Wireless Mobile & Multimedia Networking (7COM1076)

Internet of Things (part 1)

Dr Eric Chiejina
e.chiejina@herts.ac.uk

What is IoT?

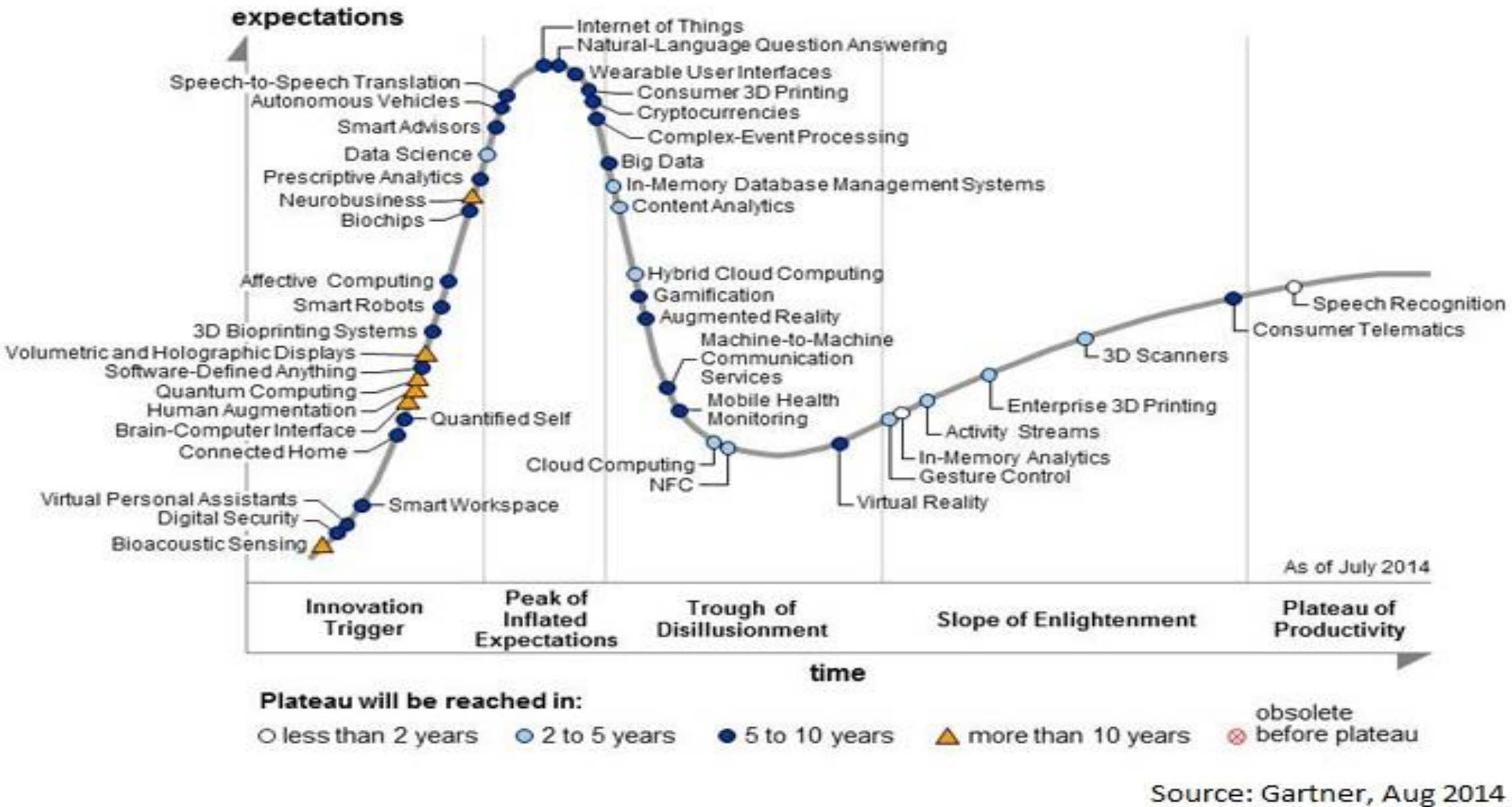
The **Internet of Things** (**IoT**) is the network of physical objects—devices, vehicles, buildings and other items embedded with electronics, software, sensors, and network connectivity—that enables these objects to collect and exchange data.

Motivation

- Ubiquitous Sensors
- Cheap Miniature Computers
- Low Power Communication
- Mobile Devices
- Cloud Power

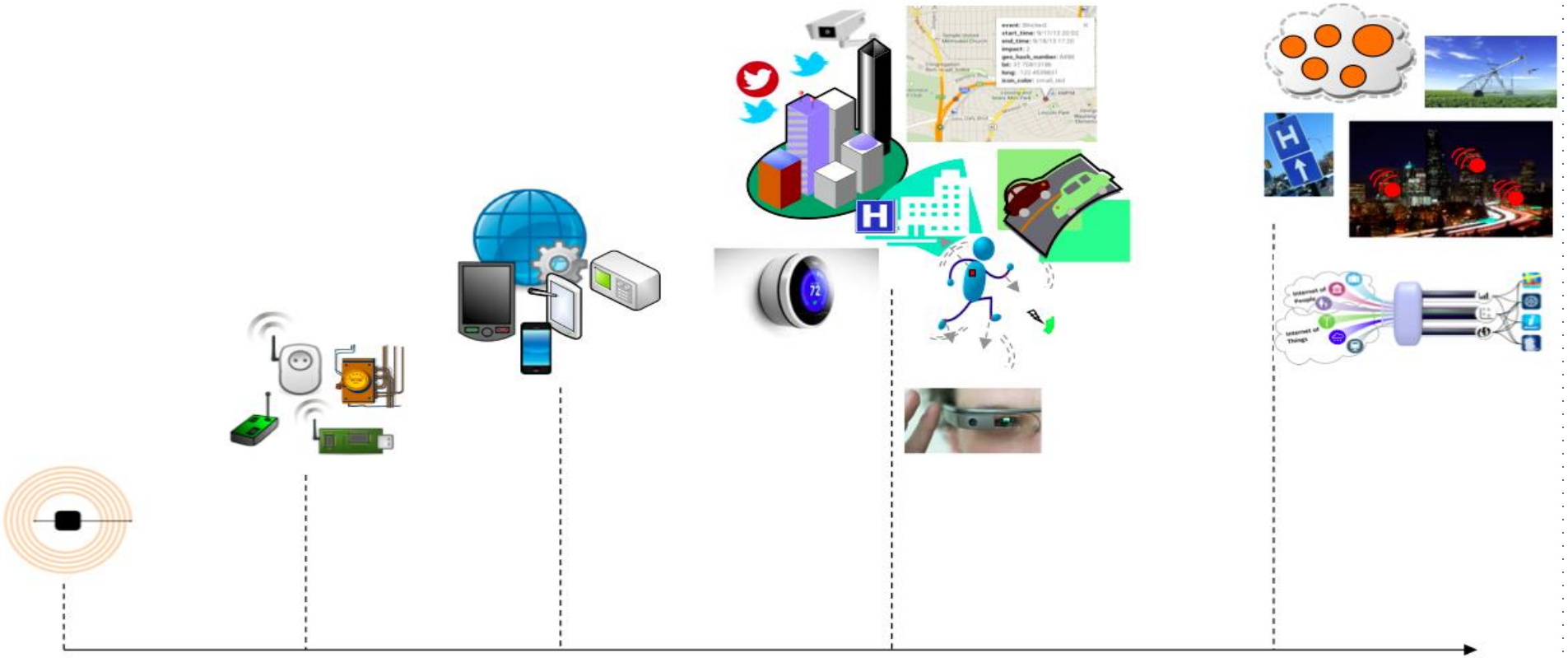
- Various Terminologies
  - Ubiquitous Sensor Networks
  - Machine to Machine
  - “Internet of Everything” (Cisco Systems)
  - “World Size Web” (Bruce Schneier)
  - Cloud of Things
  - Web of Things

Evolution Of IoT



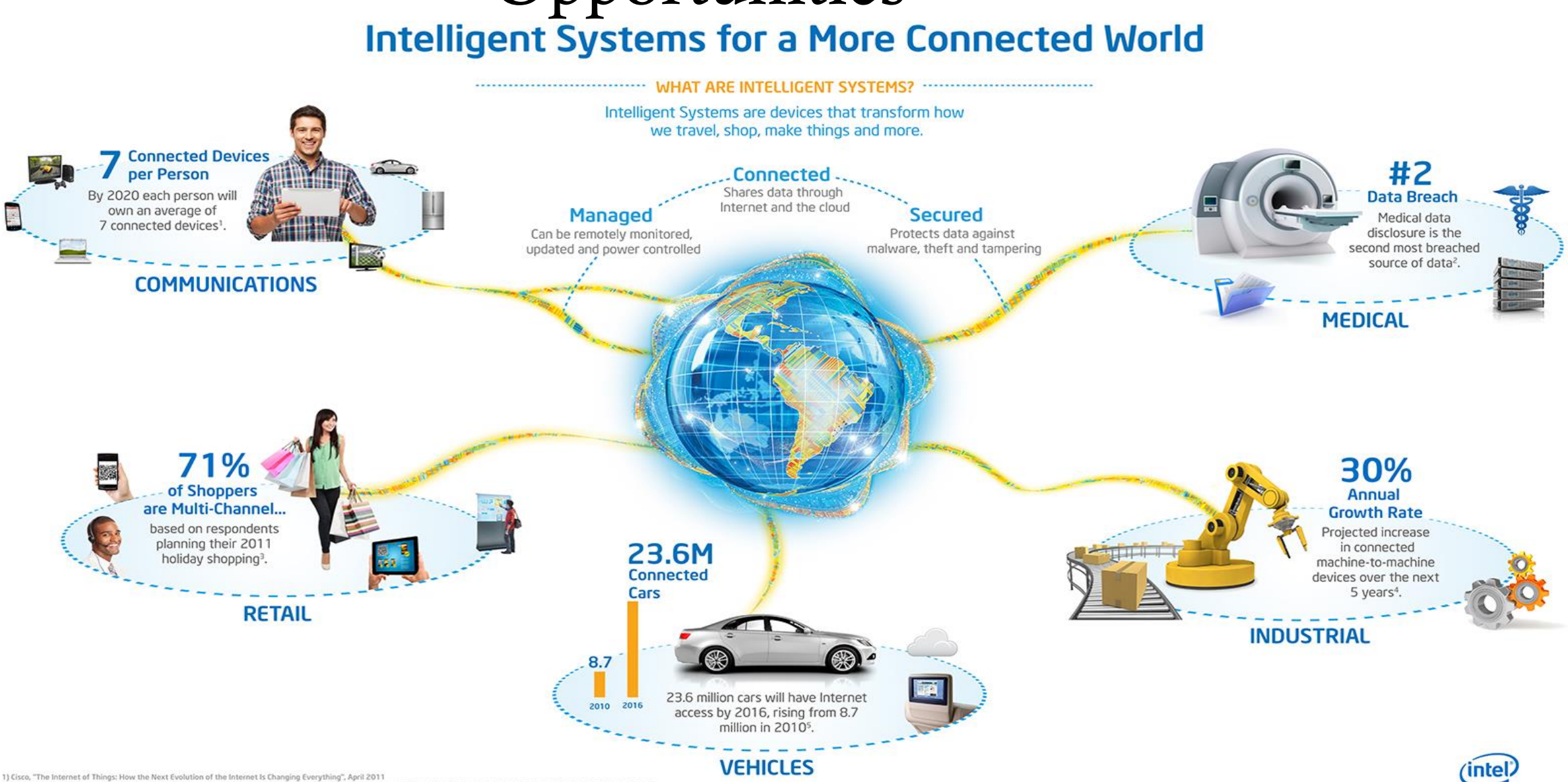
Source: Gartner, Aug 2014

Internet of Things - Progress

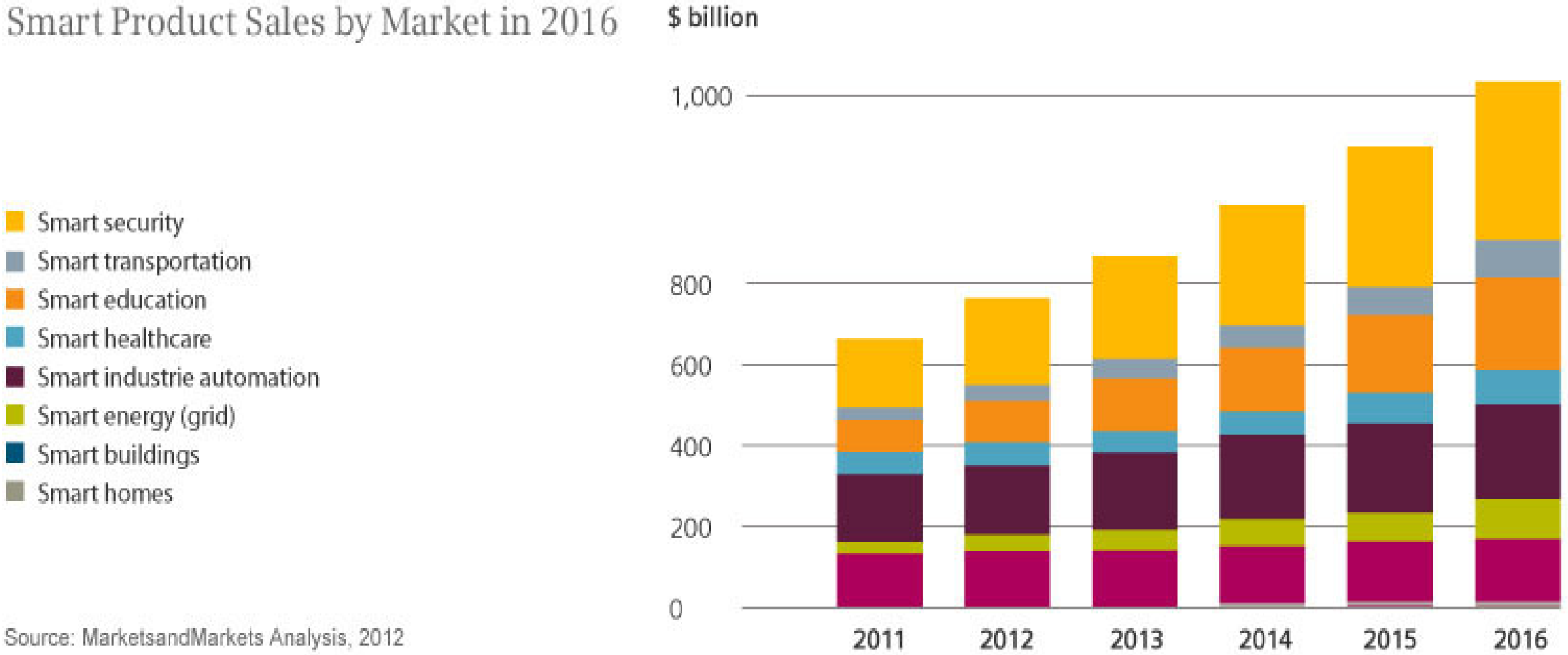


P. Barnaghi, A. Sheth, "Internet of Things, The story so far", IEEE IoT Newsletter, September 2014

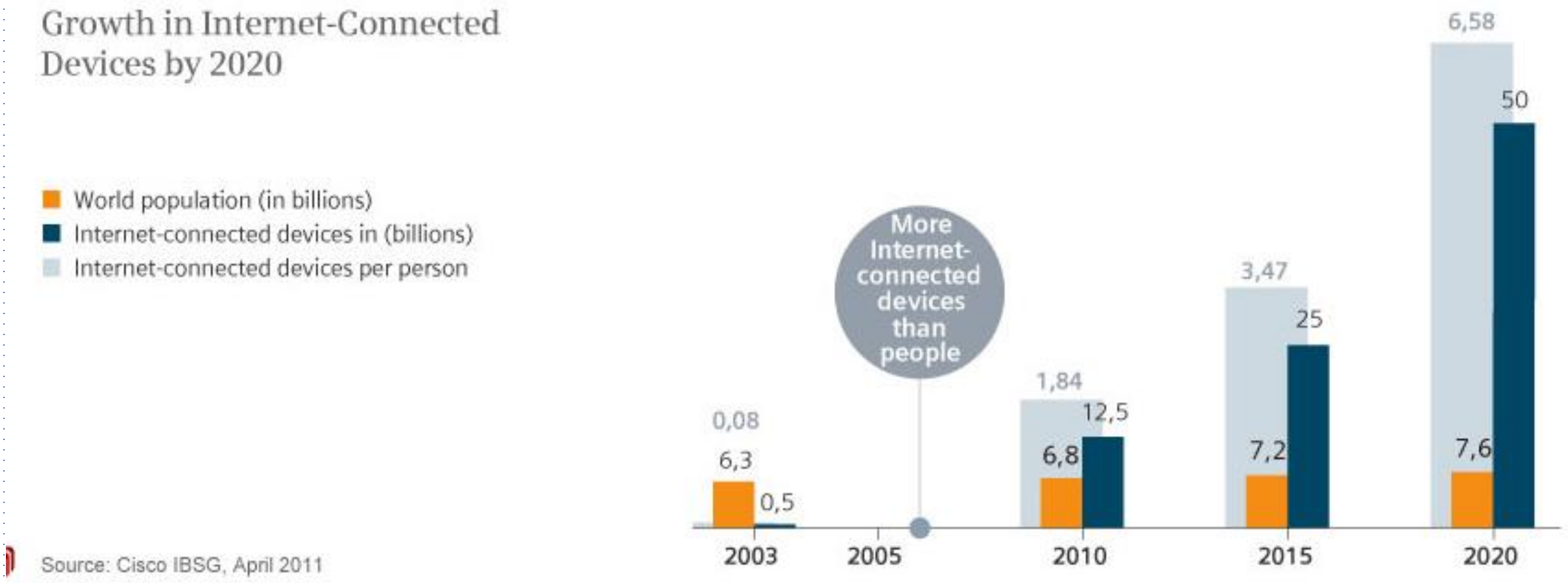
Opportunities



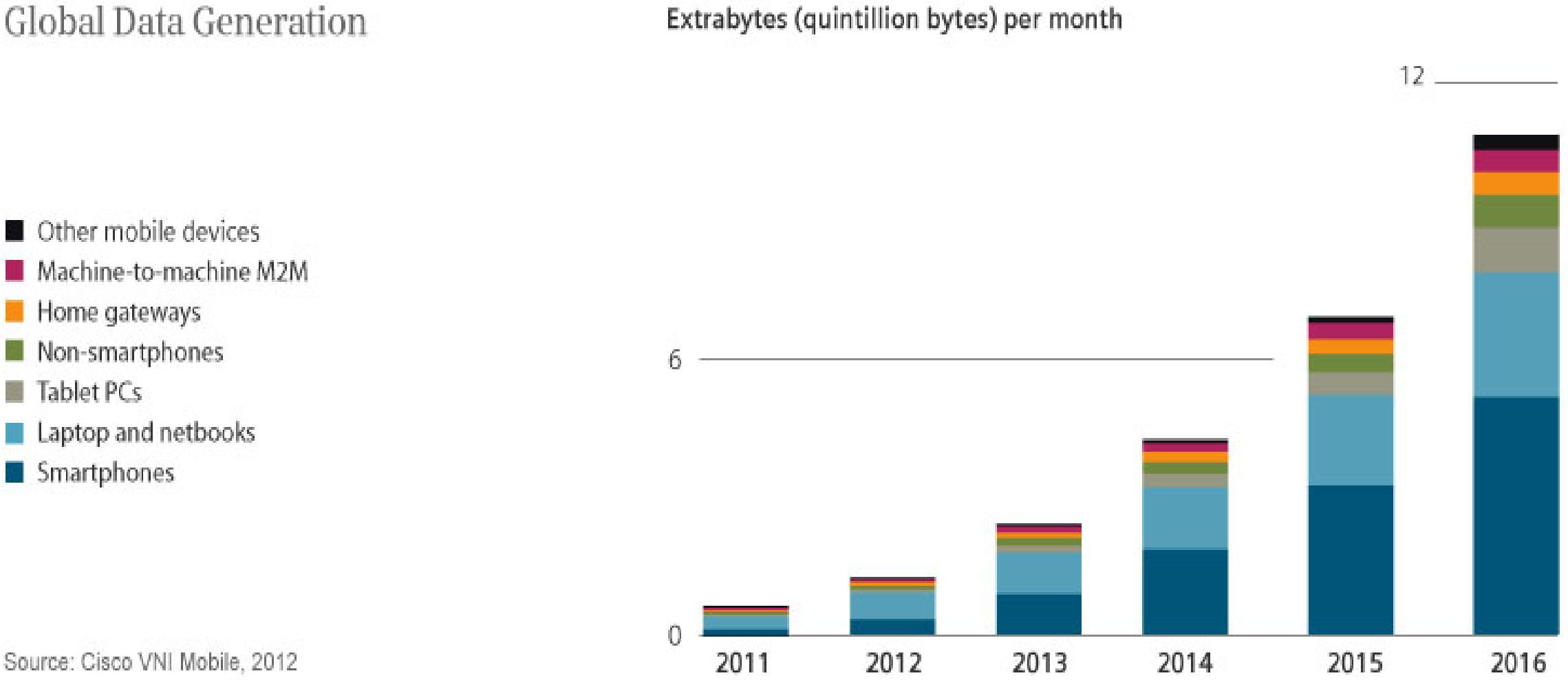
IoT Impact


Smart Product Sales by Market in 2016
$ billion
1,000
800
600
400
200
0
2011
2012
2013
2014
2015
2016
Smart security
Smart transportation
Smart education
Smart healthcare
Smart industrie automation
Smart energy (grid)
Smart buildings
Smart homes
Source: MarketsandMarkets Analysis, 2012

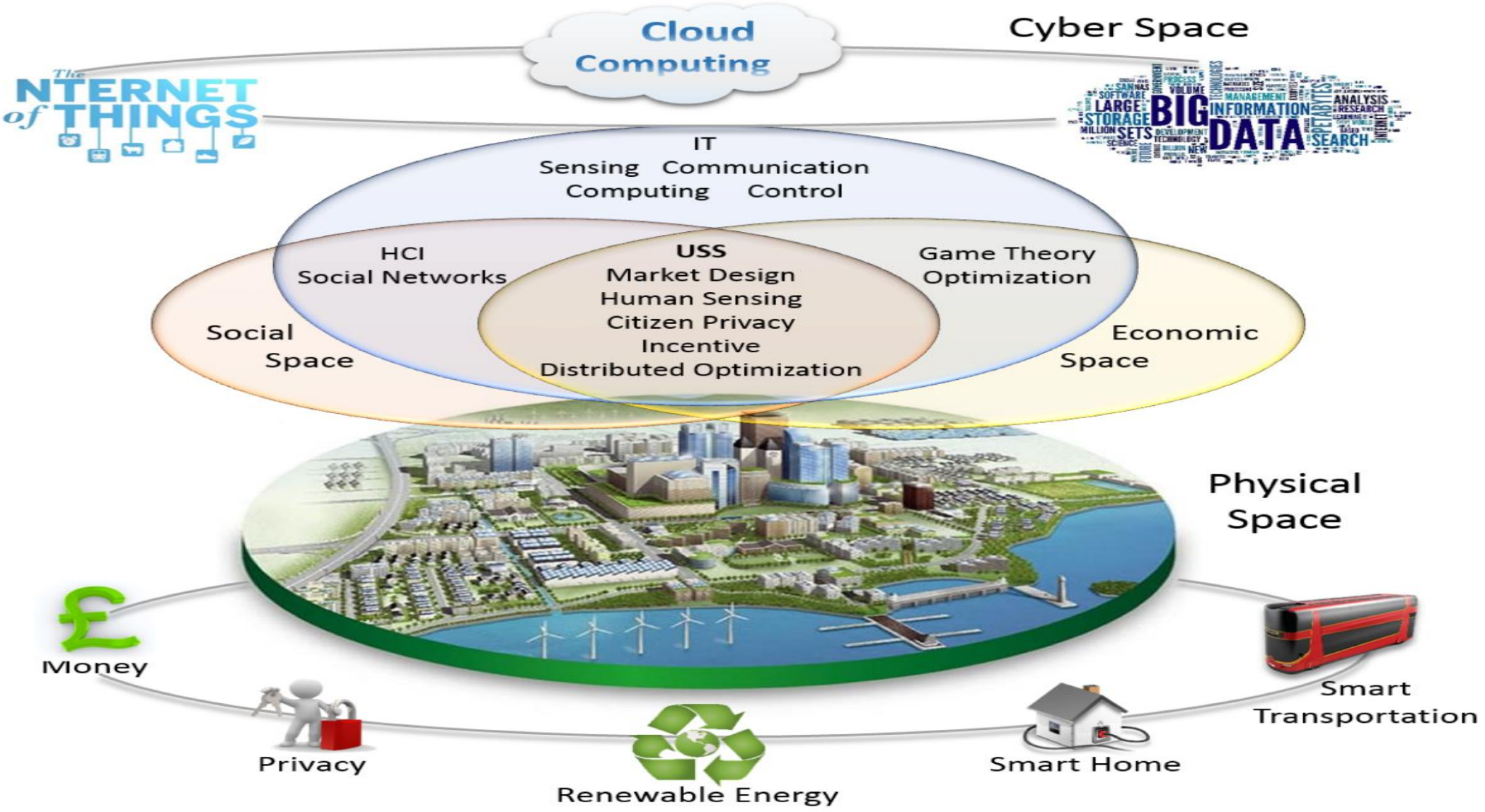
Internet Connected Devices



Data Generation



IoT Space


Cloud Computing
Cyber Space
The Internet of Things
BIG DATA
IT
Sensing Communication
Computing Control
HCI
Social Networks
USS
Market Design
Human Sensing
Citizen Privacy
Incentive
Distributed Optimization
Game Theory
Optimization
Social Space
Economic Space
Physical Space
Money
Privacy
Renewable Energy
Smart Home
Smart Transportation

Applications

Applications

- Smart Transportation
- Smart Buildings
  - Smart Home
- Smart City
- Smart Industry

https://www.youtube.com/watch?v=Q3ur8wzzhBU

Applications

Smart Home

Figure 2.3: Smart Home

(source: http://smarthomeenergy.co.uk/what-smart-home)

Smart Home Definition

What is a Smart Home? A Smart Home is "a dwelling incorporating a communications network that connects the key electrical appliances and services, and allows them to be remotely controlled, monitored or accessed. Remotely in this context can mean both within the dwelling and from outside the dwelling." King (2003).

King, N. (2003), 'Smart home - a definition', *Intertek Research & Testing Centre* .

Wearable IoT

- a technology that is wore on the human body

Figure 2.4: Wearable IoT
(source: https://dzone.com/articles/future-wearable-technology)

Figure 2.6: Smart Singapore
(source: http://www.innovationiseverywhere.com/smart-cities-asia/)

Smart City Definition

- “A Smart City is a system that enhances human and social capital wisely using and interacting with natural and economic resources via technology-based solutions and innovation to address public issues and efficiently achieve sustainable development and a high quality of life on the basis of a multi-stakeholder, municipally based partnership”, defined by Fernandez-Anez (2016)

- Fernandez-Anez, V. (2016), Stakeholders Approach to Smart Cities: A Survey on Smart City Definitions, Springer International Publishing, Cham, pp. 157–167. URL: http://dx.doi.org/10.1007/978-3-319-39595-116

Questions ?

Recap

- What is IoT?
- Evolution of IoT
- Applications
- Enablers
- Challenges

2nd Part - What We will Learn

IoT Architectures

Fog, Edge vs Cloud

Application

The IoT Architectural Challenges

- Decreasing cost and ubiquity of communication enabled devices paved the way towards numerous applications in various domains
- Dealing with the heterogeneity of devices, software, and access methods
- Different Requirements of each applications
- Interoperability

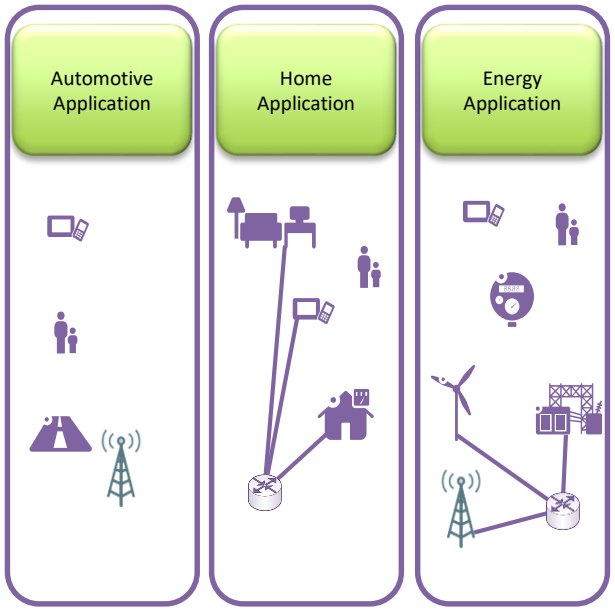
The IoT Architectural Challenges

- In the past years, several architectural standards and frameworks have emerged but documentation scattered and difficult to find in absence of a unified architecture.
- Several efforts to define common frameworks that overcome this crisis – ITU-T, 3GPP, ETSI, EC (via projects), industry consortium/players (e.g. OCF, Cisco).
- We will not cover all, but focus on the key principles these share and examine some examples.

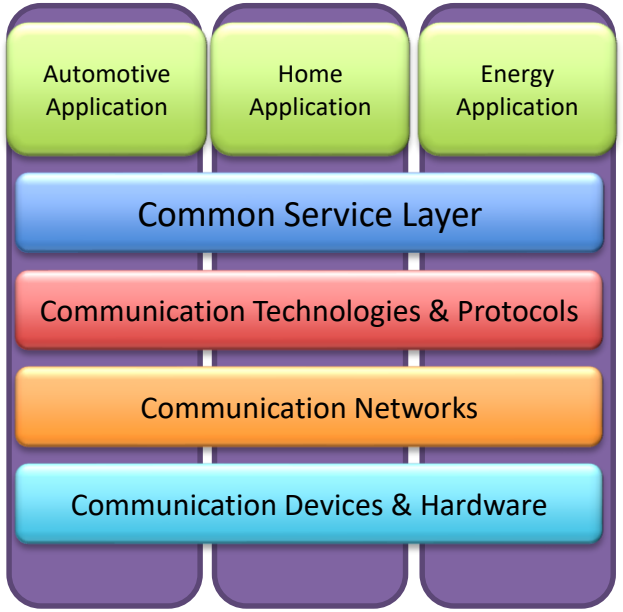
Key Considerations

- Application domains?
- Where to place the “intelligence”- Fog vs Cloud?
- Communication?
- Costs?

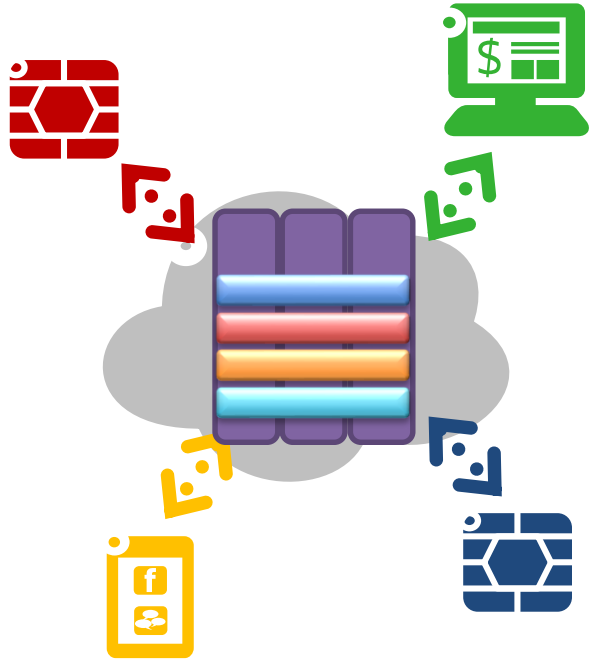
oneM2M IoT Architecture



Application Layer:



Services Layer:
Horizontal framework, Restful API

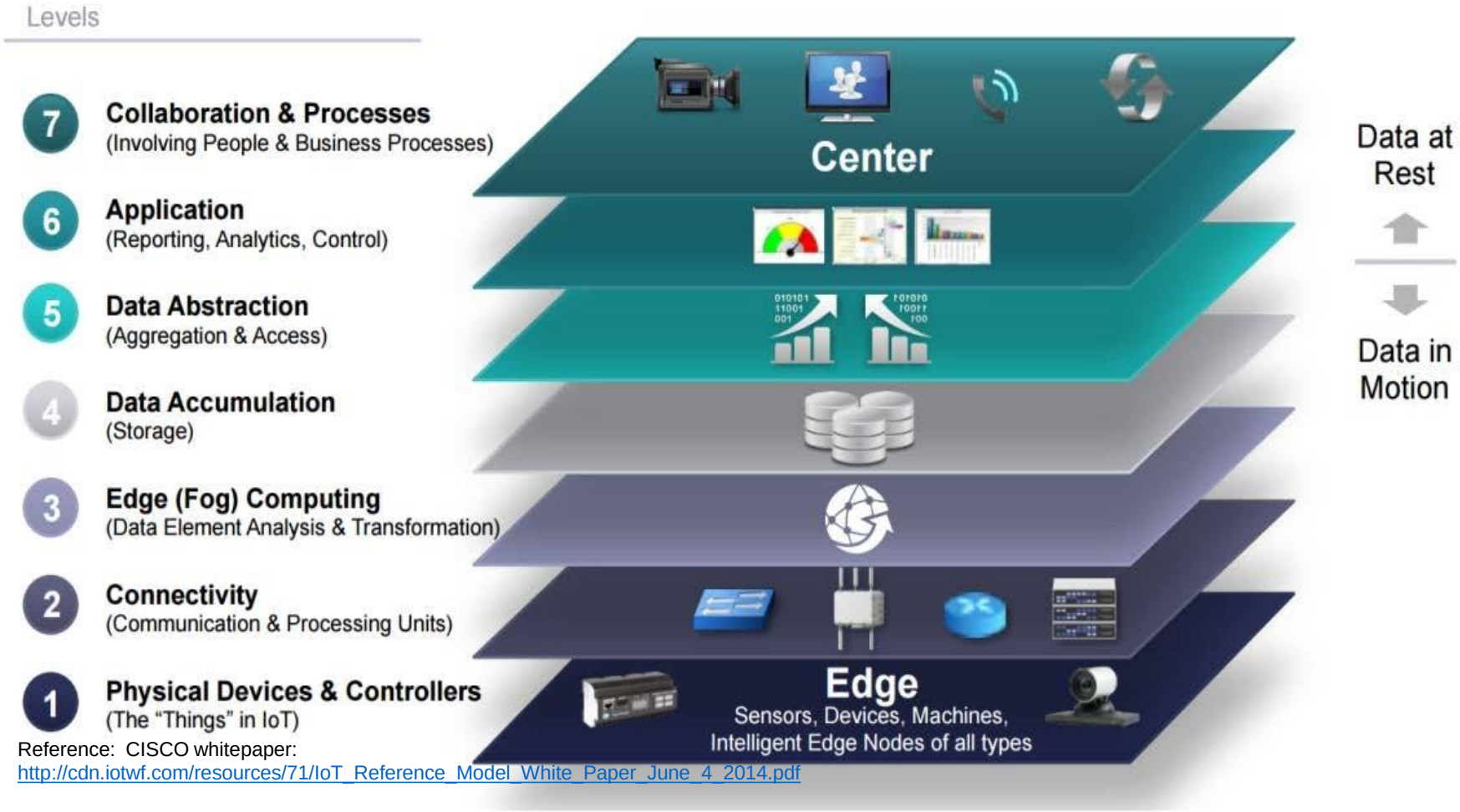


Network Layer

oneM2M Architecture

- Application Layer
  - Connectivity between devices and their applications
  - Standardize API definitions for interaction with business intelligence
- Services layer
  - Underlying management protocols, and the hardware
  - Common Services layer adds APIs and middleware supporting third-party services and applications
- Network layer
  - Devices and the communications network that links them
  - Communications infrastructure include wireless mesh technologies, such as IEEE 802.15.4, and wireless point-to-multipoint systems, such as IEEE 801.11ah.

The IoT World Forum (IoTWF) Standardized Architecture



Reference: CISCO whitepaper:
http://cdn.iotwf.com/resources/71/IoT_Reference_Model_White_Paper_June_4_2014.pdf

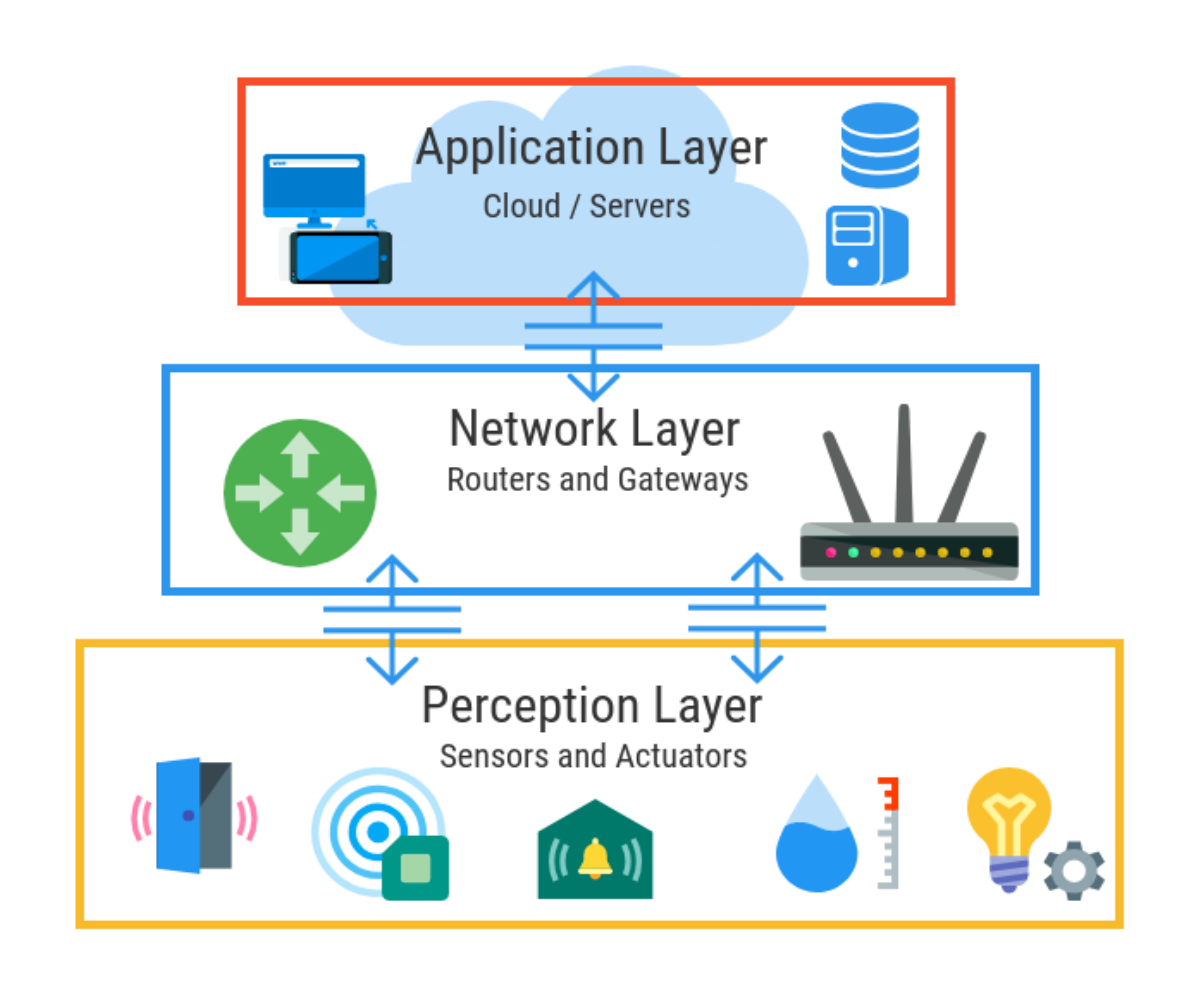
IoT Reference Model Layers

- **Layer 1: Physical Devices and Controllers Layer**
  - "Things" in the Internet of Things
- **Layer 2: Connectivity Layer**
  - Reliable and timely transmission of data.
- **Layer 3: Edge Computing Layer**
  - Data reduction and converting network data flows into information that is ready for storage and processing by higher layers

IoT Reference Model Layers

IoT Reference Model Layer	Functions
Layer 4: Data accumulation layer	Captures data and stores it so it is usable by applications when necessary. Converts event-based data to query-based processing.
Layer 5: Data abstraction layer	Reconciles multiple data formats and ensures consistent semantics from various sources. Confirms that the data set is complete and consolidates data into one place or multiple data stores using virtualization.
Layer 6: Applications layer	Interprets data using software applications. Applications may monitor, control, and provide reports based on the analysis of the data.
Layer 7: Collaboration and processes layer	Consumes and shares the application information. Collaborating on and communicating IoT information often requires multiple steps, and it is what makes IoT useful. This layer can change business processes and delivers the benefits of IoT.

A Simplified IoT Architecture



Layer 1: Perception Layer

Things: Sensors and Actuators

- **Power Requirements:**
- **Mobility**
- **Data Rate**
- **Data Characteristics**
- **Communication Range**
- **Sensors Density**

Layer 2: Network Layer

Access Network Sublayer

- **Range**
  - **PAN, HAN, FAN, LAN, WAN etc.**
- **Topology**
  - **Point-to-point, Point-to-multipoint, Mesh**
- **Gateways**

Layer 3 – Application Layer

Applications

- Analytics application:
- Control application:

Analytics

- Data analytics
- Network Analytics

Design Choices

- Data: storage and handling
  - storage location: local or cloud:
  - aggregation level (from raw data to a high level function), retention / history
- Application & control logic:
  - Application location: local (same managerial domain); remote (“in the cloud”)
  - centralized or distributed

IoT Data Management

- Cloud computing dominated the networked systems landscape until recently
  - End-devices merely information gatherers
  - All intelligence in the cloud (relational DBs, analytics, web interfaces, control functions)
- As the number of devices grow exponentially, applications diversify and generate more data, this will not scale
  - Routing and storage costs
  - Signalling overheads
  - Latency inappropriate for real-time apps

Data analysis closer to the IoT system

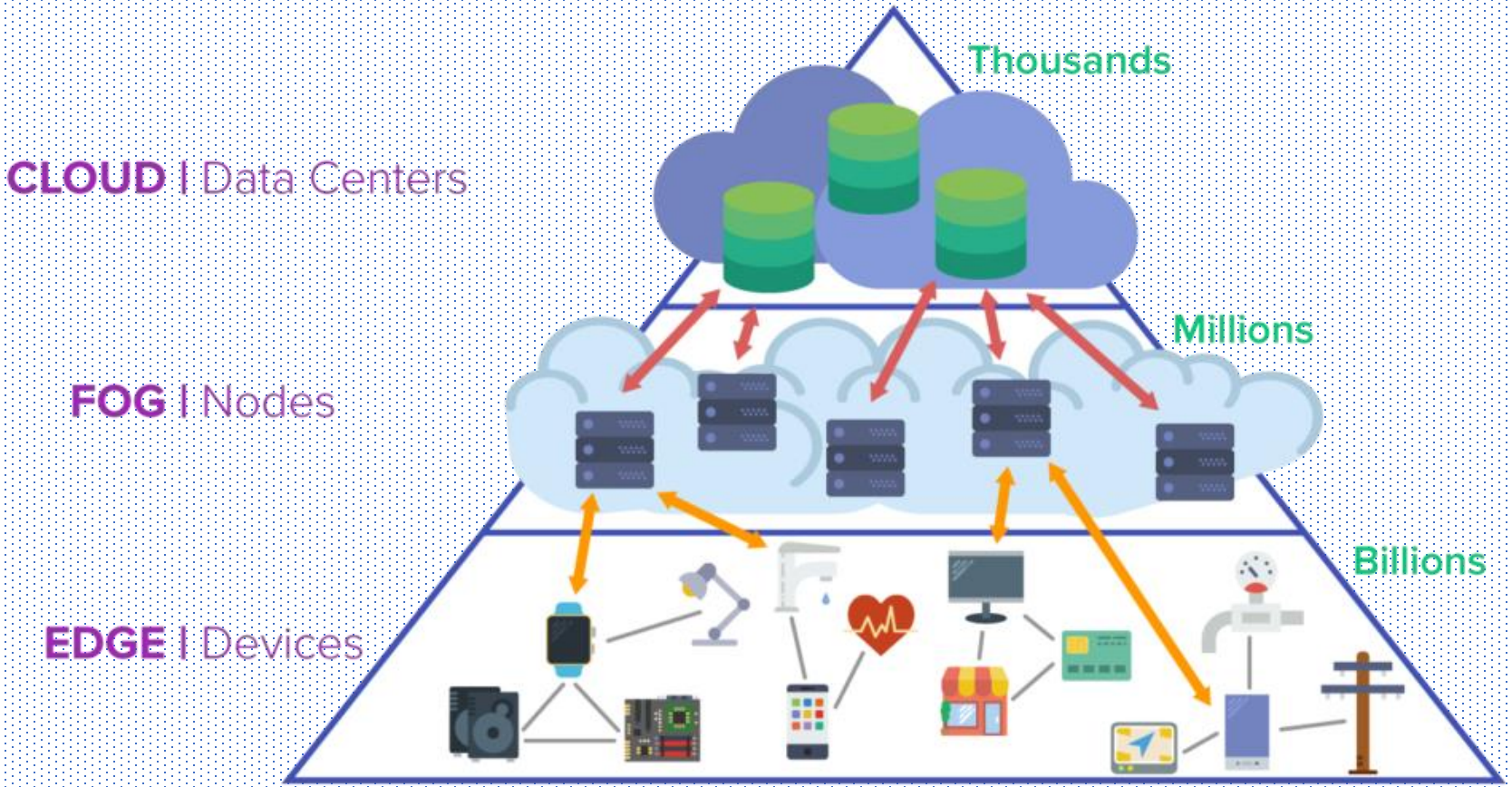
Requirements

- Minimizing latency:
- Conserving network bandwidth
- Increasing local efficiency:

Solutions

- Fog computing
- Edge computing

The Hierarchy of Edge, Fog, and Cloud



Source: pubnub.com

Direct data Indirect data

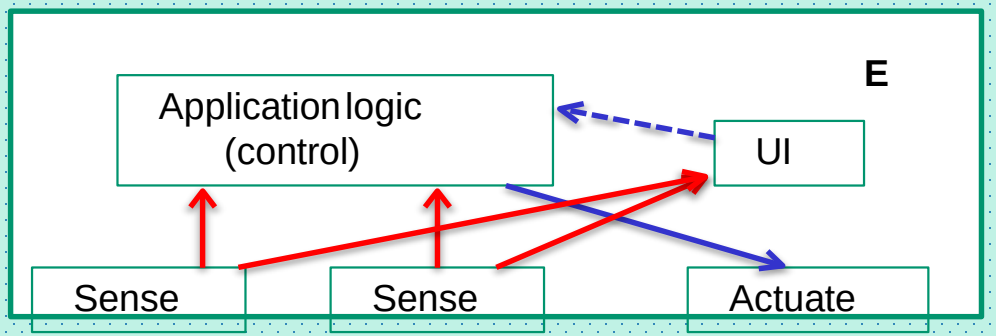
(limited)

Direct control Indirect control

(limited)

A Thermostat

- Device with integrated functionality
- Older ones are even *network unaware* (not connected to any network)

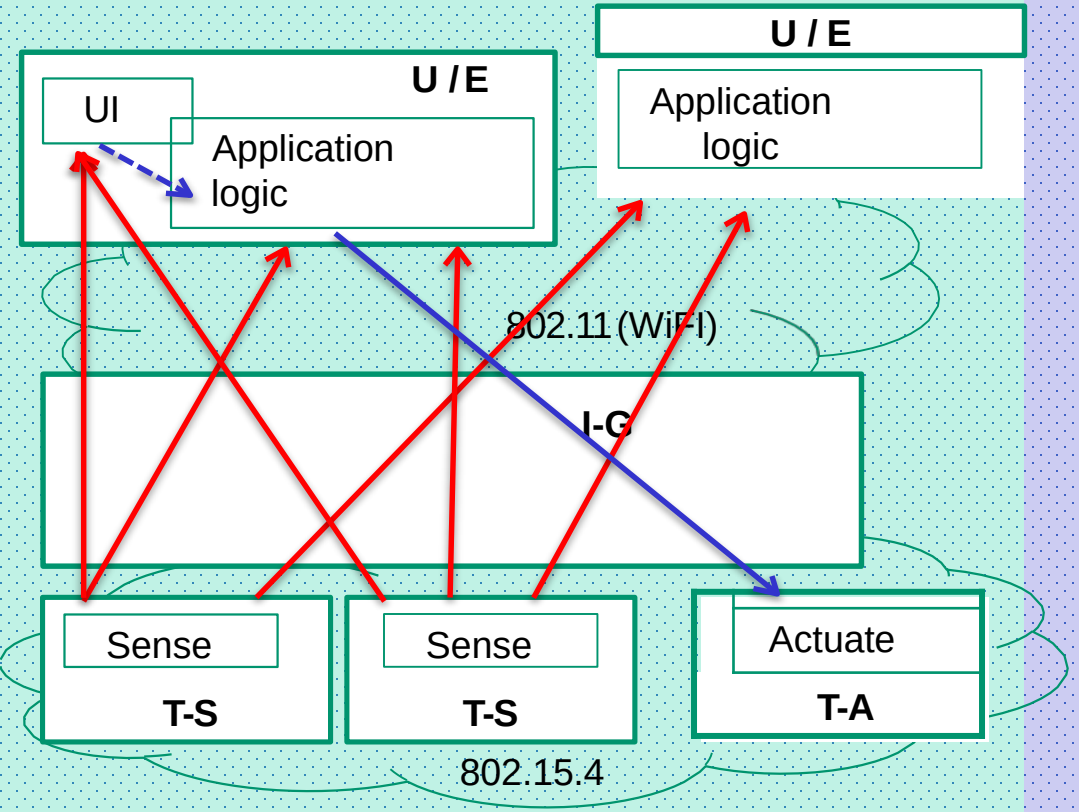


user
(home, office)

internet
provider

core internet
(clouds)

A distributed variant



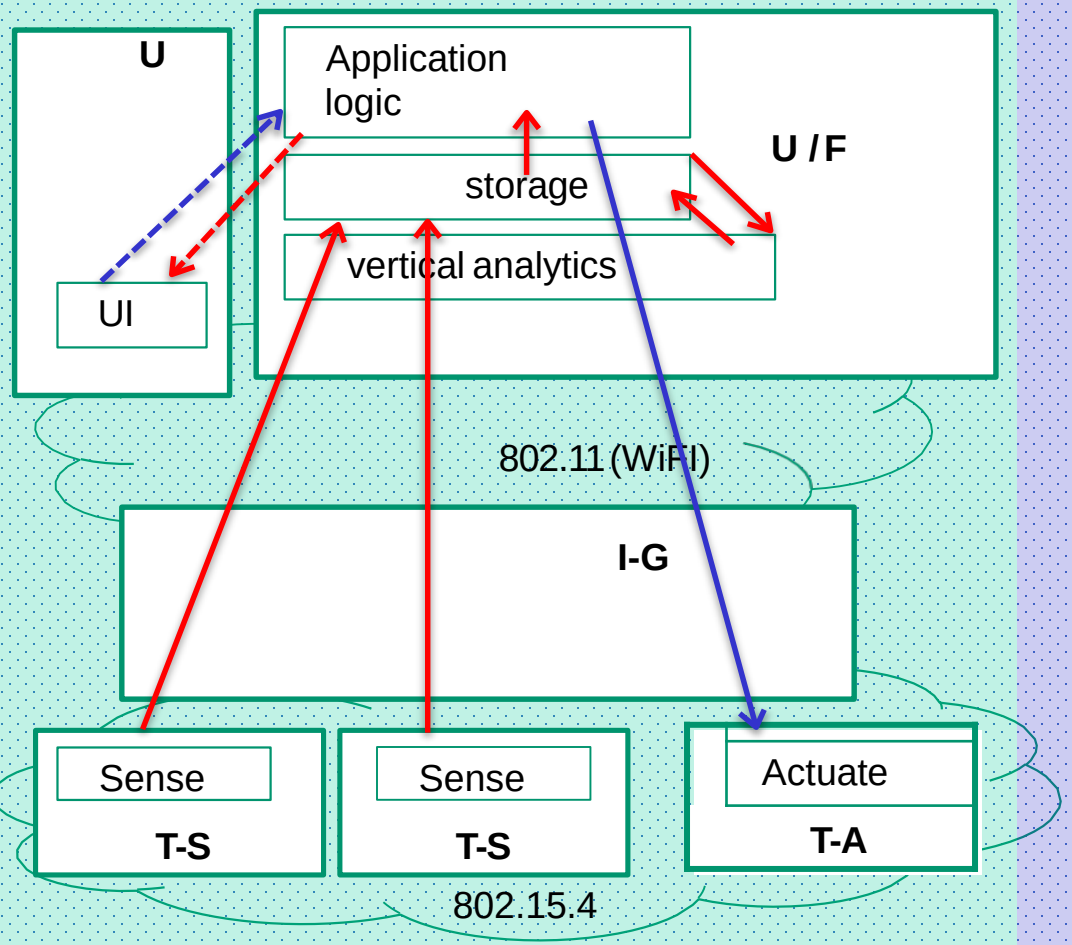
- The gateway enables IP connections to sensors / actuators
- The application logic can be just a function in a user device
- Other devices can use the sensors as well
  - e.g. just show temperature
  - this sensor access could also be achieved by virtualizing functions in a connected thermostat
    - i.e., making a single box thermostat as in the previous case but connected

user (home, office)

internet provider

core internet (clouds)

Long term storing for **optimization**



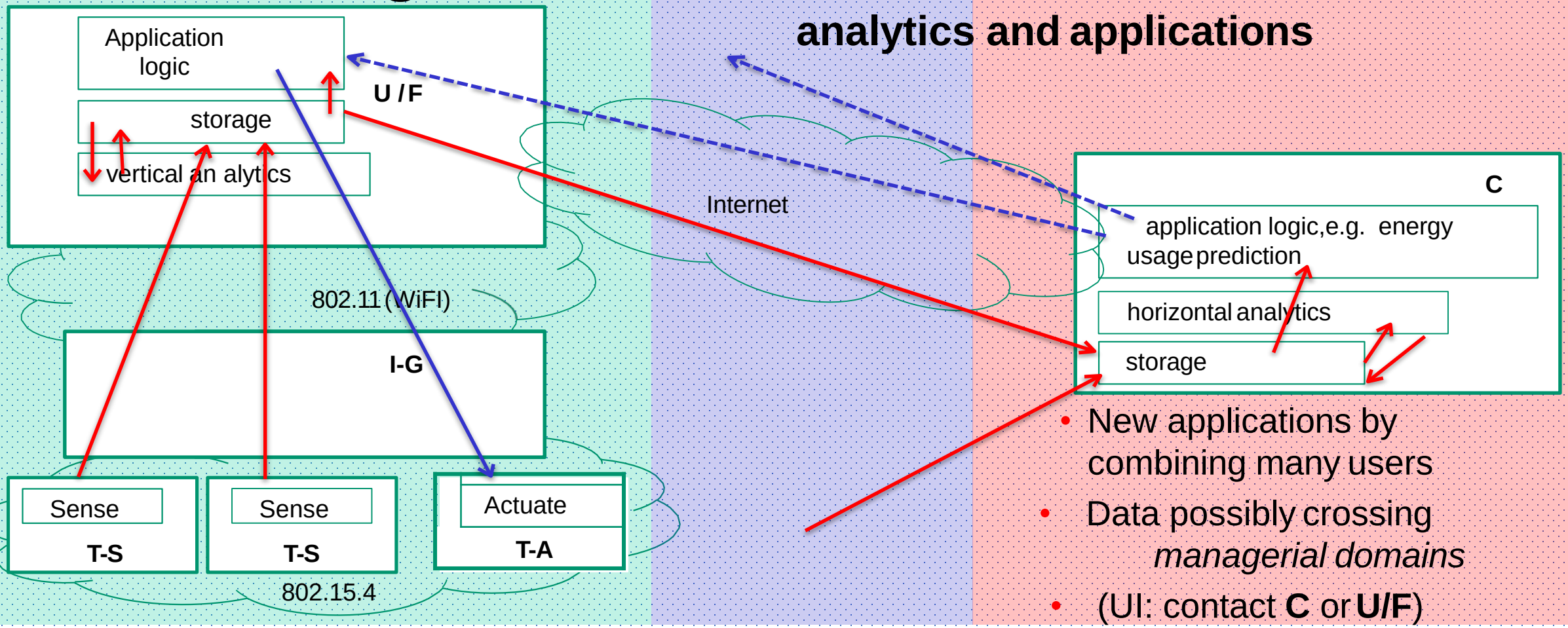
- Store data for analysis
  - storage and analytics could also be distributed again
- Show temperature profile
- Improve application behavior over time
  - learning patterns
  - using correlations (e.g. using weather info)
- Can also replace bottom with regular (connected) thermostat
- Remote UI, e.g. on phone
  - … but have to be home to see…

user (home, office)

internet provider

core internet (clouds)

Cloud storage for horizontal analytics and applications



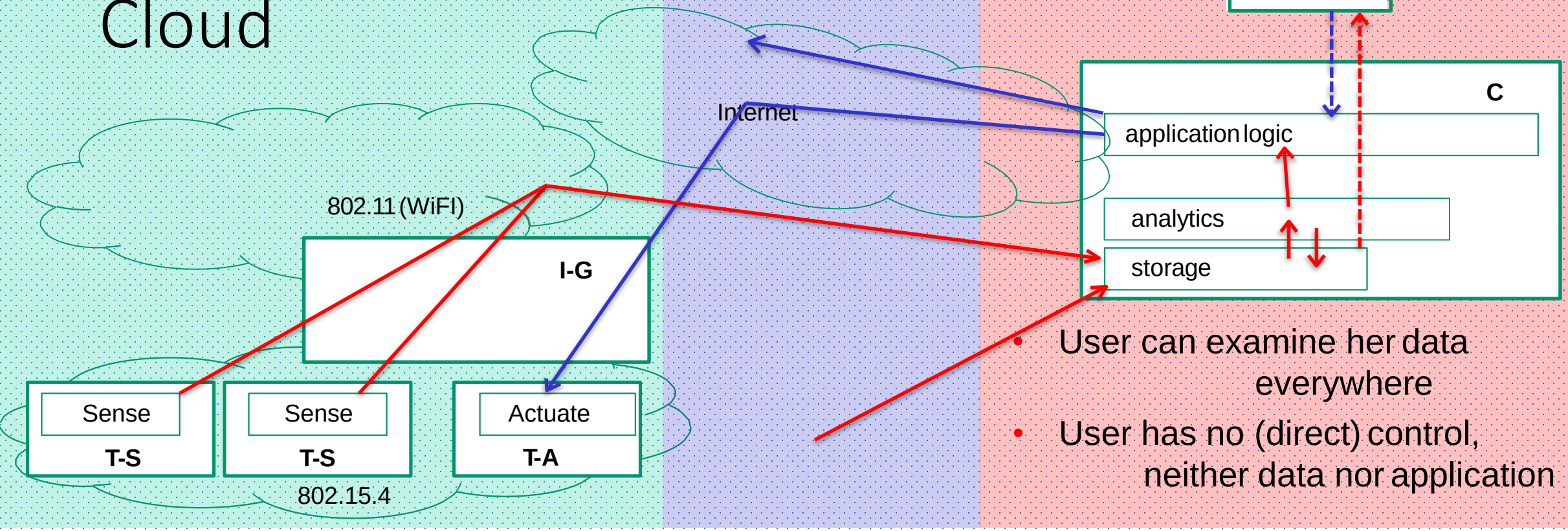
- New applications by combining many users
- Data possibly crossing *managerial domains*
- (UI: contact **C** or **U/F**)

user (home, office)

internet provider

core internet (clouds)

Everything in the Cloud



- User can examine her data everywhere
- User has no (direct) control, neither data nor application

user (home, office)

internet provider

core internet (clouds)

IoT videos

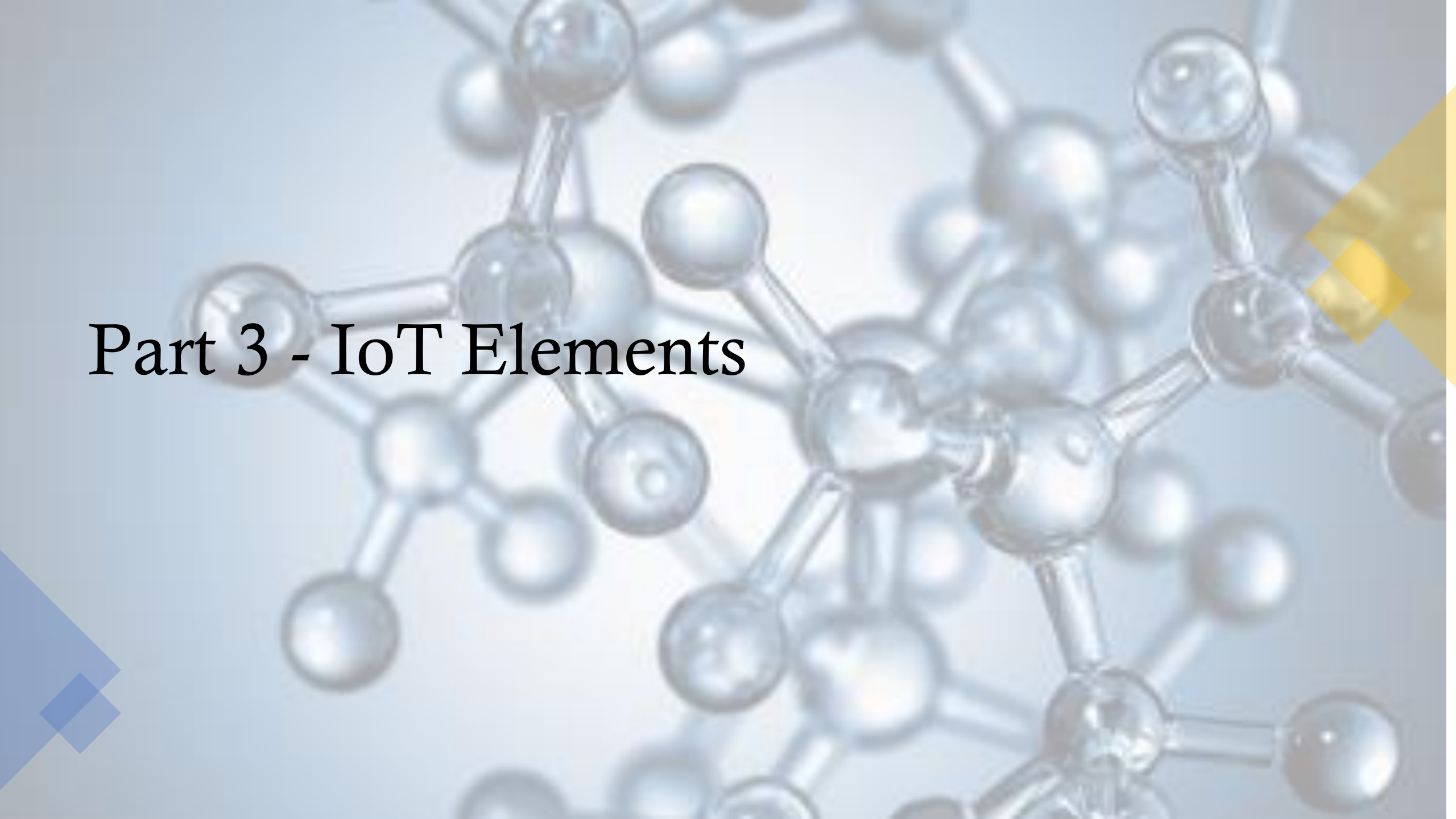
- Intel IoT -- What Does The Internet of Things Mean?
  - http://www.youtube.com/watch?v=Q3ur8wzzhBU
- Cisco - How the Internet of Things Will Change Everything--Including Ourselves
  - http://www.youtube.com/watch?v=B_hjAfPJeRA
- IBM – Internet of Things
  - https://www.youtube.com/watch?v=QSIPNhOiMoE

Recap

IoT Architectures

Fog, Edge vs Cloud

Application



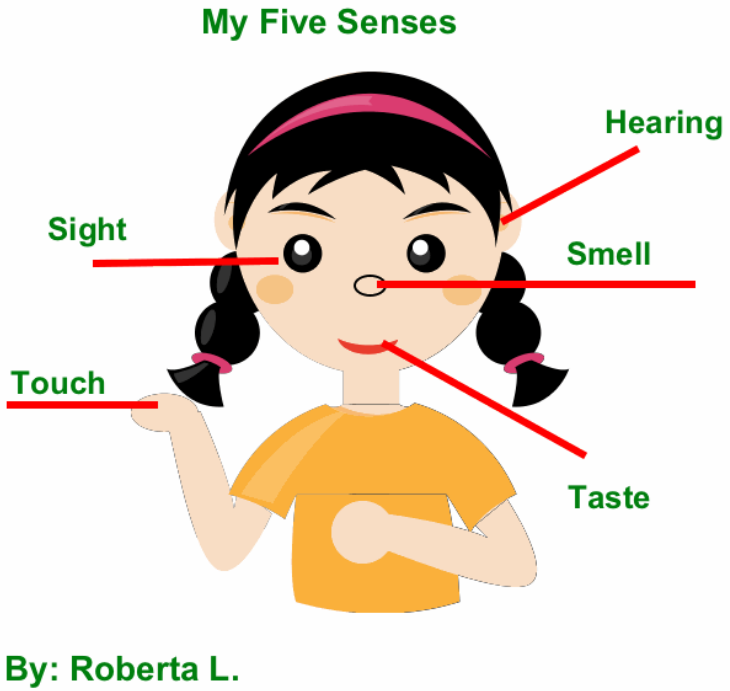
Part 3 - IoT Elements

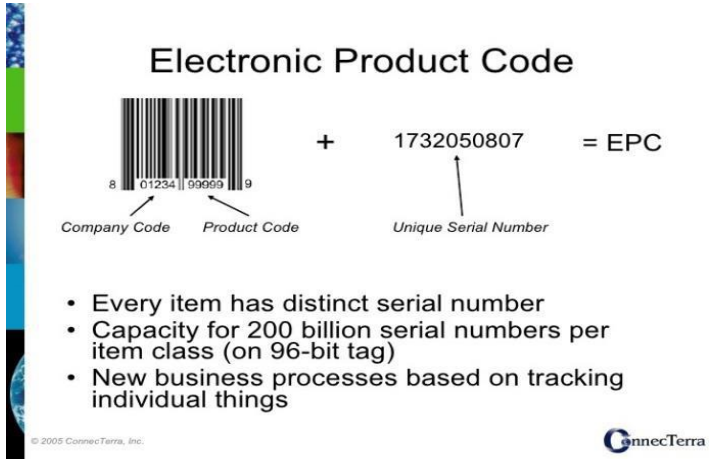
IoT Elements

- Identification
- Sensing
- Communication
- Services
- Semantics
- Can we mimic it to a human body?

Identification

- Hi, I am Rosie!
- Crucial for the IoT to name and match services with their demand

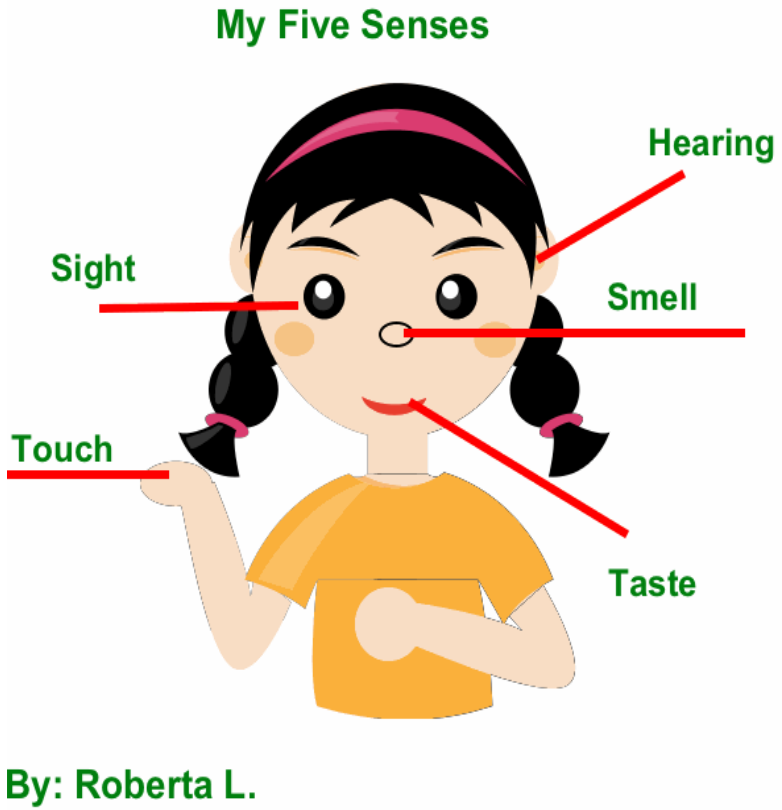




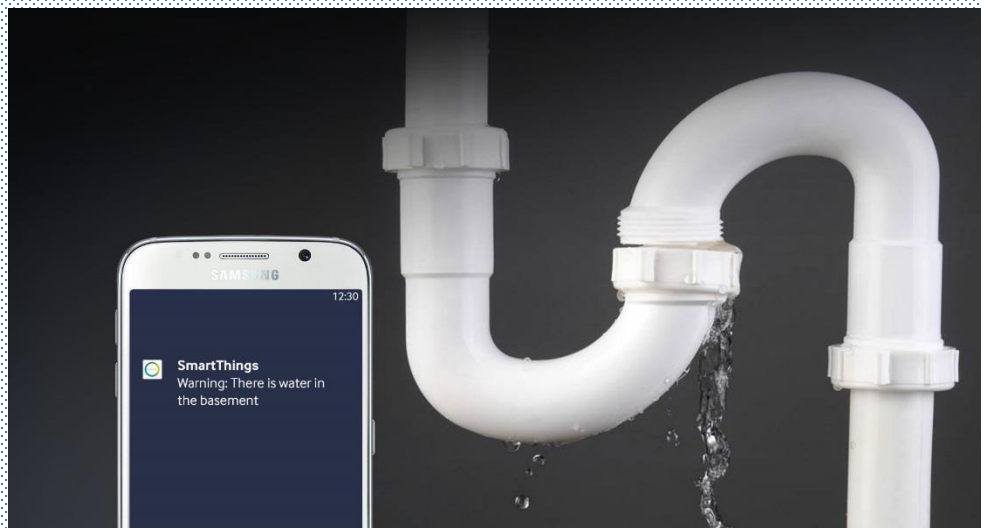
Ex. Electronic product codes (EPC)

IPv4 addresses and IPv6 addresses

Sensing



- Gather data from related objects and send it back to a data warehouse, database, or cloud.



Communication

Various technologies, such as Wi-Fi, Bluetooth, RFID, NFC, 5G

Various systems and protocols

RFID System

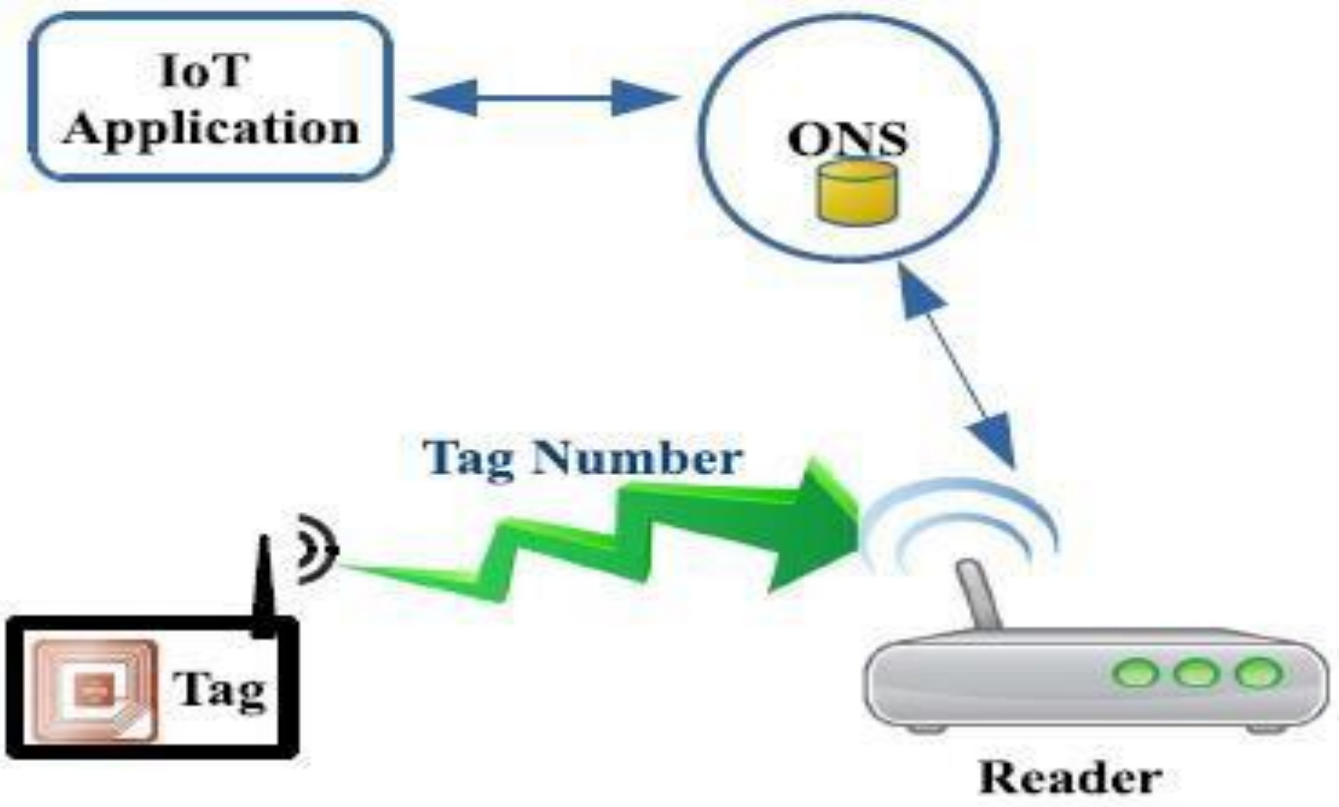


Fig. 21. RFID system.

RFID Components

- Radio signal transponder (tag)
  - a chip to store the unique identity of the object
  - an antenna to allow the chip to communicate with the tag reader using radio waves.

- Tag reader
  - The tag reader generates a radio frequency field to identify objects through reflected radio waves of the tag.

- How RFID works
  - (1) Sending the tag's number to the tag reader using radio waves
  - (2) the reader passes that number to a specific computer application

called the *Object-Naming Services* (ONS).

  - An ONS looks up the tag's details from a database such as when and where it was manufactured.

Computation

- The brain's computational ability
- Hardware: Microcontrollers, microprocessors, SoCs, FPGAs, Arduino, Raspberry PI, Gadgeteer
- Operating systems: RTOS such as Contiki, TinyOS, LiteOS
- Cloud Platforms such as the free tier of Google Cloud Platform and AWS (Amazon Cloud Plate form)

TABLE I
COMMON OPERATING SYSTEMS USED IN IoT ENVIRONMENTS

Operating System	Language Support	Minimum Memory (KB)	Event-based Programming	Multi-threading	Dynamic Memory
TinyOS	nesC	1	Yes	Partial	Yes
Contiki	C	2	Yes	Yes	Yes
LiteOS	C	4	Yes	Yes	Yes
Riot OS	C/C++	1.5	No	Yes	Yes
Android	Java	-	Yes	Yes	Yes

Services

- Various applications we already talked about
- Smart vehicles, smart school, smart market, smart industry, smart transportation, smart healthcare, smart agriculture, smart home, smart building, etc.

A Triade of IoT Services

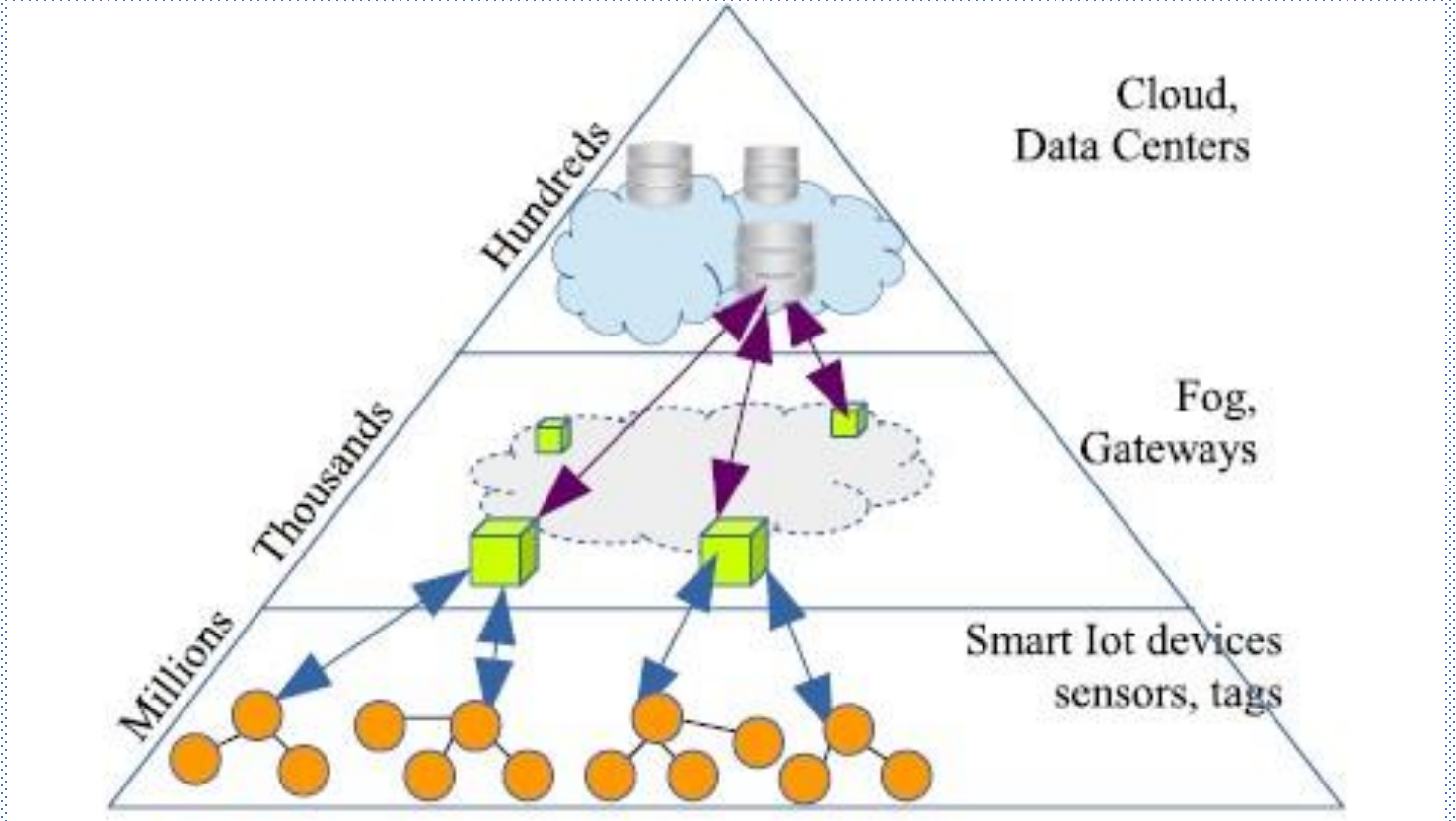


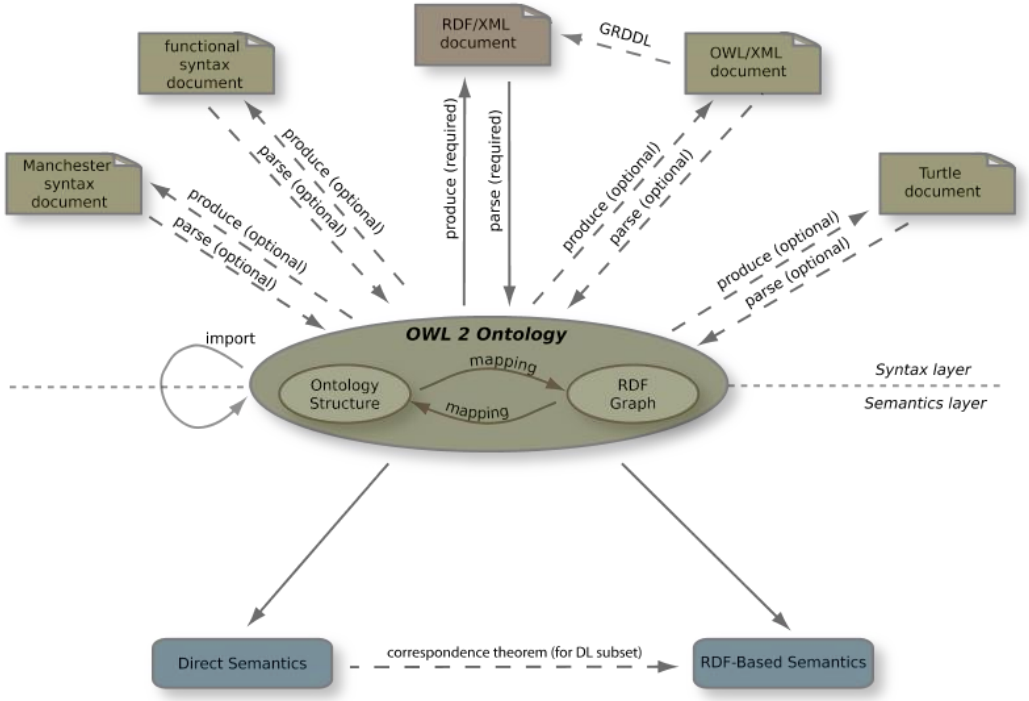
Fig. 24. The role of the cloud and fog resources in the delivery of IoT services.

Semantics

- Extract knowledge smartly by different machines to provide the required services.
- Discover and use resources, model information
- Recognise and analyse data for decision making
- Represent the brain by sending demands to the right resources

Semantics Technologies

- Resource Description Framework (RDF)
- Web Ontology Language (OWL)

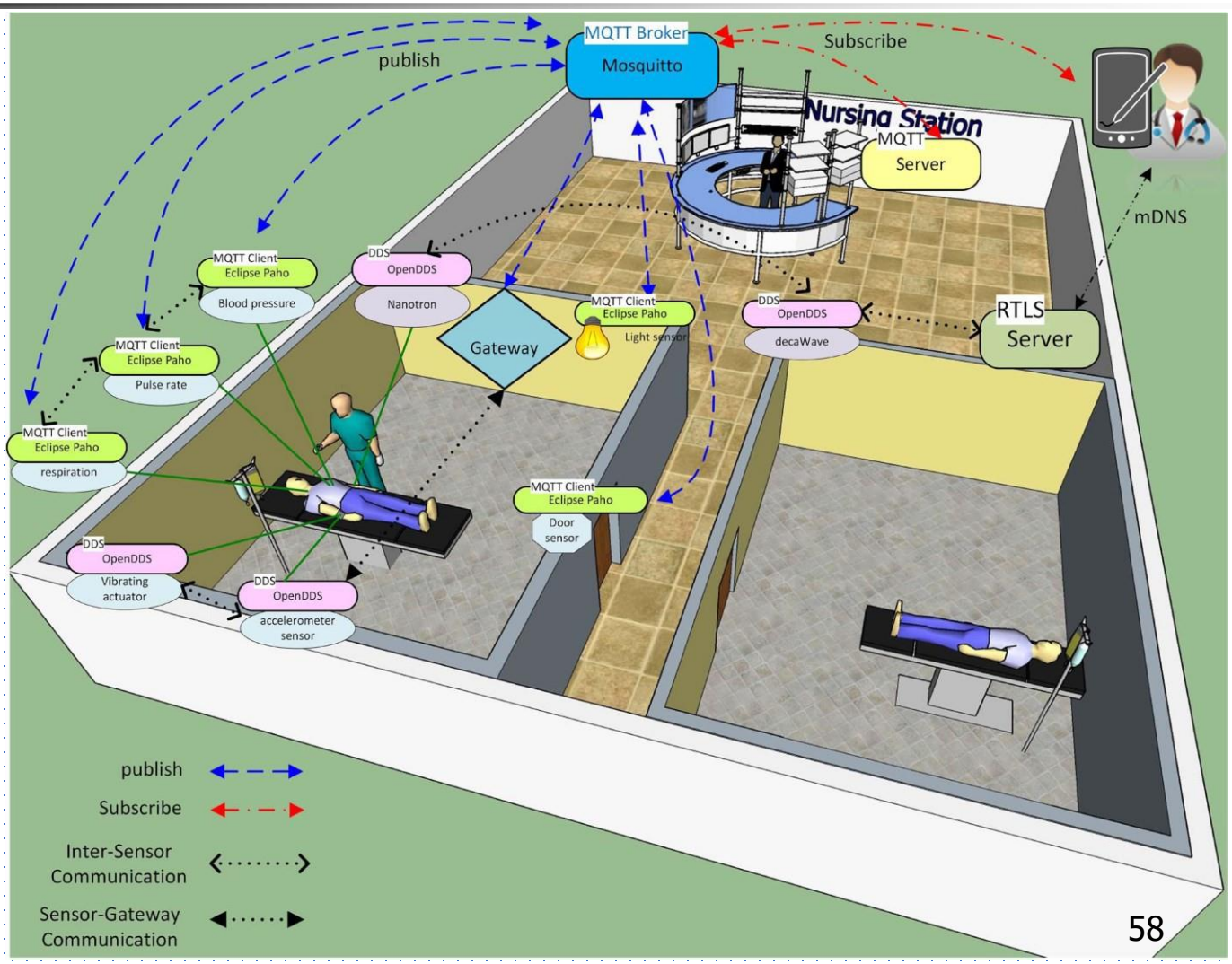


Reference

- A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347-2376, Fourth quarter, 2015.

Part 4 - IoT Protocols

The integration of IoT protocols in nursing scenario

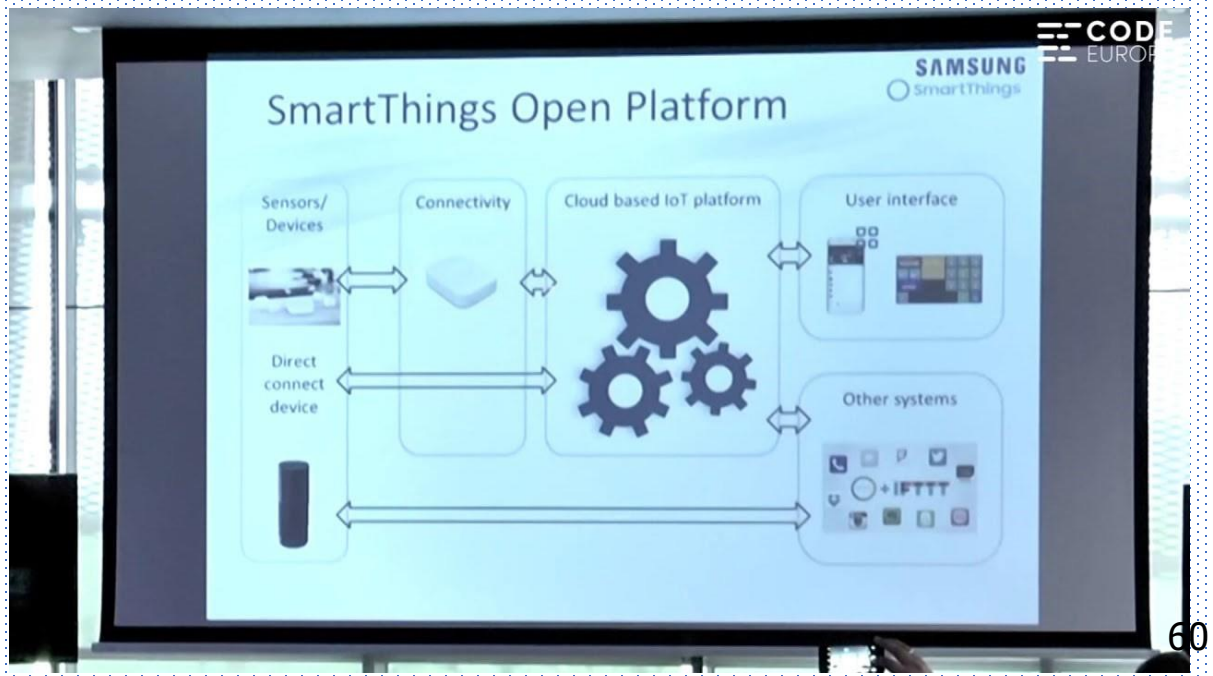


Objectives

- Collect the patients' vital sign measurements and deliver it to multiple nursing station.
- Deploy a light sensor and a door sensor to monitor the activity level of the patients
- Identify the patients suffering from depression from the level of their activities.

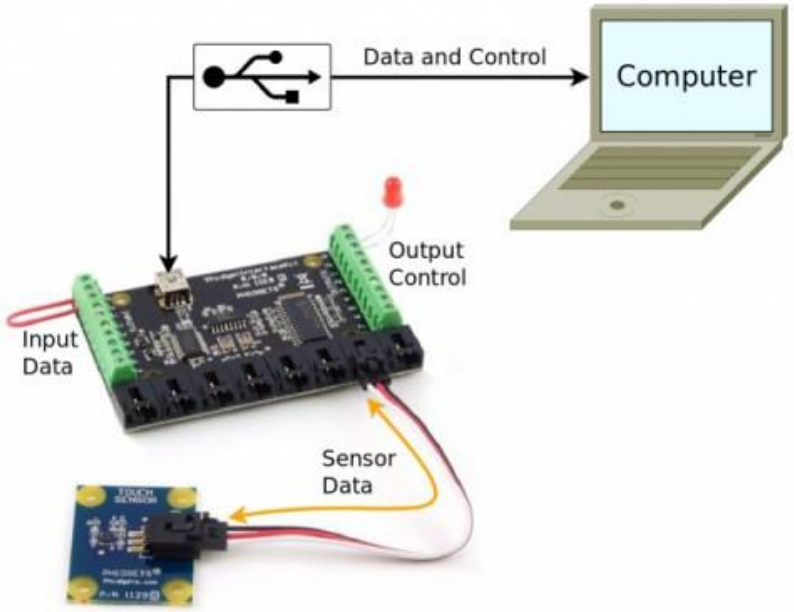
Choosing Sensors

- SmartThings Sensor or BITalino Sensor
- Sensors are ZigBee or Z-wave enabled to communicate to collect the sensor measurements on the SmartThings platform



Using SBC (Single Board Computer)

- Utilise Phidgets USB Sensors in conjunction with a microcontroller or processor based SBC
- Sensors use WiFi or IEEE 802.15.4 to communicate their measurement

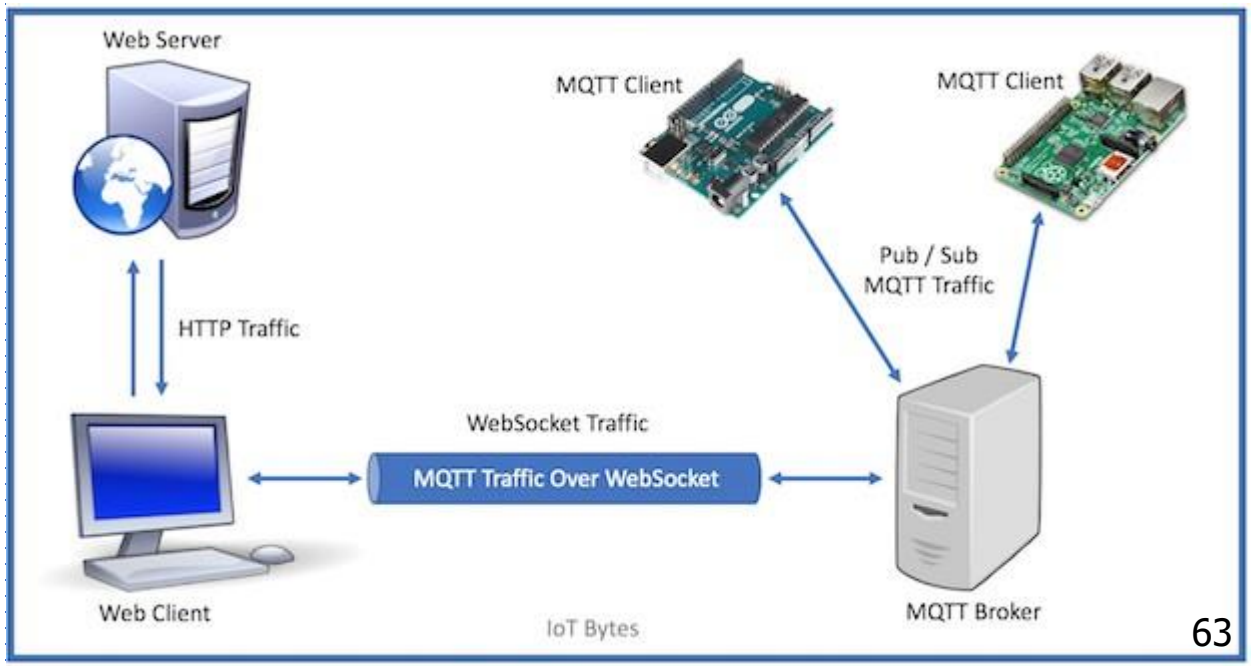


Mosquitto and MQTT

- Eclipse Mosquitto™ is an open source (EPL/EDL licensed) message broker that implements the MQTT (protocol versions 3.1 and 3.1.1. https://mosquitto.org/
- MQTT stands for MQ Telemetry Transport. It is a publish/subscribe, extremely simple and lightweight messaging protocol, designed for constrained devices and low-bandwidth, high-latency or unreliable networks. http://mqtt.org/faq
- Use Mosquitto to implement a client that runs on the SBC associated with the Phidgets USB sensors collecting the vital signs, light, and door sensor data.

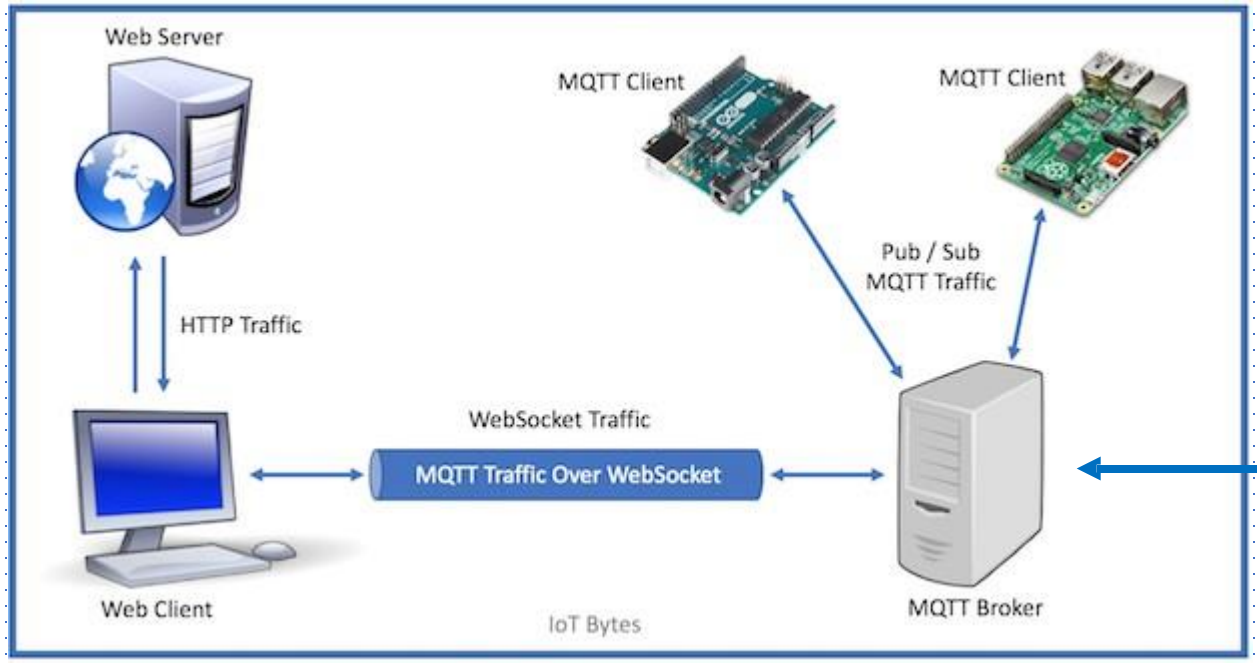
MQTT Client, MQTT Broker and MQTT Server

- The MQTT Client publishes the sensor data to the MQTT Broker
- The MQTT Server subscribes to the MQTT Broker to fetch the data of interest
- The MQTT Server connects to the Nursing Station
- RPL is utilised enable multihop delivery of data between sensors



Mobile Application

- Develop a Mobile Application for doctors to connect to the MQTT Broker to subscribe to messages that have the topic of interests.
- The broker can be publically exposed on the Internet behind a firewall.



Part 5 - IoT - Things

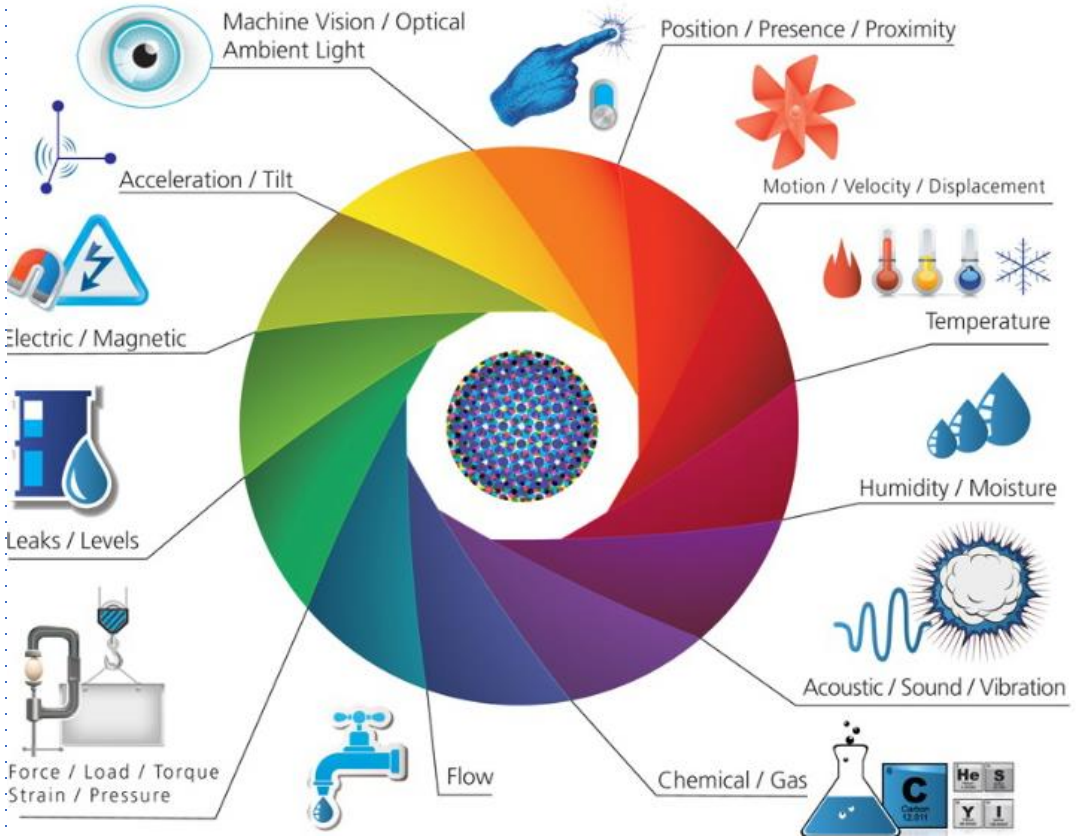
What You will Learn

- Detailed analysis of smart objects and their architecture.
  - Sensors
  - Actuators
  - Smart Objects
  - Sensor Networks

Sensors

- They are mainly input components
- They sense and collect surrounding information

- Types
  - Active or passive
  - Invasive or non-invasive:
  - Contact or no-contact:
  - Absolute or relative:
  - Area of application:



Reference: http://postscapes.com/what-exactly-is-the-internet-of-things-infographic/

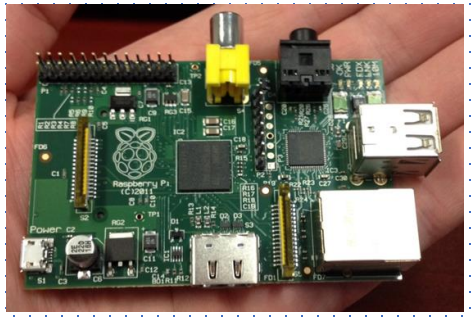
Actuators

- They are mainly output components
- They trigger a physical effect to alter the surrounding.
- Some examples:
  - Adding lighting, heat, sound, etc.
  - Controlling motors to move objects
  - Displaying messages

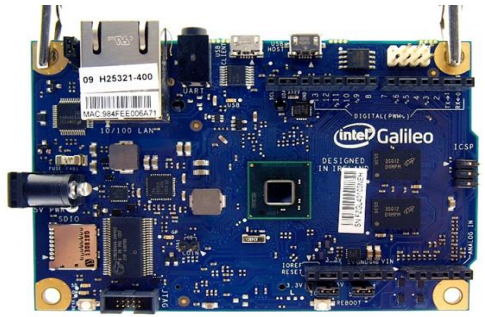
- Types
  - Type of motion:
  - Power
  - Binary or continuous
  - Area of application:

“Things” – Smart Objects

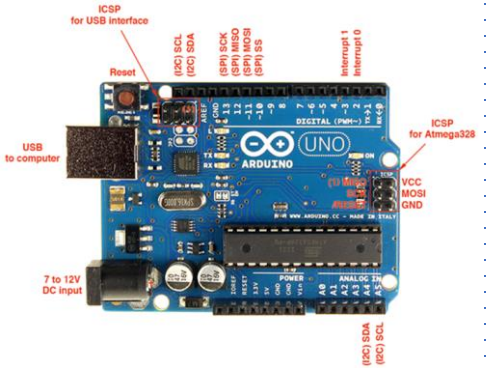
- Many Names - smart sensor, smart device, IoT device, intelligent device, thing, smart thing, intelligent node, intelligent thing, ubiquitous thing, and intelligent product
- We can turn almost every object into a “thing”.
- Similar to embedded system
- Defining Characteristics:
  - Sensors & actuators
  - Microcontroller
  - Communication unit
  - Power source



Raspberry Pi



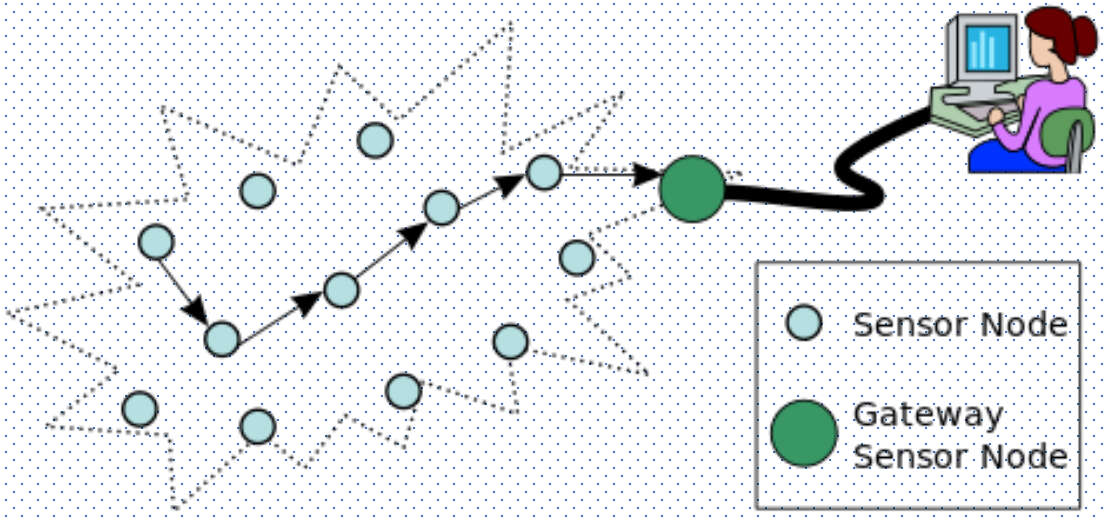
Intel Galileo



Arduino Uno

Wireless Sensor Networks

- A Wireless Sensor Network (WSN) consists of base stations and a number of wirelessly connected smart objects. (Motes – sensor nodes)



WSN Characteristics

- Characteristics of Wireless Sensor Networks

- Requirements: small size, large number, tether-less, and low cost. Constrained by
  - Energy, computation, and communication
- Small size implies small battery
- Low cost & energy implies low power CPU, radio with minimum bandwidth and range
- Ad-hoc deployment implies no maintenance or battery replacement
- To increase network lifetime, no raw data is transmitted

Overview (Cont.)

- **Lifetime**
- Nodes are battery-powered
- Each operation brings the node closer to death.

- "**Lifetime is crucial!”**
- To save energy:
- Sleep as much as possible.
- Acquire data only if indispensable.
- Use data fusion and compression.
- Transmit and receive only if necessary. Receiving is just as costly as sending.

WSN (Cont.)

- **Scalability and Reliability**
- WSNs should
- Self-configure and be robust to topology changes (e.g., node failure)
- Maintain connectivity**:** can the Base Station communicate to all nodes?
- Ensure coverage**:** Are we able to observe all phenomena of interest?

- **Maintenance**
- Only feasible maintenance is the Reprogramming
- Wireless reprogramming is It is highly desirable.

WSN (Cont.)

- **Data Collection**
- Centralized data collection puts extra load on nodes close to the base station.
- Clustering: data from groups of nodes are fused/ Aggregated before being transmitted, so that fewer transmissions are needed
- Often getting measurements from a particular area is more important than getting data from each node
- Security and authenticity should be guaranteed. However, the CPUs on the sensing nodes cannot handle fancy encryption schemes.

- **Two communication patterns:**
- Event Driven
- Periodic

Summary

- “Things” are the building blocks of IoT
- Sensors are able to measure their environment
- Actuators use environmental sensing information to perform actions based on their surroundings
- Smart objects are typically highly constrained devices with sensor(s) and/or actuator(s) along with very limited power, transmission, and compute capabilities.
- WSNs are basis of IoT, and it opens up a world of possibility, embedding sensors and/or actuators in everyday objects and networking them to enable sophisticated and well-coordinated automations that improves and simplifies our lives.