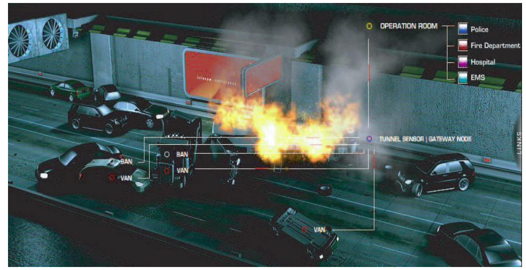



CS-541
Wireless Sensor Networks

Lecture 1: Introduction to CS-541 and Wireless Sensor Networks

Spring Semester 2017-2018

Prof Panagiotis Tsakalides, Dr Athanasia Panousopoulou, Dr Gregory Tsagkatakis

Today’s Objectives

- CS-541 Overview
- Introduction to Wireless Sensor Networks (WSN)

About CS-541

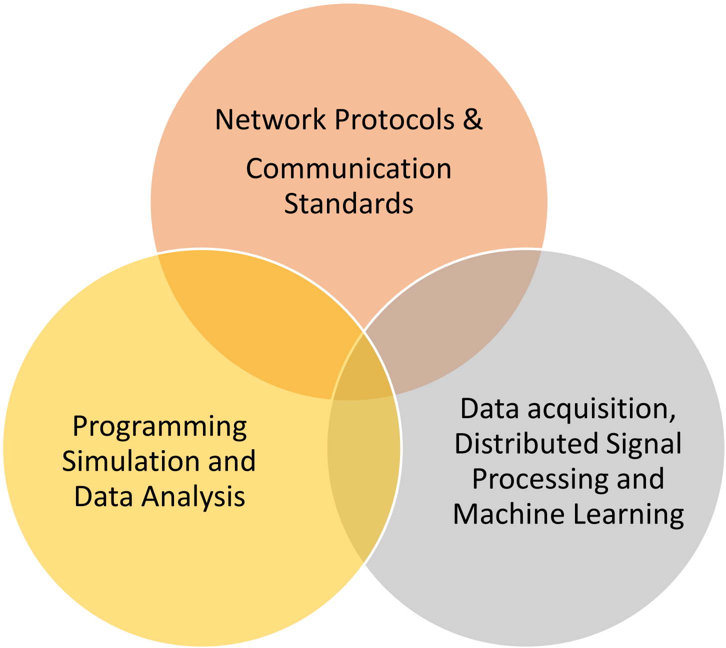
- Lectures: Monday and Wednesday 14.00-16.00, H208 &

- Office Hours: Monday and Wednesday 13.00-14.00, E304

- Prerequisites: Computer Networks (CS-335), Applied Mathematics for Engineers (CS-215)

About CS-541

- Theory, design and development aspects of WSN
- Introduction to this field
- Signal processing and network perspective



About CS-541

12/02/2018 – 18/05/2017

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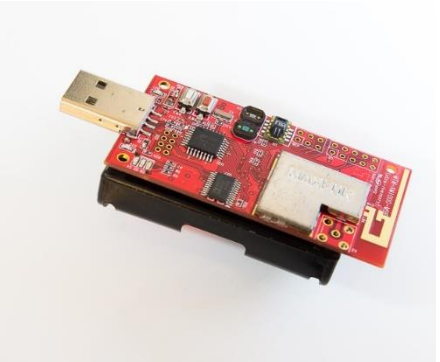
Lecture 1: Introduction to WSN and CS-541 course
Lecture 2: Protocol stacks, and wireless networks prerequisites.
Lecture 3: Network standards for Personal and Body-area networks
Lecture 4: Signal processing prerequisites.
Lecture 5: Signal Sampling for WSN
Lecture 6: Radio Duty Cycling in WSN
Lecture 7: Routing in WSN
Lecture 8: Data models and data acquisition
Lecture 9: Machine Learning for WSN
Lecture 10: Introduction to WSN programming
Lecture 11: Hands on Session I
Lecture 12: Machine learning applications in WSN
Lecture 13: Invited Lecture I
Lecture 14: Hands on Session II
Lecture 15: Special issues in WSN: Deployment & Coverage
Lecture 16: Invited Lecture II
Lecture 17: Big Data & IoT
Lecture 18: Projects progress presentations

Nancy Panousopoulou
Gregory Tsagkatakis
Maria Aspri / Antonis Tzougarakis
Invited Speaker
You ☺

About CS-541

Learning Outcomes



- Essential theoretical background and practical skills for the design and development of WSN
- State-of-the-art techniques for sensing data management
- Hands on experience with WSN technological platforms and programming tools
- Develop a research project in a multi-disciplinary field of engineering
- Improve problem solving and presentation skills

About CS-541

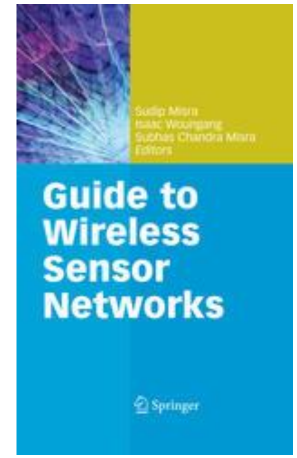
Practical Information

- 3 individual homeworks on the material taught (30% of your final grade)
  - Exercises on MATLAB
  - Contiki / Cooja
  - 1st assignment will be handed out at the middle of February
  - 2 weeks time to complete each assignment (hard deadline).
- Standalone project (max for 2 students) (50% of your final grade)
  - Research topic
  - Experimental work / analysis on experimental data
  - Submission of a project report in a technical paper form (motivation, related work, problem formulation, adopted methodology, results, conclusions & outlook)
  - Duration: mid of April - End of semester (~mid of June)
- Written Exam (20% of your final grade)

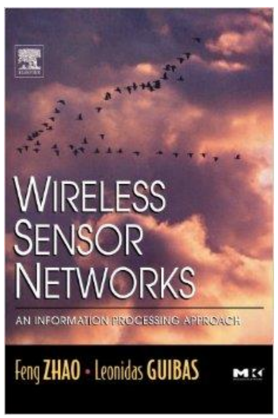
All above are compulsory for getting a grade at the end of the exam

About CS-541

Bibliography:



"Guide to Wireless Sensor Networks",S. Misra, I. Woungang, S. C. Misra, 2009, Springer



"Wireless Sensor Networks: An Information Processing Approach", F. Zhao, L. Guibas, 2004, Elsevier / Morgan Kaufmann

+ Handout notes, technical & research papers, etc. (distributed during lectures & available at CSD servers)

About CS-541

http://www.csd.uoc.gr/~hy541

- Contact Instructors & Teaching Assistant: hy541@csd.uoc.gr

- Course Email list: hy541-list@csd.uoc.gr

Introduction

Wireless Sensor Networks combine sensing, processing and networking over miniaturized embedded devices → **sensor nodes**

Key Features that differentiate them from conventional data networks

- Power autonomous (operating mainly on batteries)
- Highly scalable: distributed in scales of hundreds (or thousands)
- Operate in a **ad-hoc** manner, i.e., does not require fixed infrastructure (e.g. GSM or WiFi routers)
- Easy to deploy
- Cost-effective (cheap hardware)
- Low data rates (max 1Mbps)

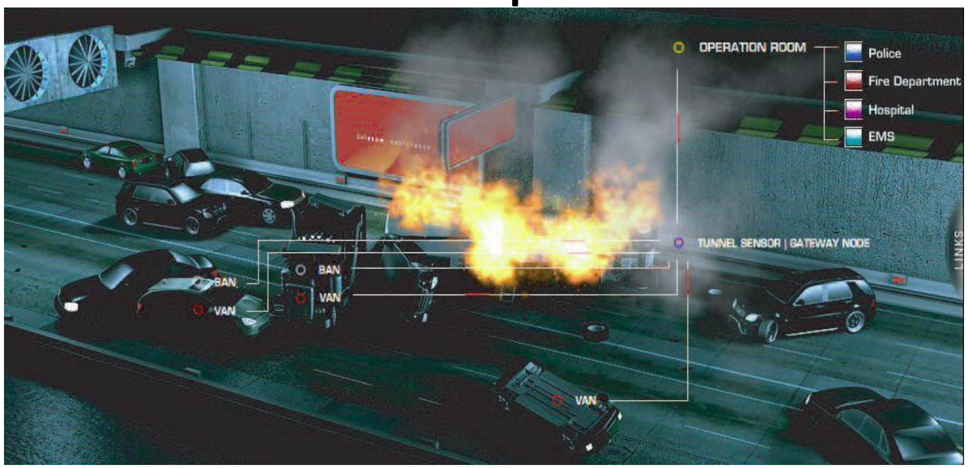
Introduction

Key characteristic that distinguishes them from remaining networks is the **reasoning of existence:**

- Collect information from the physical environment – regardless of how easily accessible that is;
- Couple the end-users directly to the sensor measurements (cyber to physical space);
- Provide information that is precisely localized (in spatio-temporal terms) according to the application demands;
- Establish a bi-directional link with the physical space (remote & adaptable actuation based on the sensing stimulus)

Introduction

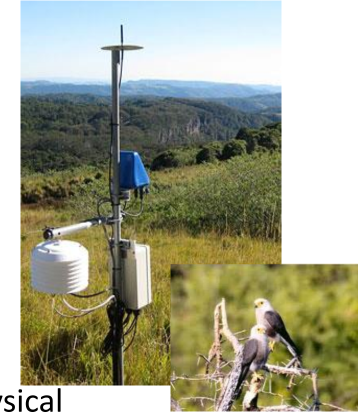
What: Necessary means for interacting with the "physical" space…



How: Distributed / Decentralized Network & Processing Algorithms on cheap hardware

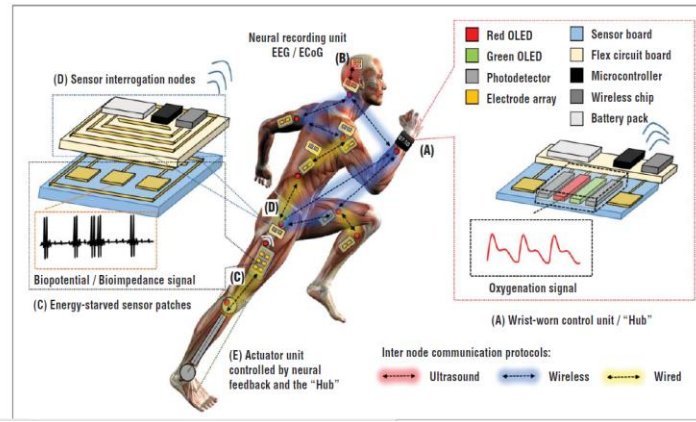
Allowing networking to become coupled with the needs of sensing, control and information semantics

Introduction



Application Areas: **Everywhere** there is a need for monitoring a physical space OR using sensors for controlling a procedure. For example:

- ➢ Industrial Control: Networked Control Systems – closing the industrial loop over WSN
- ➢ Environmental Monitoring & Agriculture: Wild Life Monitoring, Vineyards, Forest Fire Detection
- ➢ Structural Health Monitoring
- ➢ Marine monitoring: Ocean life & ecosystem
- ➢ Health Care: rehabilitation, prosthetics, chronic conditions management, emergency response
- ➢ Smart Homes – Smart Buildings – Smart Cities: Energy consumption monitoring and optimization, transportations & traffic management, etc



Introduction

The Golden Gate Bridge Case Study (Stanford Univ. - 2005)

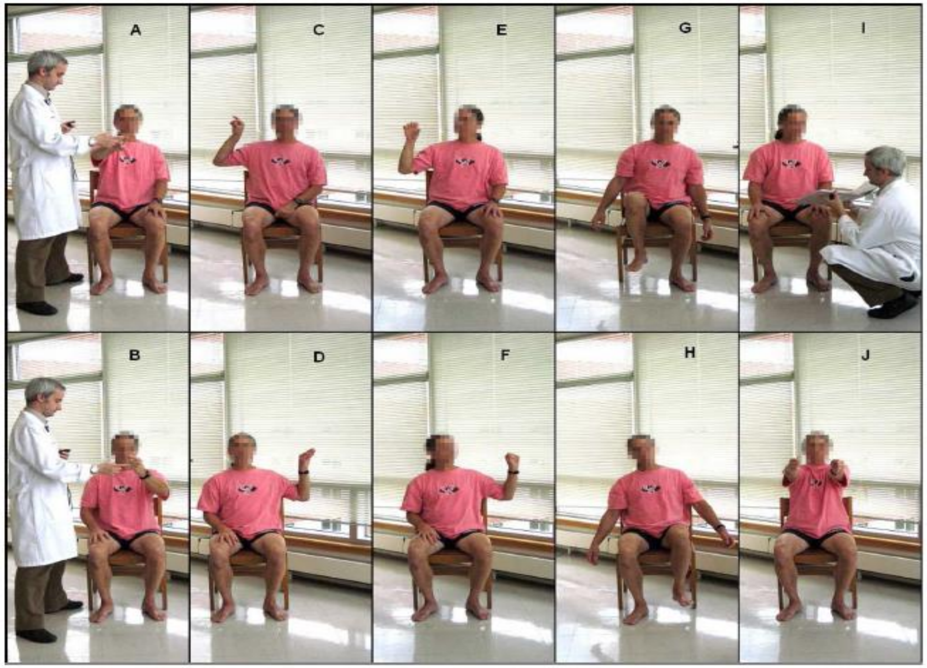
Objectives:

- determine the response of the structure to both ambient and extreme conditions
- compare actual performance to design predictions
- measure ambient structural accelerations from wind load
- measure strong shaking from a potential earthquake
- the installation and the monitoring was conducted **without the disruption of the bridge's operation**

WSN:

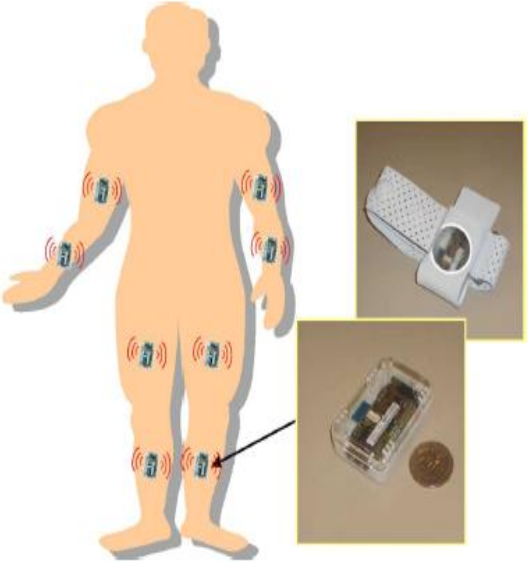
64 wireless sensor nodes
Synchronous monitoring of ambient vibrations
1 KHz rate, ≤10μs jitter, accuracy=30μg, over a 46-hop network

Introduction



Monitoring Parkinson's Disease (MIT - 2009)

- The aim is to augment or entirely replace a human observer and to help physicians fine-tune medication dosage
- 12 individuals participated at the study, performing simple tasks
- More than 80 days of continuous data collection @ 50Hz sampling rate



Introduction

- The SmartSantander Case Study (2011):

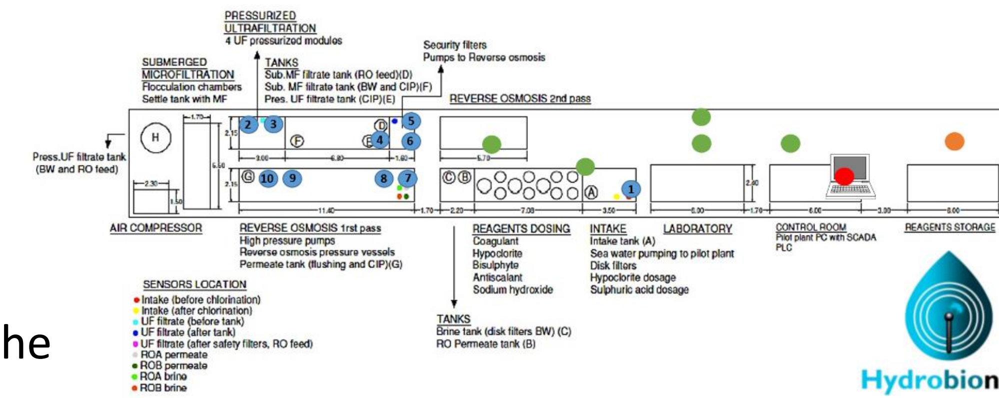
A city-wide testbed

Main WSN infrastructure with the following objectives

- Environmental Monitoring: 2000 sensing devices for temperature, CO, noise, light and car presence.
- Outdoor parking area management. 400 parking sensors, buried under the asphalt
- Mobile Environmental Monitoring: Sensors are installed in 150 public vehicles, including buses, taxis and police cars.
- Traffic Intensity Monitoring: 60 devices @ the main entrances of Santander for measuring main traffic parameters (traffic volumes, road occupancy, vehicle speed or queue length)

Introduction

By Twhair - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=36829194



Hydrobionets

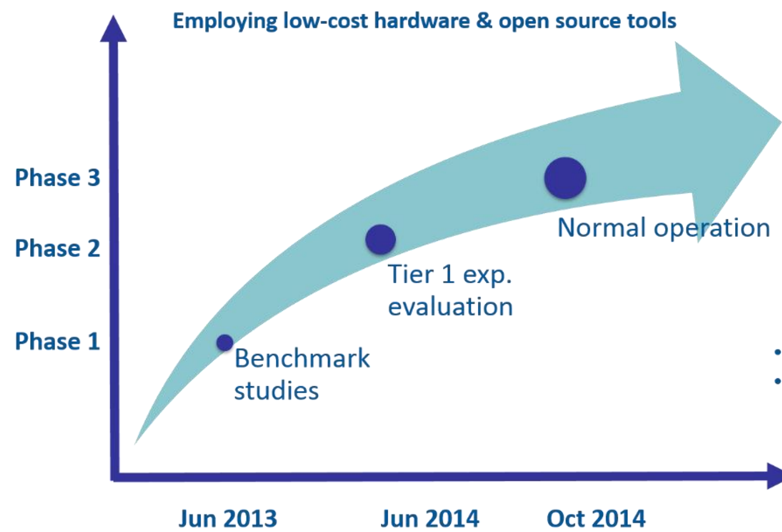
- The Hydrobionets Project (2014):

An industrial process for water desalination – the need for reducing energy

WSN – based industrial monitoring of the existence of unwanted bacteria in the water & the membranes

WSN protocol integrated protocol stack for operation in the industrial environment

Extensive field studies & 24/7 operation in industrial environment



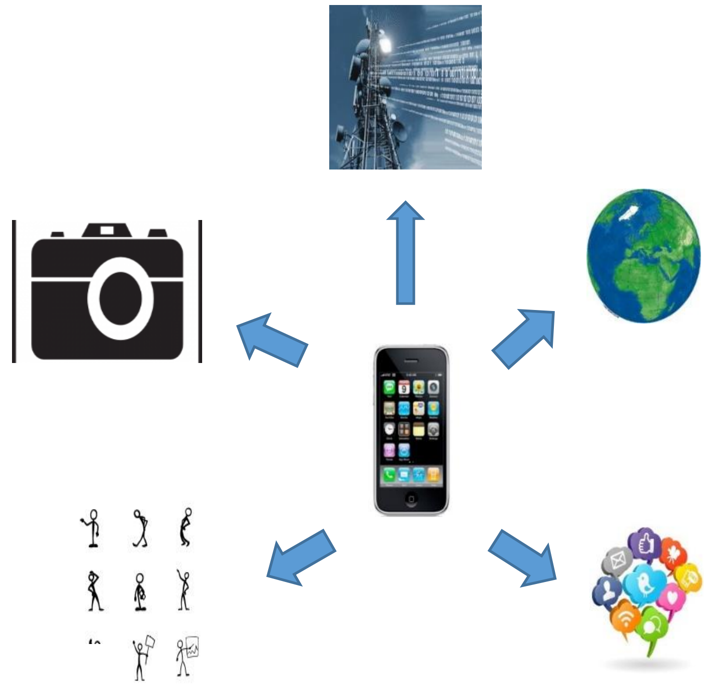
- 24/7 Operation
- Over 750,000 instances of **multi-hop** network traffic

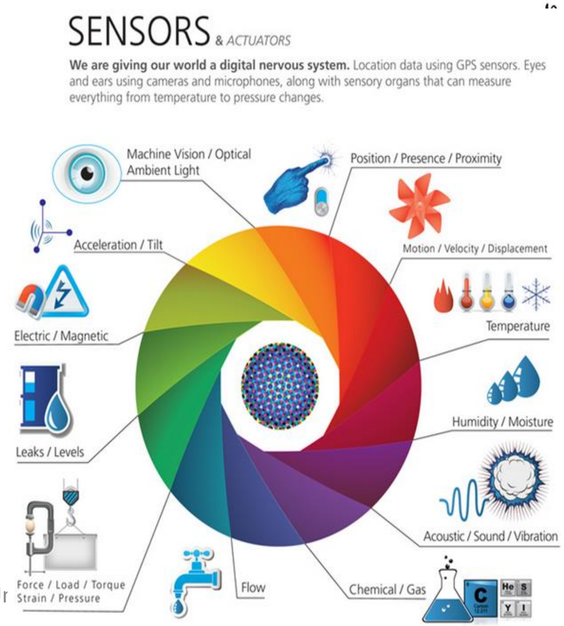
The IoT Revolution

https://www.youtube.com/watch?v=c-Ekz2kK7J4

The Internet of Things (IoT)

- By the end of 2014, the number of mobile-connected devices will exceed the number of people on earth, and by 2019 there will be nearly **1.5 mobile devices** per capita.
- **Mobile video traffic** exceeded **50%**of total mobile data traffic for the first time in 2012
- Almost **half a billion** (497 million) **mobile devices** and connections were added in 2014
- Globally, there were nearly **109 million wearable devices** in 2014 generating **15 petabytes** of monthly traffic.
- Globally, **46%** of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell in 2014
- Applications
  - Smart appliances
  - In-home medical sensors
  - Smart sensor tags (farm animals)
  - Smart cars
  - Smart weather umbrellas
  - Beacons



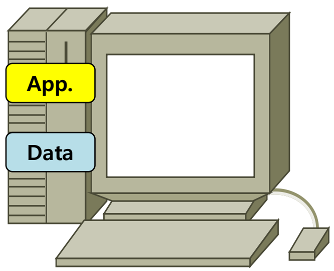


Enablers of the IoT

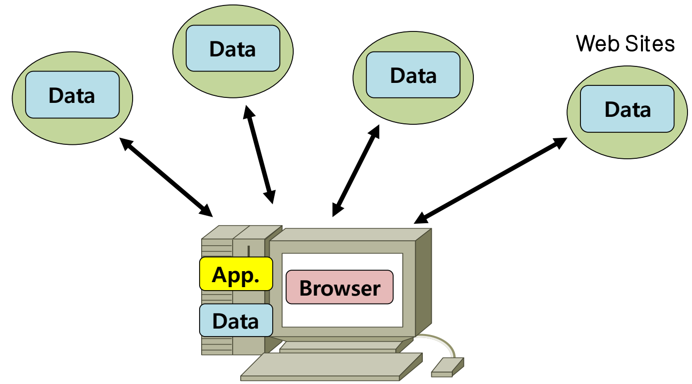
- **Cheap sensors** – Sensor prices have dropped to an average 60 cents from $1.30 in the past 10 years.
- **Cheap bandwidth** – The cost of bandwidth has also declined precipitously, by a factor of nearly 40X over the past 10 years.
- **Cheap processing** – Similarly, processing costs have declined by nearly 60X over the past 10 years, enabling more devices to be not just connected, but smart enough to know what to do with all the new data they are generating or receiving.
- **Smartphones** – Smartphones are now becoming the personal gateway to the IoT, serving as a remote control or hub for the connected home, connected car, or the health and fitness devices consumers are increasingly starting to wear.
- **Ubiquitous wireless coverage** – With Wi-Fi coverage now ubiquitous, wireless connectivity is available for free or at a very low cost, given Wi-Fi utilizes unlicensed spectrum and thus does not require monthly access fees to a carrier.
- **Big data** – As the IoT will by definition generate voluminous amounts of unstructured data, the availability of big data analytics is a key enabler.
- **IPv6** – Most networking equipment now supports IPv6, the newest version of the Internet Protocol (IP) standard that is intended to replace IPv4.

Some history

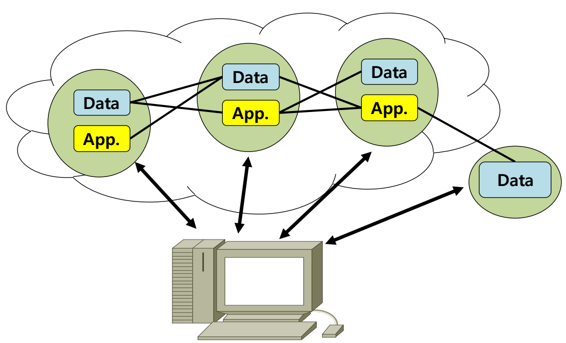
1st Phase – Stand Alone Computer



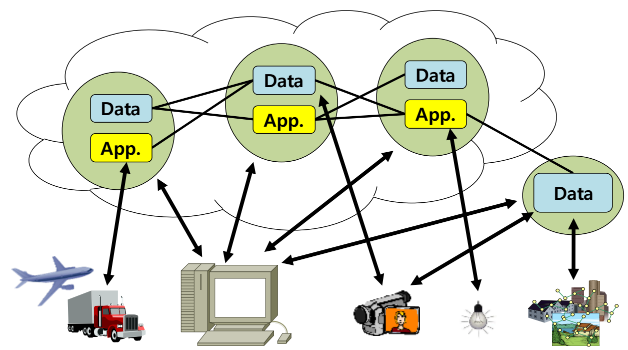
2nd Phase – The Web



3rd Phase – The Cloud



4th Phase – Cloud + IoT

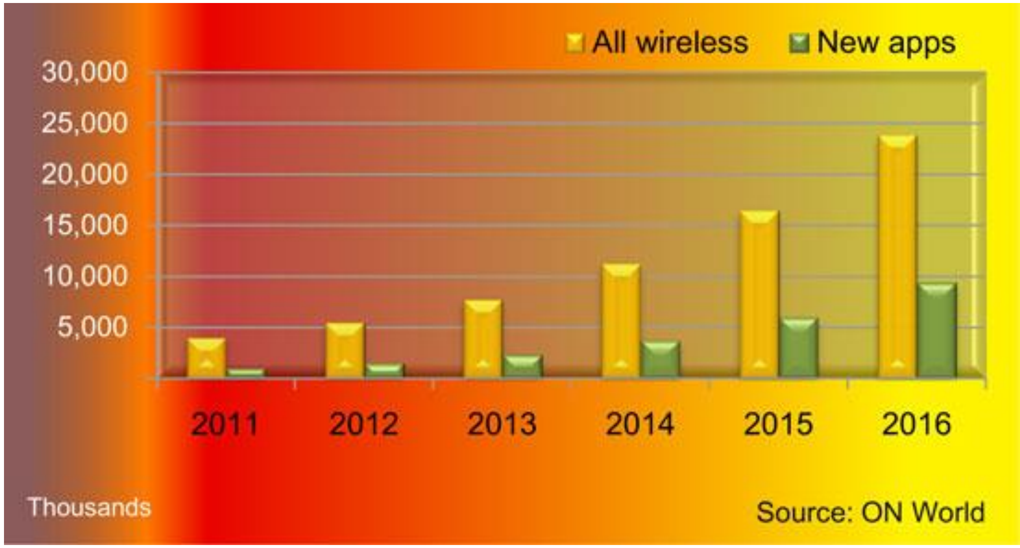


Introduction

- Market Size & Technological Trend

The global industrial wireless sensor network market size is estimated to grow from $401.23 Million in 2013 to **$944.92 Million by 2020.**

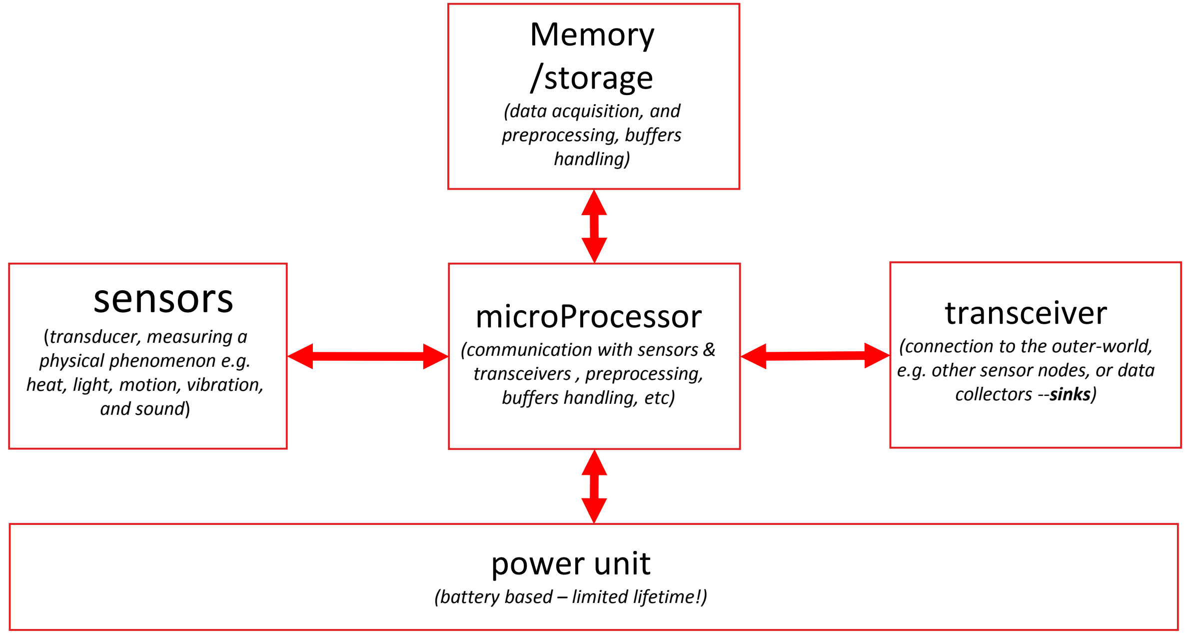
IDTechX:
The WSN market will grow to **$1.8 billion in 2024**
“Wireless Sensor Networks will eventually enable the automatic monitoring of forest fires, avalanches, hurricanes, failure of country wide utility equipment, traffic, hospitals and much more over wide areas, something previously impossible.”

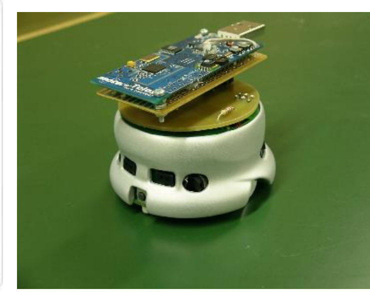


By 2016: 24 million wireless-enabled sensing points. *Source: On World Survey 2012*

Introduction

- Sensor Node
  - Basic unit in sensor network
  - Contains on-board sensors, processor, memory, transceiver, and power supply



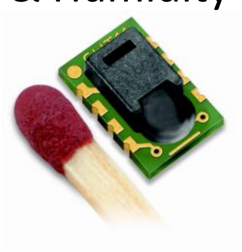


Introduction

Sensing Elements

- Sensors: capture a signal corresponding to a physical phenomenon (process, system, plant)
- Signal conditioning prepare captured signals for further use (amplification, attenuation, filtering of unwanted frequencies, etc.)
- Analog-to-digital conversion (ADC) translates analog signal into digital signal
- **Model to translate raw value to measurable unit**

Temperature & Humidity



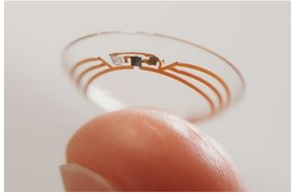
Image

Sound

Pressure

Vibration, Motion

Glucose (&biometrics)



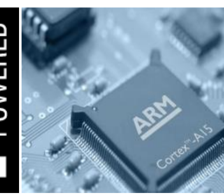
And many more….

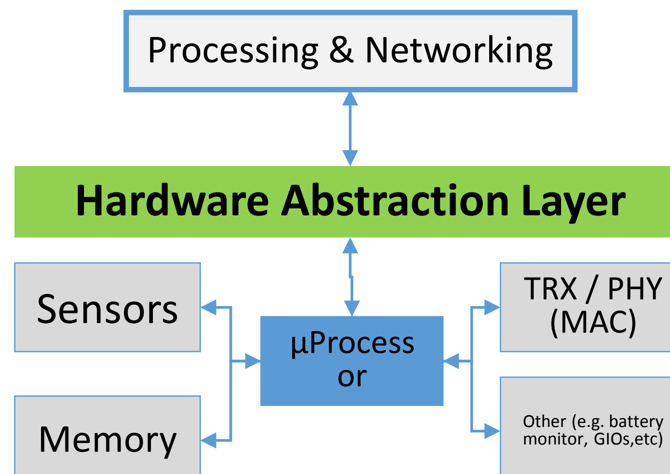
Introduction

Processing Elements

Traditionally: 16-bit archs

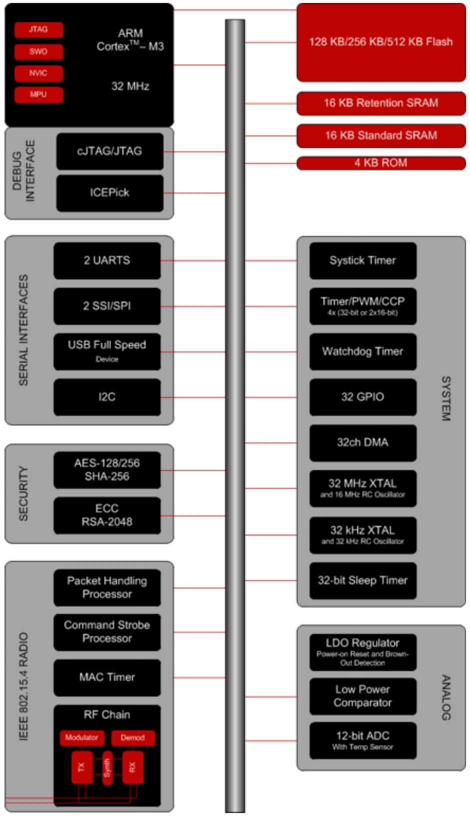
- Moving towards higher computational capacity (32 bit – ARM technologies)
- When programming a sensor node → programming its μProcessor to:
  - access the peripheral devices (transceiver, leds, sensors etc)
  - handle, store, modify the acquired information
  - Direct programming on the microprocessor (low level C / Assembly) OR using **Real-time Operating Systems**



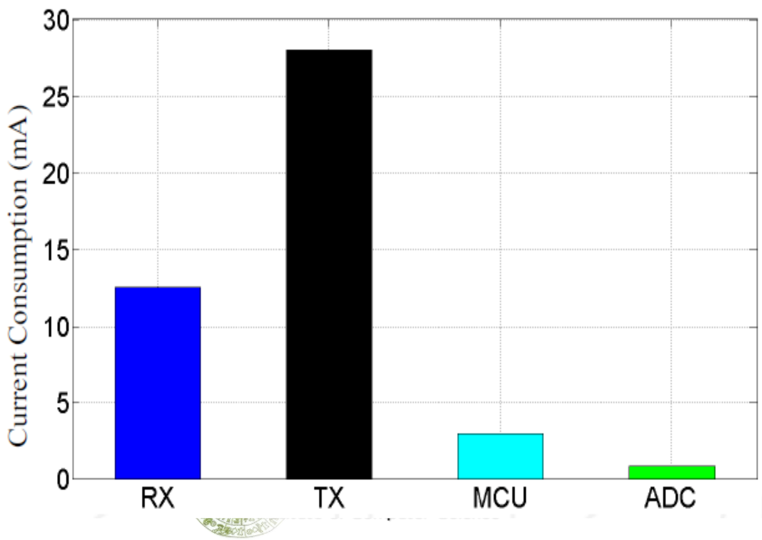


Introduction

Transceivers

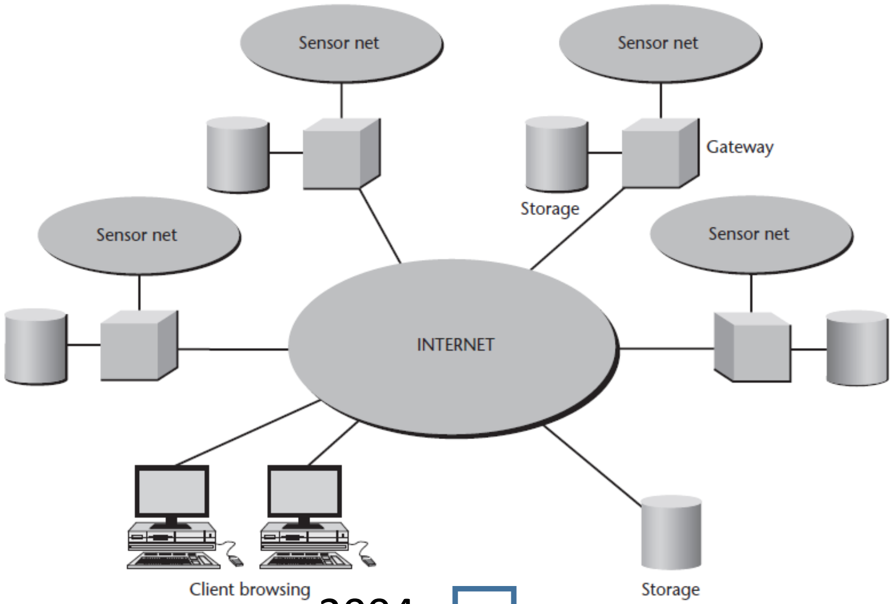


- Conventional: low-level PHY functionalities: frequency and channels, spectrum handling, modulation, bit rate. Advanced network functionalities and processing are implemented on software (i.e. microprocessor)
- Current Trend: System-on-Chip -> allows implementation of a sophisticated protocol stack on the chip (dedicated microprocessor & memory)
- Either way: it is the element with the highest power consumption
- **Radio Duty Cycling**: putting transceiver to different states:
  - Transmit / Receive
  - Idle: ready to receive
  - Sleep: significant parts of the chip are switched off



Introduction

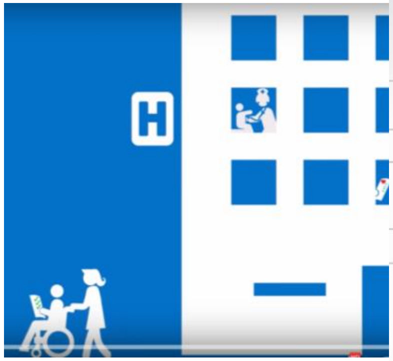
Interaction with the outer world

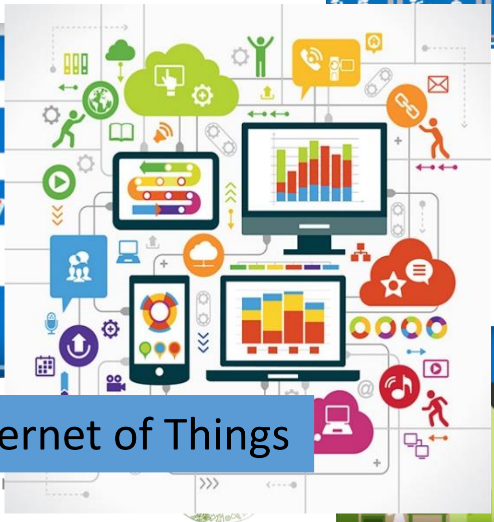


2004

2014-…

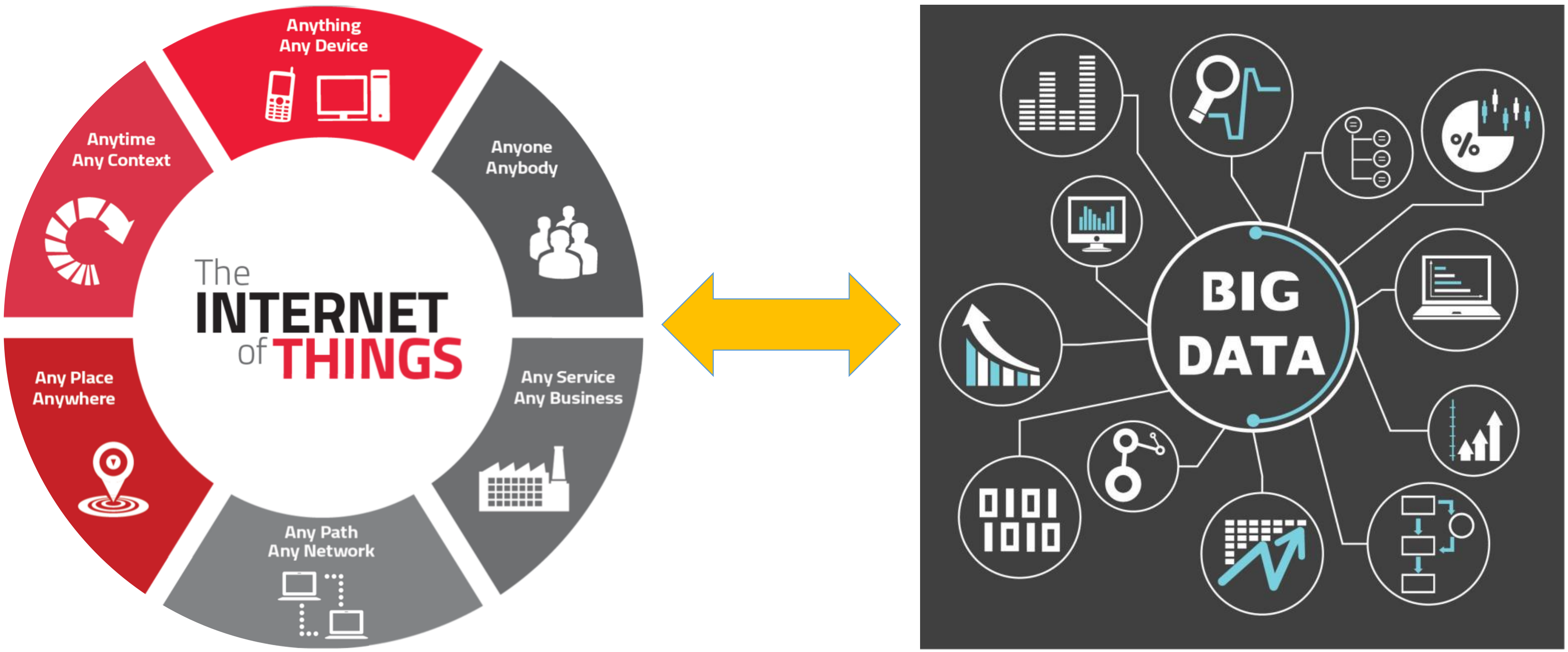
- Gateway: routes user queries or commands to appropriate nodes in a sensor network and sensor data, at times aggregated and summarized, to users who have requested it or are expected to utilize the information.
- Data repository/storage service: persistent data storage.
- *Data analytics & Provision of services*



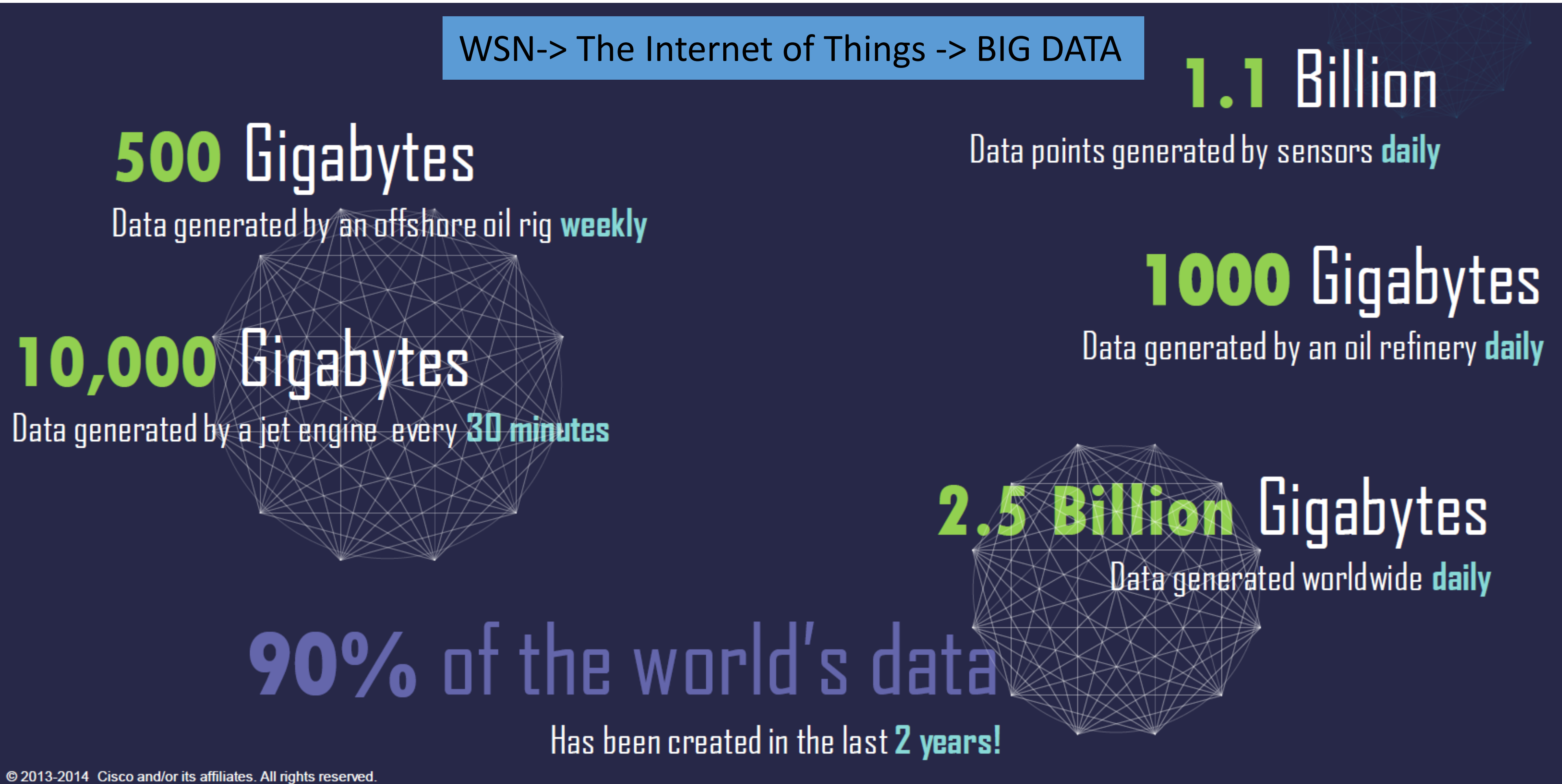


The Internet of Things

IoT Meets Big Data



Introduction

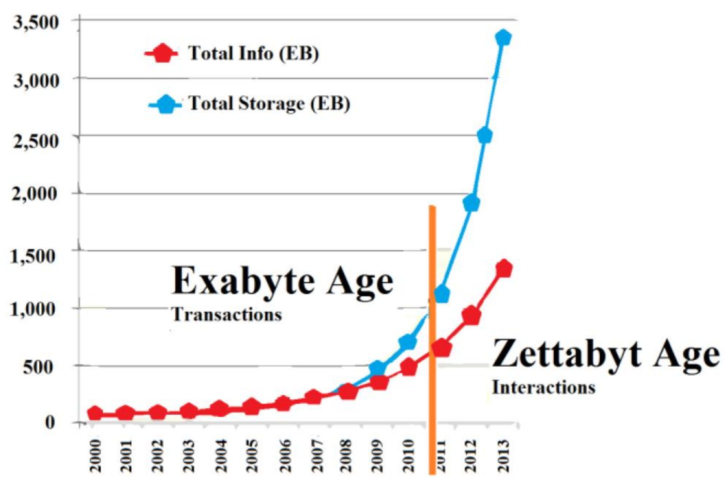


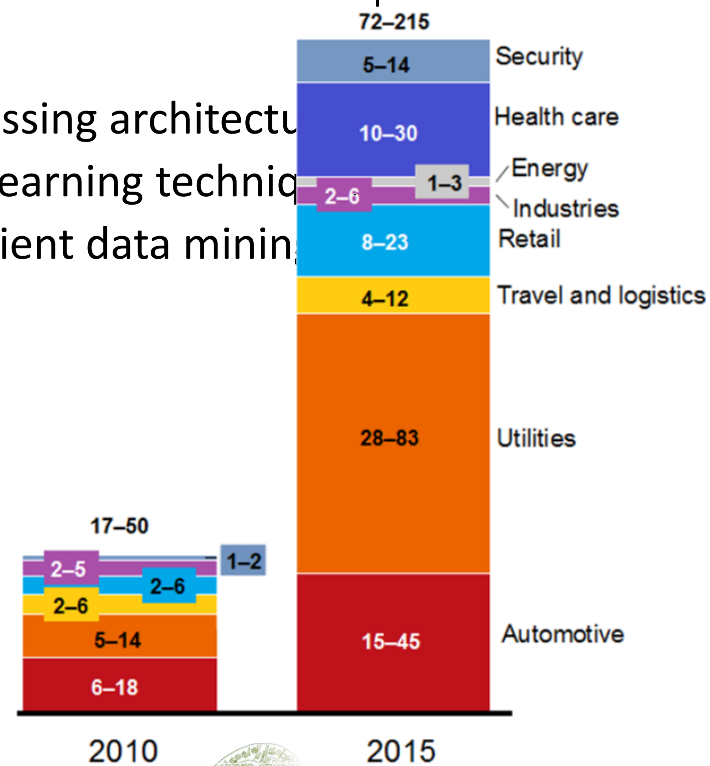
Big Data in WSN/IoT

Big Data

- **Volume**: size of data such as terabytes (TB), petabytes (PB), zettabytes (ZB),
- **Variety**: types of data from difference sources (sensors, devices, social networks, the web, mobile phones)
- **Velocity**: how frequently the data is generated (every millisecond, second, minute, hour, day, week, month, year.) Processing frequency may also differ from the user requirements.

- Challenges
  - High volume processing using low power processing architectu
  - Discovery of real-time data-adaptive Machine learning techniq
  - ovide efficient data minin

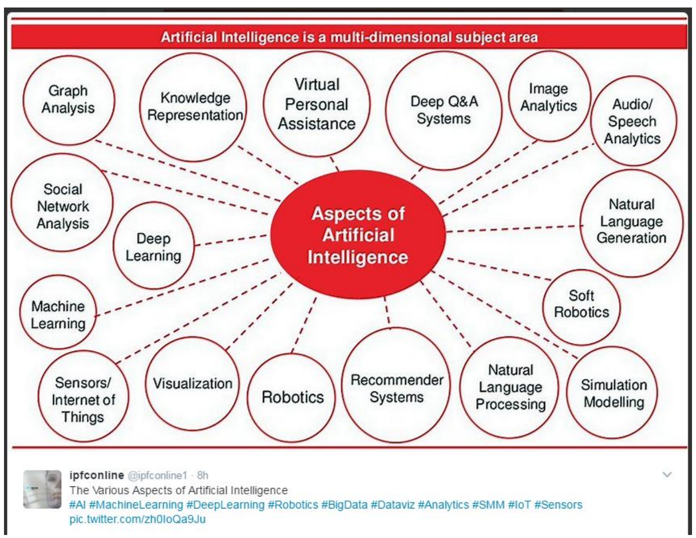


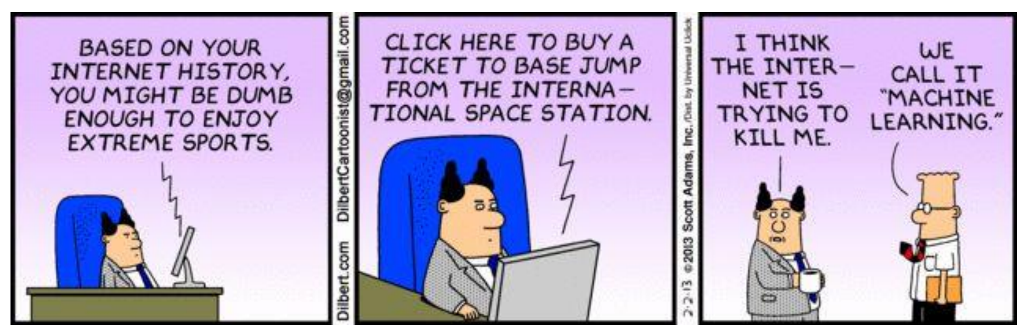


What to do with all this data

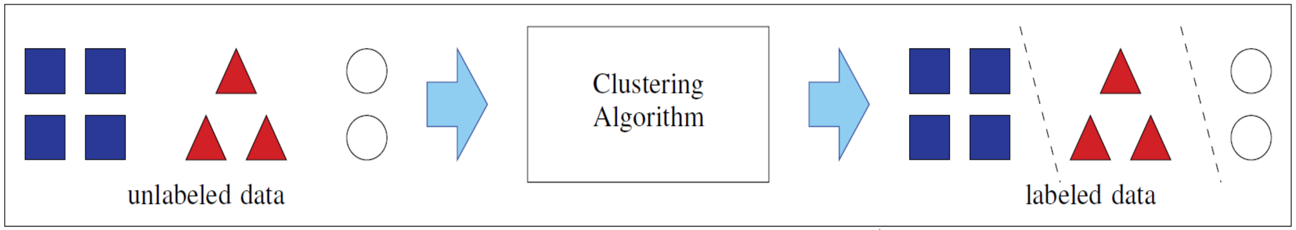
Machine Learning

- Checkers (1995)
- Chess (1997)
- jeopardy (2011)
- Go (2015)
- Poker (2017)



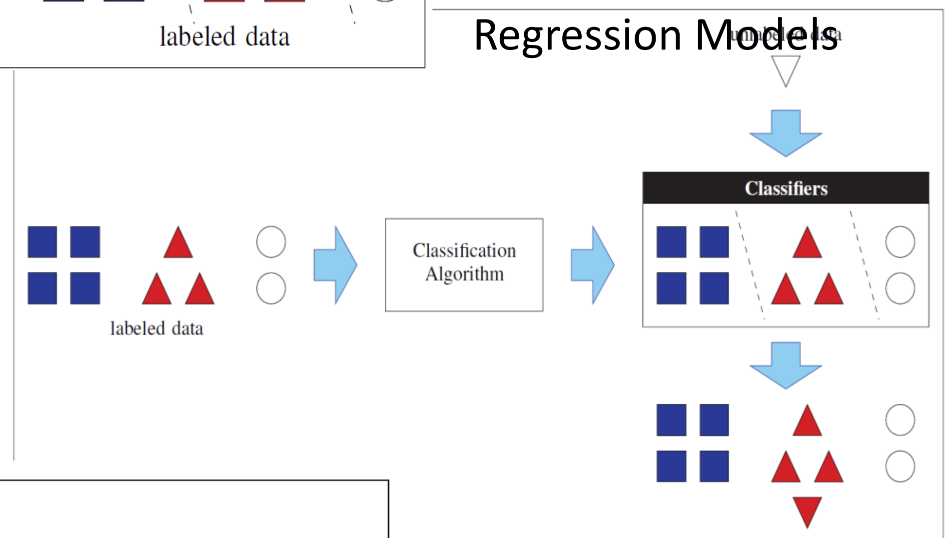


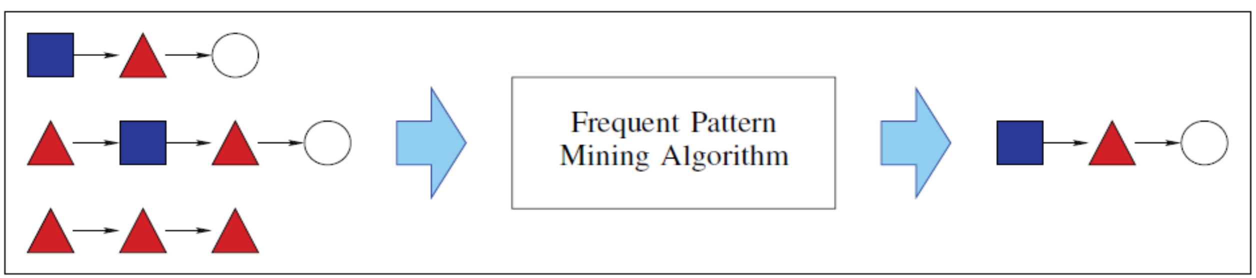
Key ML approaches



Support Vector Machines
Regression Models

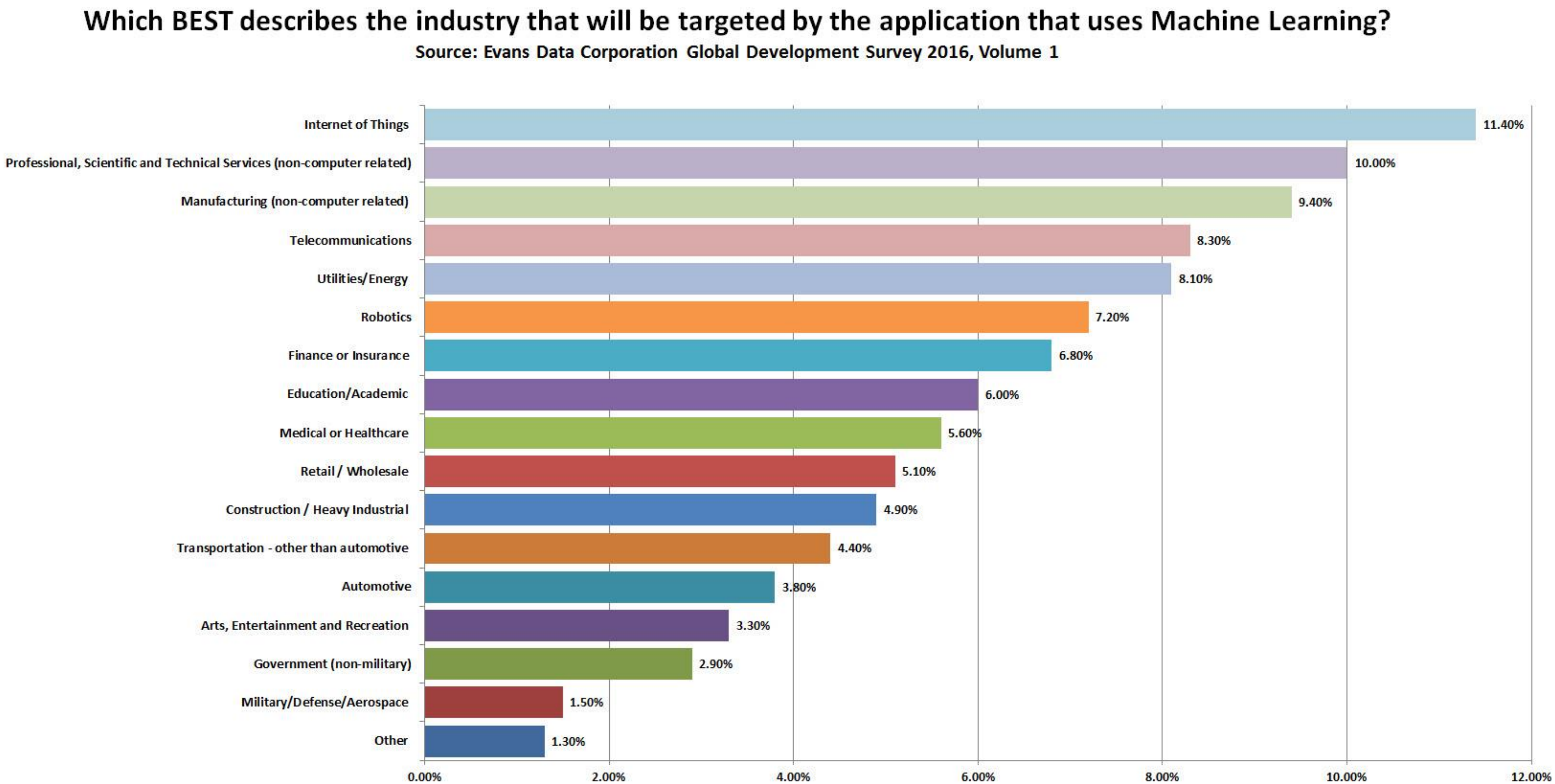
K-means
Spectral Clustering





Association rules
Distance learning

Applications



Introduction

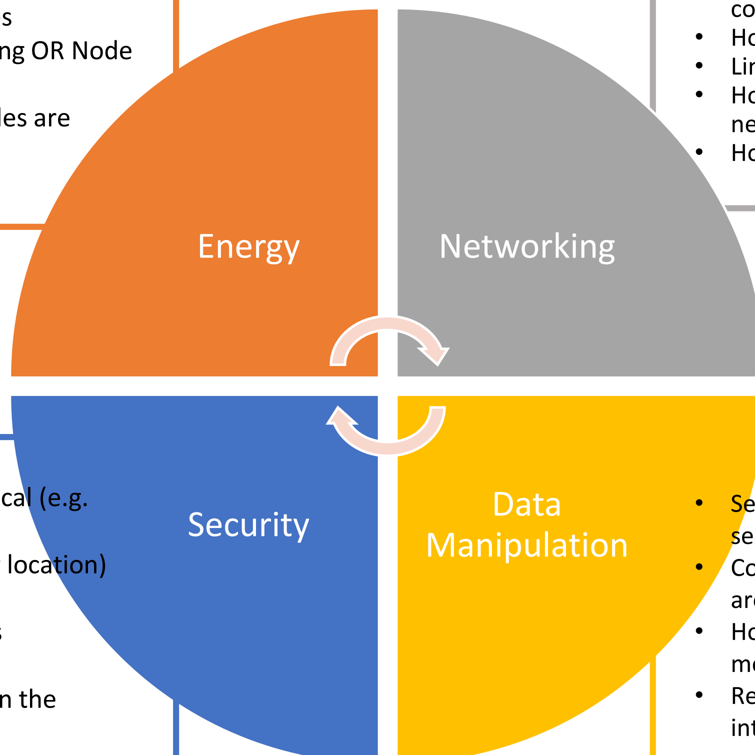
Putting things into perspective

Conventional Networks	WSN
General purpose design (many applications)	Serving a single application or a bouquet of applications
Network Performance and Latency	Energy is the primary challenge
Devices and networks operate in controlled / mild environments (or over an appropriate infrastructure)	Unattended, harsh conditions & hostile environments
Easily accessible	Physical access is difficult / undesirable
Global knowledge is feasible and centralized management is possible	Localized decisions – no support by central entity

Introduction

- Energy is limited
- Affects the lifetime of the WSN and the quality of sensing (analog sensors)
- Computation – Communication – Consumption Nexus
- Compromises its application objectives
- Recharging Batteries, Energy Harvesting OR Node Discarding?
- Dynamic topologies – even when nodes are static

- Self-organization -> Clustering?
- Re-Selection of optimal routes w.r.t to different metrics and environmental changes (and application demands)
- Energy conservative (TX is the most power hungry element)
- Cross-layer design – networking needs to couple to sensing purposes
- How to cope with delays and packet losses?
- Limited range
- How to cope with interference from "stronger" networks?
- How to retain QoS in RF harsh environments?



- Data are vulnerable (over RF) and critical (e.g. smart-grid data)
- Data are private (e.g. biometrics, your location)
- Computational complexity is poor and conventional cryptography algorithms (@computer networks) will not work
- WSN nodes are remote and exposed in the environment – physical tampering
- intrusion detection / node compromise by attacker, encryption, key establishment and distribution, node authentication, and secrecy.

- Sensing coverage – how to optimally place the sensor nodes?
- Computational complexity & storage capacity are limited
- How to cope with noisy and faulty measurements?
- Reduce dummy transmissions – increase the intelligence of the nodes -> Decentralized data models (different layers of data abstraction)
- How to combine heterogeneous, unstructured data to derive context (e.g. location)

WSN key challenges

Introduction

- Energy is limited
- Affects the lifetime of the WSN and the quality of sensing (analog sensors)
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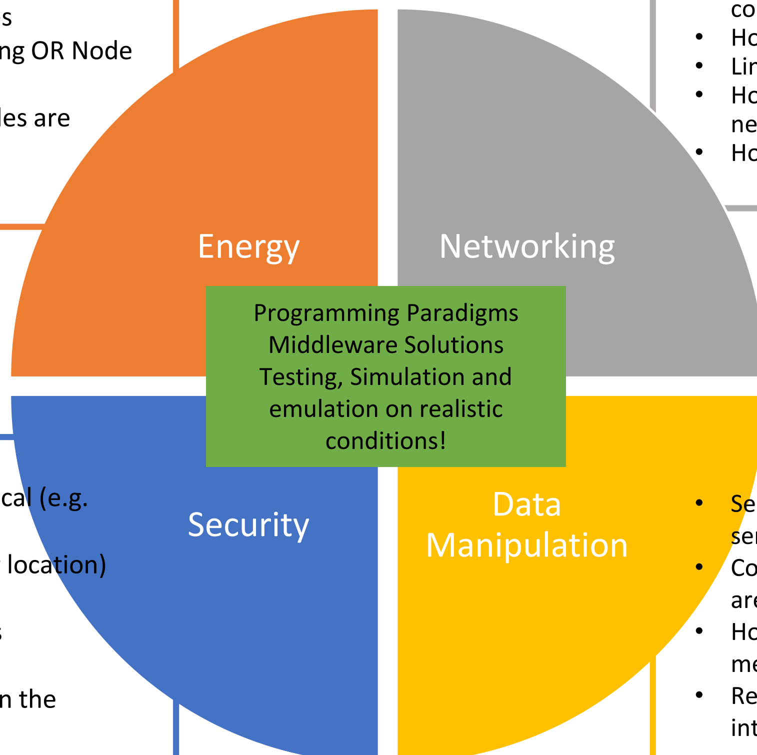
- Compromises its application objectives
- Recharging Batteries, Energy Harvesting OR Node Discarding?
- Dynamic topologies – even when nodes are static

- Self-organization -> Clustering?
- Re-Selection of optimal routes w.r.t to different metrics and environmental changes (and application demands)
- Energy conservative (TX is the most power hungry element)
- Cross-layer design – networking needs to couple to sensing purposes
- How to cope with delays and packet losses?
- Limited range
- Hoe to cope with interference from “stronger” networks?
- How to retain QoS in RF harsh environments?



- Data are vulnerable (over RF) and critical (e.g. smart-grid data)
- Data are private (e.g. biometrics, your location)
- Computational complexity is poor and conventional cryptography algorithms (@computer networks) will not work
- WSN nodes are remote and exposed in the environment – physical tampering
- intrusion detection / node compromise by attacker, encryption, key establishment and distribution, node authentication, and secrecy.

- Sensing coverage – how to optimally place the sensor nodes?
- Computational complexity & storage capacity are limited
- How to cope with noisy and faulty measurements?
- Reduce dummy transmissions – increase the intelligence of the nodes -> Decentralized data models (different layers of data abstraction)
- How to combine heterogeneous, unstructured data to derive context (e.g. location)

WSN key challenges

Introduction

In this course we will cover aspects related to Energy, Networking and Data Manipulation

- Energy is limited
- Affects the lifetime of the WSN and the quality of sensing (analog sensors)
- Computation – Communication – Consumption Nexus
- Compromises its application objectives
- Recharging Batteries, Energy Harvesting OR Node Discarding?
- Dynamic topologies – even when nodes are static

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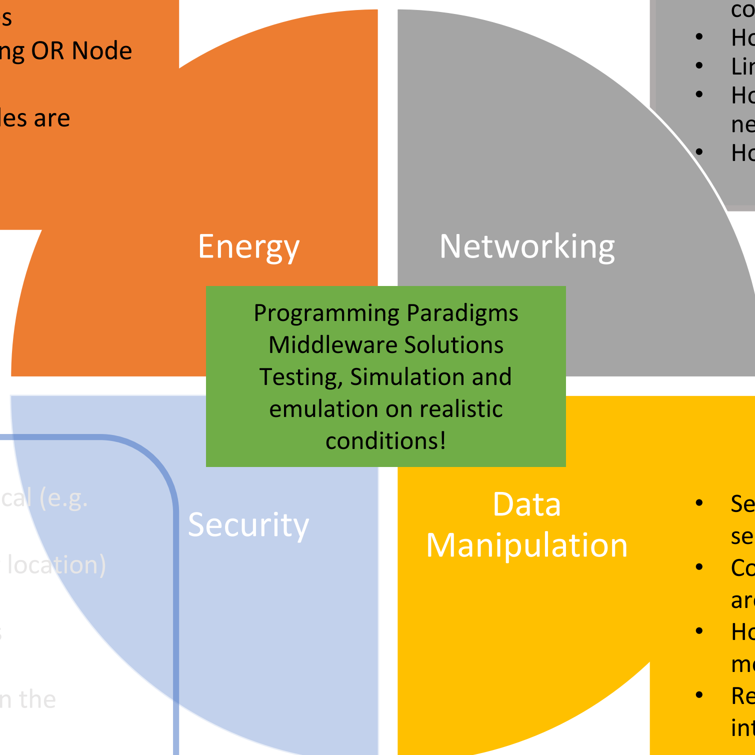

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WSN Challenges

References and Material for Reading

"Wireless Sensor Networks: An Information Processing Approach”, F. Zhao, L. Guibas, 2004, Elsevier / Morgan Kaufmann – Chapter 1

Slide Notes of “Fundamentals of Wireless Sensor Networks: Theory and Practice” , Waltenegus Dargie and Christian Poellabauer, 2010 – Chapter 1 and Chapter 2

Golden Gate Bridge project: http://www.cs.berkeley.edu/~binetude/ggb/

SmartSantander: http://www.smartsantander.eu/

Patel, S. et al. “Monitoring Motor Fluctuations in Patients With Parkinson's Disease Using Wearable Sensors.” Information Technology in Biomedicine, IEEE Transactions on 13.6 (2009): 864-873

The Hydrobionets project: http://www.hydrobionets.eu/

Pattrick Wetterwald, “Internet Of Things: 10 years later. Facts and Vision”, IEEE WF-IoT, 2015

Next Lecture

Lecture 1: Introduction to WSN and CS-541 course
Lecture 2: Protocol stacks, and wireless networks prerequisites
Lecture 3: Network standards for Personal and Body-area networks
Lecture 4: Signal processing prerequisites.
Lecture 5: Radio Duty Cycling in WSN
Lecture 6: Routing in WSN
Lecture 7: Deployment aspects in WSN
Lecture 8: Distributed Signal Processing for WSN
Lecture 9: Data models and data acquisition
Lecture 10: Machine Learning for WSN
Lecture 11: Introduction to WSN programming & Hands on Session(s)
Lecture 12: Applications of Machine Learning
Lecture 13: Over-the-air programming for WSN
Lecture 14: Localization and Tracking
Lecture 15:Invited Lecture
Lecture 16: Presentations of projects