and Charles Wheatstone, 1839)



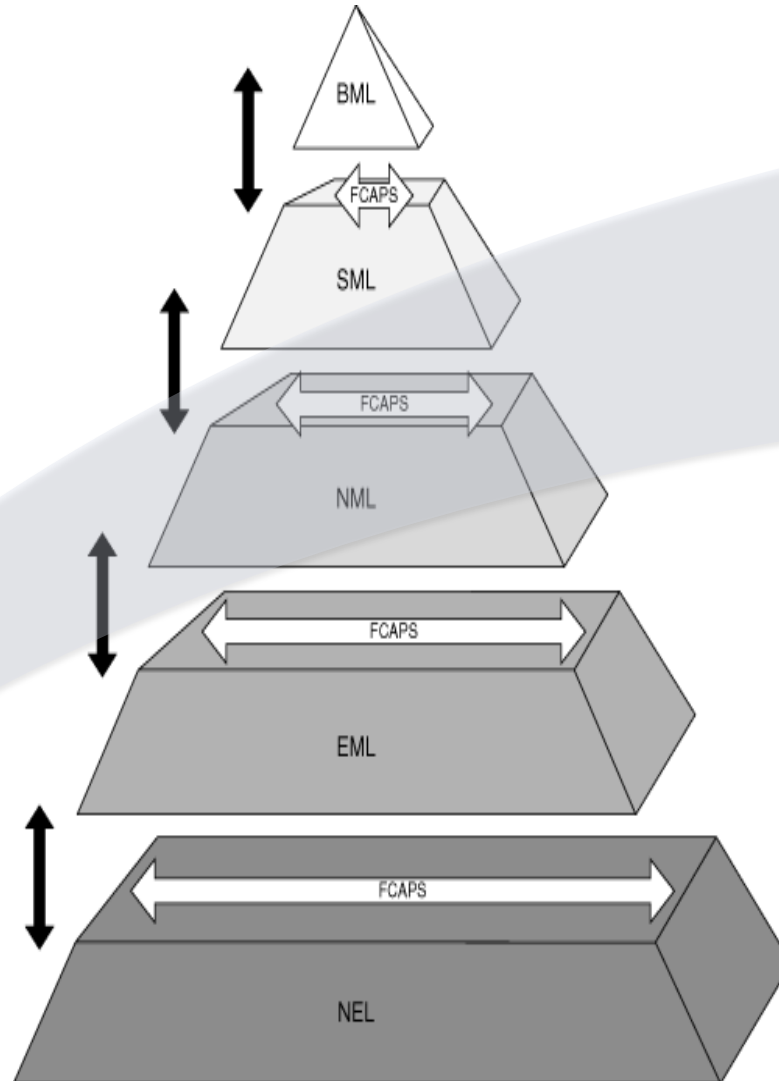
# Advances in communication networks: What was the first 'decent' switched network ?



The 'human' switch, circa 1940



# Advances in communication networks: The perfectly engineered Telecommunications Management Network

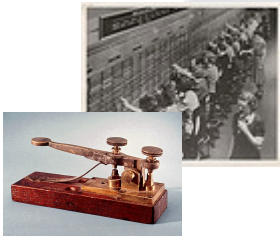


## Architecture:

- Layering
- Abstraction
- Insulation
- Deterministic

## Strategy

- Sophisticated
- Dimensioned
- Specialized
- Standardized

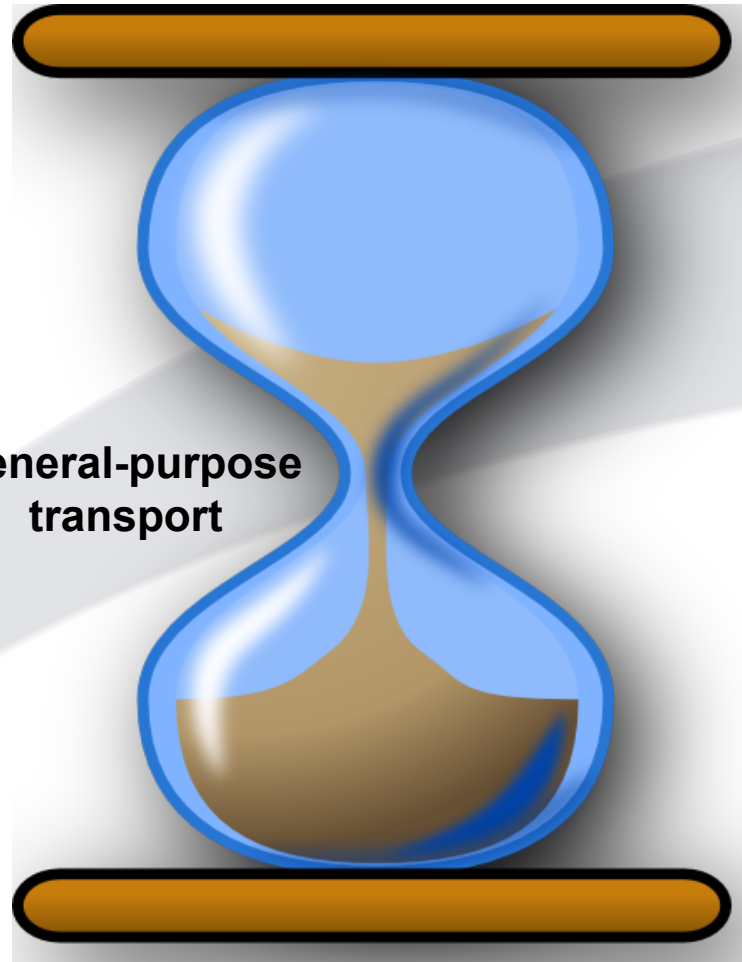


Legacy

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# Advances in communication networks: A perfectly simple network

Diverse global services



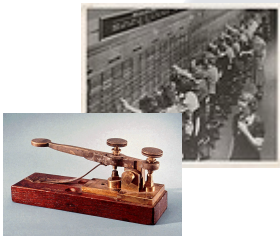
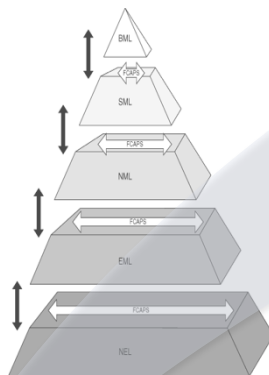
Architecture:

- Layering
- Abstraction
- Insulation
- Deterministic

Strategy

- Simple
- Over-dimensioned
- General-purpose
- Open

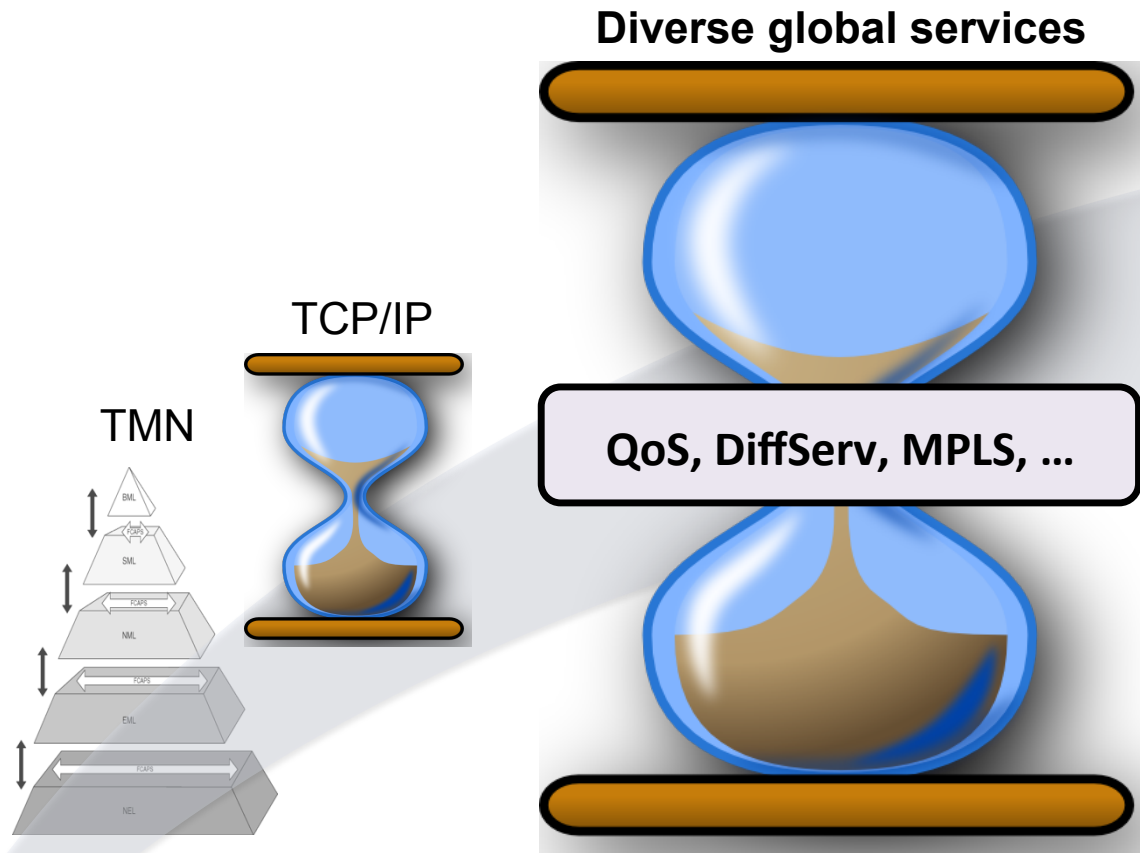
TMN



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# Advances in communication networks: The (unsuccessfully) re-engineered IP



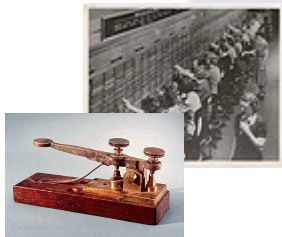
## Architecture:

- Layering
- Abstraction
- Insulation
- Deterministic

## Strategy

- **Complex**
- Dimensioned
- **General-purpose**
- Standardized

**QoS-enabled IP has failed!**



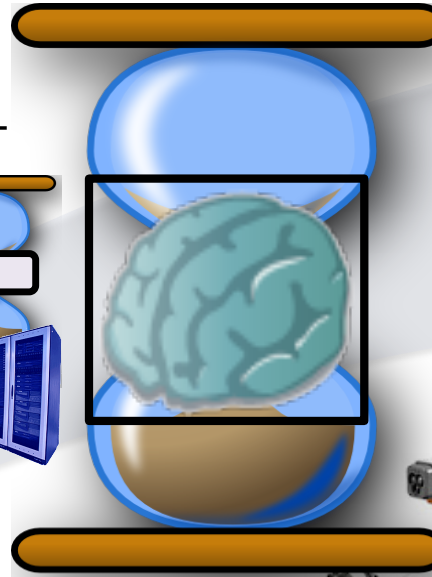
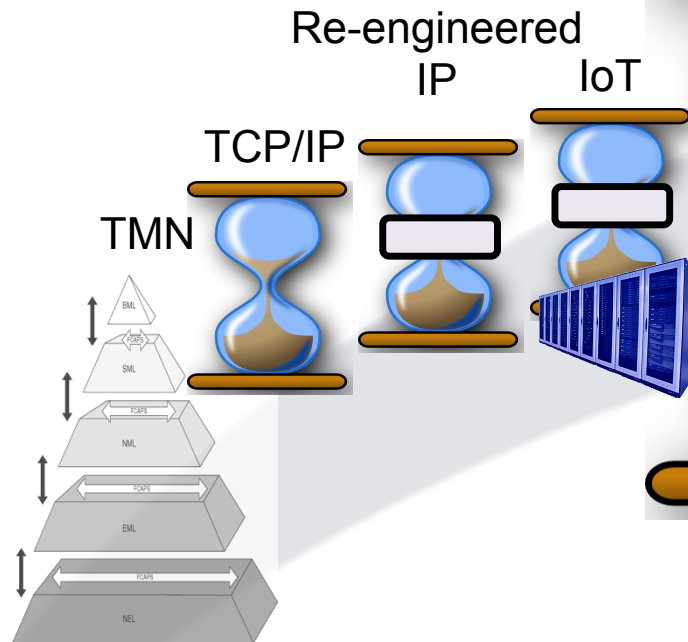
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# Next ??? IoT: smart networks to handle diverse communication requirements



## Architecture:

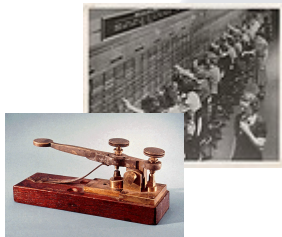
- Layering
- Abstraction
- Insulation
- Deterministic

## Strategy

- Ultra-Complex
- Over-dimensioned
- General-purpose
- Open



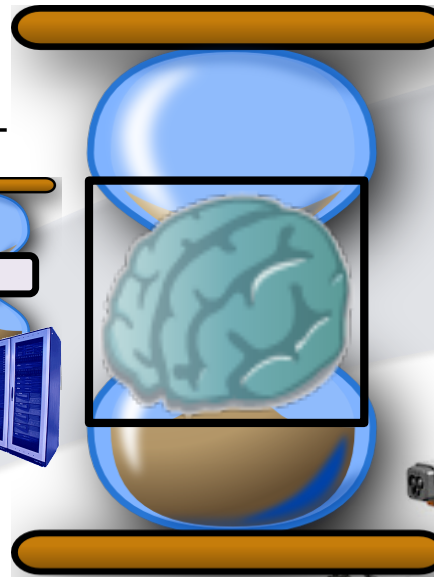
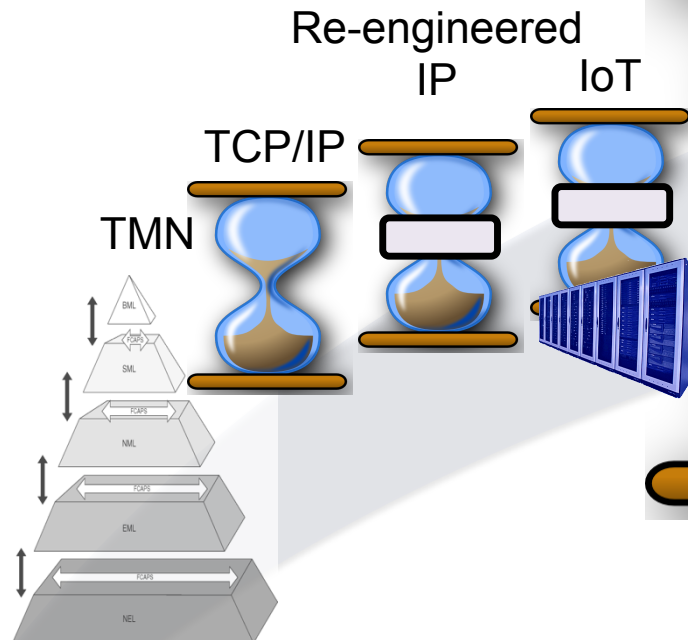
**We can no longer tackle complexity via complexity**



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# Next ??? IoT: smart networks to handle diverse communication requirements

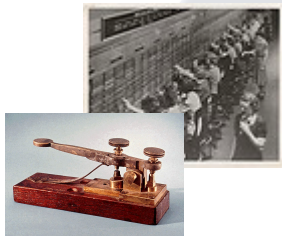


## Architecture:

- Layering
- Abstraction
- **Cross-layer data fusion**
- **Non-deterministic**

## Strategy

- **Smart**
- **Evolutionary**
- **General-purpose**
- **Open**



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**Today:** dumb, brute-force networks, raw-data hub

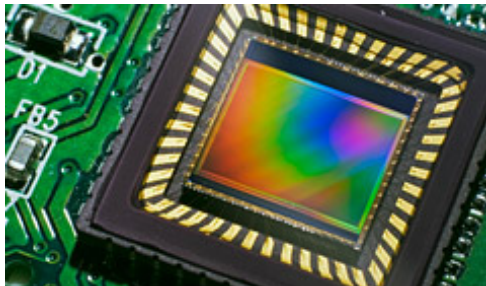
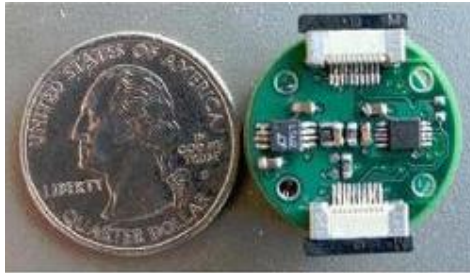


**<<The basis of the universe isn't matter or energy – it's data>>**  
*James Gleick – The Information*

# Tomorrow: smart networks are the data-fusion hub



**Today:** communication protocols assume that infinite energy is available  
**Tomorrow:** communication networks will integrate with energy networks



1trillion, each ~100 mWatt transmission power

100, each 1 Gigawatt supply

Communications must be:

- Energy-efficient
- Energy-driven
- Spectrum aware (E2E)



Some themes:

- Energy scavenging
- Cognitive networks
- Smart grid ++



**Today:** networks stay neutral from apps requirements and user perception  
**Tomorrow:** networks no longer ignore QoE!

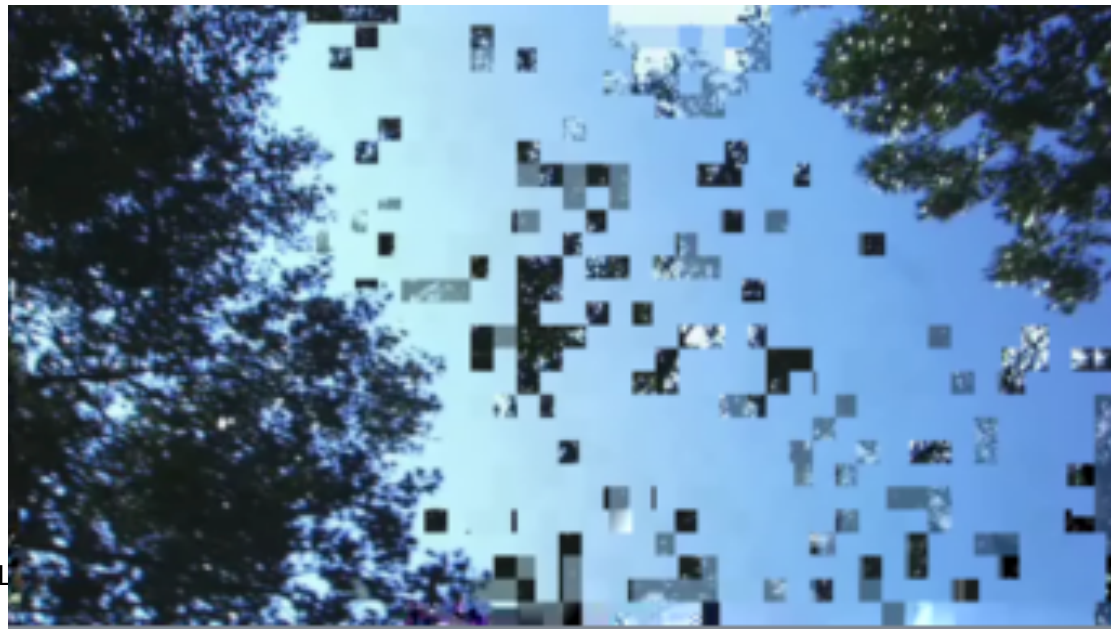
**HIGHER**

Sending rate: 2048 Kbps



**LOWER**

Received quality



39.48 dB

- 23.85 dB

15.65 dB

**Today:** networks stay neutral from apps requirements and user perception  
**Tomorrow:** networks no longer ignore QoE!

LOWER

Sending rate: 768 Kbps



HIGHER

Received quality



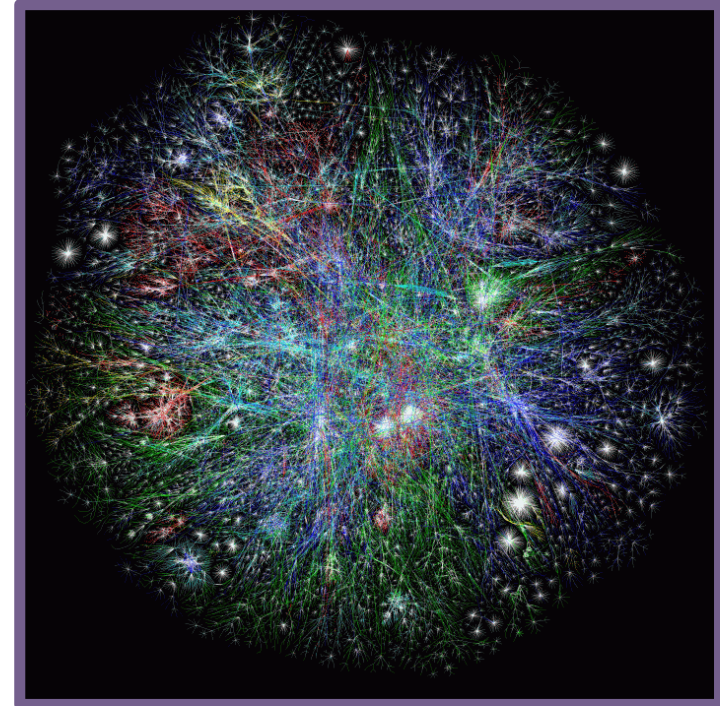
35.15 dB

- 16.03 dB

19.12 dB

# Today's network meets the definition of “complexity” set by “complexity theory”

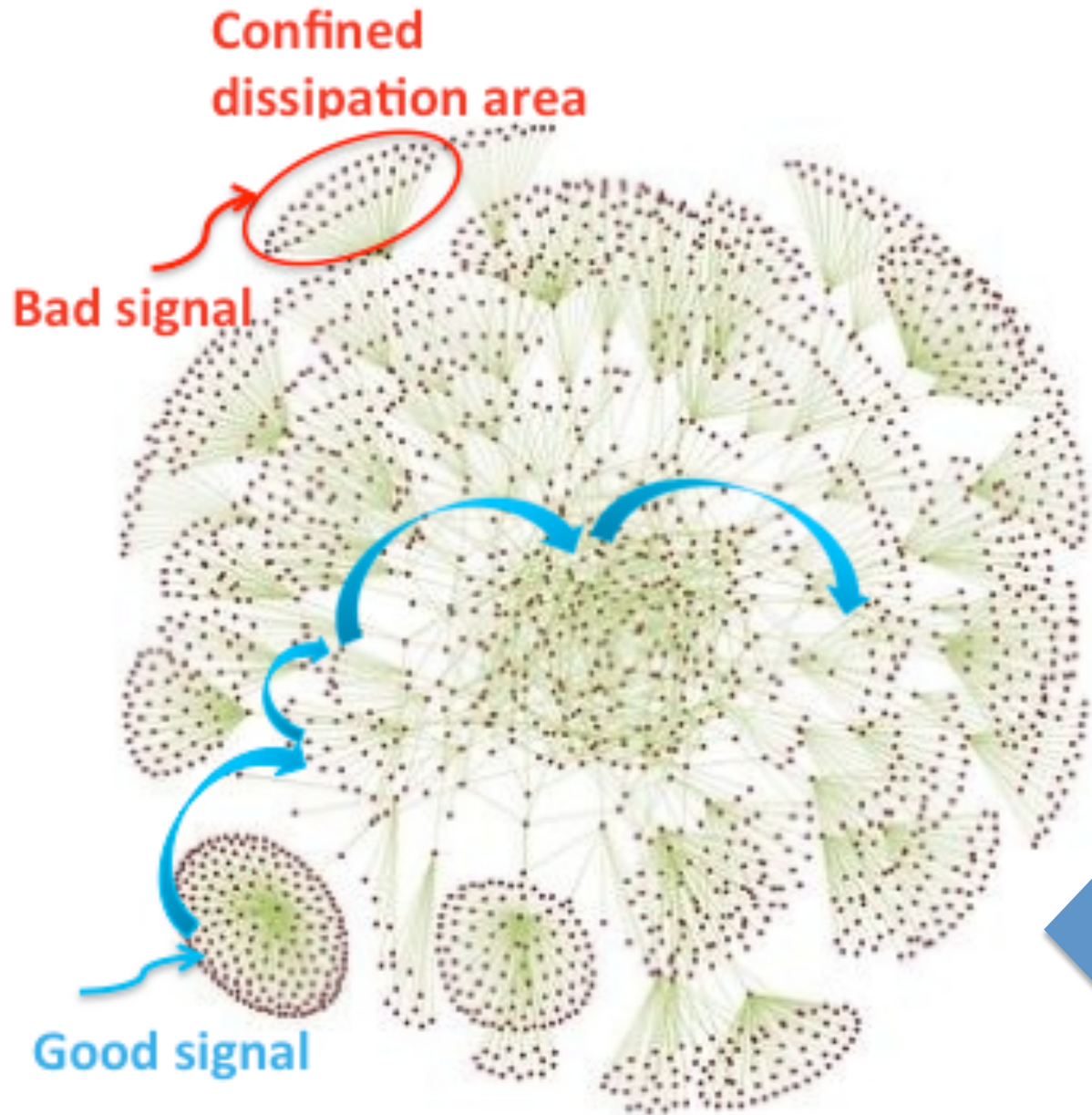
- Properties of whole can't be inferred from properties of individual parts
- Individual components interact nonlinearly, leading to emergent behavior
- Constantly evolves and unfolds over time



The future Internet will be comparatively as complex as other complex ‘natural’ networks



**Today:** networks can't catch up with complexity /diversity / dynamics  
**Smart networks:** autonomic, learning, cognitive networks



### Nature-like features

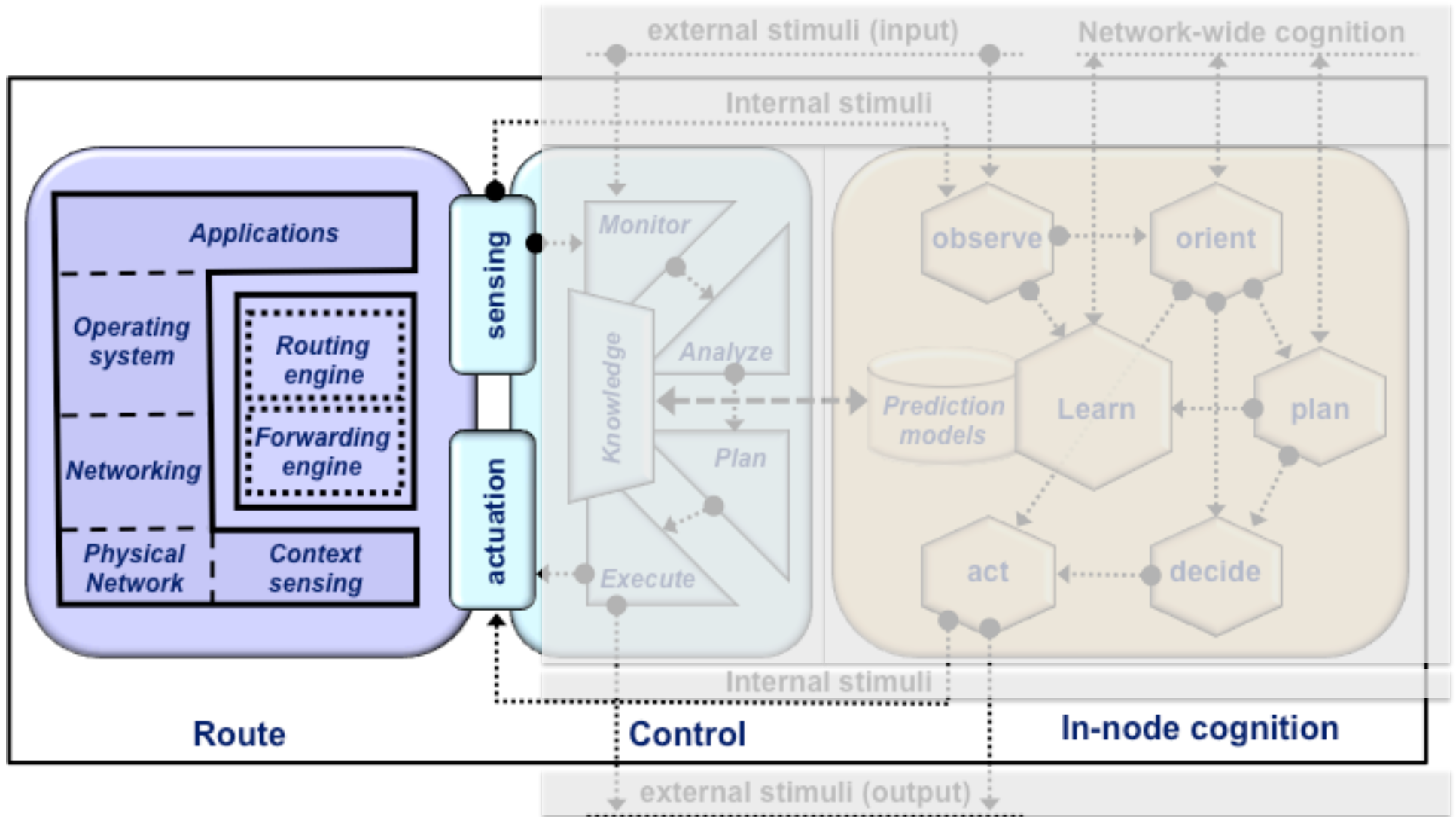
- Hidden patterns
- Emergent behavior
- Self-regulation
- Learning

Biological models

Machine learning



# The anatomy of a smart node



**Today:** we know how to build learning robots  
**Tomorrow:** networks will learn too

Original  
Clips



Difference in  
Temporal  
Motion



Initially we train the network to handle “News over Laptop”

Reinforcement Learning teaches how to handle “Sport over Phone”

# Smart networks should not be deterministic !!

Once we repel the concept of 'deterministic networks' we can tackle complex problems in the most ingenious ways (complexity, dynamics and energy through 'learning')

More nature-like communication networks  
(Autonomic; Cognitive; Evolutionary)

'Energy' is an integral part of the 'context'  
(Information flows' flowing alongside 'energy flows')

The 'human factor' is an integral part of the 'context'  
(QoE management)

Enormous potential when various forms of 'computational intelligence' are applied to various forms of hybrid 'smart networks'

How can we build 'lightweight' networks that can 'learn'?



# Thank you !

TU/e More about my work

[http://bit.ly/autonomic\\_networks](http://bit.ly/autonomic_networks)



In the press

[http://bit.ly/press\\_articles](http://bit.ly/press_articles)



My slidecasts

<http://www.slideshare.net/ucaclio>

“All of YouTube through a 40-year-old funnel”



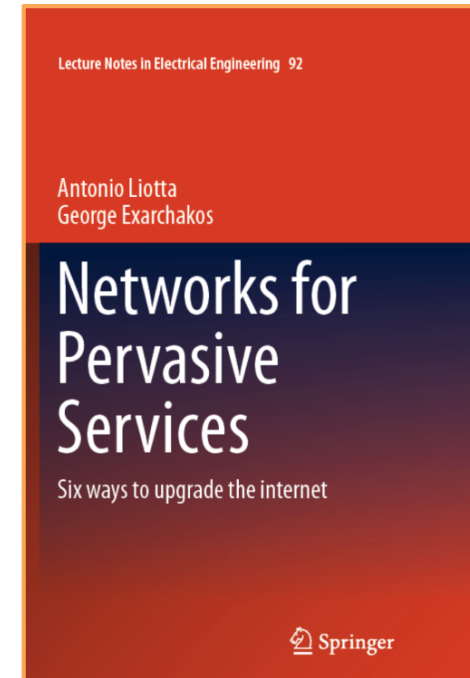
<http://bit.ly/Volkskrant-EN>

“Cognitive Interconnections”



<http://bit.ly/booklet-antonio>

“Networks for pervasive services”



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