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Signal processing: a networking perspective Part 1

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SIGnals processing & NETworking research group

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Outline

- **Part 1: introduction**
  - Who am I?
  - Signal processing at network layer
  - Where are we going?
  - 1st break
  - What are the upcoming research challenges?
  - Which are the main approaches?
  - 2nd break

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Outline

- **Part 2 – option A:**
  Signal processing at PHY/MAC layers
  - Signals and signal processing from a network perspective
  - The massive access challenge
    - RFtag counting and identification
  - Interference models & system capacity
    - Multi-packet reception and Successive Interference Cancellation

Outline

- **Part 2 – option B:**
  QoE-oriented networking
  - Mixing up PHY and application-layer signals
    - smart environments
  - Context awareness from signal processing
    - SSIM characterization of video content

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Let's start with… my self-introduction!

SIGNET people

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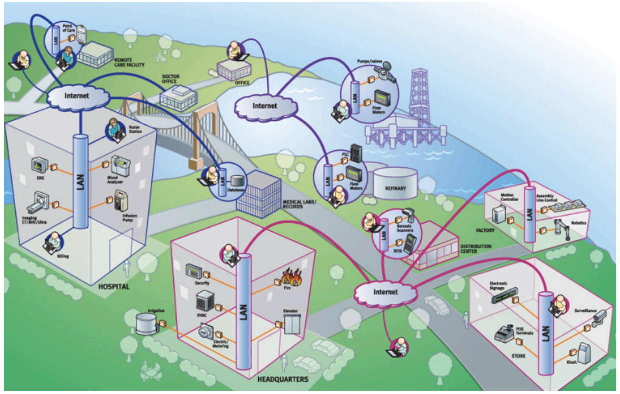
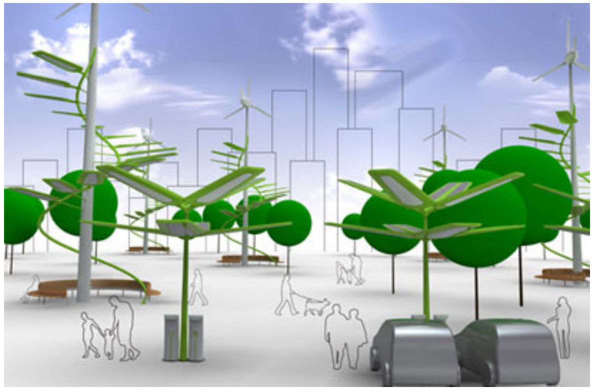
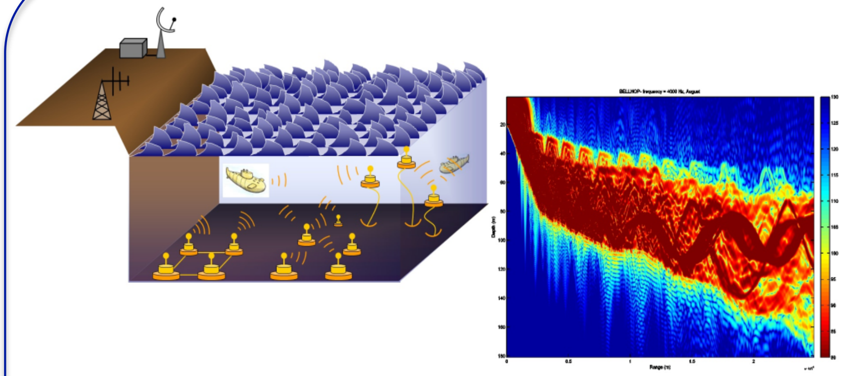
Main research areas…



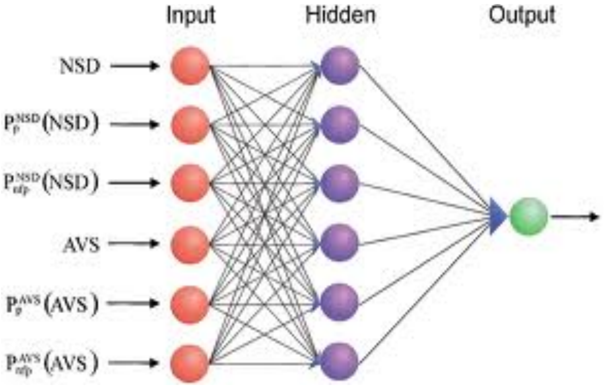
Next generation mobile & IoT



Energy harvesting

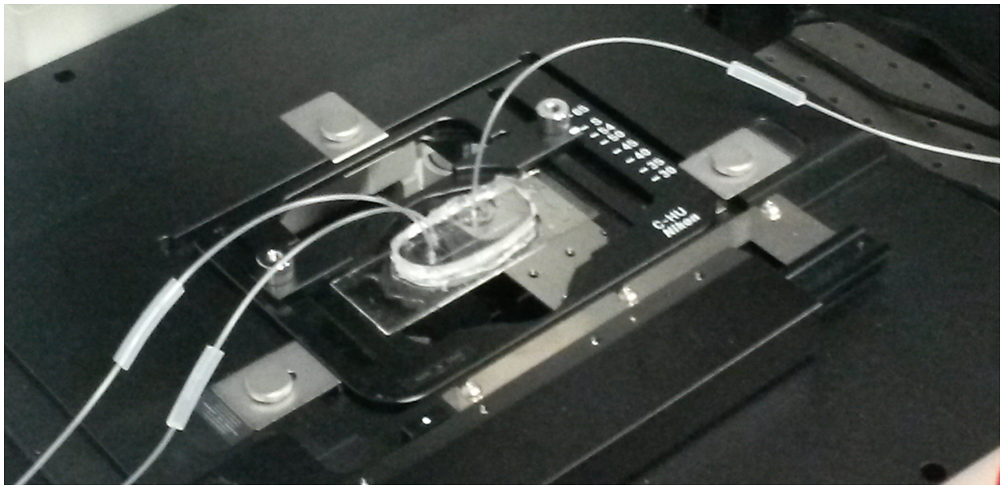


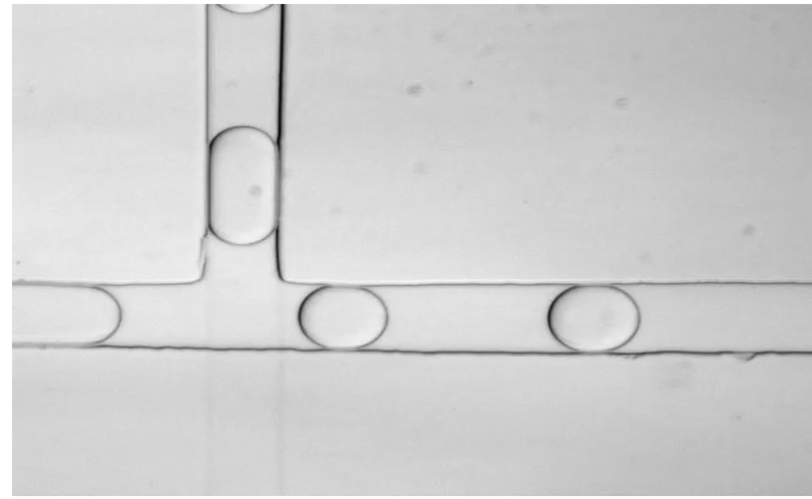
Underwater communications

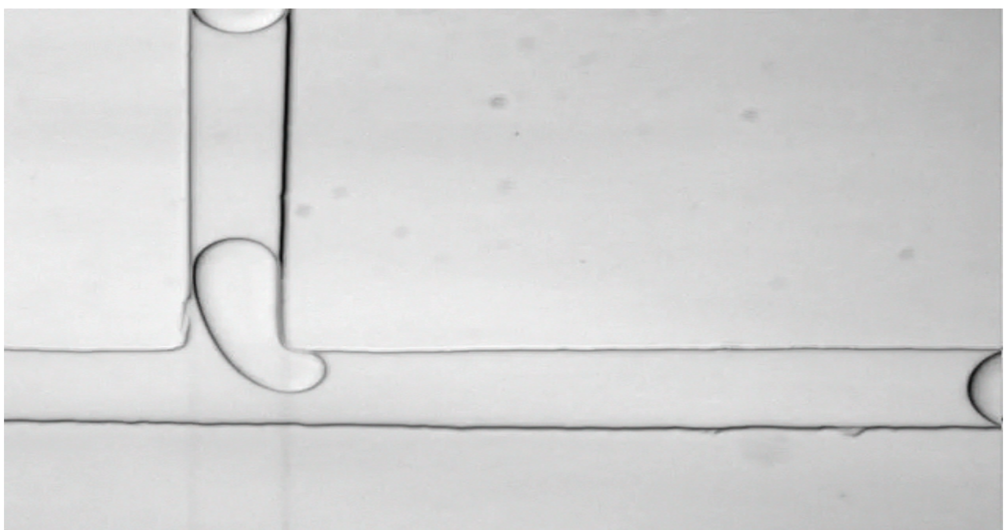


Cognitive Networks

Plus more exotic stuff...







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Recent Research Projects

European

- 2010-2013: "IoTa" (sensor networks)
- 2010-2014: "SWAP" (sensor networks)
- 2010-2013: "Medieval" (cellular networks)
- 2010-2012: "SaPHYre" (cellular networks)
- 2010-2013: "CLAM" (underwater networks)
- 2010-2013: IIT – NAUTILUS (underwater networks)
- 2008-2010: "Aragorn" (cognitive networks)
- 2009-2010: "NEWCOM++" (ad hoc networks)
- 2007-2010: "SENSEI" (sensor networks)

Others

- 2010-2014: EDA – RACUN (underwater networks)
- 2010-2012: ONR (underwater channel modeling)
- 2010-2011: JHU/APL (underwater MAC protocols)
- 2010-2011: VideoTec (wireless sensor networks)
- 2011-2012: Patavina Technologies (wireless sensor networks)
- 2009-2011: ARO@UCSD (cognitive networking)
- 2010-2013: NSF@UCSD (underwater localization and networking)

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Collaborations

Industrial

- Qualcomm
- NTT DoCoMo
- Lucent Bell Labs
- ST Microelectronics
- NATO Undersea Research Centre
- IBM Zurich research Lab
- Ericsson Research
- Telecom Italia Labs
- Alcatel CIT
- European Space Agency

Academic

- Massachusetts Institute of Technology (MIT)
- Stanford University
- Univ. of South California (USC)
- University of Illinois – Urbana Champaign
- Univ. of California San Diego (UCSD)
- Univ. of California Los Angeles (UCLA)
- Inria – Sophia Antipolis (Francia)
- Pennsylvania State University
- New Jersey Institute of Technology
- Centre Tecnològic de Telecomunicacions de Catalunya (CTTC – Barcellona)
- German Airospace Center (DLR)
- Scripps Institution of Oceanography (at UCSD)
- Woods Hole Oceanographic Institution (Massachusetts)
- National University of Singapore

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Signal processing…

from a networking perspective…

Image taken from: http://www.benheyman.com/lessons-for-better-networking-with-social-media/

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Signal processing from wikipedia perspective

Signal processing is an area of *systems engineering, electrical engineering and applied mathematics* that deals with operations on or analysis of analog as well as digitized signals, representing time-varying or spatially varying **physical quantities**. Signals of interest can include sound, electromagnetic radiation, images, and sensor readings, for example biological measurements such as electrocardiograms, control system signals, telecommunication transmission signals, and many others.

WIKIPEDIA
The Free Encyclopedia

Signal processing from IEEE prespective

"The Signal Processing Society's Field of Interest shall be the theory and application of filtering, coding, transmitting, estimating, detecting, analyzing, recognizing, synthesizing, recording, and reproducing signals by digital or analog devices or techniques. The term `signal' includes audio, video, speech, image, communication, geophysical, sonar, radar, medical, musical, and other signals."

IEEE JOURNAL OF
SELECTED TOPICS
IN SIGNAL PROCESSING
A PUBLICATION OF THE IEEE SIGNAL PROCESSING SOCIETY

Signal processing from networking perspective?

http://www.mynamesnotmommy.com/yes-there-are-dumb-questions/question-mark/

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A tentative definition

From a networking perspective, *signal processing* refers to operations on or analysis of signals of diversified nature, representing time-varying or spatially varying **physical quantities**, but also **functional processes**

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Type of signals

- **Physical signals** include
  - Radio signals
    - strength (RSS), angle of arrival, time of flight, phase…
  - Environmental signals
    - Temperature, humidity, CO2, pollution, acoustic noise,…
- **Functional processing signals** include
  - Application-related signals
    - rate/distortion characteristic of videos, traffic patterns,…
  - Protocols
    - ARQ, RTS/CTS, probing, paging, signalling,…
  - User's profile-related "signals"
    - Habits, app preferences, service preferences, mobility pattern…

Question

what do we do with such signals?

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Depends on the perspective…

- An (**ipersimplified** and totally **biased**) vision
  - **Physical layer** perspective: **more bitrate**!
  - **Application layer** perspective: **more codecs**!
  - **Network layers** perspective: **more performance**!

If communication services were hamburgers

- Physical layer → **bread**
  - Necessary to sustain all the rest
- Application layer → **sauce**
  - Different choices, different colors, different tastes, but not much substance
- Network layers → **meat**
  - what makes the difference between a sad BigMac
  - and a rich, juicy, Jack-In-the-Box house burger!

http://latimesblogs.latimes.com/dailydish/2008/12/jack-in-the-box.html

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Where are we going to?

That is to say: what shall we expect from next generation of ICT?

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Your perspective!

- What **YOU** expect from ICT's next generation?

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Audience says…

1. IP TV
2. Assisted living
3. E-health
4. Self driving cars
5. Domotica
6. Holographics videocalls
7. Teletransport
8. Advanced 3D printers
9. Augmented reality
10. Ubiquitous connectivity
11. HD mobile video (with high QoE)
12. Longer device battery life
13. Energy harvesting devices

Big players say…

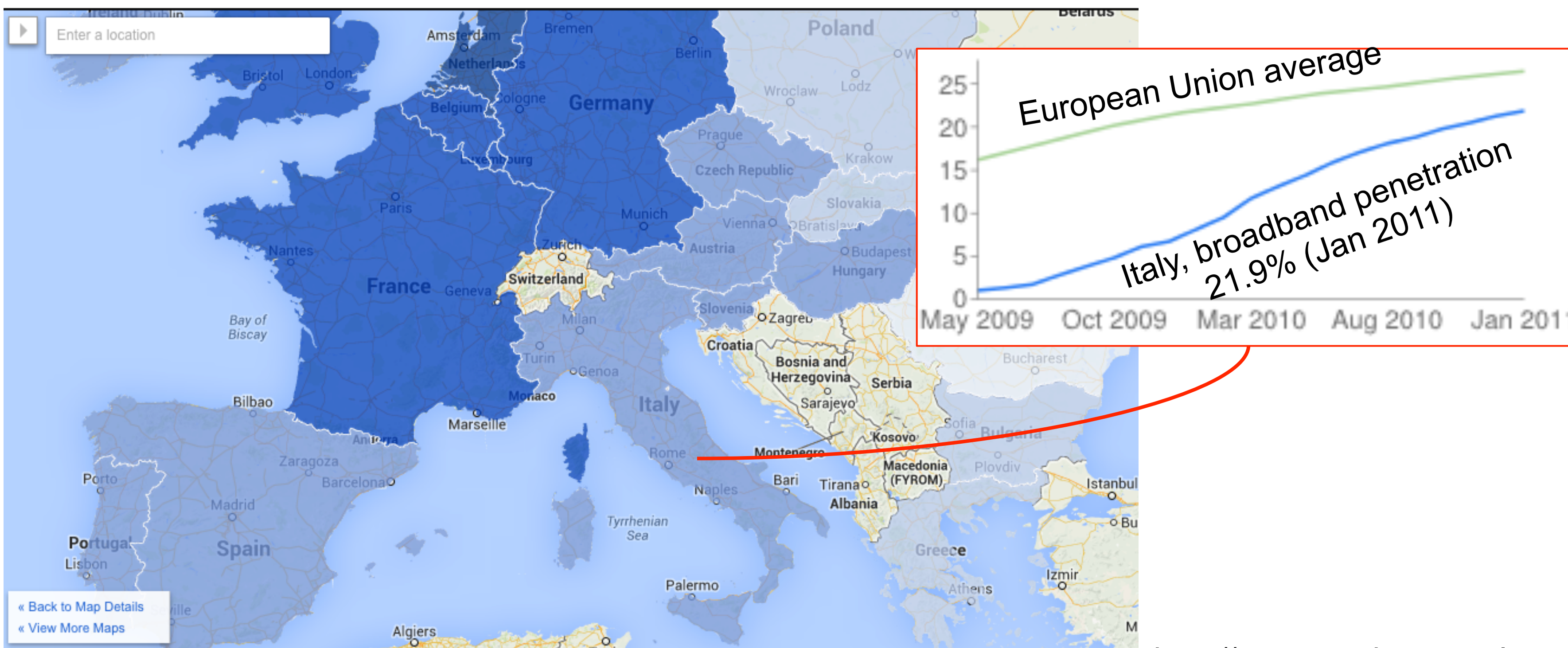
No one actually knows…

but

there's consensus on some points…

Ubiquitous connectivity

- Human users would like to be connected
  - **at all times**
  - **regardless of their current location**
  - with **good enough quality** to enjoy the required service



http://mapsengine.google.com

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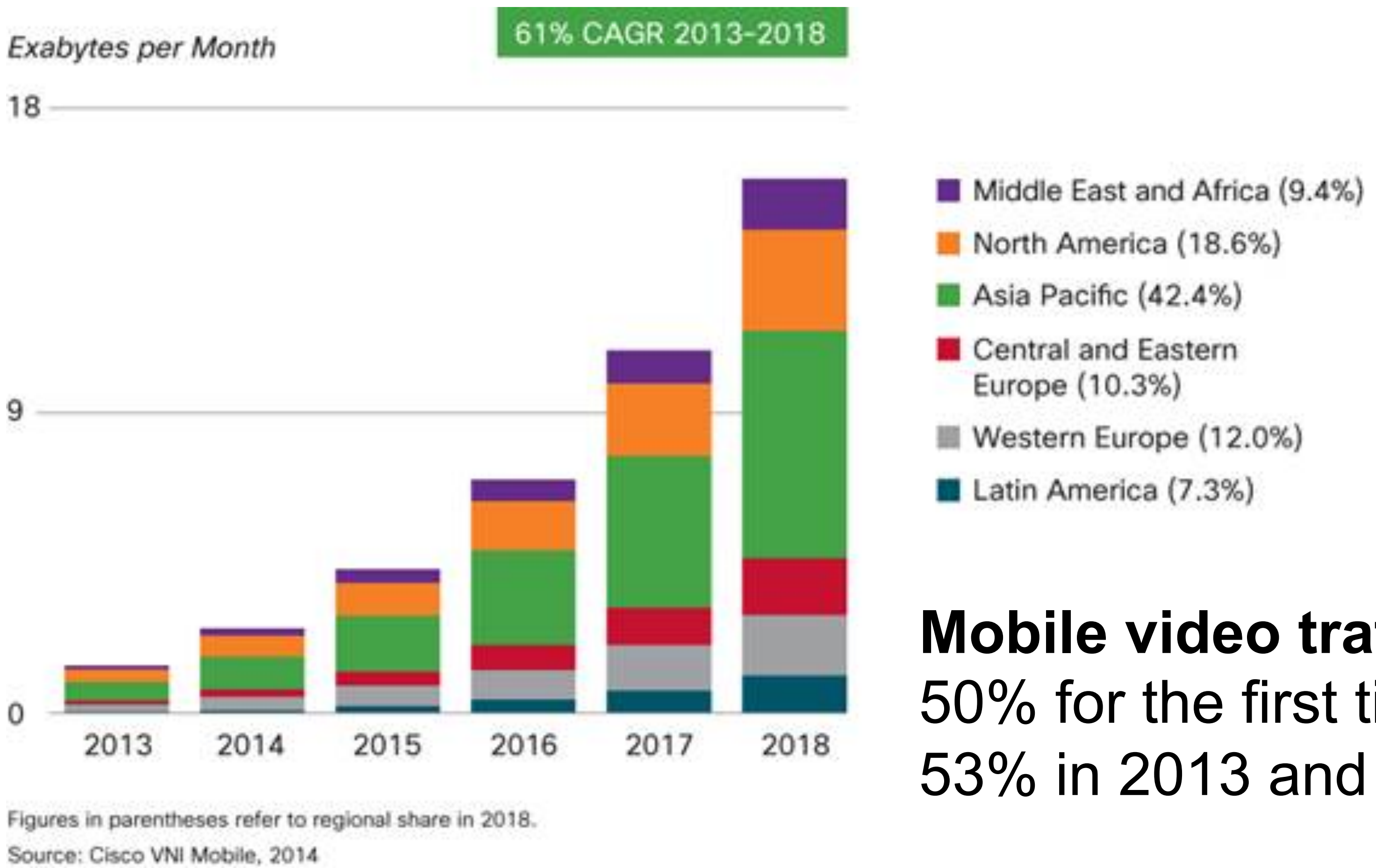
Much more mobile traffic

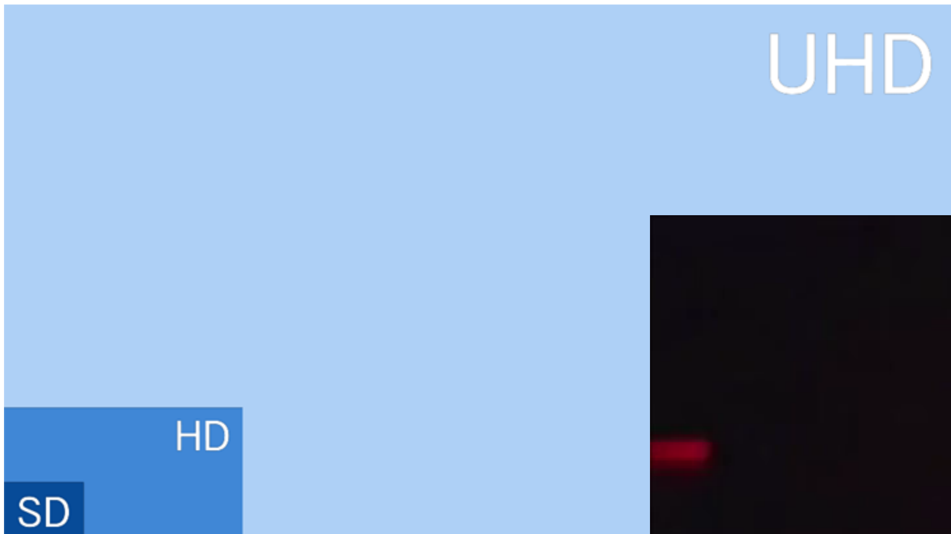
Cisco Visual Networking Index: Global **Mobile Data Traffic** Forecast Update, 2013-2018, White Paper, Feb. 2014.



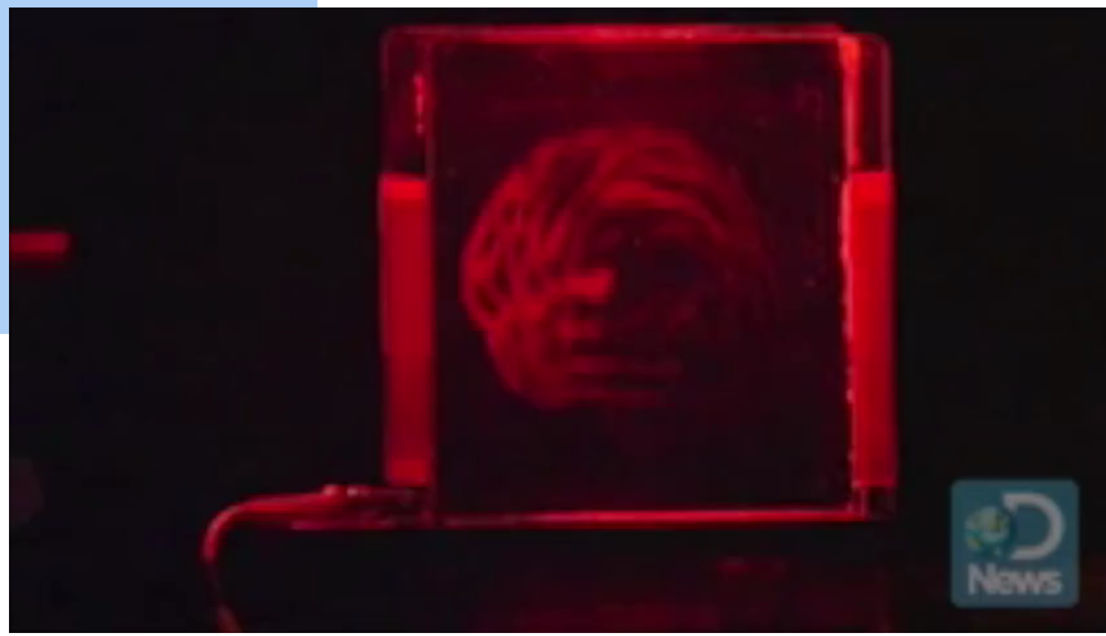
Mobile video traffic exceeded 50% for the first time in 2012, 53% in 2013 and counting…

Much more video traffic

Ultra high definition



Holographic TV



www.futuretimeline.net/21stcentury/2020.htm

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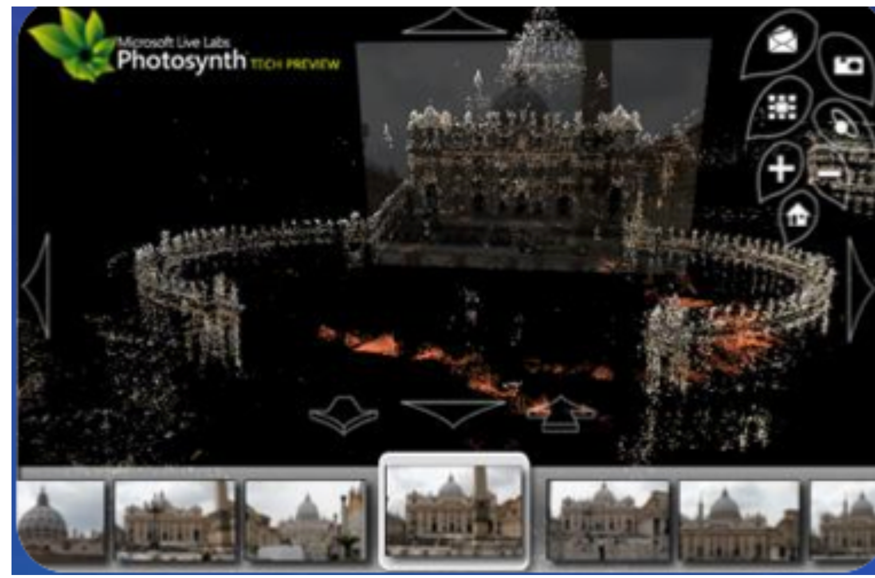
Full immersive experience



3D reconstruction
obtained from a number of pictures captured from **collaborating** different viewpoints

[Microsoft Photosynth]

http://www.text100.com/hypertext/2013/04/homo-numericus/

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Web evolution

- Web 1.0: the **world wide** web
  - Connects information
    - easy **access** to data irrespective of their location
    - Users are mainly data consumers
- Web 2.0: the **social** web
  - Connects people
    - easy **sharing** of data
    - Users are both data producers and consumers
- Web 3.0: the **sematic** web
  - Connects knowledge
    - **personalized** data
    - Geo-time tagged content, context-dependent web

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Web 4.0?

- Web 4.0: **symbiotic web**
  - Strict interaction among humans and machines
  - According to Daniel Burrus, Web 4.0 is about **"the ultra-intelligent electronic agent"**
    - It will *recognize you* when you get in front of it
    - It will know your habits and act accordingly
    - It will debate with you if you deviate from the right way…
  - Mmmmhhh… sounds like a *movie's plot*…

By the way… if you're wondering who is Burrus, well he is a **futurist** and **business strategist…** Check it out here: http://www.burrus.com

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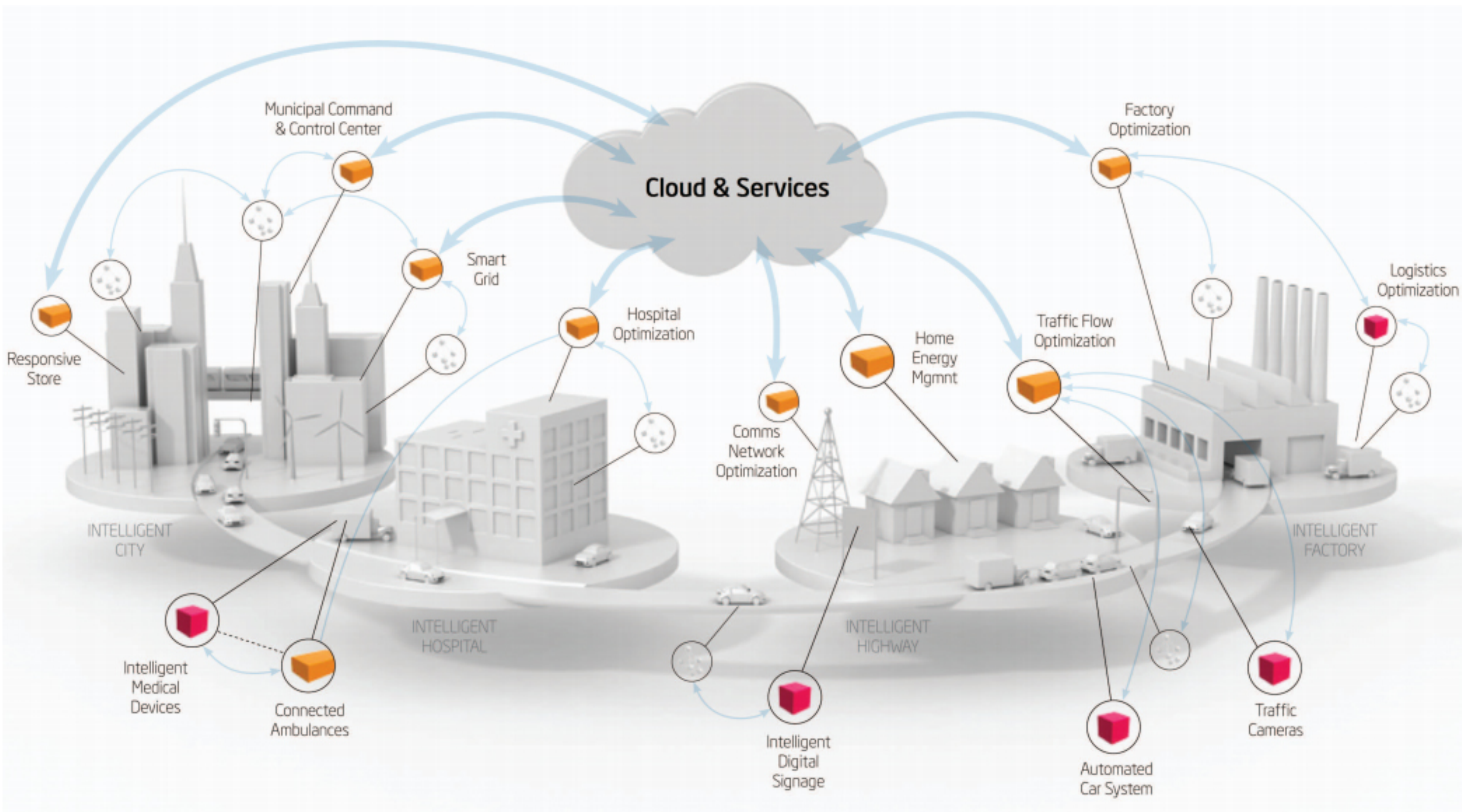
Internet of Things



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The Internet (of Things)

… is already made of things. (If that's not the case then we have a serious case of mass hysteria:-) For this reason, we prefer not to refer to a so-called "Internet of Things," nor to use the IoT acronym. Where it is necessary to distinguish our imperfect expectation of the future from the current Internet, we instead speak about the Internet with many more things but otherwise we just talk about the Internet."

Kutscher and Farrel, "Towards an Information-Centric Internet with more Things", Informational Internet-Draft draft-kutcscher-icn-wmt-00, February 2011.

Motivation

- **What**
  - Providing Internet connection to potentially ANYTHING
- **When**
  - ~1995 → WSN
  - ~2000 → IoT
  - ~2020 → hundred of BILLIONS of devices connected
- **Why**
  - A (still largely unforeseen) plethora of new services
    - Smart Cities, Smart Grids, Smart everything!
  - huge, Huge, HUGE market (again… potentially)

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The Business Perspective

- **Cisco**
  - The estimated market of $**14.4 Trillion** up for grabs in the coming decade
- **Intel**
  - IoT brought about $**2 billion** of the company's $12.8 billion in revenue, which equated to 32% growth year over year
- **IBM**
  - Since 2003 IBM spent over $**50 billion** on acquisitions and R&D in preparation for a radical shift in IBM's business

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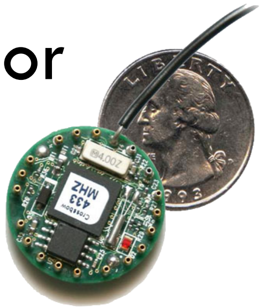
Enabling technologies

- RFID

- Wireless Sensor Networks

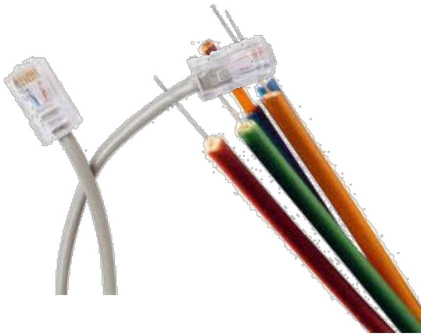


- Powerline Communication

- WiFi

- Cellular

- Wired connections




"A year from now basically every new phone that's sold will have [Near Field Communication]. It's a two-way, bio-directional RFID communication link that makes this device work as a tag or as a reader.Ó
Sony Ericsson's VP of systems architecture
Håkan Djuphammar,
Sony Ericsson

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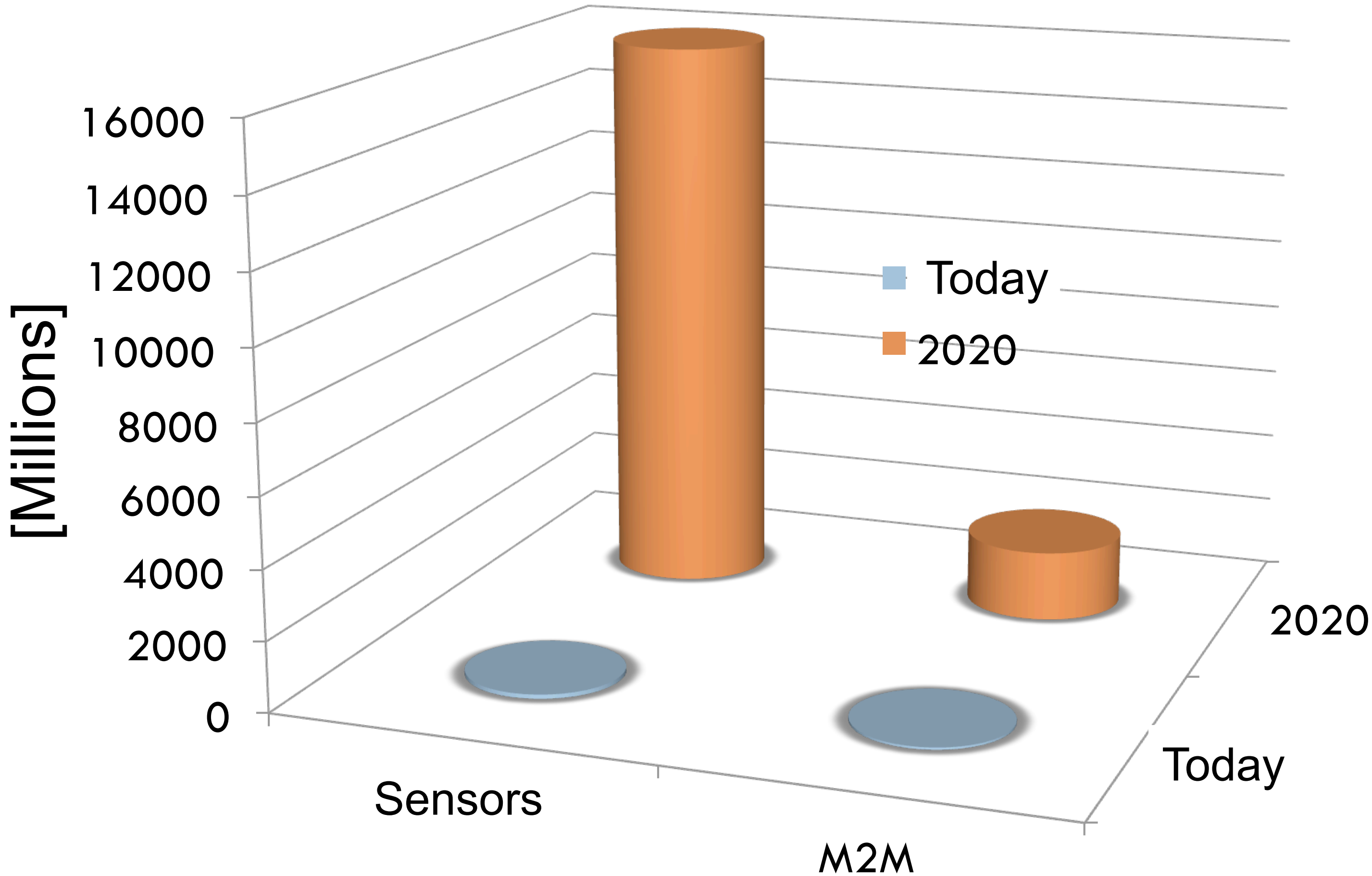
Number of interconnected objects



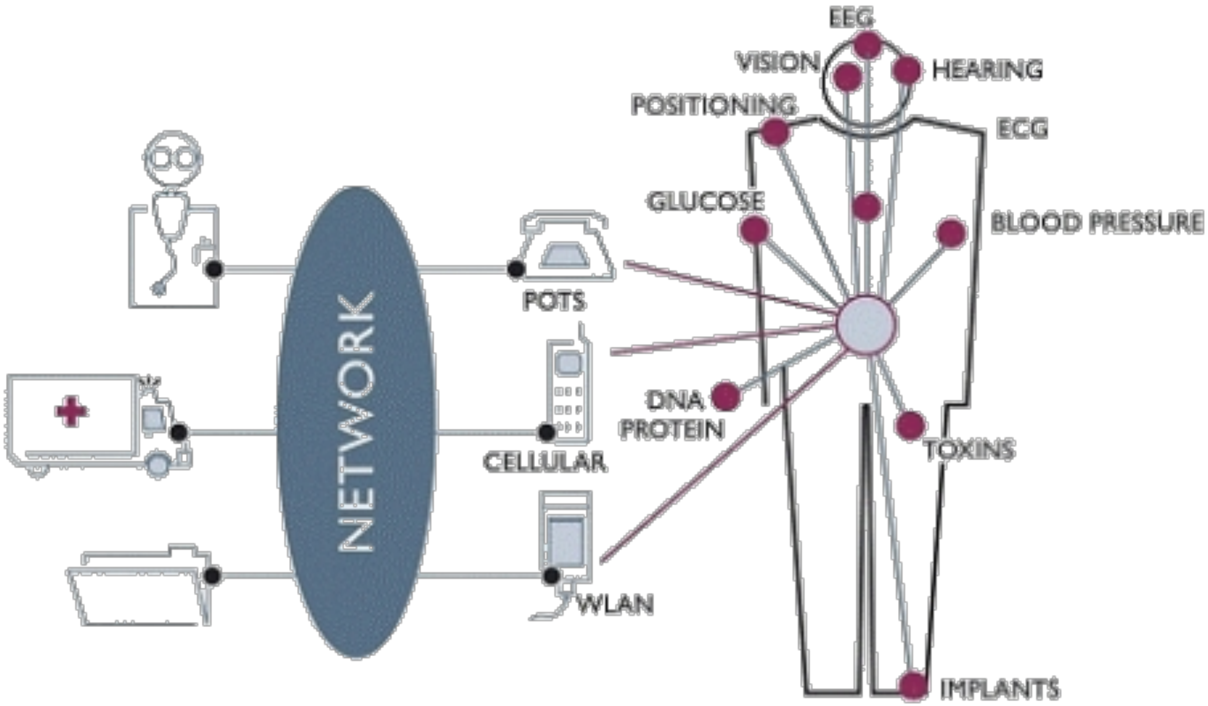
•Jim Morrish, Principal Analyst at Analysys Mason
http://www.analysysmason.com/About-Us/News/Press-releases/Internet-of-Things-will-grow-to-16-billion-connectable-consumer-devices-by-2020-says-Analysys-Mason/
Steve Hilton, Principal Analyst at Analysys Mason
http://www.analysysmason.com/Research/Content/Reports/RRE02_M2M_devices_forecast/

What's a machine

- Any device (or software) that can perform automated tasks, e.g., smartphones, refrigerator, sensors, etc.
- Devices that can
  - **take autonomous decisions** based on information received from other devices
  - in a mostly **unsupervised** manner
  - act much **smarter than traditional devices**

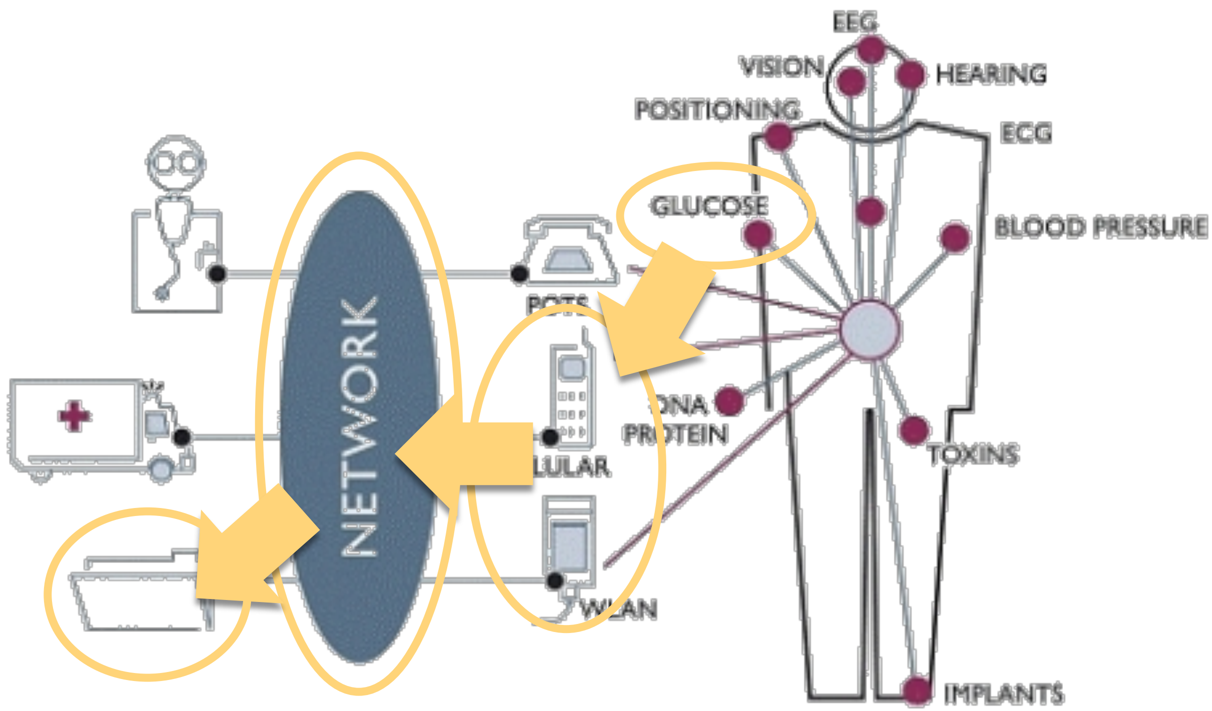
Example: assisted living

- Remote monitoring of health status



Example: assisted living

- Remote monitoring of health status
- Remote assistance



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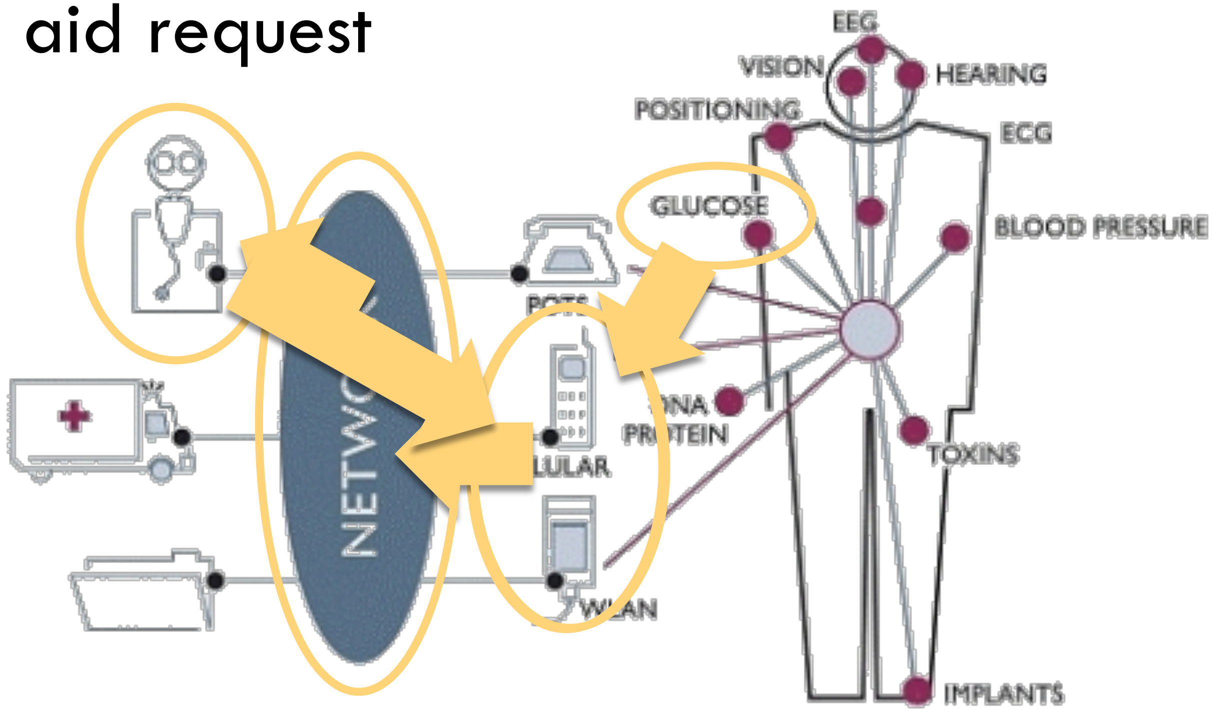
Example: assisted living

- Remote monitoring of health status
- Remote assistance
- Automatic first aid request



Example: assisted living

- Remote monitoring of health status
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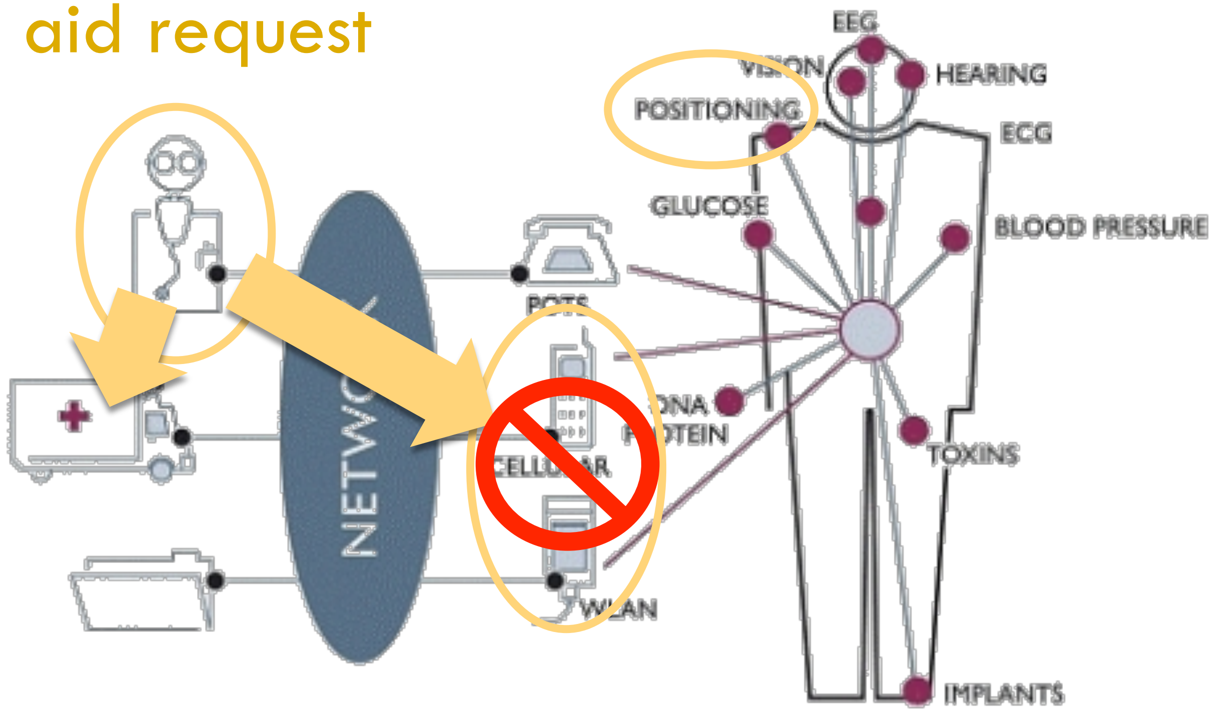

Indoor navigation

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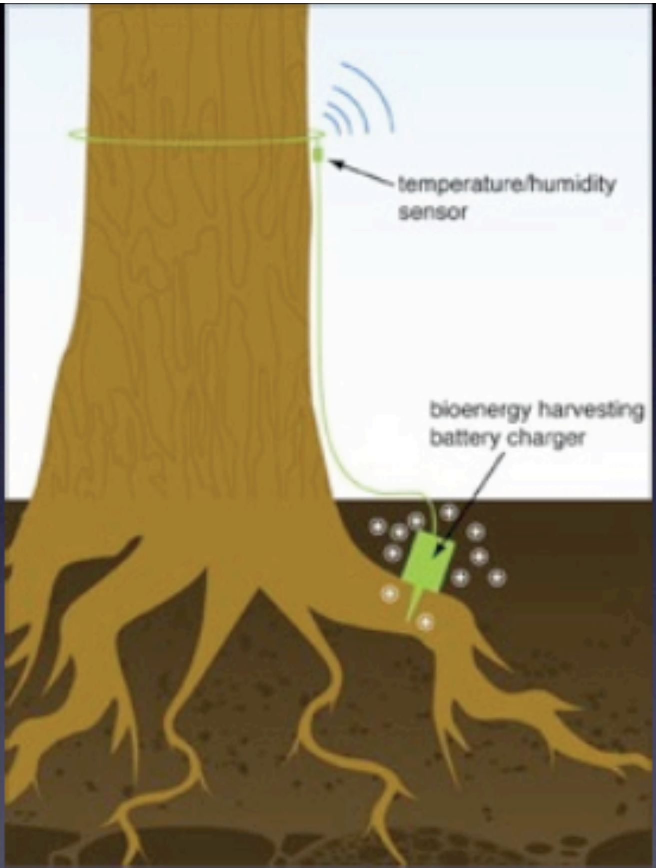
Self-sustainable forest fire detection system



Sensors powered by trees

Posted by David Pescovitz, October 7, 2008 10:02 AM
MIT researchers are developing a novel power scavenging systes for small wireless sensors that monitor for forest fires. The sensors are powered by the trees themselves. Each sensor's battery is trickle charged with the electricity generated by the imbalance in pH between the tree and the soil.

From the MIT News Office:
The system produces enough electricity to allow the temperature and humidity sensors to wirelessly transmit signals four times a day, or immediately if there's a fire. Each signal hops from one sensor to another, until it reaches an existing weather station that beams the data by satellite to a forestry command center in Boise, Idaho.

Shuguang Zhang, one of the researchers on the project and the associate director of MIT's Center for Biomedical Engineering (CBE).

boingboing

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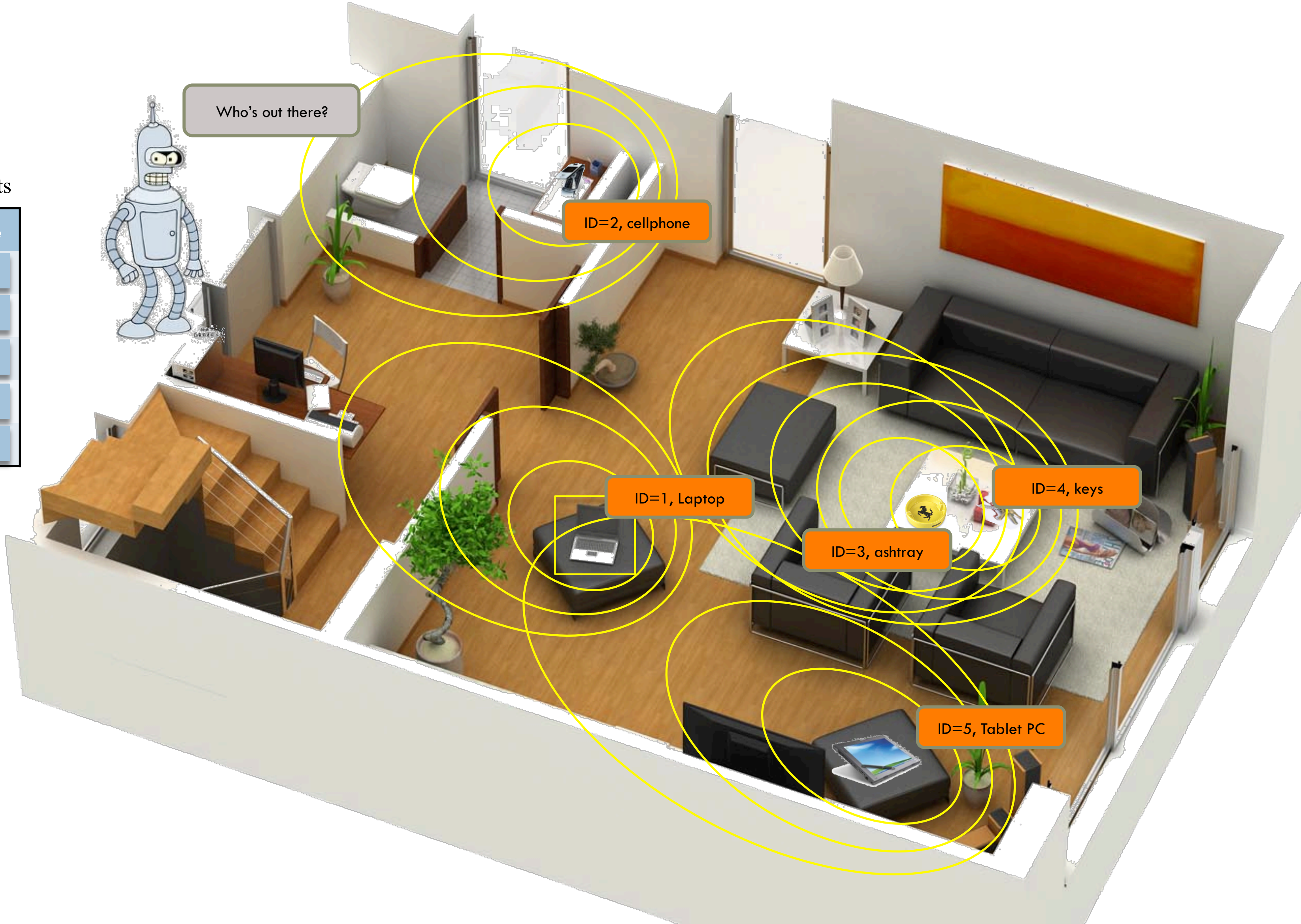
Smart ambient

Smart Objects Lists

ID	Object type



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Workplace comfort & health

- Indoor environments
  - CO_2 < 600 ppm
  - CO_2 >1000 ppm
  - CO_2 >2500 ppm
- Experimental study: scuola media Coletti Feb/2009
  - CO_2 level
    - after 30 min → 1950 ppm
    - opening the window for 5 min → 800 ppm
    - outdoor → 600 ppm

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VANET: Vehicular networks

- Vehicles Transformed into "**Computers on the Wheels**" or "**Networks on the Wheel**"
- Vehicular Communication System (VCS):
  - Vehicle to Vehicle (V2V) Communication
  - Vehicle to Infrastructure (V2I) communication
- Advantage and Usage of VCS:
  - Information sharing
  - Co-operative driving
  - Other value added services like Navigation, internet access etc.

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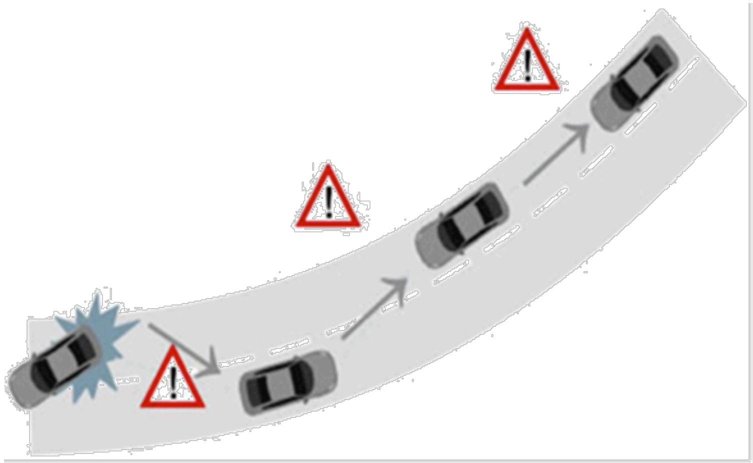
VANET services

- Propagation of emergency and alert messages
  - Uses multi-hop/multi-cast technique
  - Intelligent broadcasting
- High bandwidth link with vehicle and roadside equipment
  - Entertainment
  - Internet access
- Multi hop unicast, Geocasting, Mobicasting
  - Gaming
  - Messaging
  - Platooning
  - …



Smart Cities

- "Smart City" is all about applying ICT in operating the public affairs
  - make a better use of the public resources
  - Increase quality of life in the urban areas
  - reduce the operational costs of the public administrations
  - Reduce the gap between citizens and administrations
- One concept, several flavors
  - Smart Governance, Smart Mobility, Smart Utilities, Smart Buildings, and Smart Environment

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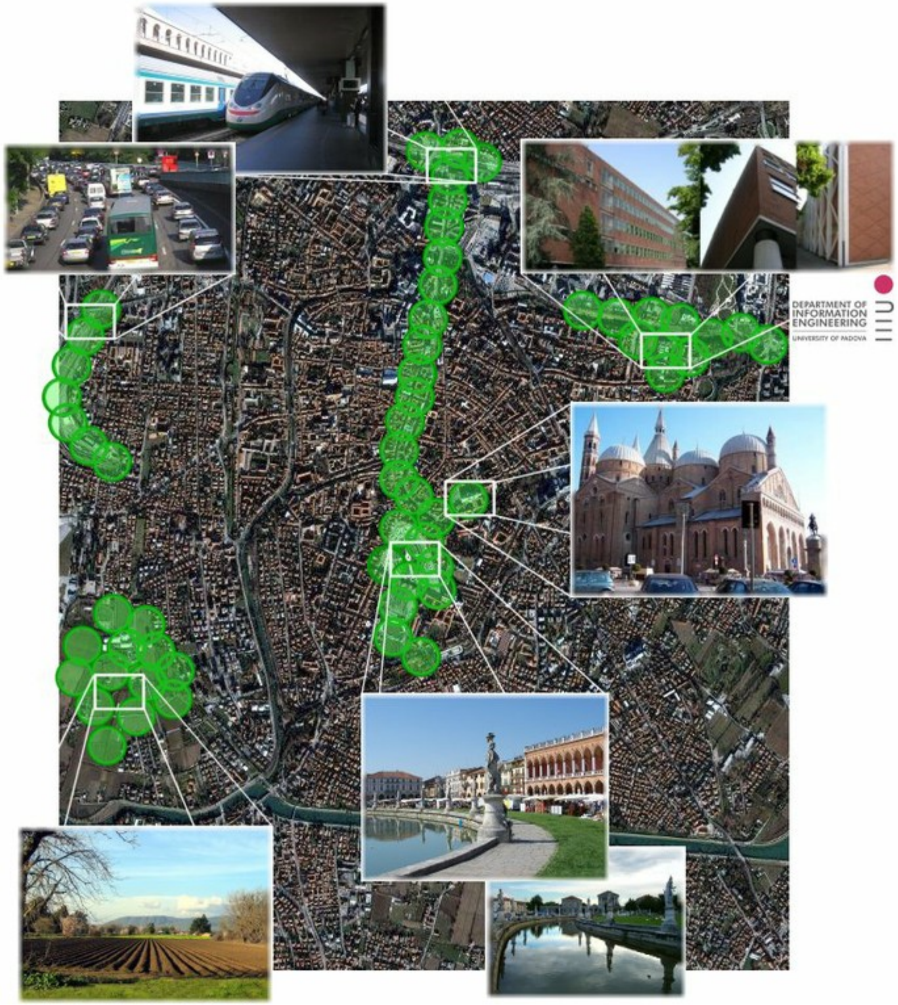
Smart City: example of services



- For the administrations
  - Monitoring of traffic
    - Real-time monitoring of city viability, help assessing impact of traffic plans, plan public events,…
  - Monitoring of public transportation
    - Timing, utilization, peak hours…
  - Monitoring of public facilities
    - Street lights, bike sharing, car sharing, trash bins, gym facilities in parks,…
  - Monitoring of pollution, noise level, maintenance teams,…
- For the citizens
  - Better services
  - Easier interaction with administrations
  - More transparency in municipality economical plans

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Smart Grid

- Household energy usage accounts for ~50% electric & ~33% energy usage in Italy
  - Extremely important to improve building energy efficiency

- In 2005 ENEL starts deploying the first SMART GRID
  - Cost: 2.1 billion euros
  - Saving: 500 milions per year!

- USA: Energy Dep. forsee up to 117 billions of dollars saving by 2030
- Smart grid can also decrease CO_2 emission of 12% in USA & 15% in India

Fonti: *Ministero dello Sviluppo Economico, 2005
•National Energy Technology Laboratory (2007-08) (PDF). NETL Modern Grid Initiative — Powering Our 21st-Century Economy. United States Department of Energy Office of Electricity Delivery and Energy Reliability. p. 17. Retrieved 2008-12-0
•R.G. Pratt, M.C.W. Kintner-Meyer, P.J. Balducci, T.F. Sanquist, C. Gerkensmeyer, K.P. Schneider, S. Katipamula, T.J. Secrest. The Smart Grid: An Estimation of the Energy and CO2 Benefits. Pacific Northwest National Laboratory Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830
•Molly Webb, McKinsey & Company. SMART 2020: Enabling the low carbon economy in the information age. A report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI)

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Summing up, ICT shall provide…

- **infinite capacity**
  - Everyone gets what needed to be happy!
- **ubiquitous coverage**
  - No more connectivity gaps!
- **pervasive connectivity**
  - "Every" object is Internet-enabled
- **customization**
  - Services adapt to the context and the personal requirements
- **flexibility**
  - Easy development and integration of new services

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First Break

We deserve it!

http://www.keepcalmstudio.com/gallery/poster/L90JKS

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Technological challenges

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Your perspective!

- What **YOU** expect is needed to realize these goals?

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Big players say…

No one actually knows…

but

there's consensus on some points…

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Technical requirements

User asks for

- **Infinite capacity**
  - Everyone gets what needed to be happy!

Engineer understands…

- More rate
- More spectrum efficiency
- More spatial reuse
- QoE-based RRM
- Dynamic content caching
- …

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Technical requirements

User asks for	Engineer understands…
ubiquitous coverage – No more connectivity gaps!	multiple RATs new frequency bands multiple antennae & beam forming cell densification higher sensitivity better handover …

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Technical requirements

User asks for	Engineer understands…

User asks for

- **pervasive connectivity**
  - "Every" object is Internet-enabled

Engineer understands…

- protocols protocols protocols!
  - 6LowPAN, RPL, CoAP,…
- massive access management
- energy efficiency
- security
- …

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Technical requirements

User asks for	Engineer understands…
customization - Services adapt to the context and the personal requirements	software adaptability quality of experience service differentiation context awareness - Machine learning - Unsupervised learning - Emergent behavior, …

Technical requirements

User asks for	Engineer understands…
flexibility - Easy development and integration of new services	semantic web - Ontologies data accessibility heterogeneous sources - wideband services (voice, video, web,…) - machine-type devices - Highly mobile users (VANET, trains,…)

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And much much more…

- Protocol transparency
- Routing
- Data storage
- Ranking
- Connectivity
- Service-enablement
- Mobility
- Heterogeneity
- Deployability
- Manageability
- …

- Scalability
- Real-time processing
- Tracking/positioning
- Application development
- Access
- Human-things interaction models and paradigms
- Service/Device discovery
- Security, access control, sharing of physical things on the Web
- …

Let's try to quantify

① Massive capacity and massive connectivity (**10^4 – 10^5** per BS)

② **1000 times higher** mobile **data volume** per unit area

③ **10-100 times higher** # of connecting **devices** & user **rate**

- e.g., peak data rate of 10 Gbps for low mobility and peak data rate of 1 Gbps for high mobility

④ **Less than 1 ms latency** to support real-time control applications

⑤ **Max 10 ms switching time** between different radio access technologies (RATs)

⑥ Communication scenarios in the range of **350 - 500 km/h**

- compared to 250 km/h in 4G networks

⑦ **10 times longer battery life**

The way forward…

Maybe…

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Your perspective!

- What **YOU** expect is the way to achieve these goals?

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Big players say…

No one actually knows…

but

there's consensus on some points…

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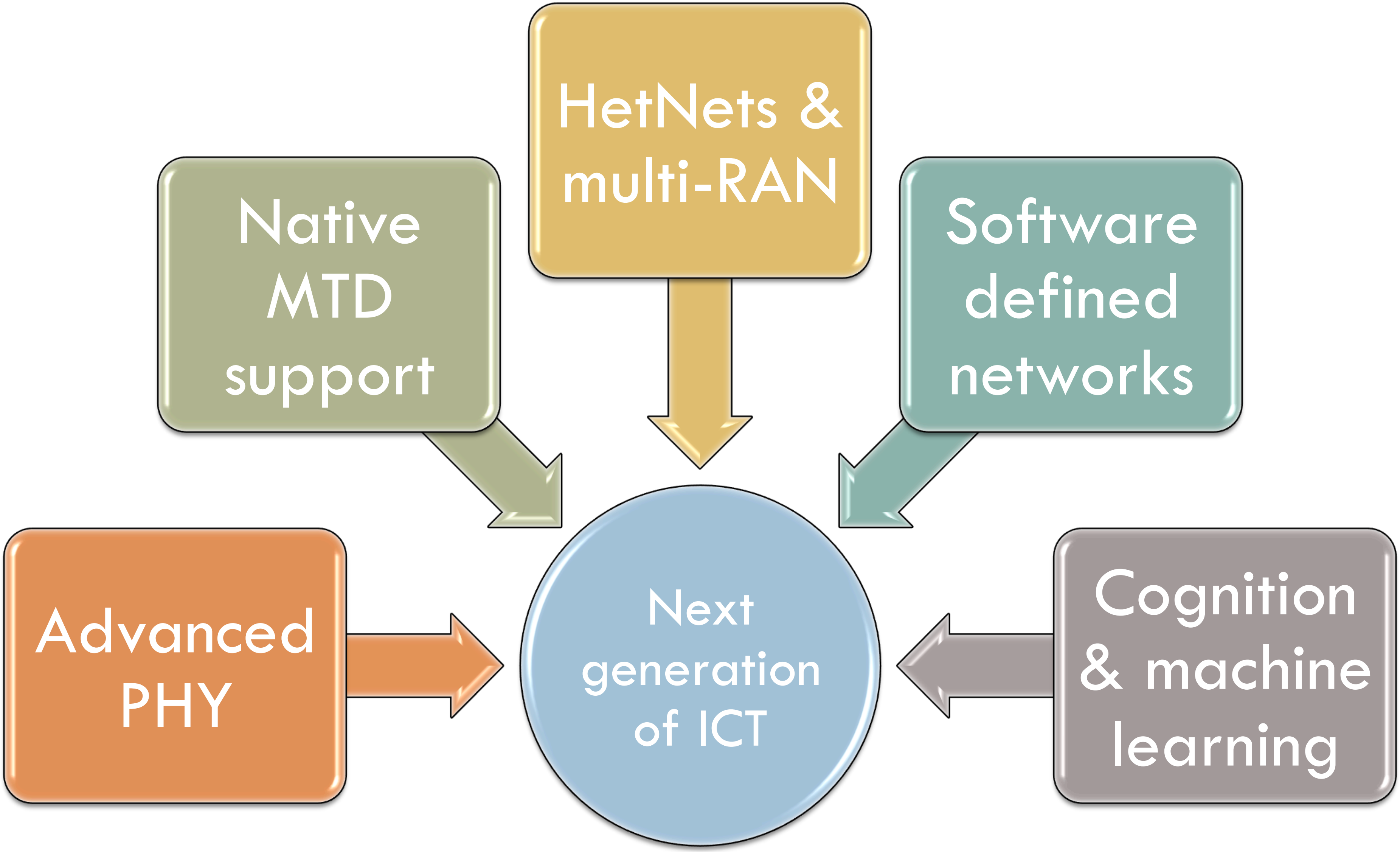
The basic ingredients



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Advanced PHY

- Massive MIMO
- Mm-wave communication
- Full duplex communication
- …

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Advanced PHY: more bitrate

- Formula for Network Throughput:

Throughput = Available spectrum · Cell density · Spectral efficiency

Throughput	Available spectrum	Cell density	Spectral efficiency
bit/s in area	Hz	Cells/area	bit/s/cell/Hz

- Ways to achieve 1000x improvement

	More spectrum	Higher cell density	Higher spectral efficiency
Nokia (2011)	10x	10x	10x
SK Telecom (2012)	3x	56x	6x
	New regulations, cognitive radio, higher frequencies	*Smaller cells, heterogeneous deployments*	***Massive MIMO***

5

http://wireless.kth.se/wp-content/uploads/2014/03/presentation_massiveMIMOmagic.pdf

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Massive MIMO

- Massive MIMO usea large arrays at BSs
  - e.g., N≈200 antennas, K≈40 users
- Key: Excessive number of antennas, $N \gg K$
- Very narrow beamforming
- Little interference leakage

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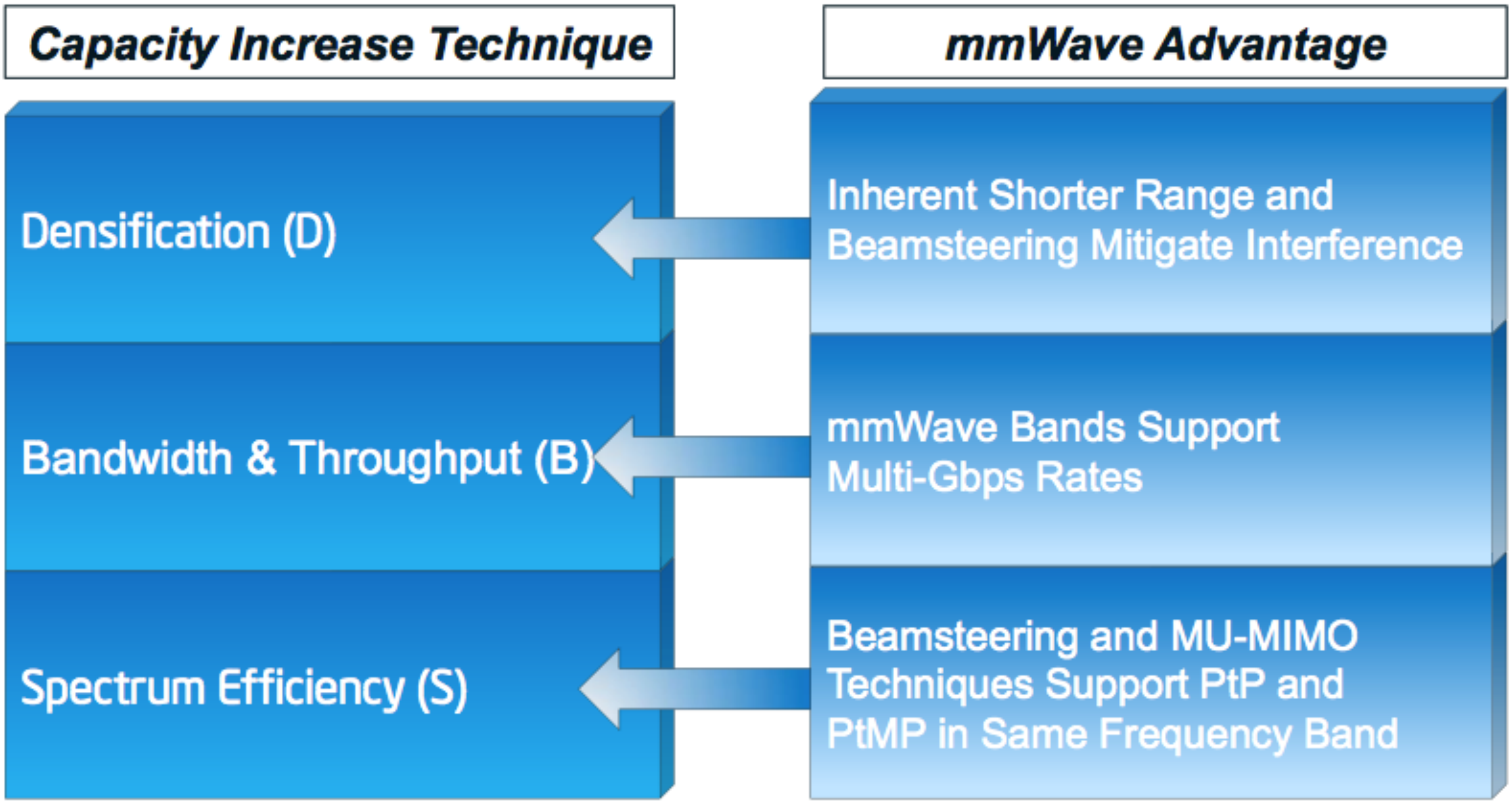
Advanced PHY: more spectrum

- New frequency bands
  - mm-wave communications (>60 GHz)
  - 5 – 9 GHz of unlicensed bandwidth
  - Ever heard of WiGig (IEEE 802.11ad)?
    - http://www.wi-fi.org/discover-wi-fi/wigig-certified

mmWave advantages



http://www.slideshare.net/allabout4g/intel-25905453

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Advanced PHY: Full duplex

- Full duplex wireless transmission
  - Passive and active cancellation of interfering transmitted signal
  - Potentially capable of doubling capacity with same RF resources
  - Need careful design of MAC as well…

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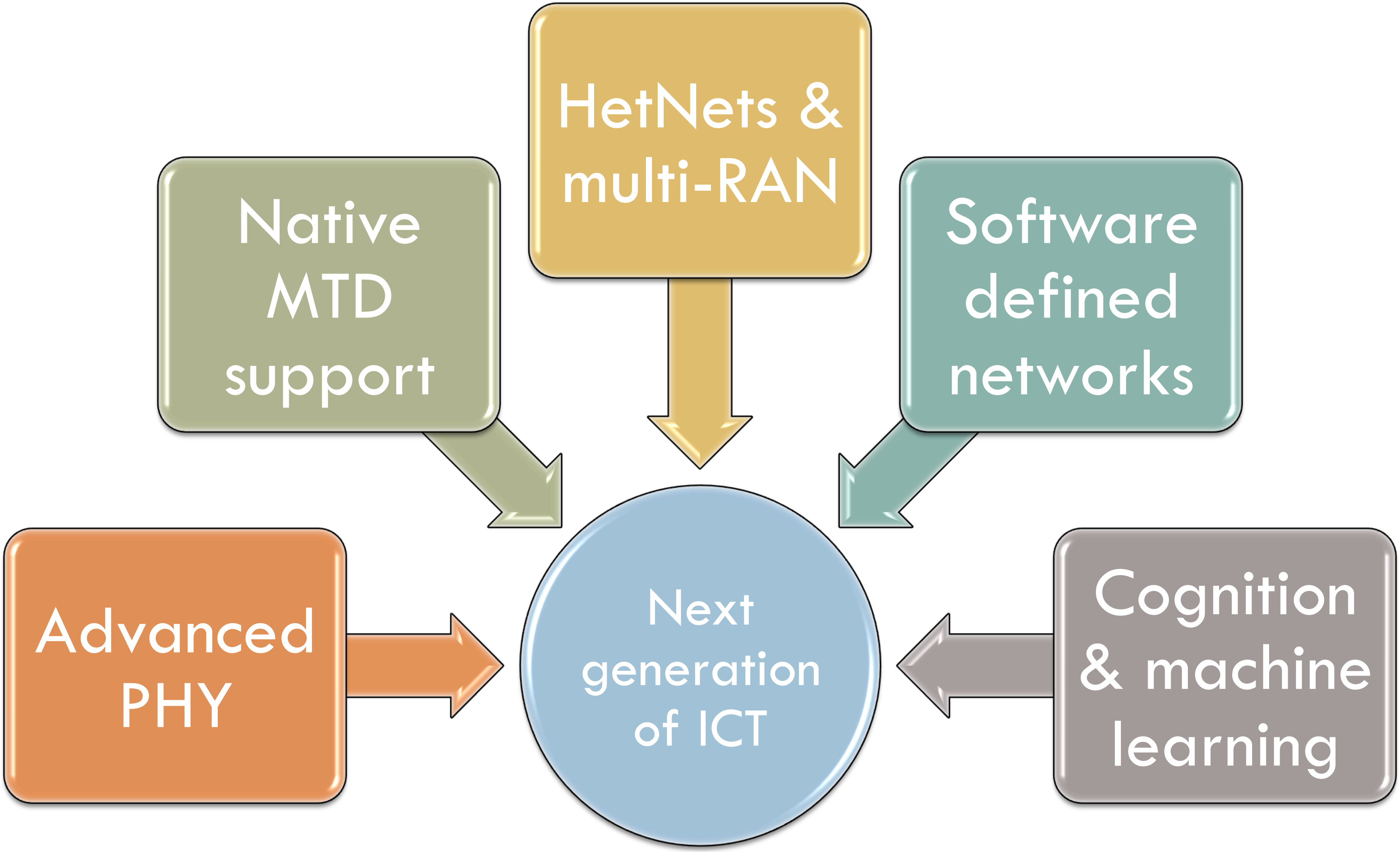

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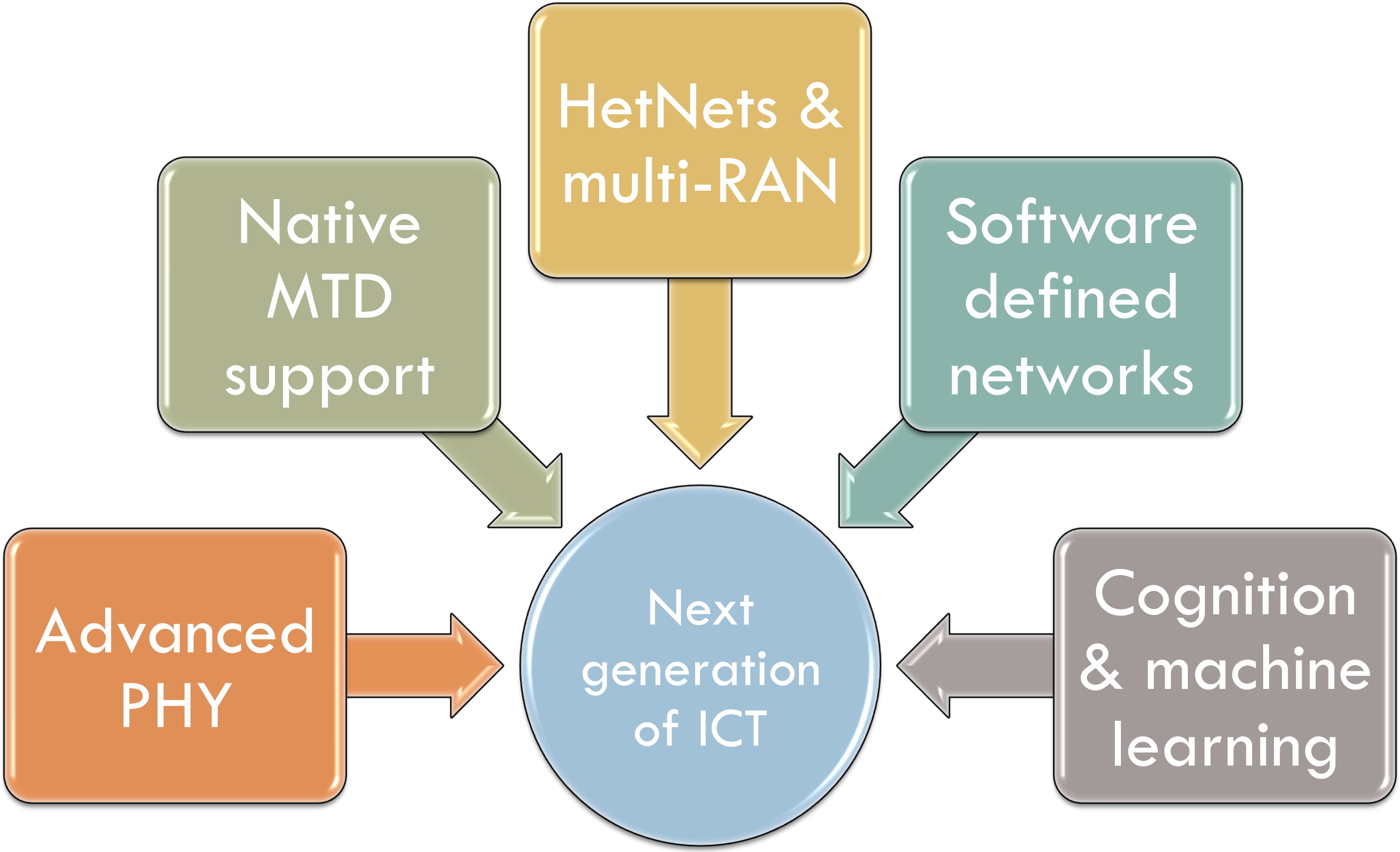
Native support for Machine-type communication (MTC)

① Exploit correlation of sensor data across space and time
- better scalability if properly used

② Radically new frame structure
- highly reliable connections despite coverage problems
- Reduce signaling
- More on this in Part 2…

③ Exploit X-layer solutions
- Spreading codes plus successive interference cancellation
- More on this in Part 2…

The basic ingredients



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HetNets & multi-RAN

- Heterogeneous networks (HetNets):
  - Small cell networks including macrocells and small cells of all types
  - Provide improved spectrum efficiency (bps/Hz/km^2), capacity, and coverage
  - Small cells can support wireless applications for homes and enterprises as well as metropolitan and rural public spaces
  - Require solutions for **cell selection, handover, dynamic content caching**, …

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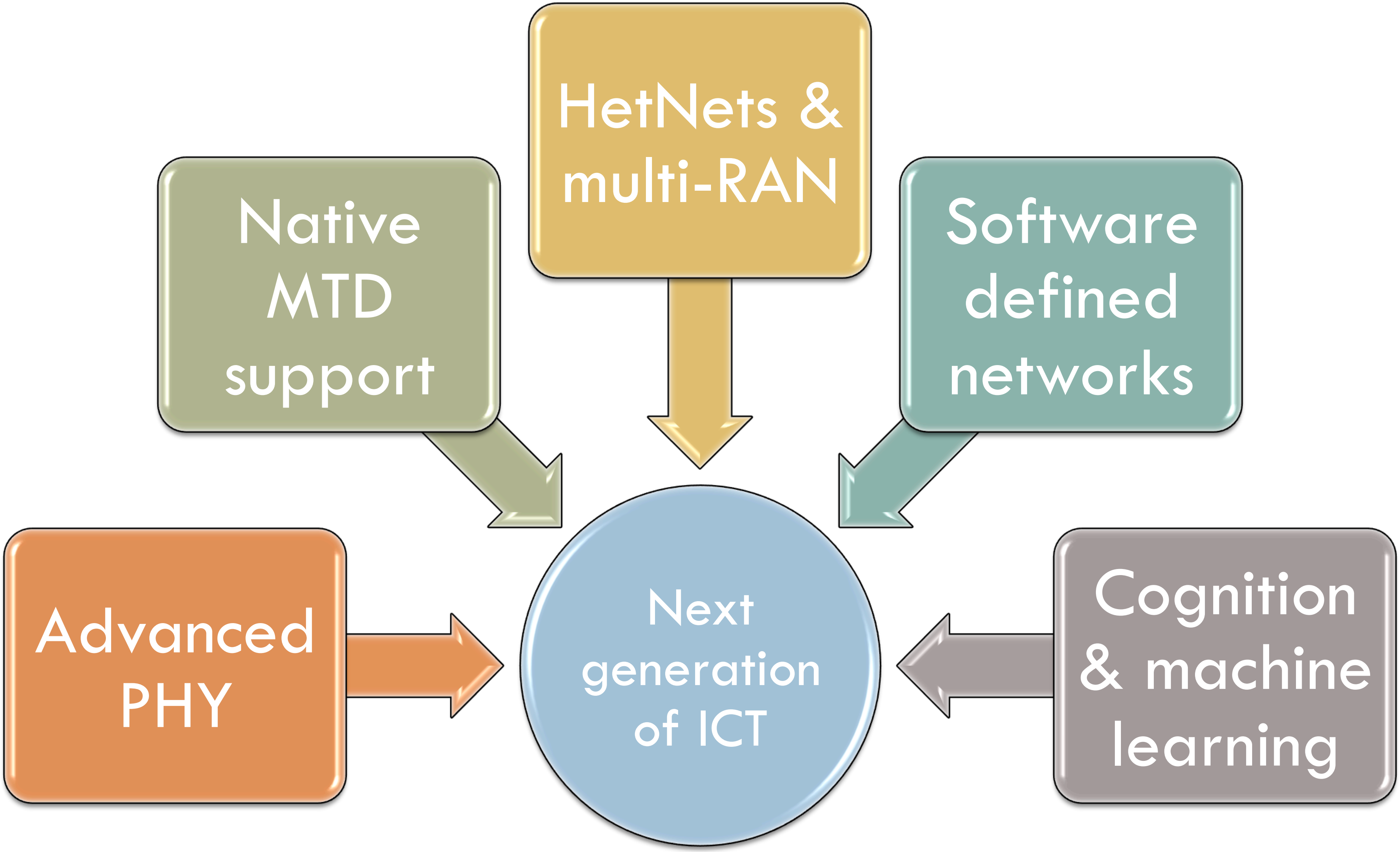

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Planes of Networking (1/2)

- Data Plane
  - All activities involving as well as resulting from data packets sent by the end user, e.g.,
    - Forwarding
    - Fragmentation and reassembly
    - Replication for multicasting
- Control Plane
  - All activities that are necessary to perform data plane activities but do not involve end-user data packets
    - Making routing tables
    - Setting packet handling policies (e.g., security)
    - Base station beacons announcing availability of services

Ref: Open Data Center Alliance Usage Model: Software Defined Networking Rev 1.0,"
http://www.opendatacenteralliance.org/docs/Software_Defined_Networking_Master_Usage_Model_Rev1.0.pdf

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Data vs control planes

- Data plane runs at line rate
  - e.g., 100 Gbps for 100 Gbps Ethernet ⇒ Fast Path
  - Typically implemented using special hardware
  - Few activities handled by CPU in switch ⇒ Slow path
    - e.g., Broadcast, Unknown, and Multicast (BUM) traffic

- All control activities are generally handled by CPU

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OpenFlow key idea

- Separation of control and data planes
- Centralization of control
- Flow based control
  - Control logic is moved to a controller
  - Switches only have forwarding elements
  - One expensive controller with a lot of cheap switches
  - **OpenFlow** is the protocol to send/receive forwarding rules from controller to switches

Ref: N. McKeown, et al., ``OpenFlow: Enabling Innovation in Campus Networks," ACM SIGCOMM CCR, Vol. 38, No. 2, April 2008, pp. 69-74.

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OpenFlow basics

- On packet arrives to the switch
- Switch logic compares header fields with flow entries in a table
  - if any entry matches → perform indicated actions
  - If no header match →
    - packet is queued and **header** is sent to the controller
    - Controller sends a new rule to the switch
    - subsequent packets of the flow are handled by this rule
- Doesn't all of this remind you anything?

Ref: N. McKeown, et al., ``OpenFlow: Enabling Innovation in Campus Networks," ACM SIGCOMM CCR, Vol. 38, No. 2, April 2008, pp. 69-74.

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What do we need SDN for?

① **Virtualization:** Use network resource without worrying about where it is physically located, how much it is, how it is organized, etc.

② **Orchestration:** Manage thousands of devices

③ **Programmable:** Should be able to change behavior on the fly

④ **Dynamic Scaling:** Should be able to change size, quantity

⑤ **Automation:** Lower OpEx

⑥ **Visibility:** Monitor resources, connectivity

⑦ **Performance:** Optimize network device utilization

⑧ **Multi-tenancy:** Sharing expensive infrastructure

⑨ **Service Integration**

⑩ **Openness:** Full choice of Modular plug-ins

11 **Unified management** of computing, networking, and storage

http://www.cse.wustl.edu/~jain/tutorials/icc14.htm

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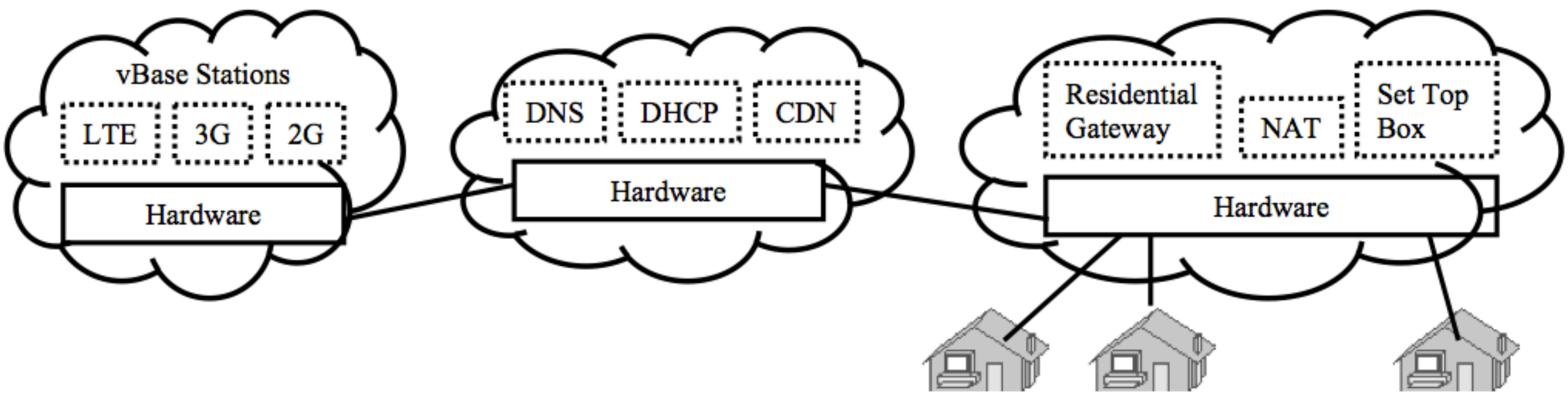
Network Function Virtualization (NFV)

- Fast standard hardware ⇒ Software based Devices
  Routers, Firewalls, Broadband Remote Access Server (BRAS) ⇒ A.k.a. white box implementation
- Function Modules (Both data plane and control plane) ⇒ DHCP (Dynamic Host control Protocol), NAT (Network Address Translation), Rate Limiting



Ref: ETSI, "NFV – Update White Paper," Oct 2013, http://www.tid.es/es/Documents/NFV_White_PaperV2.pdf (Must read)

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Overall "software-defined" summary

- **OpenFlow** separates control plane and moves it to a central controller
  - Simplifies the forwarding element
- **SDN** is the framework to automatically manage and control a large number of multi-tenant network devices and services
  - OpenFlow originated SDN but now many different southbound and northbound APIs, intermediate services and tools are being discussed and implemented by the industry
- **OpenDaylight SDN Controller** platform is the leading open source SDN controller project under Linux Foundation
- **NFV** reduces OpEx by automation and scalability provided by implementing network functions as virtual appliances

http://www.cse.wustl.edu/~jain/tutorials/icc14.htm

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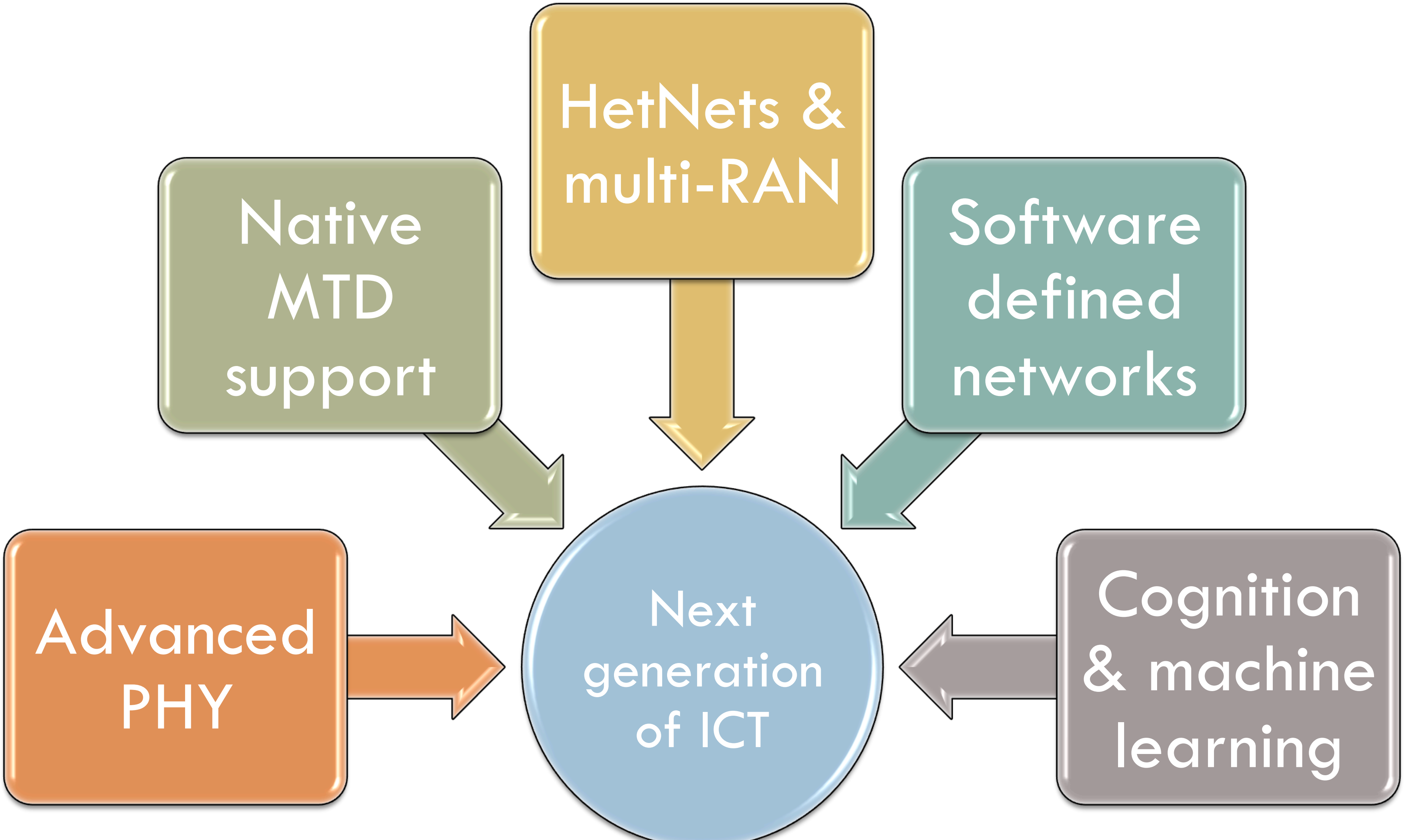
The basic ingredients



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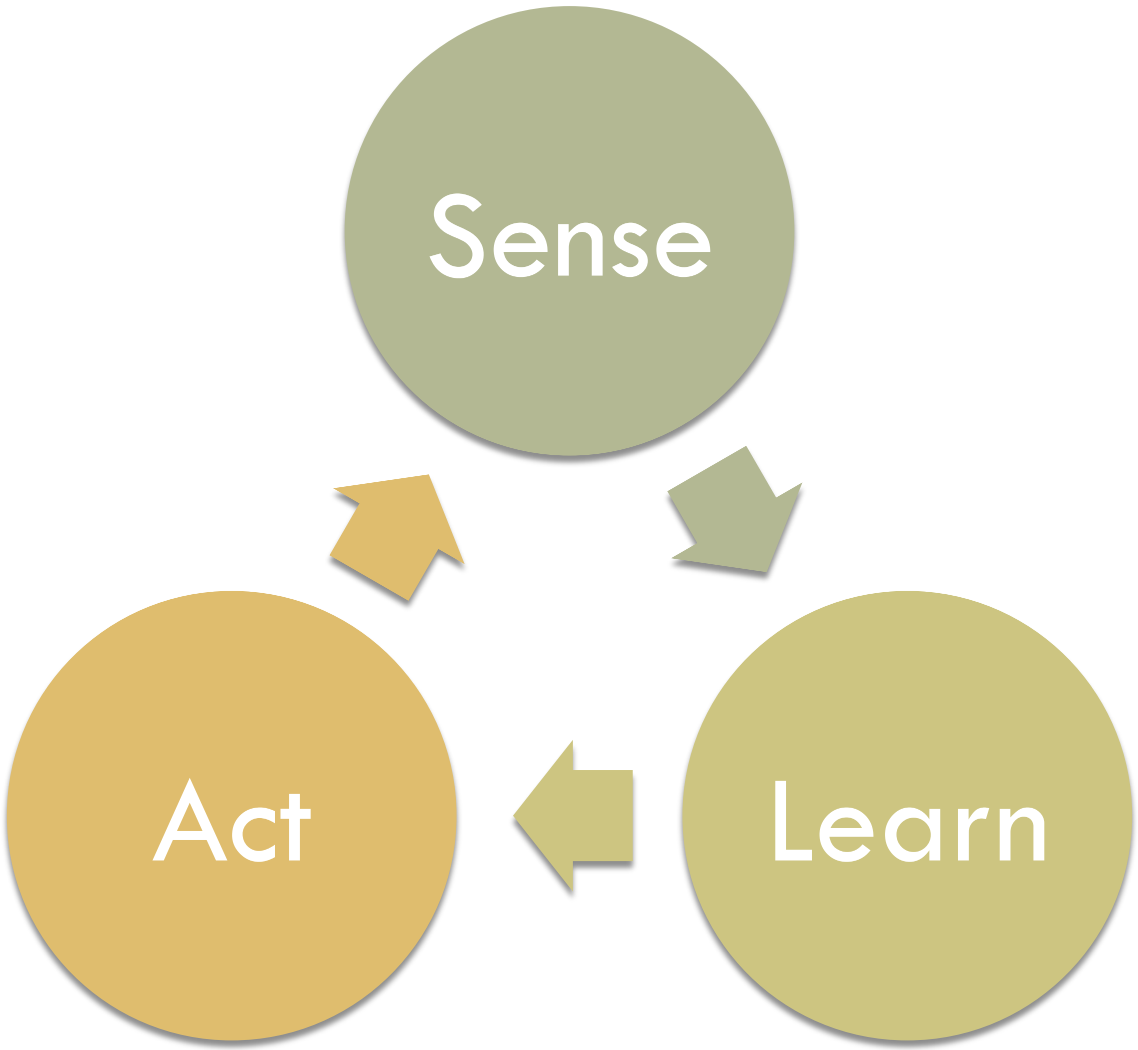
The cognition cycle



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True for human, true for networks

- **Sense**: nowadays devices are crammed with transducers/sensing apparatuses
  - needs efficient data handling
- **Learn**: optimization algorithms can be run at each node individually
  - needs (i) efficient algos (ii) harmonization
- **Act**: network modifies the environment
  - requires convergence of multiple devices

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Supervised vs unsupervised learning

- Supervised learning requires a training set and/or instructions of good/bad
  - Better for limited improvements in well known scenarios

- Unsupervised has no prior knowledge
  - No pre-existing (arbitrary) model
  - Just emerging behavior
  - and distributed optimization

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Cognition-based Network

Each node of the network:

- exploits local information to achieve its goal
- shares it with its neighbors

↓

Self-adaptation to the environment to achieve network wide goals

Cognition applied to the entire network **(more on this on Part 2 – option B)**

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Conclusions of Part 1 (1/3)

- Big expectations for next generation ICT
  - "Infinite" capacity & "zero" delay
  - Full coverage & pervasive connectivity
  - Energy efficiency & self sustainable systems
  - New services and applications

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Conclusions of Part 1 (2/3)

- A lot of open problems
  - Massive access
  - Extremely heterogeneous traffic patterns
  - Higher and higher user mobility
  - Increased traffic demand
  - Increased QoE expectation
  - Self adaptability and "smart" behavior
  - …

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Conclusions of Part 1 (3/3)

- A lot of possible solutions
  - **New PHY**: e.g., massive MIMO, mmwave, full duplex,…
  - **Clean-slate design of control plane**: native support for MTC & wideband services
  - **HetNets:** cell densification, multi-RAN, multi-hop, cooperative transmissions,…
  - **Software-defined:** SDN, NFV, Cloud
  - **Cognitive approach**: instill intelligence into network elements

Break!!!! We all need it!

http://www.overstock.com/Home-Garden/Keep-Calm-and-Drink-Coffee-Unframed-Print/7967447/product.html

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Spare slides

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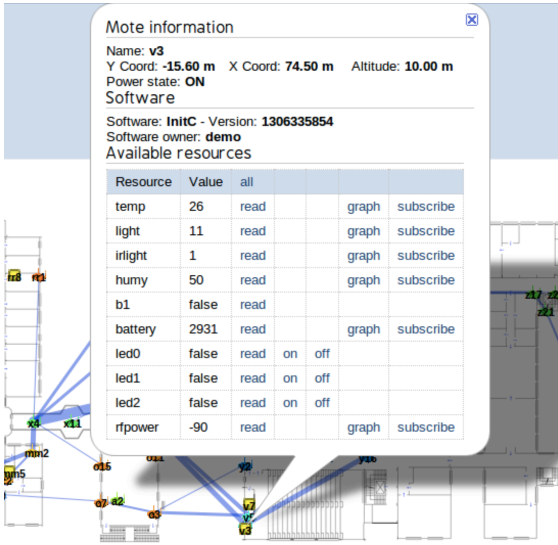
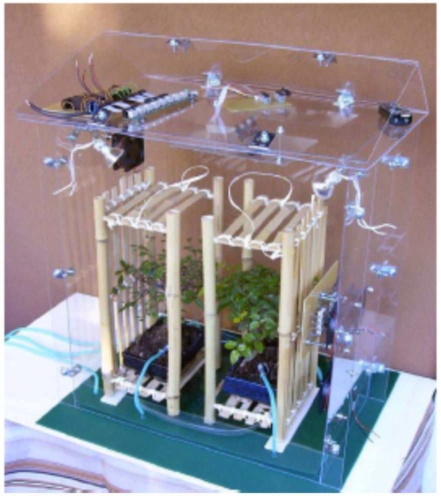
IoT: sw&hw

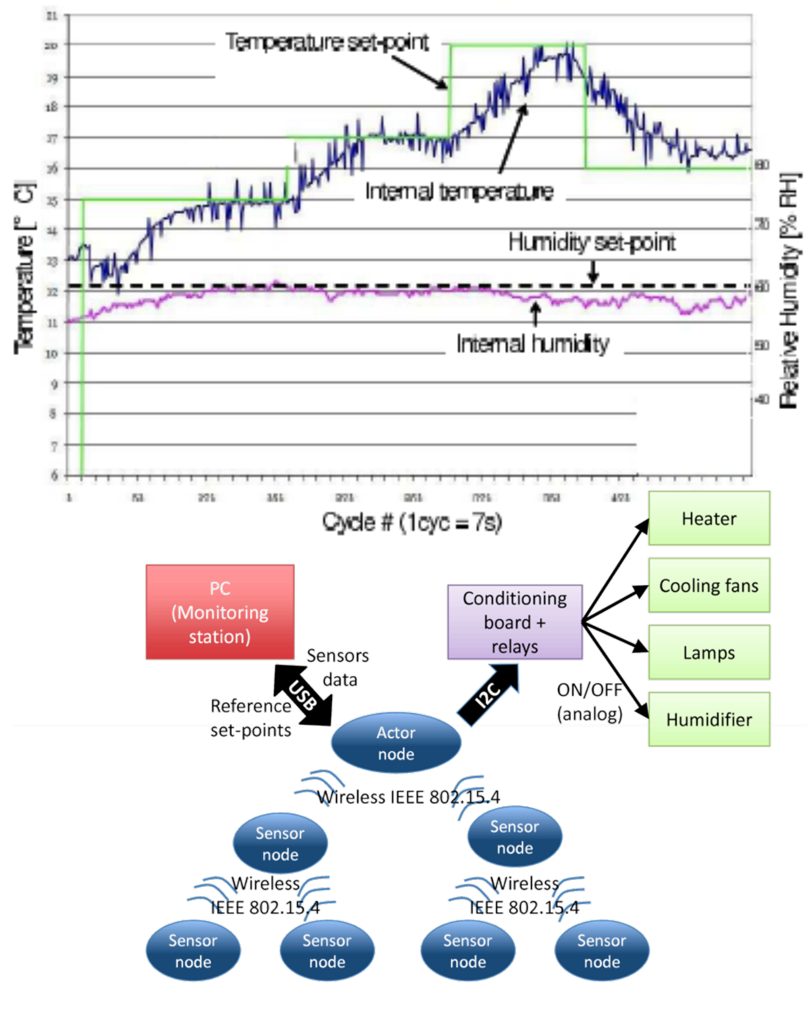
- Protocols and interfaces
  - Theory, Simulation, Implementation
  - Highly scalable
  - Easy data access
  - Robustness and security
- Performance optimization
  - Low energy consumption
  - Energy harvesting
  - Real time features
  - Data redundancy and consistency
- Optimization of the hardware and software
  - Lower devices cost
  - Lower maintenance costs

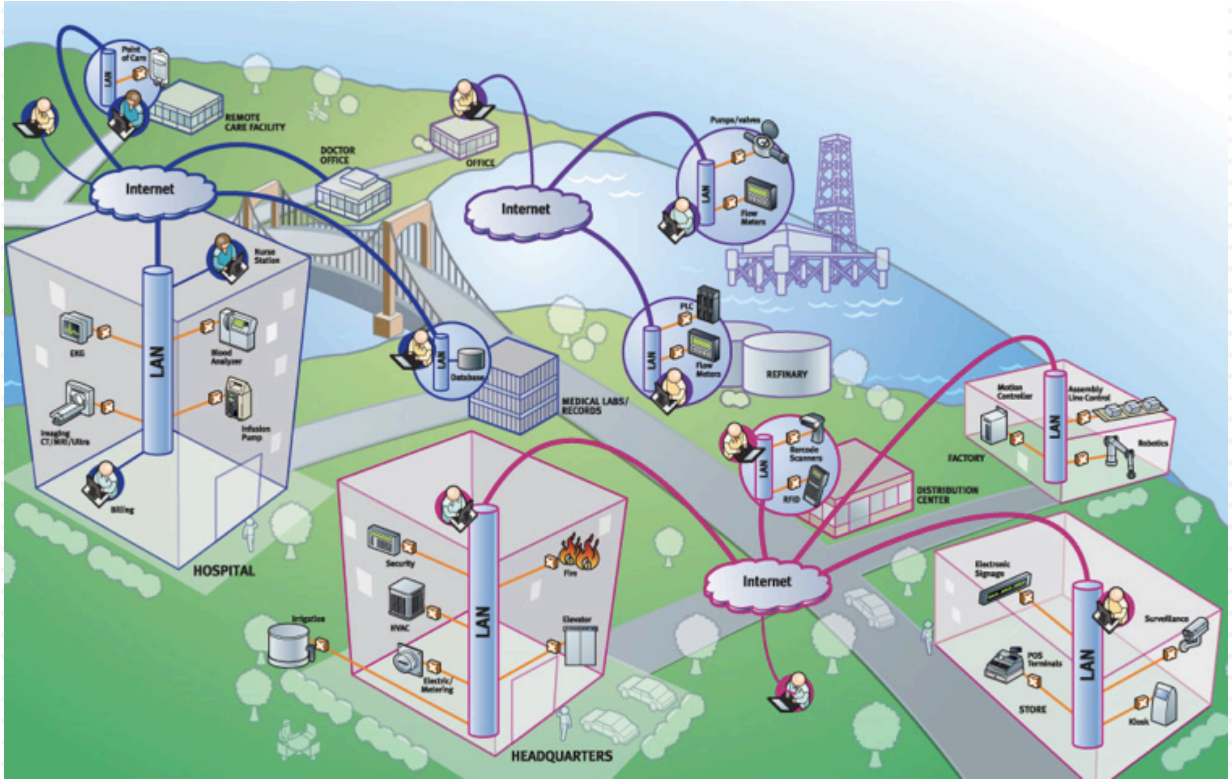




IoT: modelling and analysis

- Accurate models for environment and physical processes
  - Estimate and prediction of the monitored processes
  - Minimization of data exchange
    - Lower interferences
    - Lower power consumption





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Net generation mobile

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5G networks and services

- **What**
  - 4th generation: LTE-Advanced, based on OFDMA
  - Wireless LANs and emerging .11 standards
  - Multimedia: adaptive and scalable contents
- **When**
  - LTE-A started being deployed end of 2012
  - Video has been the majority of traffic since 2012
- **Why**
  - Many resources (peak rates of 1Gb/s) but even higher requirements due to several users

Example: emergency scenarios

- Forest fires: 50k/year in Europe
- Road accidents: 2M/year in Europe with 100k deaths and 3.5M injured
- Earthquakes, tsunamis, terrorist strikes
- **Problems:** Unreliable infrastructure, rescuers are not coordinated
- **Challenges:** Avoid network collapse, replace destroyed networks, keep enabling rescue communications

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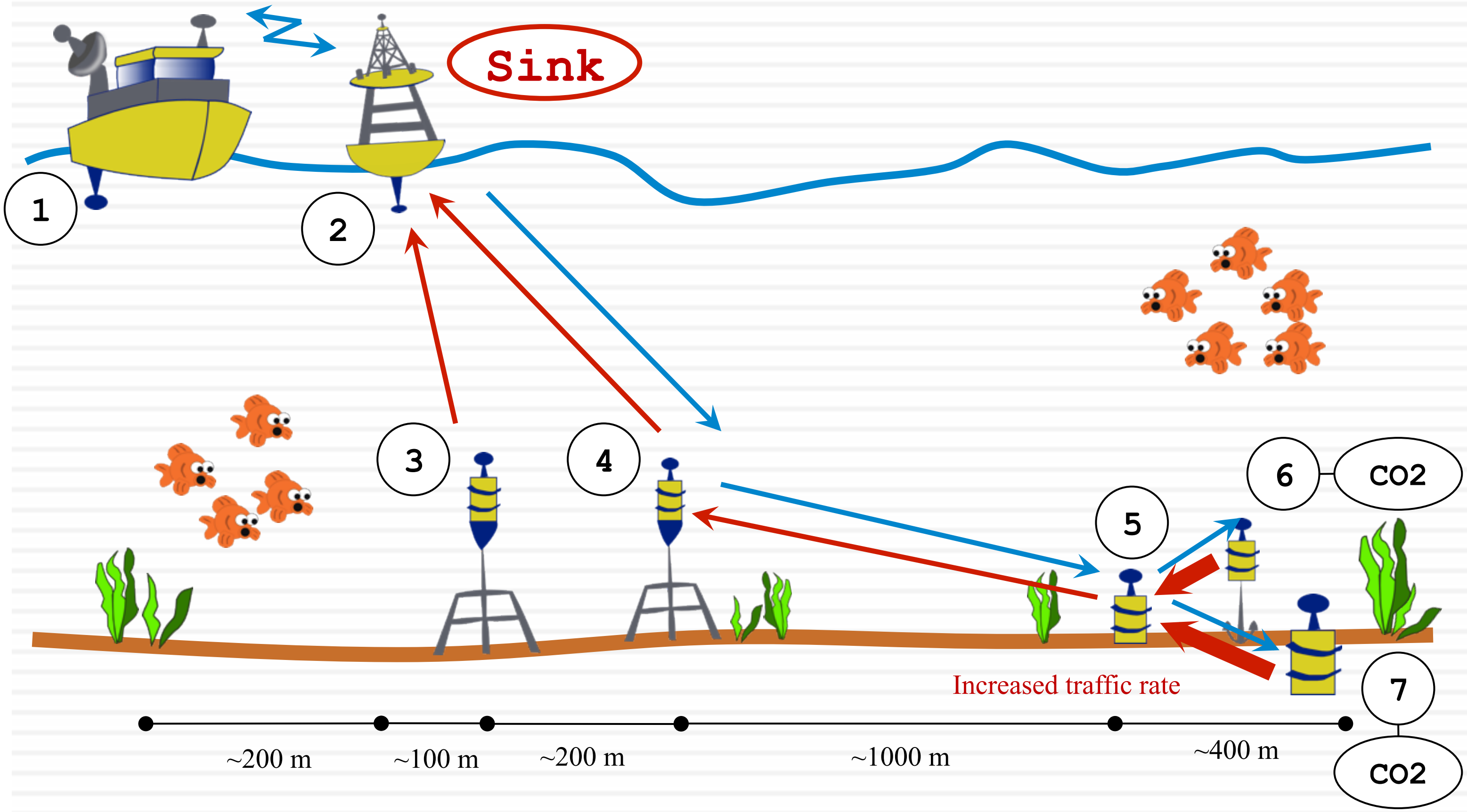
Research topics

Resource allocation strategies for LTE

- Handover strategies

Adaptation and optimization



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Underwater communications

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Underwater communications

- **What**
  - Acoustic communications instead of radio
- **When**
  - Sonar technologies have been used since 1930s
  - 21st century technologies: higher bandwidth/rate
- **Why**
  - Oceanography/security/monitoring applications
  - The channel is extremely difficult to characterize
  - Infrastructure monitoring is critical (oil pipes)
  - Networking under development

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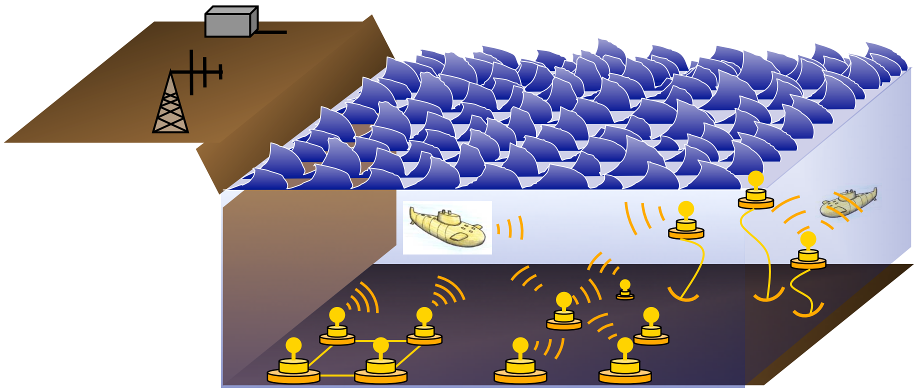
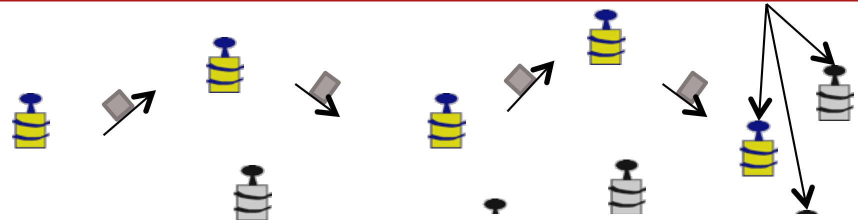
Example

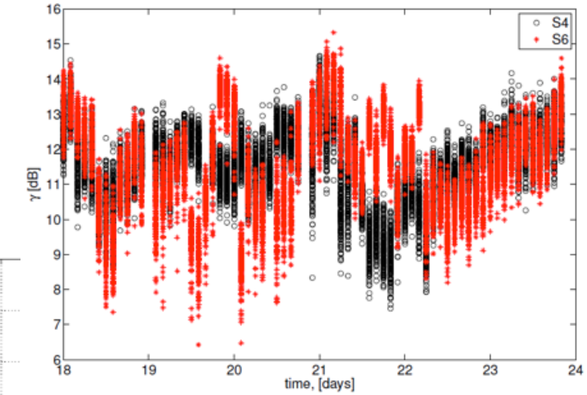
- Application funded by US NAVY
- Endurance test: keep the submarine under!
  - Rather than emerging to communicate, stay underwater and make use of a relay network of seabed anchored repeaters
  - Saving in the order of milions of $$$!

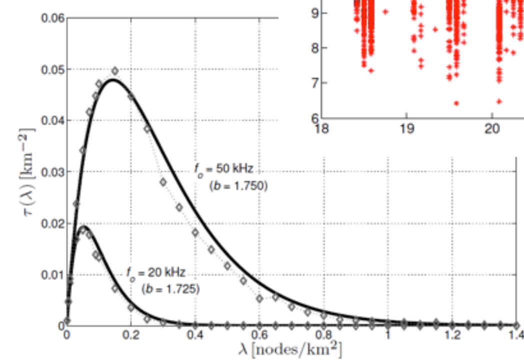


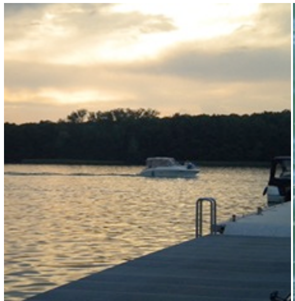
Research topics

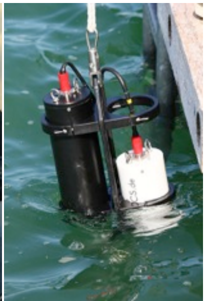
- **Protocol design**
  - MAC, Routing, Error control
- **Channel characterization**
  - Correlation, impact on protocols
  - Real data sets
- **Performance analysis**
- **Experiments and sea trials**

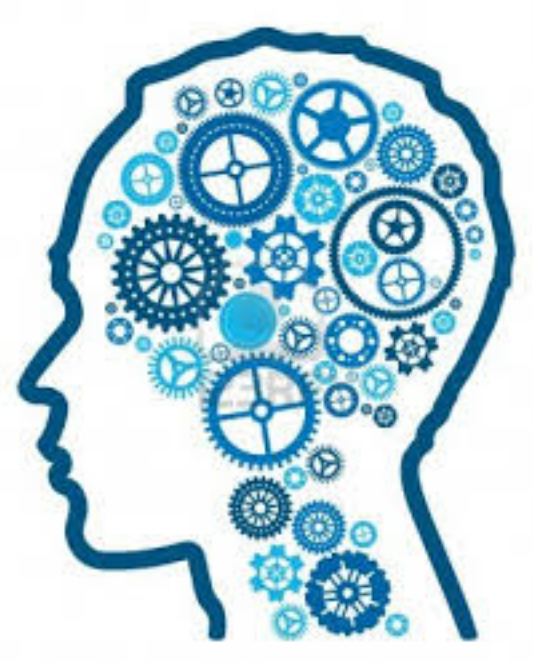












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Cognitive networks

Image taken from

http://www.cosolen.com/syntactic-variation-in-cognition/

Cognition-based networks

- **What**
  - Heterogeneous *access technologies*…
    - WiFi, LTE, Ethernet, ZigBee,...
  - and *traffic*: video, voice, sensorial/tracking data..
- **When**
  - Relevant standards 802.21-22 released 2009-11
  - MIMO in next LTE-A, IEEE 802.11ac (exp 2014)
- **Why**
  - Complicated X-layer optimization
  - Context awareness and adaptability
  - Exploitation of known patterns

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Example: video via WiFi

- No congestion, close to AP → smooth, HD video ☺
- Suddenly, video starts freezing: why?
  1. user moving away from the AP → poor RF signal
  2. Internet connection is congested → poor ADSL
  3. other users are watching videos → poor scheduling
- Countermeasures are different:
  1. switch to APs with better signal, use collaborative techniques, change video codec,…
  2. tune RTP parameters, change video codec,…
  3. cache video content at AP, implement VAC, switch to multicast…
- How to choose? **Cognitive techniques!**

Research topics

- **Context classification techniques**
  - Infer congestions, channel conditions, traffic types, in-network delays,…
- **Convergence to global optimal behavior**
  - Apply emergent behavior techniques to find optimal parameters setting in a distributed fashion
- **Network optimization**
  - Learn optimal actions by means of neural networks

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HetNets: cell sizes

- Femtocell
  - small area covered by a femto access point (FAP), intended for residential indoor applications, installed and managed by the customers
  - Key attributes: IP backhaul, self-optimization, low power consumption, ease of deployment (user-deployed), closed/open/hybrid access
- Picocell
  - low-power compact base stations, used in enterprise or public indoor areas, encompasses outdoor small cells as well
  - Key attributes: wired or wireless backhaul, operator deployed, self-optimization, open access
- Microcell
  - outdoor short-range base station aiming at enhancing coverage for both indoor and outdoor users
  - Key attributes: wired or wireless backhaul, self-optimization, low power consumption, open access
- Metrocell
  - small cell technologies designed for high-capacity metropolitan areas, typically installed on building walls, lampposts; can include technologies such as femtocells, picocells, and microcells
  - Key attributes: wired or wireless backhaul, operator deployed, self-optimization, open access
- Relays: operator deployed, open access, wireless backhaul

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Planes of networking (2/2)

- Management Plane
  - All activities related to provisioning and monitoring of the networks
    - Fault, Configuration, Accounting, Performance and Security (FCAPS)
    - Instantiate new devices and protocols (Turn devices on/off)
    - Optional $\Rightarrow$ May be handled manually for small networks
- Services Plane
  - Middlebox services to improve performance or security, e.g.,
    - Load Balancers, Proxy Service, Intrusion Detection, Firewalls, SSL Off-loaders
    - Optional $\Rightarrow$ Not required for small networks