UNIVERSITÀ DEGLI STUDI DI PADOVA

Master's degree ICT Internet Multimedia Engineering

Department of Information Engineering (DEI)
Master degree on ICT for Internet and Multimedia Engineering (MIME)

Internet of Things and Smart Cities
02 – Introduction

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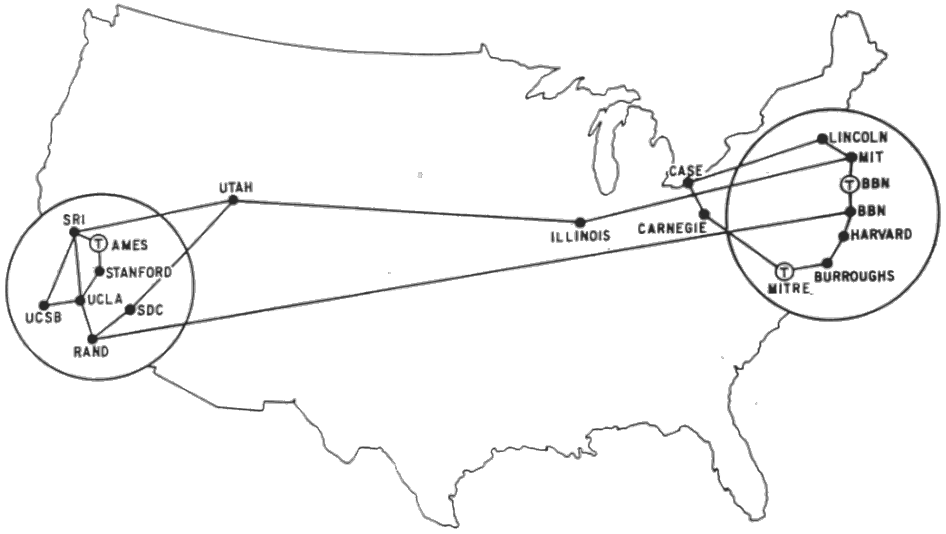
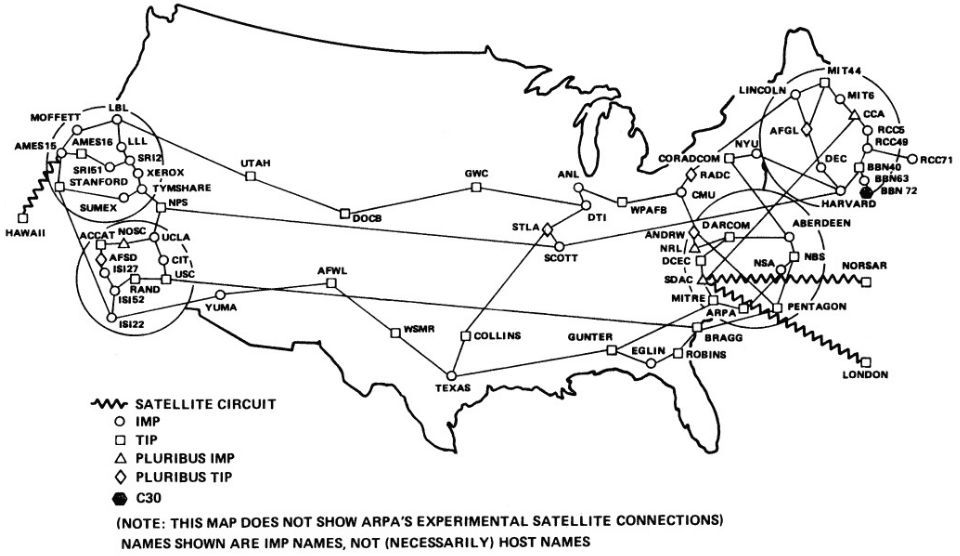
The Internet of computers

- The precursors of the modern Internet (ARPANET, CSNET, NSFNET) were resource sharing networks: computers were bulky and expensive, and researchers used nationwide connections to access them from far away.



MAP 4 September 1971

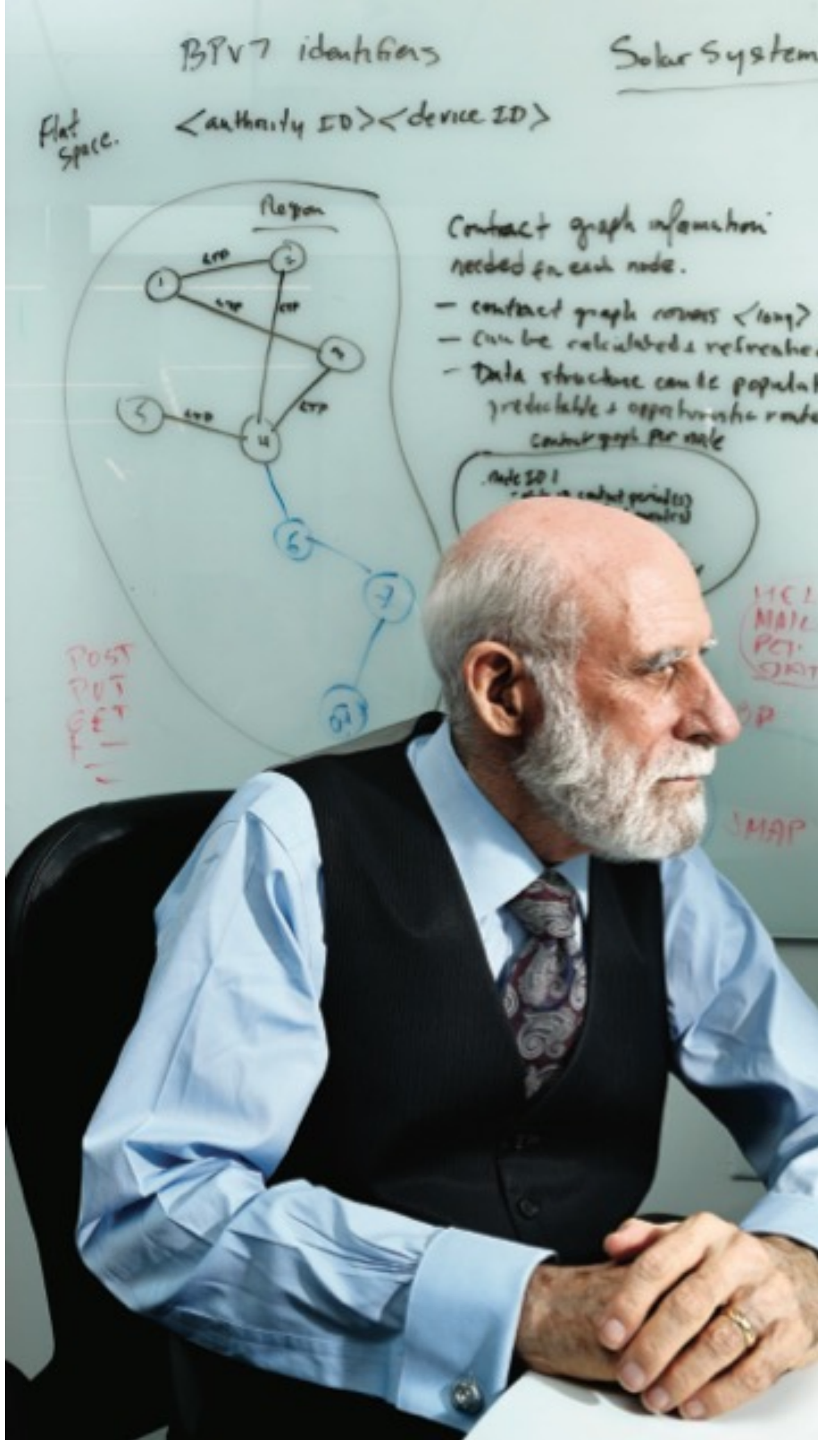
ARPANET GEOGRAPHIC MAP, OCTOBER 1980



The Internet of computers

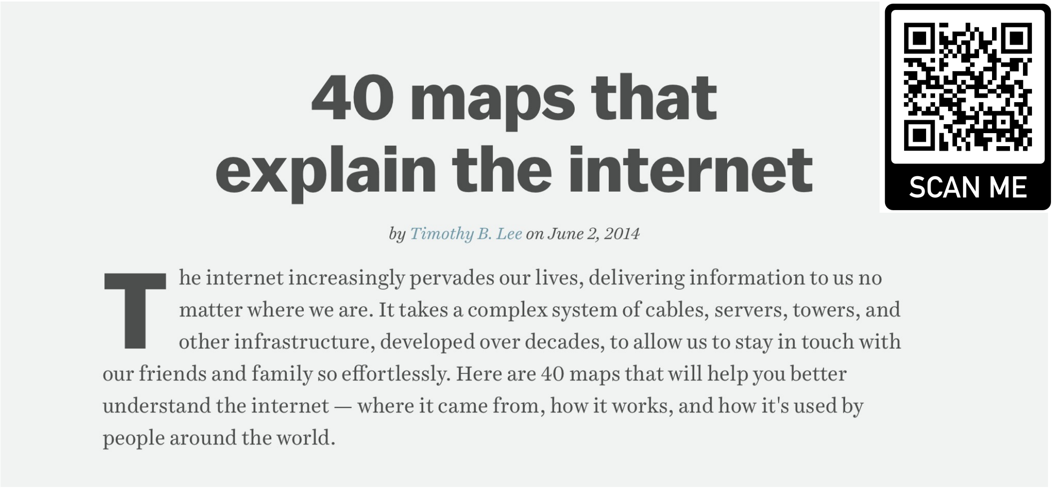
> *Cerf describes the communication protocols that he and Kahn came up with as comparable to a set of postcards and envelopes: The postcard has a message and an address for the intended destination. The address on the envelope is either that of the destination host in the local network or of a gateway that leads toward the next network along the route to the final destination. When a message arrives at that next gateway, the gateway opens the envelope and checks the address on the postcard. If the message is intended for a destination inside the gateway's home network, it gets delivered in an appropriate envelope; if not, it goes in an envelope addressed to the next gateway en route to the destination network, where the process repeats.*

T. S. Perry, "Mr. Internet: Vint Cerf's 1973 sketch kicked off five decades of improving and evangelizing what we now know as the Internet," in IEEE Spectrum, vol. 60, no. 5, pp. 24-31, May 2023



The Internet of people

- As personal computers became ubiquitous, and packet-switched traffic was ported to the ubiquitous telephone network, the Internet became the means for people all over the world to communicate with each other.
- In 1990, Tim Berners-Lee defines HTTP and HTML, leading to the explosion of the World Wide Web.



40 maps that explain the internet

by Timothy B. Lee on June 2, 2014

The internet increasingly pervades our lives, delivering information to us no matter where we are. It takes a complex system of cables, servers, towers, and other infrastructure, developed over decades, to allow us to stay in touch with our friends and family so effortlessly. Here are 40 maps that will help you better understand the internet — where it came from, how it works, and how it's used by people around the world.

The Internet of Things

- Information about objects in the world can be integrated in the Internet:
  - 2030 → **40 billion connected “things”**.
- Computing power is **cheap** and **everywhere**, and even trivial objects can now connect to the Internet (e.g., thermometers, parking spots, watches, etc.).
- <u>Basic idea</u>: make computing ubiquitous and invisible to users.
  - A smart object collects, transmit and processes data, but is not always that clever!
  - Smart environments have collections of interacting smart objects, which can measure and affect the environment in multiple ways.

The Internet of Things

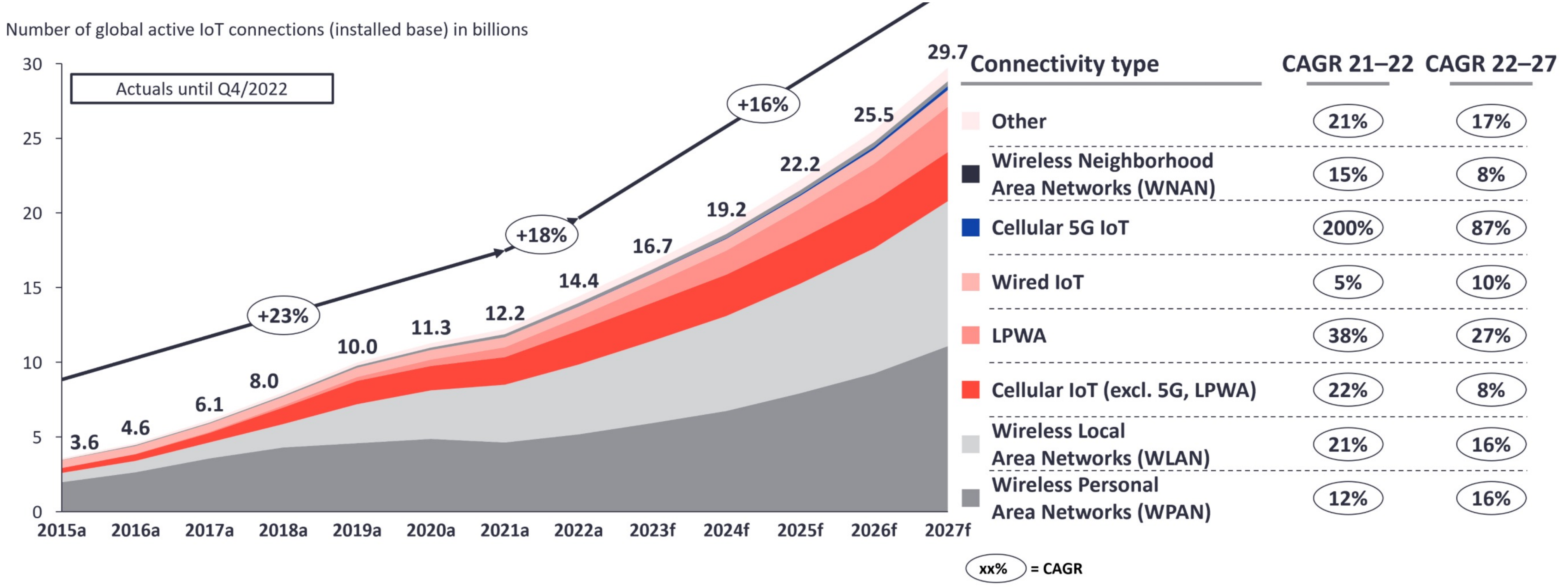
> *In the twentieth century, computers were brains without senses – they only knew what we told them. In the twenty-first century, because of the Internet of Things, computers can sense things for themselves.*

Kevin Ashton, who coined the term Internet of Things.

The Internet of Things

Some statistics

- Number of connected IoT devices growing 16% to ~19 billion globally in 2024.

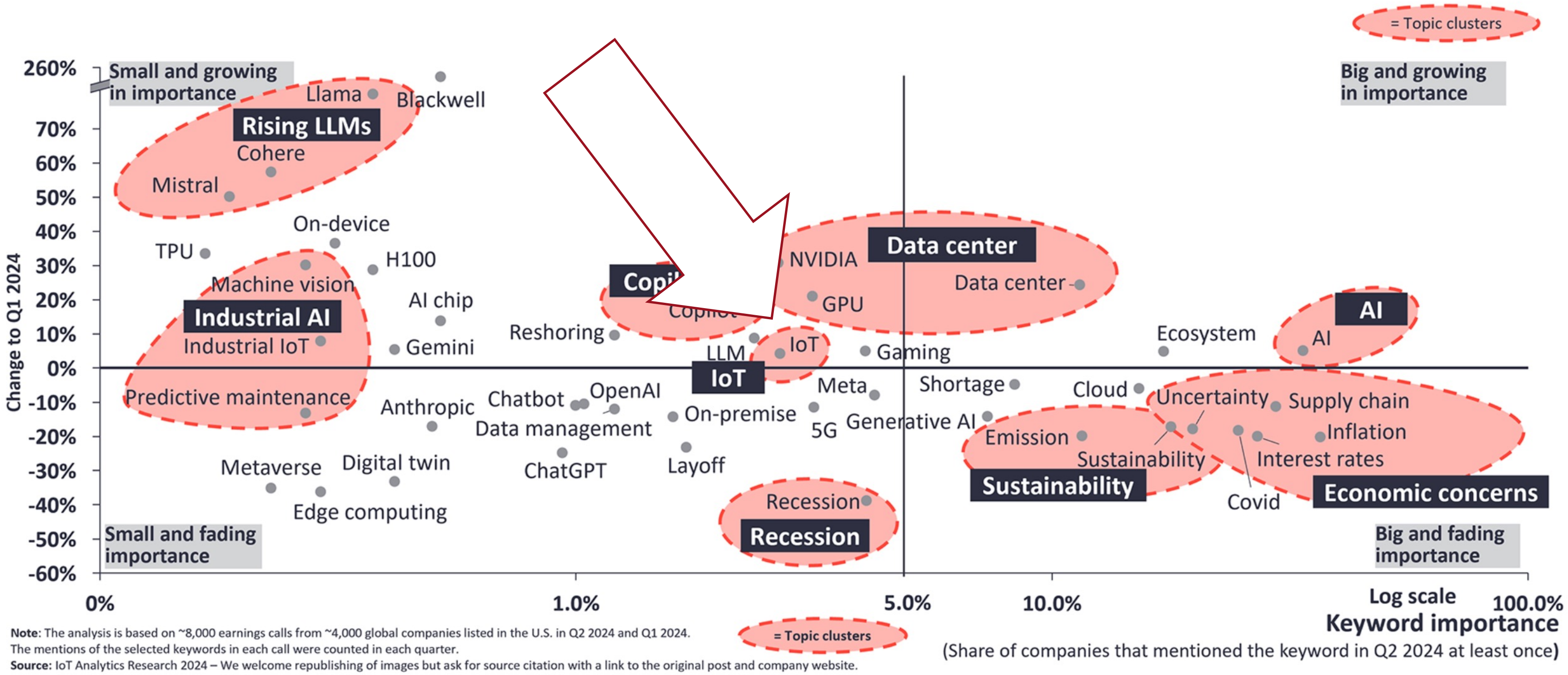


https://iot-analytics.com/number-connected-iot-devices/

The Internet of Things

Some statistics

- What CEOs talked about in Q2 2024: AI, data centers, and up-and-coming LLMs.

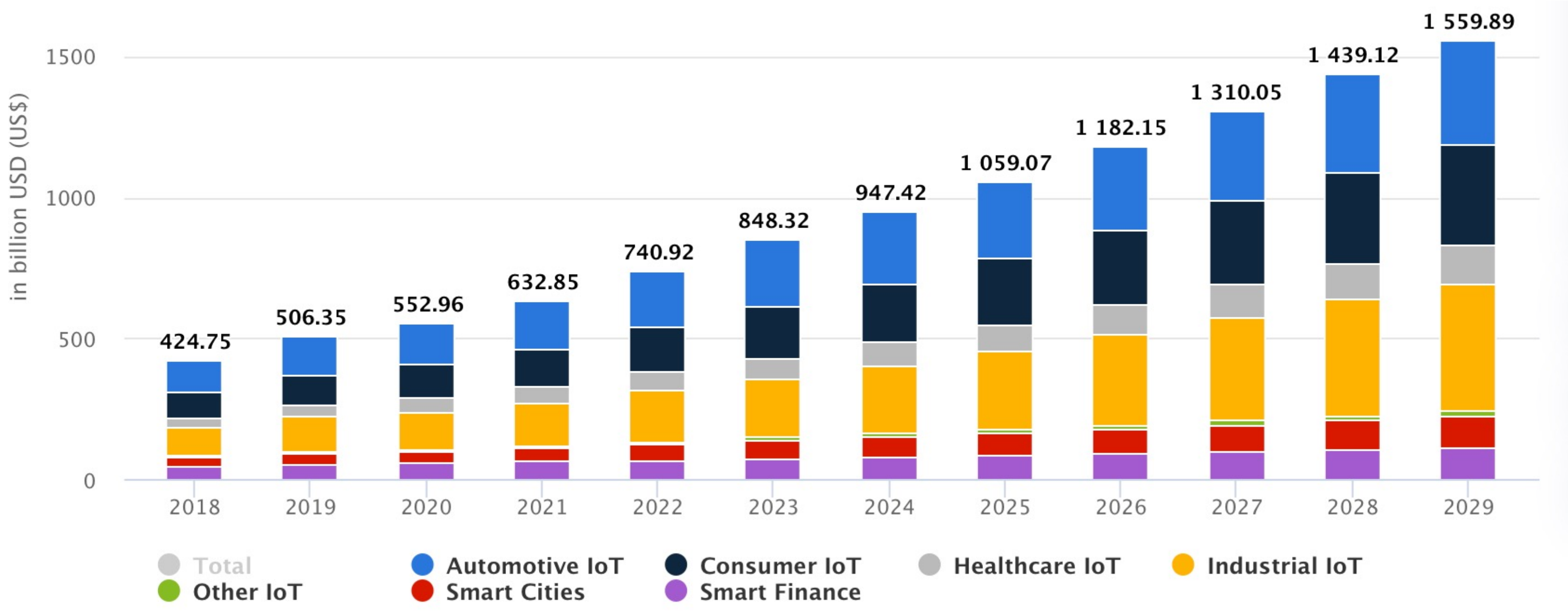


https://iot-analytics.com/what-ceos-talked-about-in-q2-2024/

The Internet of Things

Some statistics

- IoT revenue worldwide (billion USD)

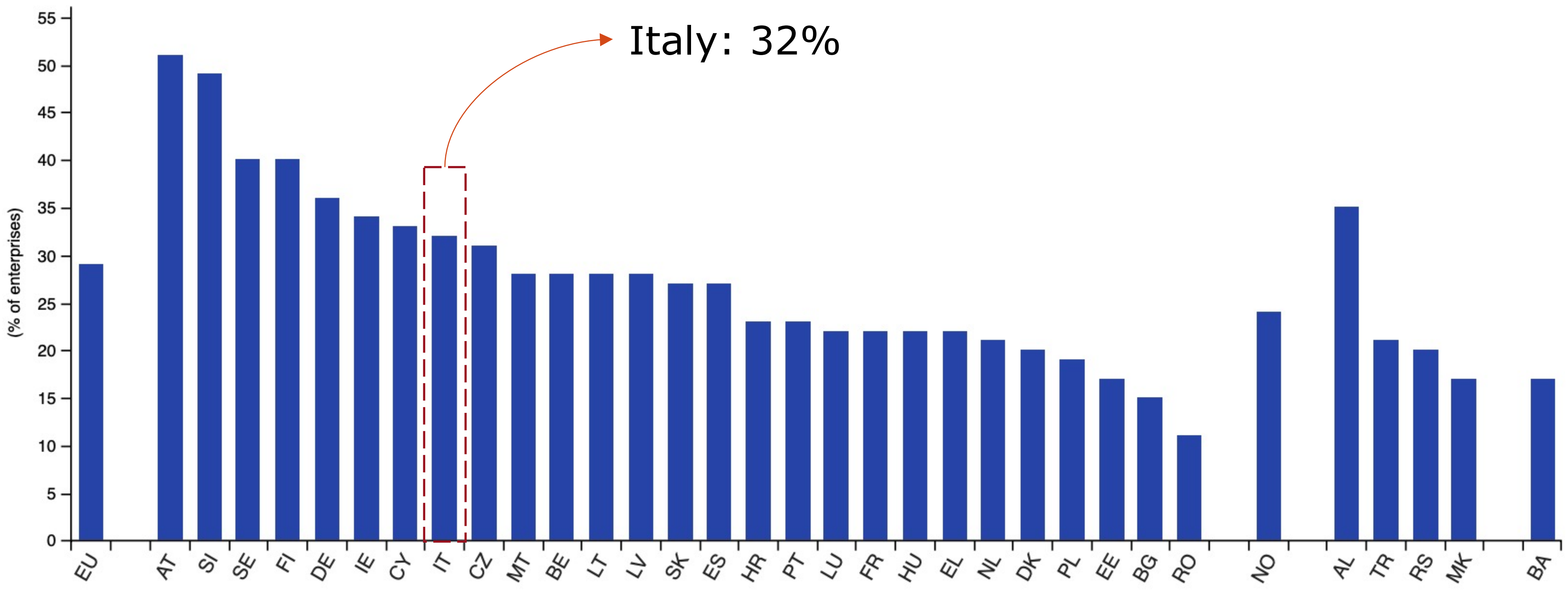


https://www.statista.com/outlook/tmo/internet-of-things/worldwide#revenue

The Internet of Things

Some statistics

- Number of enterprires using IoT technologies



The Internet of Things

Definition(s)

The **textbook** provide a couple of definitions of IoT such as:

> *"A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" or "the extension of Internet connectivity into physical devices and everyday objects. Embedded with electronics, Internet connectivity, and other forms of hardware (such as sensors), these devices can communicate and interact with others over the Internet, and they can be remotely monitored and controlled. The IoT adds the ability for IoT devices to interoperate with the existing Internet infrastructure."*

The Internet of Things

Definition(s)

The **IEEE** describes "Internet of Things" as:

> *"A network of items — each embedded with sensors — which are connected to the Internet."*

Definition(s)

The **ITU** endorses the definition of IoT as a network, that is:

> *"Available anywhere, anytime, by anything and anyone. A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."*

The Internet of Things

Definition(s)

The **IETF** provides its own description of IoT, with definitions of “Internet” and “thing”:

> *“The basic idea is that IoT will connect objects around us (electronic, electrical, non-electrical) to provide seamless communication and contextual services provided by them. Development of RFID tags, sensors, actuators, mobile phones make it possible to materialize IoT which interact and coOoperate each other to make the service better and accessible anytime, from anywhere.”*

Definition(s)

NIST defines IoT in terms of a “Cyber-Physical Systems (CPS)” as follows:

> *“Cyber-physical systems (CPS) – sometimes referred to as the Internet of Things (IoT) – involves connecting smart devices and systems in diverse sectors like transportation, energy, manufacturing and healthcare in fundamentally new ways. Smart Cities/Communities are increasingly adopting CPS/IoT technologies to enhance the efficiency and sustainability of their operation and improve the quality of life."*

The Internet of Things

Definition(s)

W3C defines IoT as follows:

> *"The Web of Things is essentially about the role of Web technologies to facilitate the development of applications and services for the Internet of Things, i.e., physical objects and their virtual representation. This includes sensors and actuators, as well as physical objects tagged with a bar code or NFC. Some relevant Web technologies include HTTP for accessing RESTful services, and for naming objects as a basis for linked data and rich descriptions, and JavaScript APIs for virtual objects acting as proxies for real-world objects."*

The Internet of Things

A more formal definition

- Internet of things means **connecting <u>every</u> <u>thing</u>**.
  - To what? How? This is a sloppy definition…
- The key part of the definition of <u>Internet</u> of Things is the **Internet**, where Internet means IP protocol: No IP → No IoT

> *"Internet of Things is a paradigm according to which every thing, real or virtual, is assigned an IP(v6) address and can be reached (for example for sensing or actuating purposes) via the standard Internet Protocol stack."*

An example of a “Smart” IoT system

Description

- One typical evening planning next working day...
  - Tomorrow first office meeting at 8:30 am.
  - Typical car trip in these days: 1 hour time.
  - 45 minutes to wake up and get ready.
- I decide to set my alarm to **wake up at 6:45 am.**

What could (will) possibly go wrong?

Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna

An example of a “Smart” IoT system

What could (will) possibly go wrong?

- At 4:30 am it starts snowing
- Truck obstruction along the usual path
- Traffic congestion on alternative paths
- No parking at destination
- Bathroom cold when having shower
- Coffee cold when having breakfast
- Left my car keys at home when in garage
- Elevator busy when leaving my flat

Leaving 10 min. late + 30 min. additional travel time → missed the meeting!

Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna
© *Introduction to IoT enabling Digital Revolution(s): technologies, applications, perspectives*

An example of a “Smart” IoT system

The IoT approach

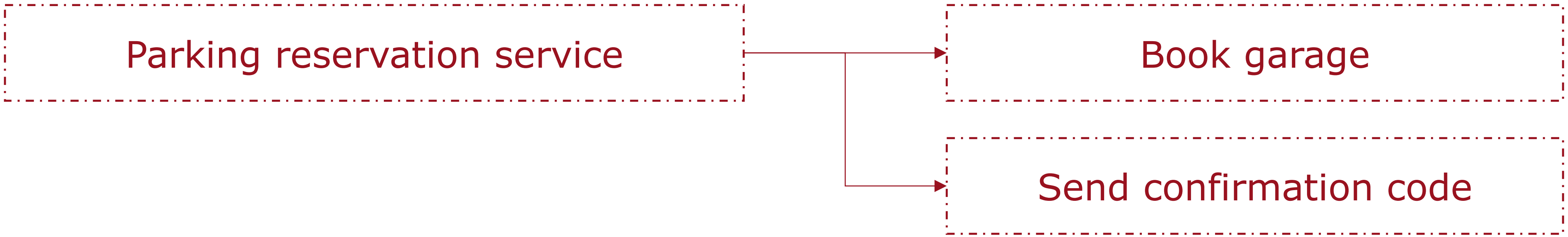
- **Truck obstruction along the usual path**
- **Traffic congestion on alternative paths**
- **At 4:30 am it starts snowing**
  - Get notified in real time by the Weather Monitoring System or device.
  - Get notified in real time by the Traffic Monitoring System Information.
  - Based on forecasts it anticipates the alarm clock to 6:00 am (30 minutes before)

Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna

An example of a “Smart” IoT system

What could (will) possibly go wrong?

- **No parking at destination**
  - Based on previous experience data and the available parking reservation services decides to reserve a indoor parking slot in a garage.
  - Reservation code uploaded on the mobile phone to access garage at destination



Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna

An example of a “Smart” IoT system

What could (will) possibly go wrong?

- **Bathroom cold when having shower**
  - 10 minutes before at 5:50 am... started warming up the bathroom to 23 degrees

Temperature sensor → Warm up the bathroom

Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna

An example of a "Smart" IoT system

What could (will) possibly go wrong?

- **Coffee cold when having breakfast**
    - The mirror notifies I am leaving the bathroom, and while I get dressed in my bedroom, the coffee machine is activated in the kitchen, and the warming up of the bathroom is switched off.

Bathroom notification → Activate the coffee machine

Bathroom notification → Switch off the heather

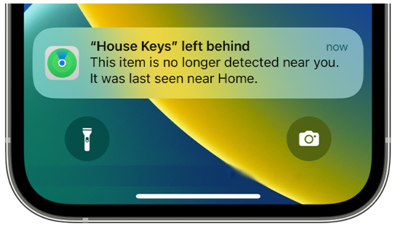
Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna
© *Introduction to IoT enabling Digital Revolution(s): technologies, applications, perspectives*

An example of a “Smart” IoT system

What could (will) possibly go wrong?

- **Left my car keys at home when in garage**
  - When I leave my home passing through the main door I got a message on my phone advising me that I do not have the car keys with me...
  - When I re-enter the door my phone informs me that the keys are in proximity of the lamp on the table in the living room, and the lamp flashes to help me to find the keys.

“Airtag-like” sensor



“Keys left behind” notification

Lamp flashes

Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna
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An example of a “Smart” IoT system

What could (will) possibly go wrong?

- **Elevator busy when leaving my flat**
  - When I reach the elevator, it has been called and it is waiting for me with open doors.

Elevator sensor → Open the elevator doors

An example of a "Smart" IoT system

Finally…

- I am leaving with my car right in (planned) time, with my path already set in the navigation system, getting alerted of any problem on the path and need to make detours in real time.
- ... and when at destination I will have my car parked in reserved indoor garage with no delays. Barriers open with my contactless smartphone code...

I participate at the 8:30am meeting RIGHT IN TIME!

Source from: Proff. Luciano Bononi, Marco di Felice
Dept. of Computer Science and Engineering, University of Bologna
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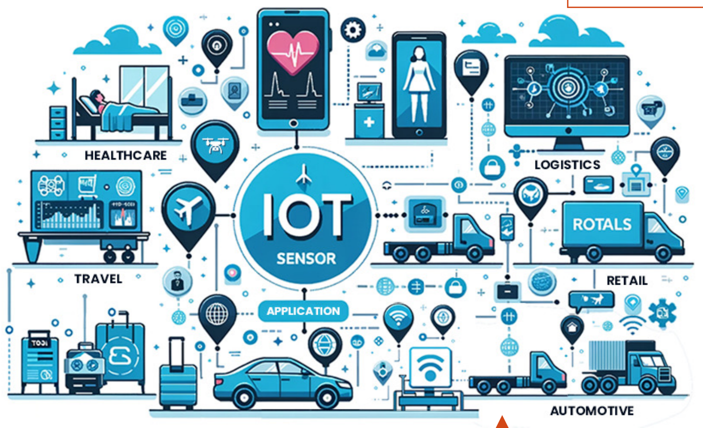
The Internet of Things

A functional overview

Sensing (sensors)



Data collection

Data processing

Visualization

Acting (actuators)

A functional overview

Data collection

- Sensors acting as a physical-cyber interface that **monitors** and **reports states** of some physical entity or device.
- Produce a **digital representation** suitable for use in the cyberspace.
- Relatively early in the process, **metadata** needs to be captured and used to annotate the data. In IoT systems, metadata generally describe the nature and context of data capture, such as the **sensor type**, its **location**, and in some cases structural **relationships** to other elements of the system.

A functional overview

Processing and visualization

- Types of IoT **data processing**:
  - (Simple) **control loop** algorithms performed on the incoming data as they arrive.
  - Sophisticated forms of **analytics** and machine-learning algorithms based on past behaviours and observations of the system.
  - Common **data processing** steps:
    - Sampling, aliasing, quantization, saturation, hysteresis and non-linearities, calibration, error propagation, optimization and predictions (we'll see…).
- In industrial and complex control systems, it is customary to **visualize** the system state and points of interest to system operators → **digital twin** / **dashboard.**
  - System **state**, **notifications**, **alarms** when faults or anomalous behaviors are detected.

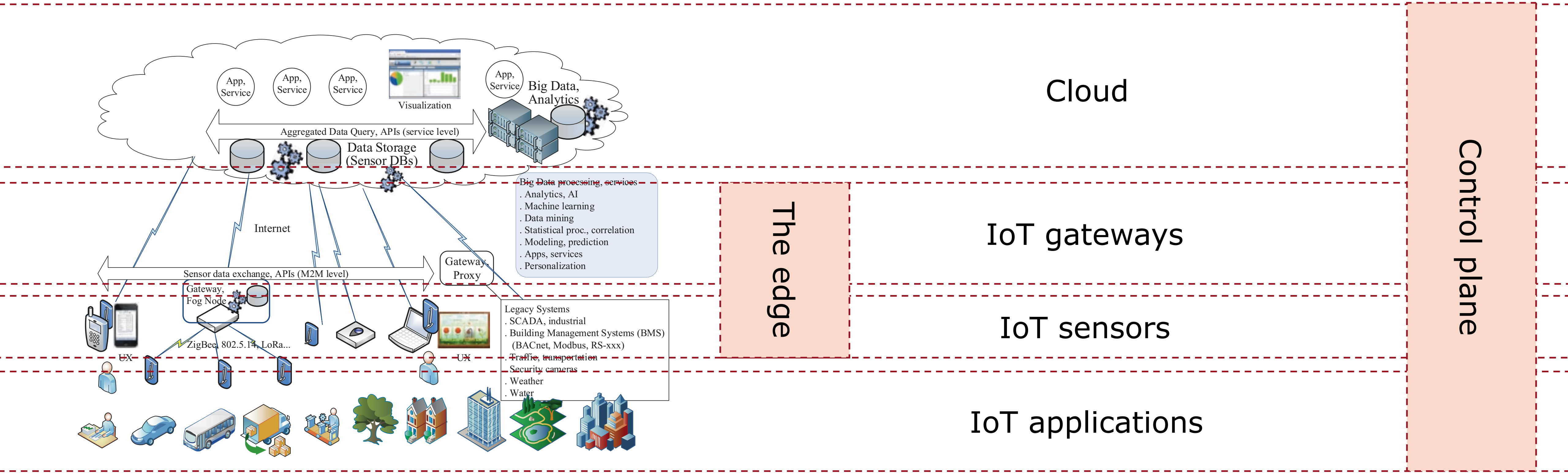
A functional overview

Acting

- Acting upon insights and predictions is the output and the ultimate purpose of deploying IoT systems.
- Common types of actions:
  - From simple **remote actuation** initiated by operators in response to visualized conditions in a basic monitoring configuration to **automated guidance** of control points.
- Actions can be implemented as **direct** actuation or **indirectly**, in the form of advice to system operators or optimizations resulting in adjustments to the manufacturing process.
- Identification of cause of failures and anomalous conditions followed by **direct or indirect** execution of the appropriate remediation actions.

The Internet of Things

A system overview (preferred)



A system overview

IoT applications

- IoT → Improved life quality in several sectors:
  - Production environments – factories
  - Cities
  - Human health and fitness
  - Retail environments
  - Transportation and automotive
  - Oil and gas and mining
  - Utilities and energy
  - Home
  - Offices
  - …

A system overview

Examples of IoT applications: Industry 4.0

- Safety improvement
- Predictive maintenance
- Energy management
- Supply chain optimization
- Quality assurance
- Data-driven decision making
- Real-time product enhancement

https://www.itransition.com/iot/manufacturing

A system overview

Examples of IoT applications: Industry 4.0

- **Tenaris**: smart sensors on each of the plants' motors that send performance data to a dedicated platform so that the Tenaris engineering team could monitor the condition of all motors in real time.
- **Unilever**: digital twin of its production facilities.
- **Volkswagen**: Industrial Cloud bringing together data from machines, plants, and various systems located across 120+ factory sites to improve production.
- **Sealed Air**: IoT-enabled soap dispensers to know exactly a device is getting low on soap and know how much soap is used by employees.

A system overview

Examples of IoT applications: Industry 4.0

- **Unilever**: digital twin of its production facilities.

Unilever is on a journey to become a data insights-driven company
https://youtu.be/CipLPyFjlPI?si=2vGtd4bnll-gST3N

A system overview

Examples of IoT applications: smart shops/retail

- Self-checkout
- Marketing personalization
- Inventory management
- Retail store layout optimization
- Product tracking
- Supply chain optimization
- Cold chain monitoring

https://www.itransition.com/iot/retail

A system overview

Examples of IoT applications: smart shops/retail

- Retail store layout optimization

https://youtu.be/VCf3L4pUpOg?si=NM6QCcRsSzYMhzZ8

A system overview

Examples of IoT applications: smart shops/retail

- **Rebecca** Minkoff: Smart mirrors.
- **Kroger**: Smart shelfs.
- **AmazonGo**: Cashierless shopping.
- **Auchan**: Beacons for wayfinding and promotions.

A system overview

Examples of IoT applications: smart shops/retail

- **AmazonGo**: Cashierless shopping

Introducing Amazon Go and the world's most advanced shopping technology
https://youtu.be/NrmMk1Myrxc?si=_O6K45ddVrdZHCTR

A system overview

Examples of IoT applications: healthcare

- Remote patient monitoring
- Medical alert systems
- In-hospital patient monitoring & diagnostics
- Medication dispensing
- Asthma management
- Medicinal footwear & clothing
- Environment monitoring
- Item inventory tracking
- Patient flow tracking & management
- Predictive maintenance

https://www.itransition.com/healthcare/iot

A system overview

Examples of IoT applications: healthcare

- **iRhythm**: cardiac monitoring Zio patch that helps prevent atrial fibrillation.
- **Eversense**: continuous glucose monitoring (CGM) system, implanted under a person’s skin, transmits data to a smart patch that synchronizes glucose level data.
- **Purell**: devices to track entries and exits in hallways to capture soap and sanitizer dispenser activations.

A system overview

Examples of IoT applications: smart cities/homes

- Lighting
- Security cameras
- Safety systems
- Smart locks
- Smart appliances (e.g., using face recognition)
- Gardening
- Traffic sensors
- Air quality monitors
- Smart street lighting
- Smart parking
- Heating, ventilation, and air conditioning (HVAC) systems

https://www.itransition.com/iot/home-automation

A system overview

Examples of IoT applications: smart cities/homes

- **LG**: Smart control for refrigerators, laundry machines, vacuum cleaners
- **Digital Keys**: IoT smart lock
- **Philips Hue**: smart lighting
- **Gardena**: Smart irrigation system

A system overview

Examples of IoT applications: smart cities/homes

- **Gardena**: Smart irrigation system

GARDENA smart system 2022
https://youtu.be/vyVft_XEqLQ?si=vr1xemeg9l9V2G7B

A system overview

Examples of IoT applications: transportation and automotive

- Predictive vehicle maintenance
- In-car infotainment
- Usage-based insurance
- Manufacturing quality control
- Real-time route optimization
- Smart fleet management
- Usage-based insurance (UBI)
- Over-the-air software updates
- Autonomous driving (sensors)

https://www.itransition.com/iot/automotive

A system overview

Examples of IoT applications: transportation and automotive

- **Waymo**: self-driving cars
- **Tesla**: autopilot
- **BMW**: remote control parking
- **Cadillac Escalade**: in-car infotainment
- **MineStar**: management solution from Cat

A system overview

Examples of IoT applications: transportation and automotive

- **Waymo:** self-driving cars

Sense, Solve, and Go: The Magic of the Waymo Driver
https://youtu.be/hA_-MkU0Nfw?si=rwewdnhL0Tojk_9S

A system overview

Sensors

- **Sensors** can measure some quantity in the environment (e.g., a thermometer).
- **Actuators** can do something in the environment (e.g., turn on the heating system).
- Some sensors contain sufficient functionality to perform some **local operations**.
- Some sensors and things are designed to connect directly to the Internet and communicate with applications and services residing in the cloud.
  - It may require external computation platforms given energy constraints.
  - Security cameras, fire sensors, thermostats, appliances, and power meters, …

A system overview

Gateways

- Sensors connect to the Internet using intermediaries, such as **gateways**.
- Gateways (and **fog nodes**) are usually more powerful devices.
- Connection via local network links, often wireless, such as:
  - ZigBee, variants of 802.5.14 networks, Bluetooth, and low-power Wi-Fi, LoRa, NB-IoT, …
- Gateways usually provide **wide-area connectivity and edge processing** for the attached sensors that may come in the form of protocol conversion, data storage and filtering, event processing, and analytics.

A system overview

Communication layers

- Enables a vast array of edge devices and things to **exchange messages** with each other, the rest of the IoT system, and ultimately the Internet.
- May include a variety of **wireless** and **wired** links, spanning local areas and including long-haul connections.
- Represent a **complex infrastructure** of links, bridges, and routers that can transport payloads from local point-to-point segments all the way to any endpoint and application on the Internet.

A system overview

The cloud

- “Back-end” processing is depicted by a generic **cloud**.
  - Data from a variety of diverse sources are **aggregated** and **processed** for optimization and discovery of global trends and relations.
  - Depending on nature and real-time requirements, sensor data may be **processed** “in-flight” as streams, **stored** for post-processing and archival purposes, or **both**.
  - May also contain some common services such as large-scale **storage**, **analytics-processing** engines, data **visualization** and graphing, as well as **management** functions such as **security** and provisioning.
  - Machine learning (ML) and artificial intelligence (AI) algorithms are usually operated in the cloud where they can work with large aggregations of data.

A system overview

Control plane

- **Data plane / user plane**: main IoT functionalities.
  - Collect, process, and act on data.
- **Control plane**: task of keeping the IoT infrastructure itself running and secure.
  - Service configuration and aggregation
  - Service problem management
  - Service quality management
  - Resource provisioning
  - Trouble and anomaly management
  - Performance management

The Internet of Things

Why today?

A confluence of technological and infrastructure developments centered around the Internet forms much of the basis and impetus for the construction of IoT systems.

- **Industry 4.0** and digitalization
- **Sensors** – installed base, variety, lower cost, and easier integration
- Multi-sensors **miniaturization and mass production**
- **Smart phones** – sensors, gateways, and UI devices
- **Cloud computing** – global and capacity on demand
- **AI and ML technologies** – actionable insights with IoT data
- **Internet** – technology, global infrastructure, and users
- **Pervasive communications**: mobile devices always connected to the Internet

The main problems in the IoT

The energy problem

- Sensors might be placed in hard-to-reach locations: they need to be battery-powered and work for months or years.
- Sometimes they have solar panels or other energy harvesting methods, but we need to be careful: size and cost matter!
- Energy has a significant impact on every IoT operation: communication, computation, sensing, actuators...
- Due to the energy problem, sensors are often optimized to consume little power:
  - We cannot operate on an always-on basis.
  - We need to consider every aspect: any calculation or long transmission is expensive.
- For this reason, sensors often transmit **very few bytes** at relatively long intervals (no transmissions for hours or days in some applications).
- Limited processing capabilities (and so latency concerns).

The main problems in the IoT

The security problem

Novel Botnet Dubbed 'Zerobot' Targets Slew of IoT Devices

Zerobot Operators Quickly Updated Malware With Propagation Exploit, Says Fortinet

Prajeet Nair (@prajeetspeaks) • December 8, 2022

Security could be a fly in the ointment for the IoT boom

Written by Andrew Wooden | 23 January 2023 @ 14:00

Realtek Vulnerability Under Attack: Over 134 Million Attempts to Hack IoT Devices

Jan 30, 2023 Ravie Lakshmanan Internet of Things / Malware

Security Malware

New PoC Shows IoT Devices Can Be Hacked to Install Ransomware on OT Networks

BY DEEBA AHMED · JUNE 1, 2022 · 3 MINUTE READ

FEATURE

How a new generation of IoT botnets is amplifying DDoS attacks

IoT botnets are not new. Nor are DDoS attacks. But the two are on a trajectory that is raising the stakes in DDoS protection and bot takeover prevention.

By Deb Radcliff
CSO | APR 25, 2022 2:00 AM PDT

CYBER REPORT

The dark web's criminal minds see Internet of Things as next big hacking prize

PUBLISHED MON, JAN 9 2023-9:29 AM EST

Elizabeth MacBride
@EDITORSMACB

The main problems in the IoT

The security problem

- The **simplicity** of IoT devices also makes them hard to secure.
  - Impossible to run strong cryptography.
  - Difficult to patch and update to solve vulnerabilities.
  - Connected by design to the open Internet.
- There are possible security solutions against hackers, but there is also a privacy issue: what do sensors say about our lives? Who gets to see the data?
- Sensor data can tell a lot about our lives:
  - Location data can identify movements and activities.
  - Domotic systems tell stories about our habits.
- Data are often used by IoT companies and law enforcement agencies.

The main problems in the IoT

The scalability problem

- Cellular networks and wireless technologies were designed for few devices with high requirements (e.g., humans streaming videos)
- In the IoT, we have **thousands** or **millions** of devices with very little data to send.
    - New access mechanisms.
    - Sensor identification problems.
    - How do we get the data with the minimum amount of transmissions?

The main problems in the IoT

The reliability problem

- The "**converse**" **problem** (what do we need to ensure that we get the relevant information) can be crucial in industrial and safety systems:
  - How do we identify anomalous (and potentially hazardous) situations?
  - Anomalies can be single-sensor or multi-sensor.
  - How do we trust that there is an anomaly when sensors are unreliable?