Karlsruhe Institute of Technology

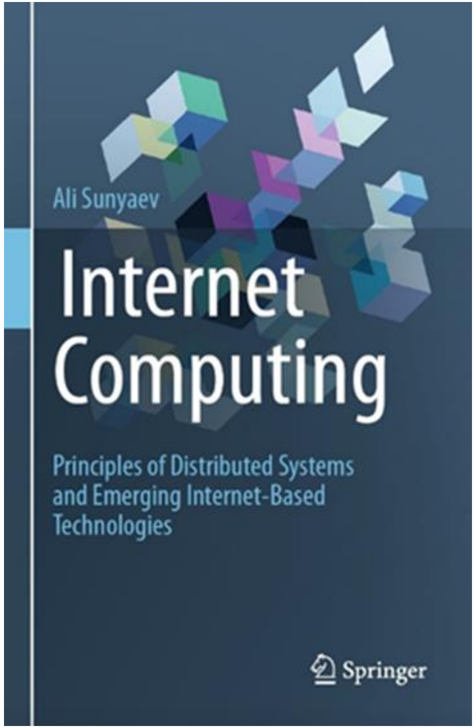
AI: Internet Computing

Lecture 10 — Internet of Things

Learning Goals of the Lecture

- Gaining a basic understanding of the Internet of Things, its essential characteristics and historical background
- Understanding foundational technologies and core concepts of the Internet of Things
- Knowing about architectural models for the Internet of Things and how they differ from each other
- Learning about how the Internet of Things impacts individuals, organizations, and society, and gaining the ability to explain the role of the Internet of Things in presented use cases
- Understanding central challenges associated with the diffusion of the Internet of Things

Reference to the Teaching Material Provided



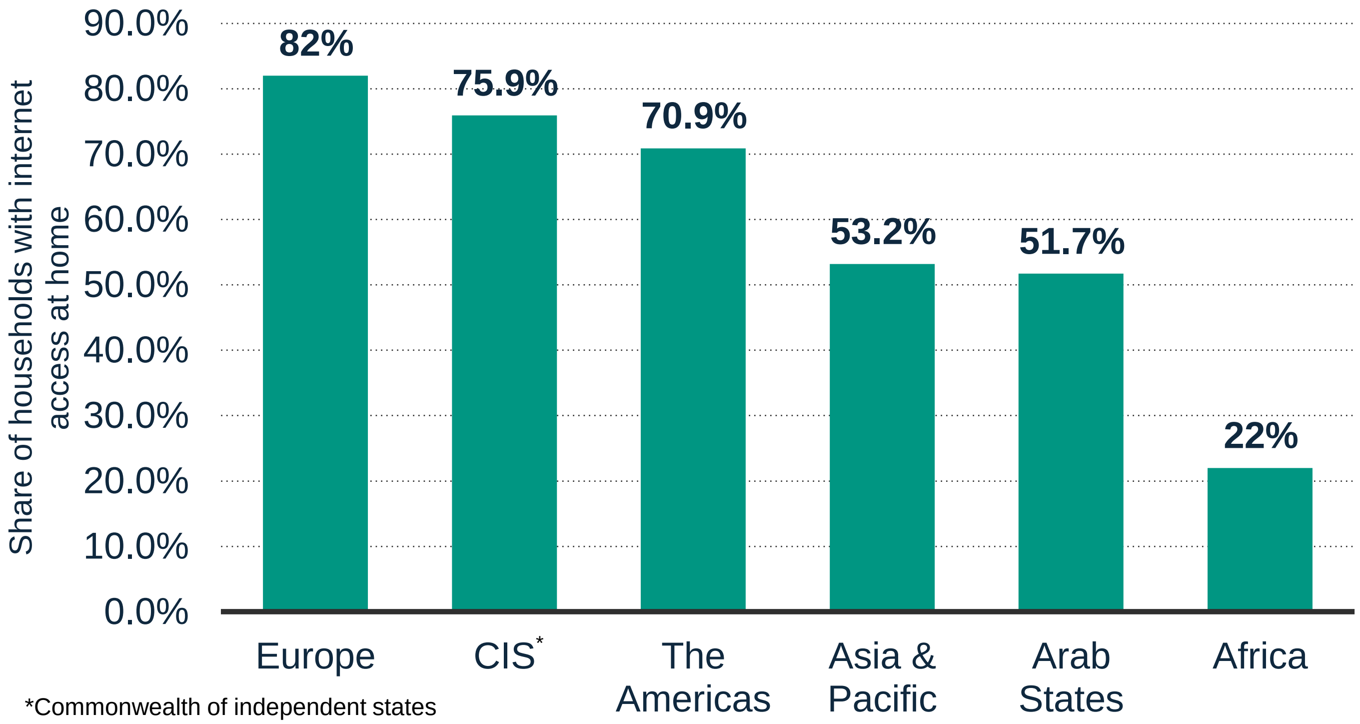
Chapter 10
The Internet of Things

Abstract
Building on the Internet's success story over the past decades, the Internet of Things will profoundly change how people consume information and interact with their immediate environments. This chapter introduces the Internet of Things as a paradigm in which not only human-to-human and human-to-machine communication, but also machine-to-machine communication between smart everyday objects occur over the Internet. Besides a brief definition and overview of the Internet of Things' historical background in the early 1990s, several of its enabling technologies and basic concepts are also covered. Furthermore, this chapter also presents an overview of important architectural models of the Internet of Things put forward by researchers and practitioners. To conclude this introduction, this chapter deals with several common use cases of the Internet of Things, such as smart homes, smart cities, and the Industrial Internet of Things (with a specific focus on the implications for the energy and health care sectors), as well as important challenges to and potential future developments of the Internet of Things.

Learning Objectives of this Chapter
This chapter's main learning objective is to help students understand the Internet of Things concept and its implications for individuals, organizations, and

Motivation

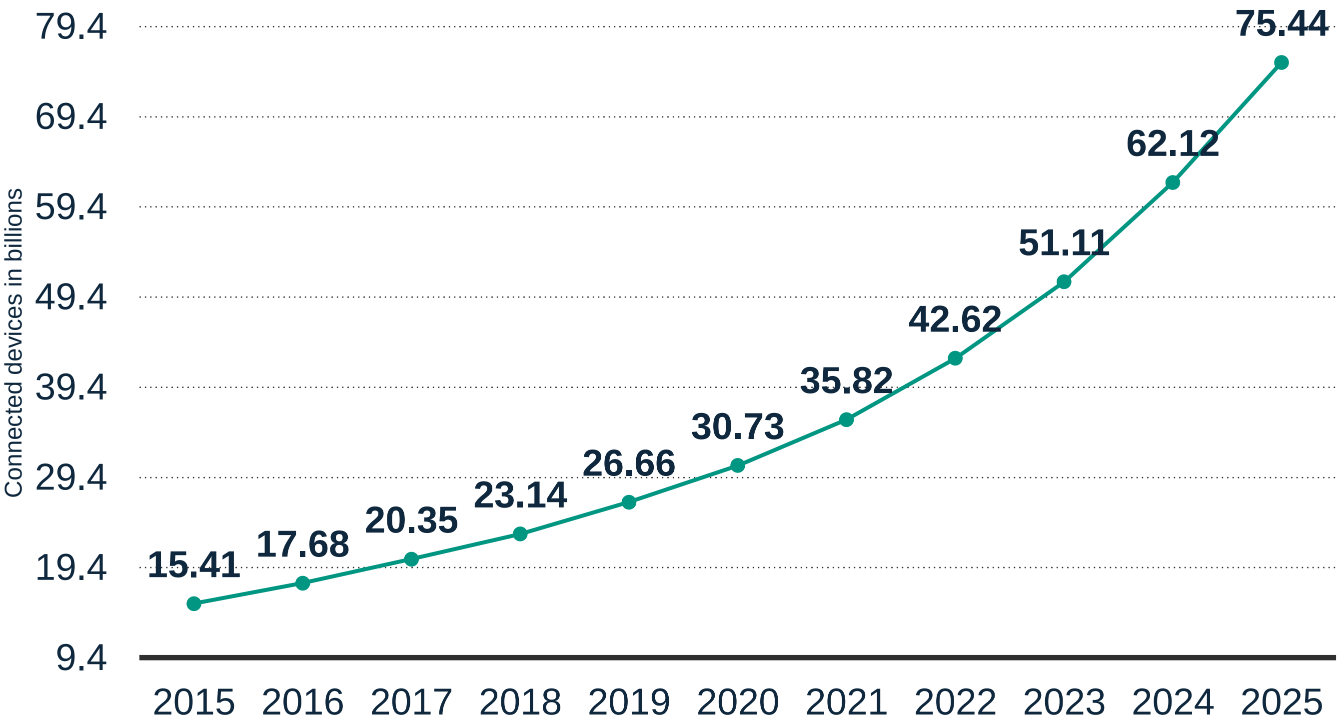
Percentage of Households with Internet Access Worldwide in 2018



*Commonwealth of independent states

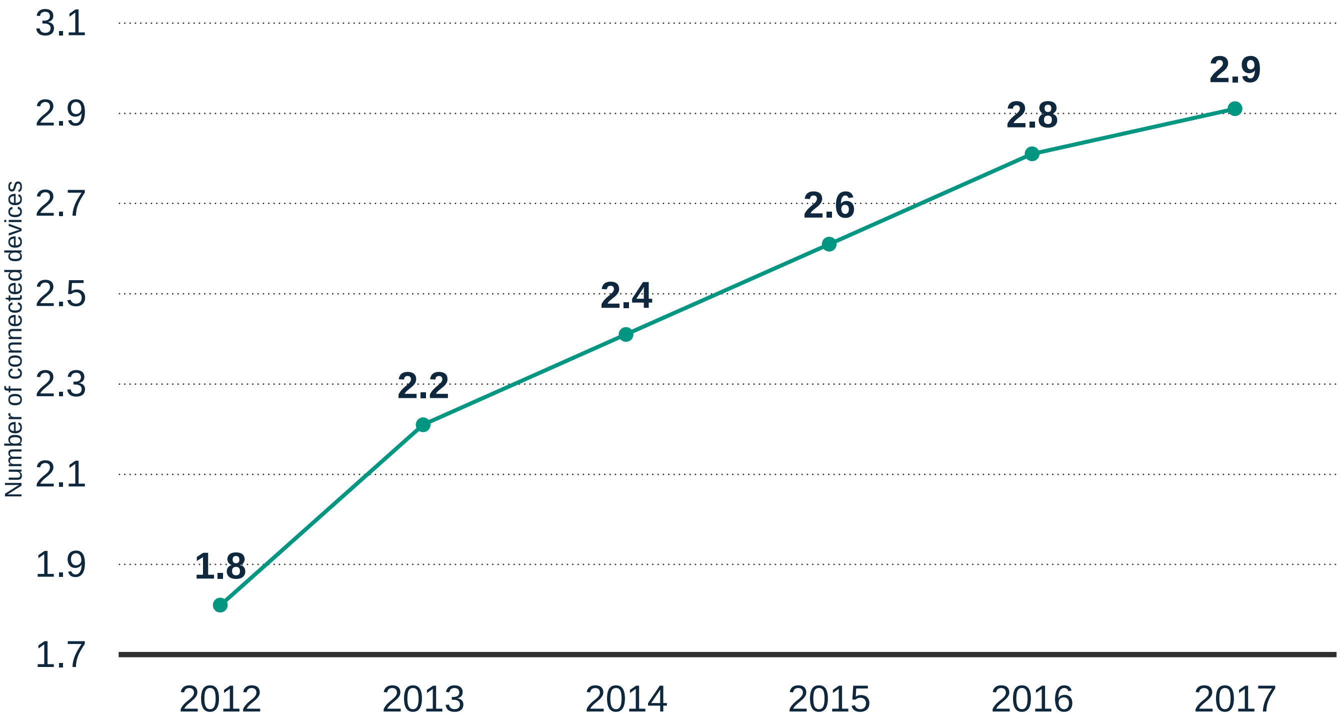
Source: "Percentage with Internet access" by Statista

Number of Devices Connected to the Internet Worldwide



Source: "Number of Devices Connected" by Statista

Average Number of Connected Devices Used per Person in Germany



Source: "Average Number of Connected Devices“ by Statista

Hype Cycle for Emerging Technologies (2018)

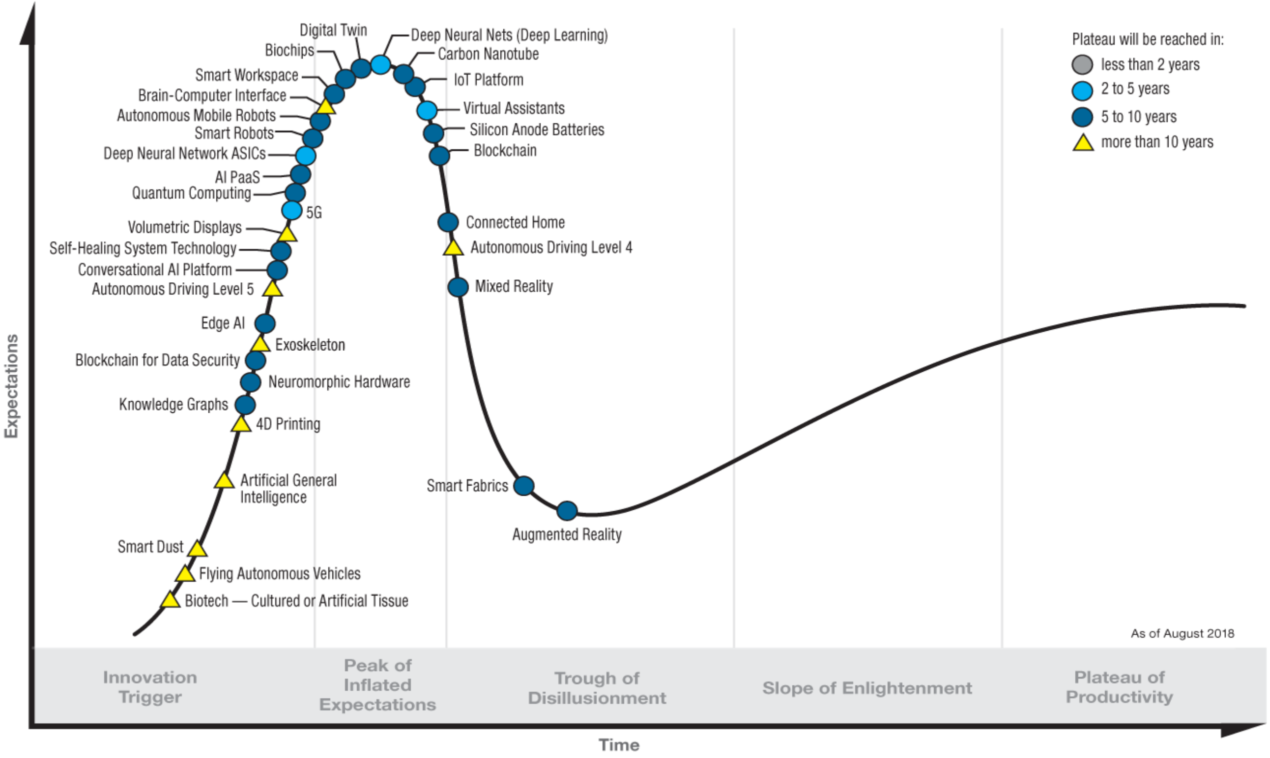
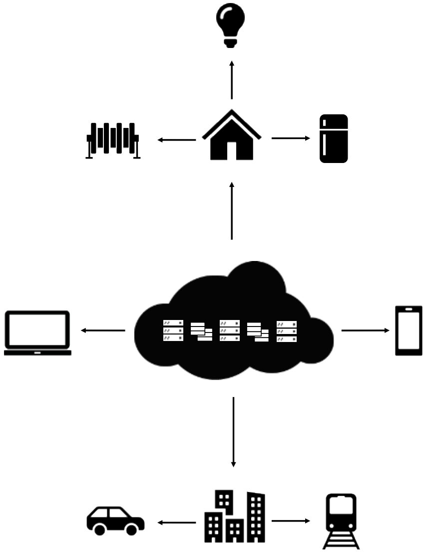


Image Source: "Hype Cycle for Emerging Technologies" by © Gartner 2018.

Toward an Internet of Things

- Technological progress is changing the way we use information systems, at work and in our free time
- The Internet has dramatically changed the way we consume and exchange information and how we interact witch each other
- More and more areas of everyday life are being computerized and connected to the Internet
- Internet use is not restricted to humans accessing the internet over devices, but expands to objects of everyday life and our immediate environment



The Internet is increasingly being used for **machine-to-machine** communication between objects of everyday life.

Definition and Historical Background

Definition of the Internet of Things 1/11

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Definition

The **Internet of Things** is a self-configuring, adaptive, and complex network that interconnects ’things’ with a physical and virtual representation over the Internet, based on standard communication protocols.

- Essential characteristics:
  - Interconnection of things
  - Connection of things to the Internet
  - Uniquely identifiable things
  - Ubiquity
  - Sensing (and actuation) capabilities
  - Embedded intelligence
  - Interoperable communication capability
  - Self-configurability
  - Programmability

Definition of the Internet of Things 2/10

Characteristics of the Internet of Things

- **Interconnection of things**
- Connection of things to the Internet
- Uniquely identifiable things
- Ubiquity
- Sensing (and actuation) capabilities
- Embedded intelligence
- Interoperable communication capability
- Self-configurability
- Programmability

- Any Internet of Things interconnects "things" with each other
- A "thing" can be any physical object that is of relevance for users of the Internet of Things
- Example: Smart lights can be connected to Amazon's Echo in order to be controlled via voice commands

Definition of the Internet of Things 3/10

Characteristics of the Internet of Things

- Interconnection of things
- **Connection of things to the Internet**
- Uniquely identifiable things
- Ubiquity
- Sensing (and actuation) capabilities
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- Interoperable communication capability
- Self-configurability
- Programmability

- The Internet of Things is neither an intranet nor an extranet
- Any physical object (“thing”) in the Internet of Things is connected to the Internet
- Example: Amazon’s Echo is connected to the Amazon Cloud

Definition of the Internet of Things 4/10

Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- **Uniquely identifiable things**
- Ubiquity
- Sensing (and actuation) capabilities
- Embedded intelligence
- Interoperable communication capability
- Self-configurability
- Programmability

- Each and every physical object connected to the Internet of Things possesses a virtual representation
- Each and every object is uniquely identifiable
- Example: Every Echo has its own MAC address to uniquely identify them over the Internet

Definition of the Internet of Things 5/10

Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- Uniquely identifiable things
- **Ubiquity**
- Sensing (and actuation) capabilities
- Embedded intelligence
- Interoperable communication capability
- Self-configurability
- Programmability

- The network is available at any time and from everywhere, when needed
- Example: No matter where your Echo is placed in your house, it is always connected to the Internet

Definition of the Internet of Things 6/10

Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- Uniquely identifiable things
- Ubiquity
- **Sensing (and actuation) capabilities**
- Embedded intelligence
- Interoperable communication capability
- Self-configurability
- Programmability

- The physical objects connected to the Internet of Things possess at least some sensing capabilities
- Many physical objects also possess actuation capabilities, allowing them to interact with the environment
- Example: Your Echo senses the acoustic waves when you speak and is able to control your smart lights by that

Definition of the Internet of Things 7/10

Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- Uniquely identifiable things
- Ubiquity
- Sensing (and actuation) capabilities
- **Embedded intelligence**
- Interoperable communication capability
- Self-configurability
- Programmability

- Physical objects in the Internet of Things possess some form of embedded intelligence (although often only rudimentary)
- That enables them to act as extensions to the human body and mind
- Example: Your Echo contains many different micro chips

Definition of the Internet of Things 8/10

Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- Uniquely identifiable things
- Ubiquity
- Sensing (and actuation) capabilities
- Embedded intelligence
- **Interoperable communication capability**
- Self-configurability
- Programmability

- The Internet of Things allows for communication based on standardized and interoperable protocols
- Example: Your Echo is able to control your smart lights via the ZigBee communication protocol

Definition of the Internet of Things 9/10

Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- Uniquely identifiable things
- Ubiquity
- Sensing (and actuation) capabilities
- Embedded intelligence
- Interoperable communication capability
- **Self-configurability**
- Programmability

- The Internet of Things is self-configurable
- It is able to self-discover new physical objects and services, as well as manage the network and resource usage
- Example: Your Echo learns through your input and adapts to your behaviour

Definition of the Internet of Things 10/10

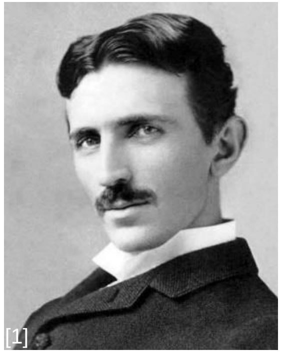
Characteristics of the Internet of Things

- Interconnection of things
- Connection of things to the Internet
- Uniquely identifiable things
- Ubiquity
- Sensing (and actuation) capabilities
- Embedded intelligence
- Interoperable communication capability
- Self-configurability
- **Programmability**

- The physical objects in an Internet of Things are programmable
- Programmable in a sense that users can change and adapt their behaviour without the need to change their physical representation
- Example: You can configure your Echo via the Alexa App and use Amazon's Alexa Skill Kit (ASK) to develop your own Alexa Skills

Historical Background (1/6)

1920s – 1930s:
- Beginning of IoT (?)
- ”Connected World” by Nikola Tesla
- Discovery of the radar by Sir Robert Alexander Watson-Watt



1970s:
- Roots of IoT
- Demand for large mainframe computers started to shift to smaller minicomputers and eventually personal computers
- Strong miniaturization trend

Image source [1]: [Nikolai Tesla] by Sarony Napoleon, 1890. Public Domain.
Image source [2]: [Robert Watson] by Unknown, December 31th 1954. Public Domain.

Historical Background 2/6

1980s:
- Shaping of the phrase “Ubiquitous Computing” by Mark Weiser (Chief Technologist at the Xerox Palo Alto Research Center)


[1]

1990:
- First IoT device
- Internet-connected toaster by John Romkey and Simon Hackett


[2]

Image source [1]: [Internet Toaster from John Romkey] by Unknown, 1989. Public Domain.
Image source [2]: [Toaster] by Unknown, May 15th 2005. Licensed under CC BY-SA 3.0.

Historical Background 3/6

1999:
- Coining of the term “Internet of Things” by Kevin Ashton (Co-founder of the Auto-ID Center at the MIT)
- The group worked on RFID and barcodes for supply-chain management


[1]

2000:
- First Internet-connected refrigerator by LG
- Ambient Orb by Ambient Devices
- Nabaztag by Violet
- Appearance of the term Internet of Things in mainstream media and books


[2]

Image source [1]: [Internet refrigerator] by LG전자, October 15th 2012. Licensed under CC BY 2.0.
Image source [2]: [Nabaztag] by Unknown, January 3rd 2007. Licensed under CC BY-SA 2.5.

Historical Background 4/6

2005:
- First report on the Internet of Things by the United Nations' ITU (International Telecommunications Unit)

2008:
- First European Internet of Things conference
- Internet of Things being cited as one of six disruptive civil technologies that could potentially have an impact on the US by the US' International Intelligence Council

Image source: [ITU Logo] by © ITU 2022.

Historical Background 5/6

2010:

- The Chinese government declared the Internet of Things a key industry sector

2011:

- The Internet of Things being added to the annual Hype Cycle by Gartner (IT market research and analysis firm)

Image source: [Gartner Logo] by © Gartner 2022.

Historical Background 6/6

2014:
- Internet of Things reached the peak of inflated expectations

2018 and future:
- Expected to progress to the plateau of productivity within the next five to ten years

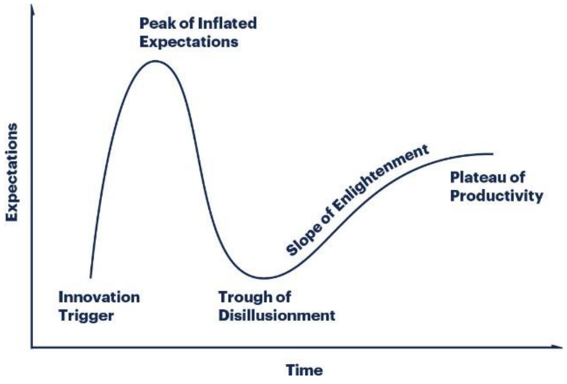


Image source: Adapted from Hype Cycle for Emerging Technologies by © Gartner 2018.

Enabling Technologies and Core Concepts

Overview of Enabling Technologies

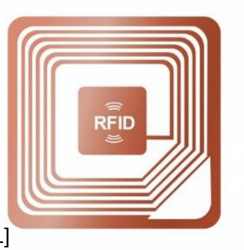
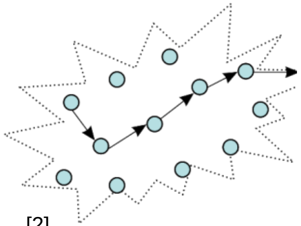
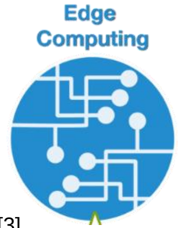
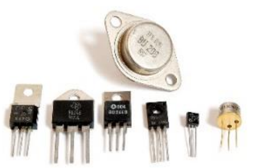
Tagging Technologies	Sensor Technologies	Smart Technologies	Miniaturization Technologies
 [1]	 [2]	 [3]	 [4]
Identification	Perception	Intelligence	Size

Image source [1]: [Tagging Technologies] by Sparkfun, n.d. SparkFun Electronics ®
Image source [2]: Adapted from [Wireless Sensor Network] by Mohammed Mehdi Saleh, April 16th 2019.
Image source [3]: Adapted from [Edge Computing] by Met Dem, n.d.
Image source [4]: [Transistors] by Seidl Benedikt, September 8th 2007. Public Domain.

Enabling Technologies – Tagging Technologies (1/3)

Tagging technologies allow to **track and count** virtually **any physical object**. Due to the large number of potential objects, inexpensive and easy-to-use tagging technologies are imperative for the Internet of Things.

Two common types of tagging technologies:

1. Barcodes
   - Barcodes are a form of optical tagging
   - Anyone who wants to read a barcode will need a direct line of sight
2. RFID Tags
   - RFID tags are a form of tagging over radio waves
   - A direct line of sight is not needed
   - Communication range: from few centimetres to approximately one meter

Tagging Technologies 2/3

Barcodes:

- Represent information by
  - Vertical lines of varying width
  - Varying spacing between every line

0 36000 29145 2

[1]

- Are able to convey only limited amount of information

- Usually used to identify groups of product

Example! All boxes of milk of the same type from the supermarket will have the same barcode that convey exactly the same information.

[2]

Image source [1]: [Barcode] by Unknown, March 15th 2018. Licensed under CC0 1.0.
Image source [2]: [Milk Box] by 3dsguru, Feburuary 27th 2012.

Tagging Technologies 3/3

RFID Tags:

- RFID tags address the limitations of traditional barcodes
- A single tag is able to store and transmit much more information (up to two kilobytes)
- They enable tracking of many more objects

[4]

Example! Expensive brand clothing items are tagged individually.


[3]

Active Tags

- Transmit data without the need for an external power source

[1]


Passive Tags

- Transmit data by drawing energy from the reading device

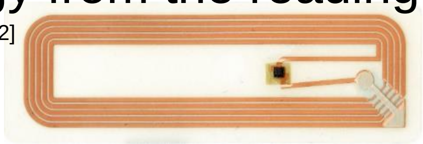
[2]


Image source [1]: [RDIF Tags] by Copyright © 2022 RDF.Inc.
Image source [3]: [Burberry Scarf] by Neimanmarcus, n.d. Public Domain.
Image source [4]: [Tagging Technologies] by Sparkfun, n.d. SparkFun Electronics ®

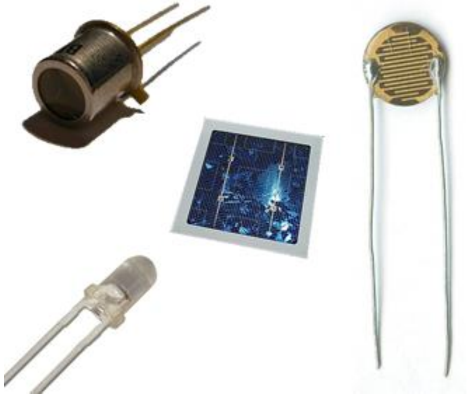
Image source [2]: [Transponder] by Unknown, March 21th 2006. Licensed under CC BY-SA 3.0.

Sensor Technologies 1/3

Sensors **collect data about the real world**. They can augment and complement human senses.

There is a wide range of sensing capabilities:

- Light, movement, pressure, temperature, smoke, proximity, acceleration, etc.



A single unconnected sensor is of little value:

- The collected data must be processed and interpreted
- Within the Internet of Things, sensors are connected to the Internet, with their sensor data being sent to cloud services

Image source: [Light Sensor] by Vickyvxr, May 7th 2009. Licensed under CC BY 2.0.

Sensor Technologies 2/3

Definition

A Wireless Sensor Network (WSN) is a network of distributed autonomous devices that use sensors to record physical quantities and thus map environmental conditions.

- Sensors become even more powerful and valuable when multiple of them are being linked together via the Internet
- They are the foundational technology of smart cities, Industry 4.0, etc.

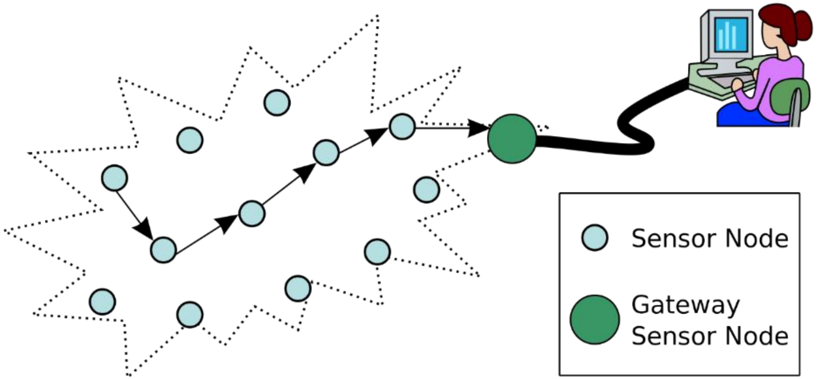


Image source: [Wireless Sensor Network] by Mohammed Mehdi Saleh, April 16th 2019.

Sensor Technologies 3/3

Wireless Sensor and Actuator Network (WSAN):

- In many scenarios it is not enough for physical objects to only sense something and report this data
- Physical objects are expected to interact autonomously with other objects or people
- Actuators complement sensors by giving the ability to interact with the environment
- They are the foundational technology for smart fire sprinklers, window shades, etc.

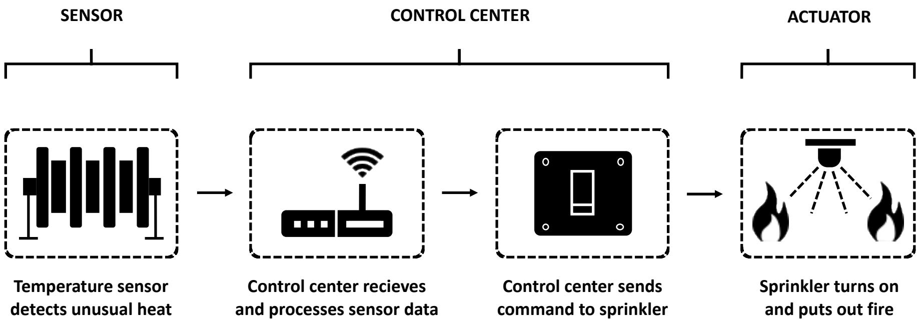


Image source: Adapted from Misra J (2017) IoT system | sensors and actuators. https://bridgera.com/iot-system-sensors-actuators/. Accessed 23 June 2021.

Smart Technologies

“Things” become smart in a sense that they are increasingly being equipped with microprocessors and internal data processing capabilities.

- Sensors produce a rapidly increasing amount of data
- This data needs to be processed and interpreted to provide services and applications
- Most of the data is sent to cloud services
- (Smart) ’things’ increasingly contain intelligence to process most data before sending it to cloud services

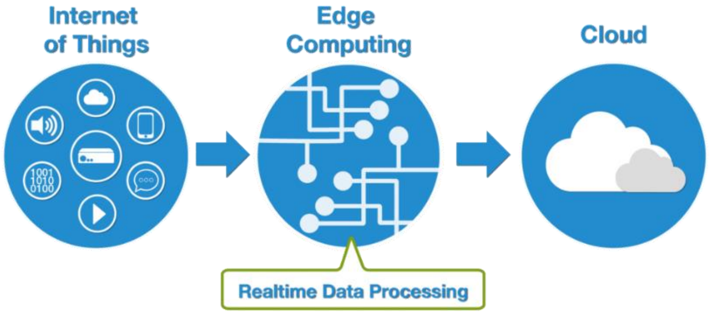


Image source: Adapted from [Edge Computing] by Met Dem, n.d.

Miniaturization Technologies

In order to embed intelligence in all kinds of physical objects, computer chips and sensors need to become ever so smaller.

- Advances in miniaturization and nanotechnology during the last decades led to computer chips being found in almost every electronics device nowadays
- Without such advances the Internet of Things in its current form would not have been possible


[1]


[2]

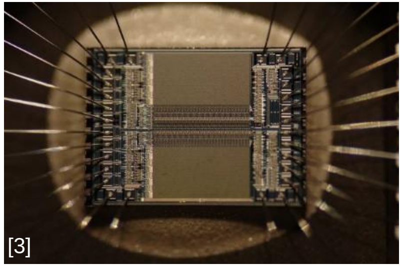

[3]

Image source [1]: [Vacuum Tube] by Materialscientist, May 11th 2011. Licensed under CC BY-SA 2.0 DE.
Image source [2]: [Transistor] by Seidl Benedikt, September 8th 2007. Public Domain.
Image source [3]: [Microchip SuperMacro] by Zephyris, October 27th 2011. Licensed under CC BY-SA 3.0.

Summary of Enabling Technologies

Enabling Technologies	Purposes	Examples	Typical Challenges
Tagging Technologies	Identify and track individual physical objects	active/passive RFID tags	Cost of tags are still considerably higher than printed barcodes
Sensor Technologies	Collect data about the real world and augment human senses	temperature sensor, proximity sensor, GPS	Processing and sense making of the vast amounts of collected sensor data
Smart Technologies	Provide processing capabilities to physical objects	microprocessors	With improved capabilities smart technologies require an increasing amount energy
Miniaturization Technologies	Shrinking of information technology to be able to fit it into everyday objects	7 nanometers transistor manufacturing processes	As miniaturization continues it becomes increasingly difficult to produce smaller and smaller things

Core Concepts — Overview

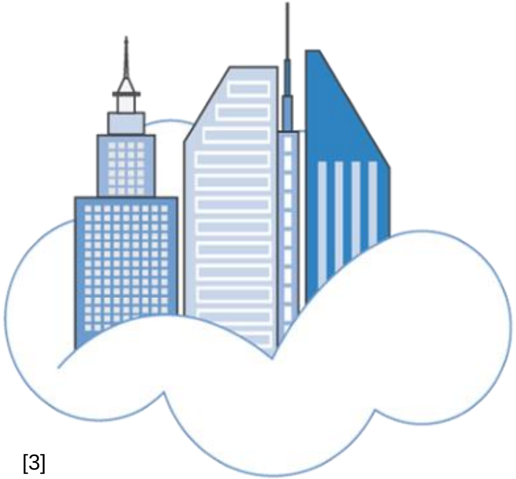
Smart devices

[1]

Smart objects

[2]

Smart environments



[3]

Image source [1]: [Gold iPhone XS] by Fernandez Rafael, September 12th 2018. Licensed under CC BY-SA 4.0
Image source [2]: [Google Smart Speaker] by NBD Fotos, March 16th 2017. Licensed under CC BY-SA 2.0.
Image source [3]: [Smart Cities Webcast] © 2022, Amazon Web Services.

Core Concepts — Smart Devices

Definition

Internet-connected physical objects with embedded intelligence (smart ’things’) are an integral aspect of the Internet of Things.
Two types of such smart ‘things’ can be distinguished, smart **devices** and smart **objects**.

Smart Devices:

- Smart devices are portable multi-purpose information and communication technology devices that enable access to (several) application services located locally on the device or remotely on servers.

[1]

[2]

Core Concepts — Smart Devices

Characteristics:

- Smart devices usually belong, or are used by a specific person
- They are usually multi-functional and mobile (to different degrees)
- They are able to dynamically discover new or extant services
- Have intermittent access to resources
- Most smart devices today also exhibit some form of location awareness and self-awareness

[1]

[2]

Image source [1]: [Gold iPhone XS] by Fernandez Rafael, September 12th 2018. Licensed under CC BY-SA 4.0
Image source [2]: [Samsung Smart TV] by Unknown, n.d. Copyright © 1995-2022 Samsung.

Core Concepts — Other Types of Smart Devices

Smart Dusts:

- Are miniaturized smart devices with sensing and processing capabilities without an integrated display
- They are deployed to unobtrusively collect data within an area
- For example monitoring of engines, the environment, or wildlife

[1]

Smart Skins:

- Are fabrics-based, non planar, flexible and stretchable smart devices
- They seek to imitate human or animal skin
- Their prominent application area is health care monitoring and prosthetics

[2]

Image source [1]: [Box camera] by Berthold Werner, May 1st 2008. Public Domain.
Image source [2]: [A prototype of a wireless sensor] by GE Global research © 2022 General Electric

Core Concepts — Smart Objects

Characteristics:

- Smart objects can autonomously interact with humans and other (smart) objects in their environment

- They are able to:
  - Recognize and collect data about their environment through implemented sensors
  - To process and store this data due to embedded microprocessors and memory
  - To communicate through network and user interfaces

[1]

[2]

Image source [1]: [Google Smart Speaker] by NBD Fotos, March 16th 2017. Licensed under CC BY-SA 2.0.
Image source [2]: [Apple Homepod] by Apple, n.d. Copyright © 2022 Apple Inc.

Core Concepts — Different Types of Smart Objects

Activity-Aware Smart Objects:

- Activity-aware smart objects possess the ability to collect and record information about work activities on their own

Policy-Aware Smart Objects:

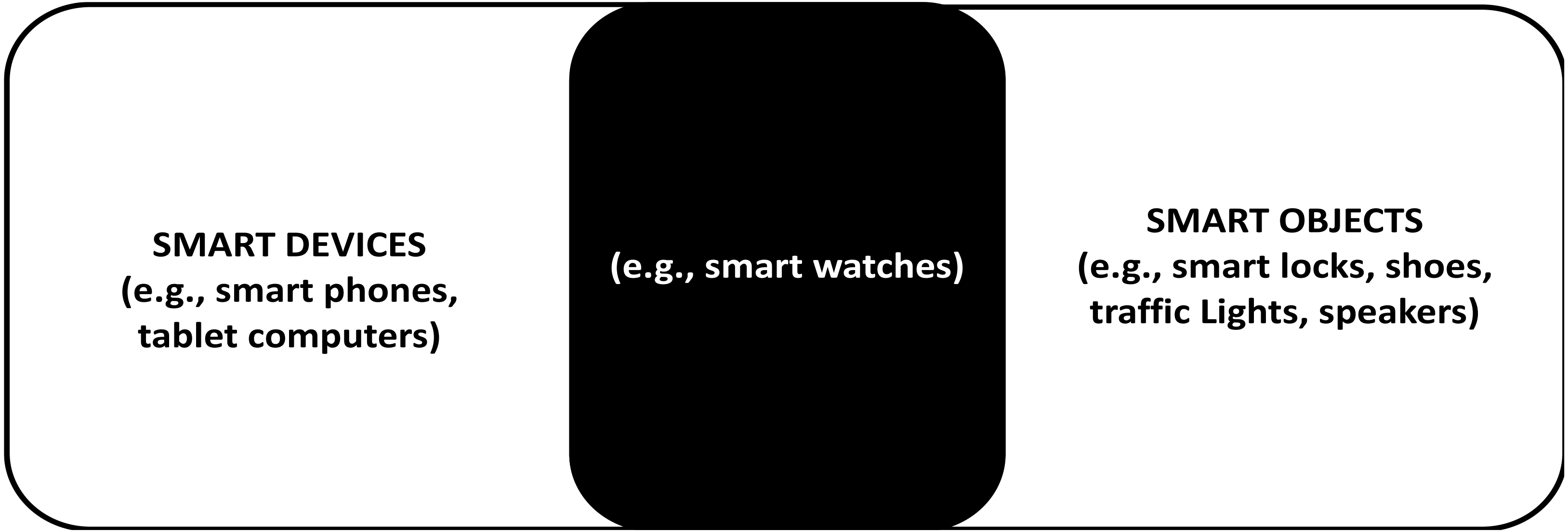
- Policy-aware smart objects are activity-aware smart objects that understand and process events and activities with regard to organizational policies

Process-Aware Smart Objects:

- Process-aware smart objects are able to understand and support organizational processes and individuals involved in these processes

Core Concepts — Overlapping Terms

Smart devices and **smart objects** overlap to some degree. An example of this overlap are smart watches and other wearable devices, which are often referred to as smart objects but also fit our definition of smart devices.



Core Concepts — Smart Environment

Definition

A smart environment is a physical world interwoven with a multitude of sensors, actuators, displays, and computing elements, seamlessly interacting with everyday objects of our lives, and connected by a continuous network.

A central property is context-awareness:

- Being able to sense and interpret context in order to provide a variety of context-dependent information and services

Smart environments are closely related to the concept of Ubiquitous Computing:

- Ubiquitous Computing refers to a physical world that is interwoven with computing devices
- Smart environments refer to a physical world that is interwoven with smart objects

Image source: [Smart Cities Webcast] © 2022, Amazon Web Services.

Architectural Models

Architectural Models — Overview

Three-Layer Model

- Application Layer
- Network Layer
- Perception Layer

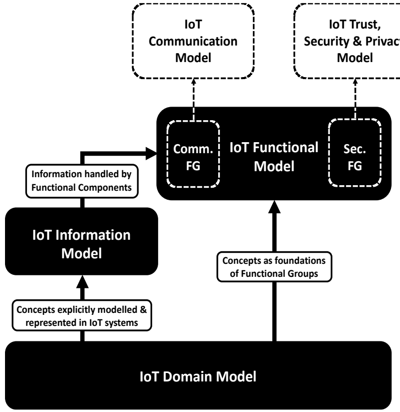
Five-Layer Model

- Business Layer
- Application Layer
- Processing Layer
- Transport Layer
- Perception Layer

Seven-Layer Model

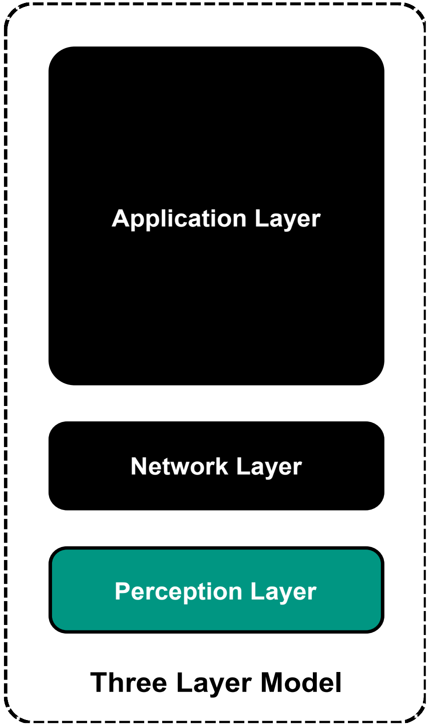
7. **Collaboration & Processes** (Involwing People & Business Processes)
6. **Application** (Reporting, Analytics, Control)
5. **Data Abstraction** (Aggregation & Access)
4. **Data Accumulation** (Storage)
3. **Edge (Fog) Computing** (Data Element Analysis & Transformation)
2. **Connectivity** (Communication & Processing Units)
1. **Physical Devices & Controllers** (The ‘‘Things’’ in IoT)

IoT-A



Architectural Models 1/12

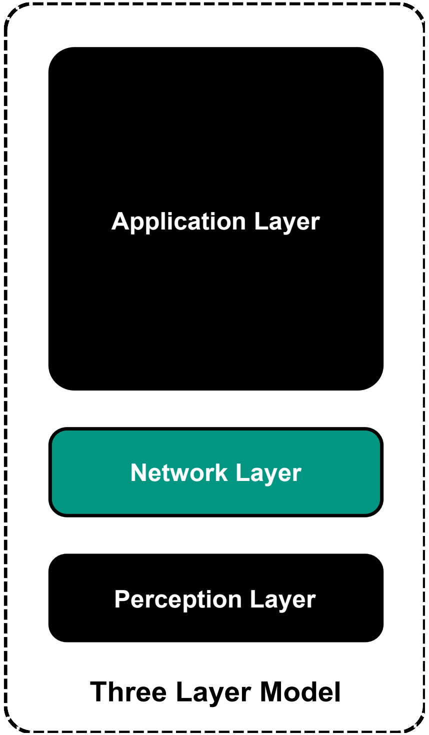
Three-Layer Architecture



- The Perception Layer is also known as the recognition or sensing layer
- It is responsible for sensing and collecting useful information about the environment
- It is the layer where all smart objects are situated

Architectural Models 2/12

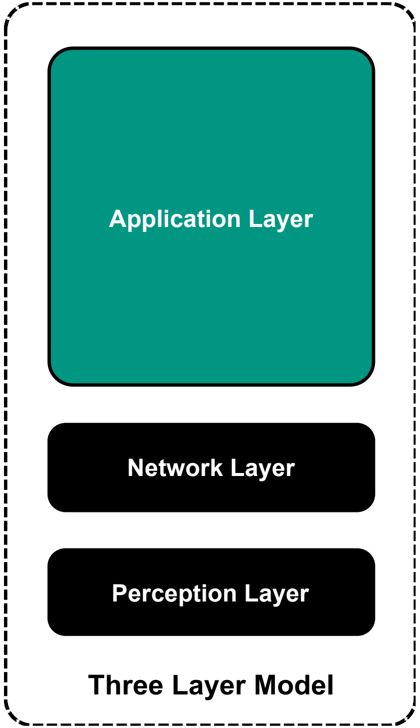
Three-Layer Architecture



- The Network Layer is also known as the communication layer, it forms the backbone of the Internet of Things
- It is responsible for securely transmitting information collected on the Perception Layer to the Application Layer and back
- All network technologies are located in this layer (WSNs, WSANs, the Internet structure itself, etc.)

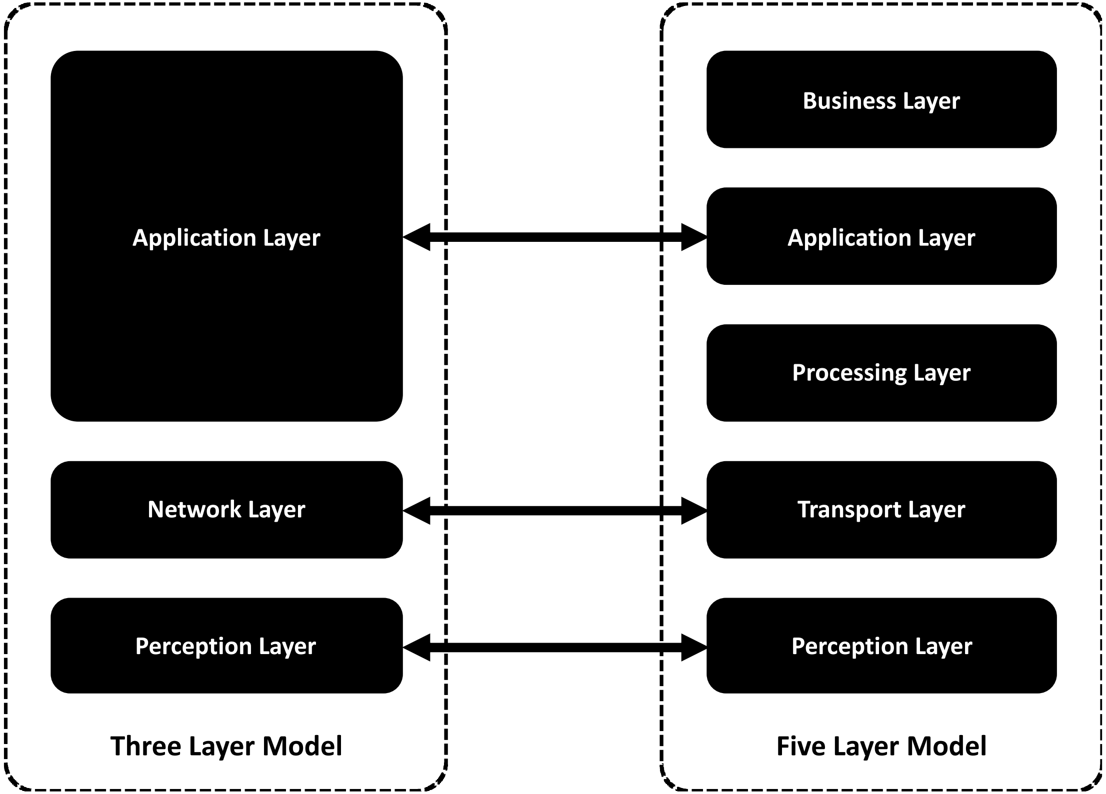
Architectural Models 3/12

Three-Layer Architecture



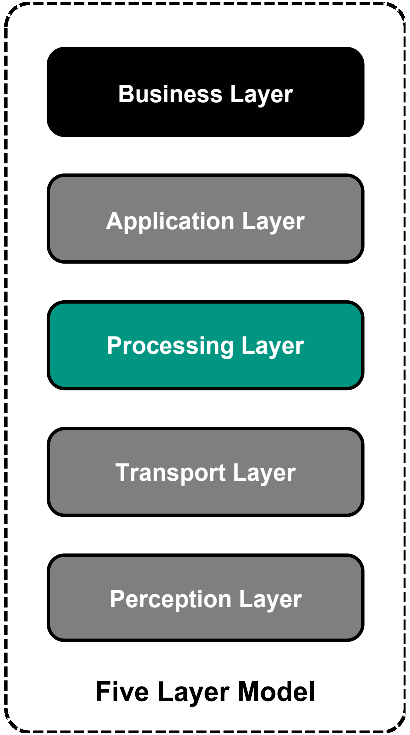
- The Application Layer is responsible for providing services to users of the Internet of Things
- It is usually the layer that is most prevalent to users as they often directly interact with applications situated on this layer

Architectural Models — Comparison



Architectural Models 4/12

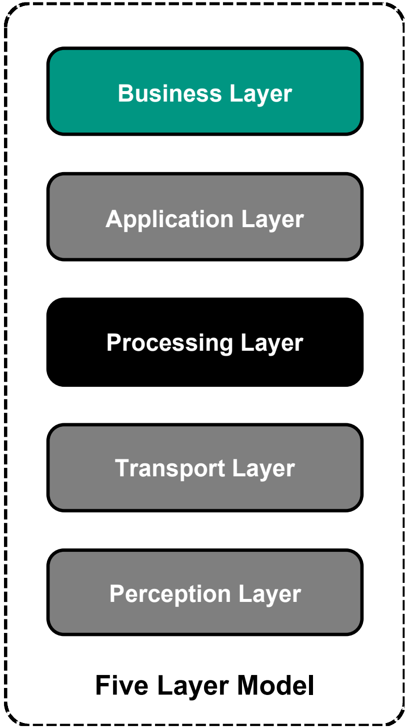
Five-Layer Architecture



- The Processing Layer is also known as the Middleware Layer
- It stores and processes the vast amounts of data that are produced by the Internet of Things and is received from the Perception Layer through the Transport Layer
- Technologies such as databases or cloud computing can be situated on this layer

Architectural Models 5/12

Five-Layer Architecture



- The Business Layer manages the entire system that comprises the Internet of Things
- This includes the management of applications, business models, and user privacy

Architectural Models — Seven Layer Architecture

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7 **Collaboratıon & Processes**
(Involwing People & Business Processes)

6 **Application**
(Reporting, Analytics, Control)

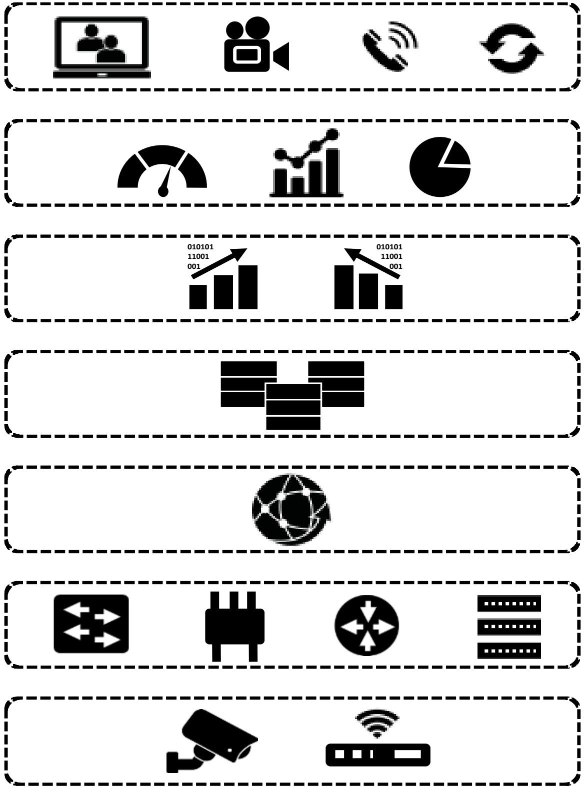
5 **Data Abstraction**
(Aggregation & Access)

4 **Data Accumulation**
(Storage)

3 **Edge (Fog) Computing**
(Data Element Analysis & Transformation)

2 **Connectivity**
(Communication & Processing Units)

1 **Physical Devices & Controllers**
(The ‘‘Things’’ in IoT)



CENTER

Data at Rest

Data in Motion

EDGE

Architectural Models 6/12

Seven-Layer Architecture

7 **Collaboration & Processes**
(Involwing People & Business Processes)

6 **Application**
(Reporting, Analytics, Control)

5 **Data Abstraction**
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3 **Edge (Fog) Computing**
(Data Element Analysis & Transformation)

2 **Connectivity**
(Communication & Processing Units)

1 **Physical Devices & Controllers**
(The "Things" in IoT)

- This is the level where all the physical (smart) objects that participate in the Internet of Things are located

Architectural Models 7/12

Seven-Layer Architecture

7	**Collaboration & Processes** (Involwing People & Business Processes)
6	**Application** (Reporting, Analytics, Control)
5	**Data Abstraction** (Aggregation & Access)
4	**Data Accumulation** (Storage)
3	**Edge (Fog) Computing** (Data Element Analysis & Transformation)
2	**Connectivity** (Communication & Processing Units)
1	**Physical Devices & Controllers** (The "Things" in IoT)

- This level is responsible for the reliable and timely transmission of data
- Thus it corresponds to the Network and Transport Layers of the previously discussed models

Architectural Models 8/12

Seven-Layer Architecture

7	**Collaboration & Processes** (Involwing People & Business Processes)
6	**Application** (Reporting, Analytics, Control)
5	**Data Abstraction** (Aggregation & Access)
4	**Data Accumulation** (Storage)
3	**Edge (Fog) Computing** (Data Element Analysis & Transformation)
2	**Connectivity** (Communication & Processing Units)
1	**Physical Devices & Controllers** (The ‘‘Things’’ in IoT)

- The purpose of this level is it to convert a flood of data into information
- That information can be stored and used for higher level processing at the Data Accumulation Level

Architectural Models 9/12

Seven-Layer Architecture

- **7** — **Collaboration & Processes** (Involwing People & Business Processes)
- **6** — **Application** (Reporting, Analytics, Control)
- **5** — **Data Abstraction** (Aggregation & Access)
- **4** — **Data Accumulation** (Storage)
- **3** — **Edge (Fog) Computing** (Data Element Analysis & Transformation)
- **2** — **Connectivity** (Communication & Processing Units)
- **1** — **Physical Devices & Controllers** (The ‘‘Things’’ in IoT)

- The Data Accumulation Level puts this data at rest
- So it is usable by applications when needed on a non-real-time basis

Architectural Models 10/12

Seven-Layer Architecture

- **7** **Collaboratıon & Processes**
  (Involwing People & Business Processes)
- **6** **Application**
  (Reporting, Analytics, Control)
- **5** **Data Abstraction**
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  (Data Element Analysis & Transformation)
- **2** **Connectivity**
  (Communication & Processing Units)
- **1** **Physical Devices & Controllers**
  (The ‘‘Things’’ in IoT)

- This level provides data abstraction functions to the upper levels
- These functions enable upper levels to handle the flood of data that is produced by the Internet of Things

Architectural Models 11/12

Seven-Layer Architecture

- **7 Collaboration & Processes** (Involwing People & Business Processes)
- **6 Application** (Reporting, Analytics, Control)
- **5 Data Abstraction** (Aggregation & Access)
- **4 Data Accumulation** (Storage)
- **3 Edge (Fog) Computing** (Data Element Analysis & Transformation)
- **2 Connectivity** (Communication & Processing Units)
- **1 Physical Devices & Controllers** (The "Things" in IoT)

- At this level the information interpretation occurs by the diverse applications that reside on this level

Architectural Models 12/12

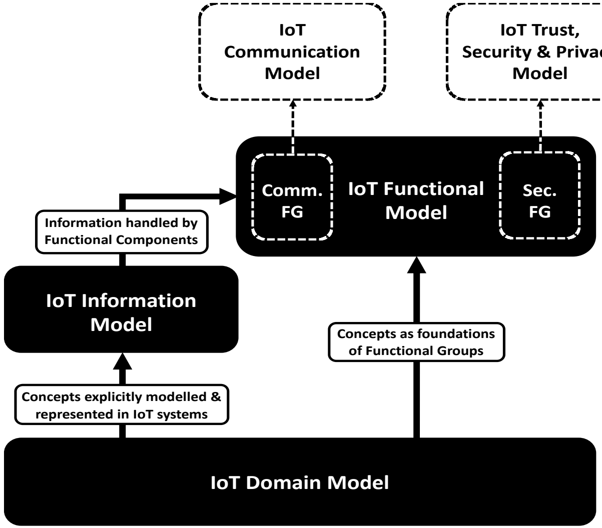
Seven-Layer Architecture

- **7 Collaboration & Processes** (Involwing People & Business Processes)
- **6 Application** (Reporting, Analytics, Control)
- **5 Data Abstraction** (Aggregation & Access)
- **4 Data Accumulation** (Storage)
- **3 Edge (Fog) Computing** (Data Element Analysis & Transformation)
- **2 Connectivity** (Communication & Processing Units)
- **1 Physical Devices & Controllers** (The ‘‘Things’’ in IoT)

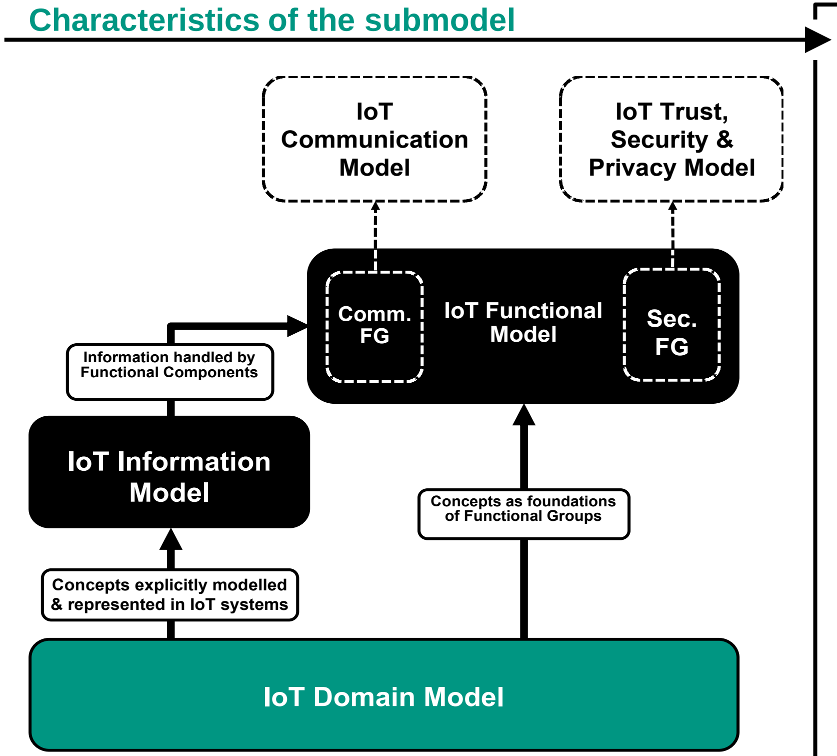
- The top level goes beyond the pure technical aspects and represents the socio-technical aspects
- It Includes people and processes that connect multiple applications provided by the Internet of Things

Architectural Models — IoT-A (Internet of Things Architecture)

The IoT-A architecture is developed by a consortium of members within the framework programme for research and technological development of the EU. It is not based on a layered architecture but of five sub-models that interact with each other.

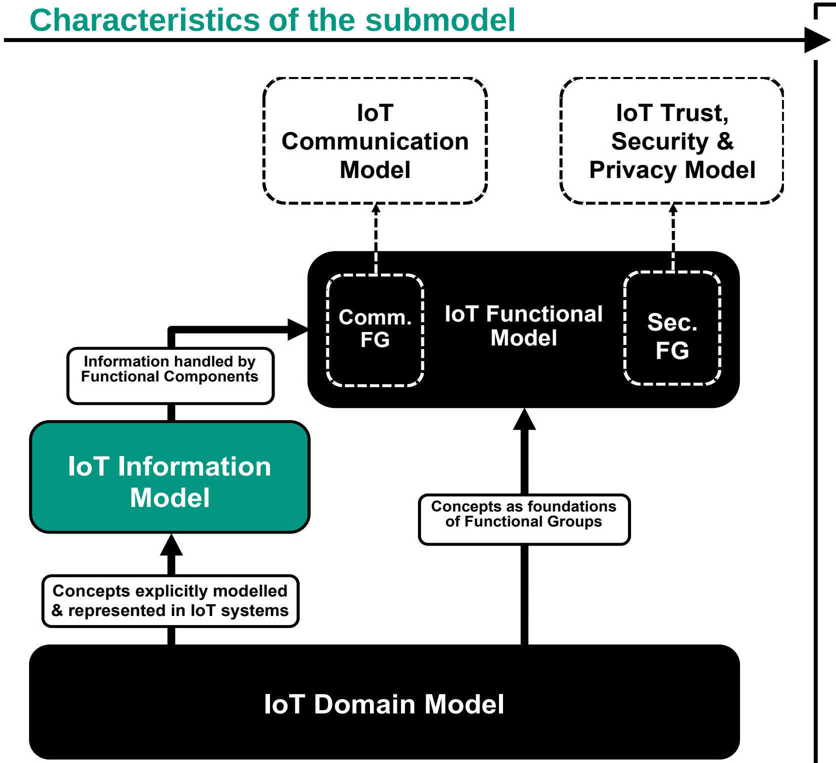


Architectural Models — Submodels of IoT-A



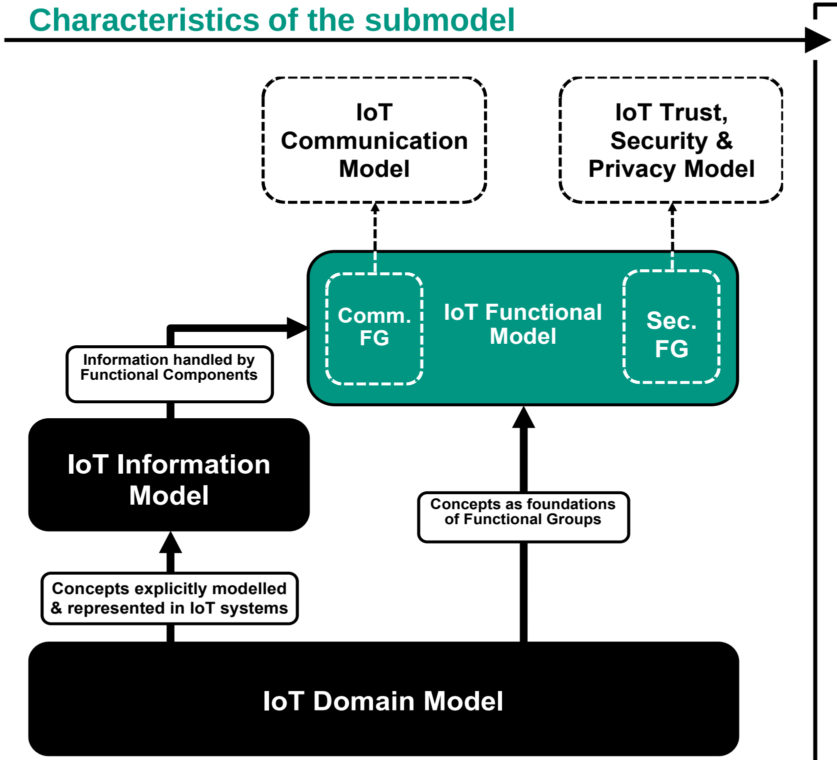
- The IoT Domain Model is responsible for introducing the basic concepts of the Internet of Things and their relationships
- For example, smart objects, smart devices, etc.

Architectural Models — Submodels of IoT-A



- The IoT Information Model describes the structure of relevant information within the context of the Internet of Things

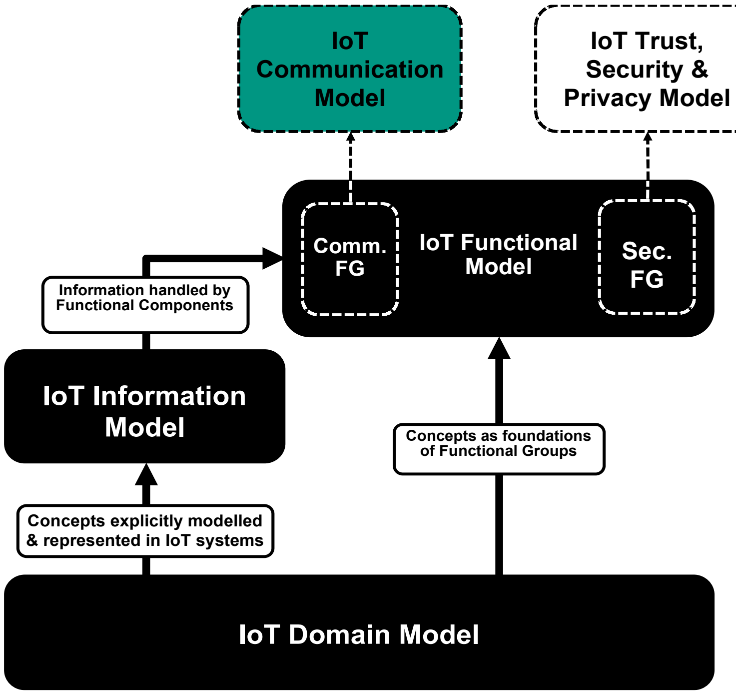
Architectural Models — Submodels of IoT-A



- The IoT Functional Model follows the idea of functional decomposition in order to break up the complexity of systems that are built upon the IoT-A reference model

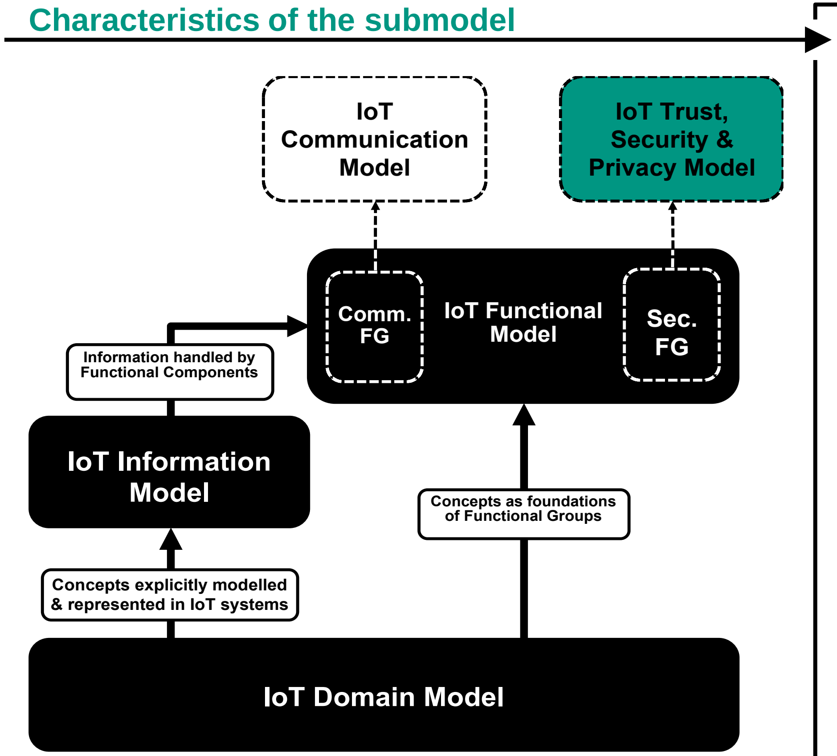
Architectural Models — Submodels of IoT-A

Characteristics of the submodel



- The IoT Communication Model defines the communication paradigms that support communication between the basic concepts as defined by the IoT Domain Model

Architectural Models — Submodels of IoT-A



- The IoT Trust, Security & Privacy Model defines several guidelines to ensure trust, security and privacy
- Several more models possible within the IoT Functional Model

Common Use Cases, Challenges, and Future Developments

Use Cases — Smart Homes

Definition

Smart homes are a kind of smart environment. They are homes that are interspersed with smart objects and devices, which allow for homes to be aware of what happens inside.

- In a fully realized smart home, all the different smart objects and devices work together in a well-orchestrated manner in order to
  - provide higher comfort
  - reduce resource usage
  - provide increasing security

- Requires home automation standards and protocols, for example
  - Z-Wave
  - ZigBee

Image source: [Smart Home] by Kroschel Sabine, January 24th 2017. Pixabay License.

Use Cases — Smart Homes

Comfort

- E.g., smart lights
  - Remotely or automatically change color or brightness at specific times
- E.g., smart speakers
  - Voice control other smart objects and offer a variety of services

[1]

Resource Usage

- E.g., smart meters
  - Monitor and record the consumption of electricity
  - Help develop awareness of electricity usage

[2]

Security

- E.g., smart doors, smart locks
  - Give real-time information if a door has been unlocked or opened
- E.g., smart smoke detectors and sprinklers
  - Can detect a fire, set off the sprinklers, and notify the fire department

Image source [1]: [Philips Hue Bridge 2 and light bulbs] by Philips © 2018-2022 Signify Holding.
Image source [2]: [Smart Meter] by EVB Energie AG, August 12th 2008. Licensed under CC BY-SA 3.0.

Use-cases – Smart home standards

	Z-Wave	ZigBee
Developer	Zensys / Z-Wave Alliance	ZigBee Alliance
Year developed	2001	2004
Network type	Mesh	Mesh
Frequencies	800 – 900 MHz	2,4 GHz
Transmission rates	100 kB per second	250 kB per second
Range	24 meters (indoors) 100 meters (outdoors)	10 – 100 meters
Maximum number of devices per network	232	65.000

Use Cases — Smart Cities

Definition

Smart cities are urban areas with sustainable development and high quality of living.

€ Smart Economy (Competitiveness)

- Innovative spirit
- Entrepeneurship
- Economic image & trademarks
- Productivity
- Flexibilty of labor market
- International embeddedness
- Ability to transform

Smart People (Social and Human Capital)

- Level of qualification
- Affinity to lifelong learning
- Social and ethnic plurality
- Flexibility
- Creativity
- Cosmopolitanism / Open mindedness
- Participation in public life

Smart Governance (Participation)

- Participation in decision – making
- Public and social services
- Transparent governance
- Political strategies and perspectives

Smart Mobility (Transport and ICT)

- Local accesibility
- National and international accesibility
- Availability of ICT infrastructure
- Sustainable, innovative, and safe transport systems

Smart Environment (Natural resources)

- Attractivity of natural conditions
- Pollution
- Environmental protection
- Sustainable resource management

Smart Living (Quality of life)

- Cultural facilities
- Health conditions
- Individual safety
- Housing quality
- Education facilities
- Touristic attractivity
- Social cohesion

Use Cases — Darmstadt

[1]

[2]

Participated in the German digital city competition in 2016 and won

Concepts of the cities were evaluated based on their impact on…

- Education, data platforms, energy and environment, society, health, trade, ICT infrastructure, security, transport, and governance

Aim is to turn the city into a digital role model for other cities in Germany

Current projects:

- Extensive investments in local ICT infrastructure
- Designated programs in schools to prepare children for a digital society
- Online municipal services like a chatbot for getting information
- Online platform that allows to participate in political discussion
- Smart waste system

Image source [1]: [Wappen Darmstadt] by Ritt Heinz (1927). Public Domain.
Image source [2]: [PLZ Germany] by vioma GmbH. Public Domain.

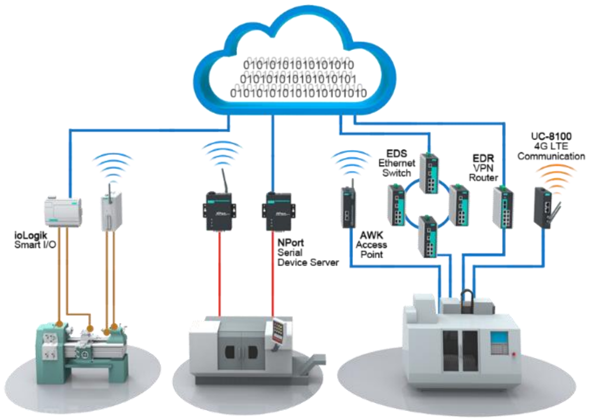
Use Cases —
Industrial Internet of Things (Industry 4.0)

Karlsruhe Institute of Technology

A **factory interspersed with sensors and smart objects** that are connected to each other in a factory-spanning network. It allows for the sensing and tracking of goods and production flows and provides additional context information.

The aim is to improve operational efficiency

- Improve asset utilization
- Increase productivity
- Cut down on operational expenses



The gathered information can be used

- To analyze and optimize production flows
- For inventory management
- In analytics to predict maintenance to avoid downtimes

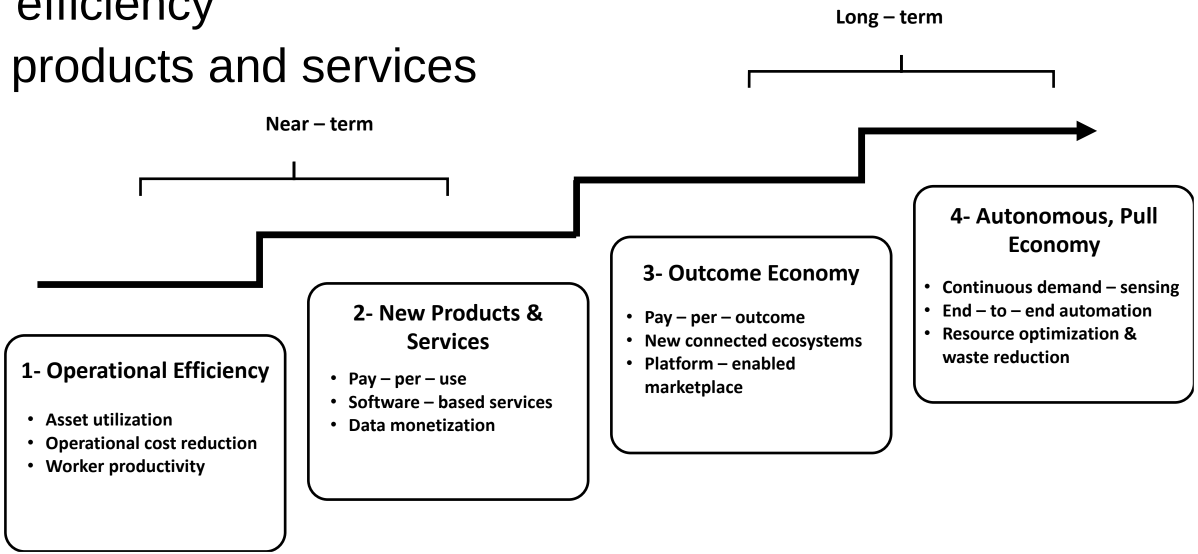
Image source: Turker, A. K., Aktepe, A., Inal, A. F., Ersoz, O. O., Das, G. S., & Birgoren, B. (2019). A decision support system for dynamic job-shop scheduling using real-time data with simulation. *Mathematics*, *7*(3), 278.

Use Cases —
Industrial Internet of Things (Industry 4.0)

Expected evolutionary stages of the Industrial Internet of Things:

Stages range from near-term adoption by industry in order to realize near-term benefits to long term structural changes in the economy:

1. Increased operational efficiency
2. Opportunities for new products and services
3. Outcome economy
4. Entirely autonomous pull economy



Use Cases — Energy sector

The aim of the Internet of Things in the energy sector is to **save** significant amounts of energy and **deliver energy more efficient**.

- The energy sector is shifting towards renewable energies and global demand for energy is growing steadily
- The amount of generated energy heavily relies on weather conditions

Smart Grids

- Present themselves as a solution to this problem
- Is an electricity transmission and distribution system that uses information and communication technologies to improve reliability, security and efficiency of the electric grid

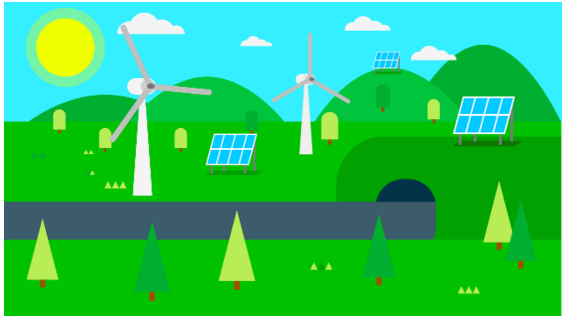
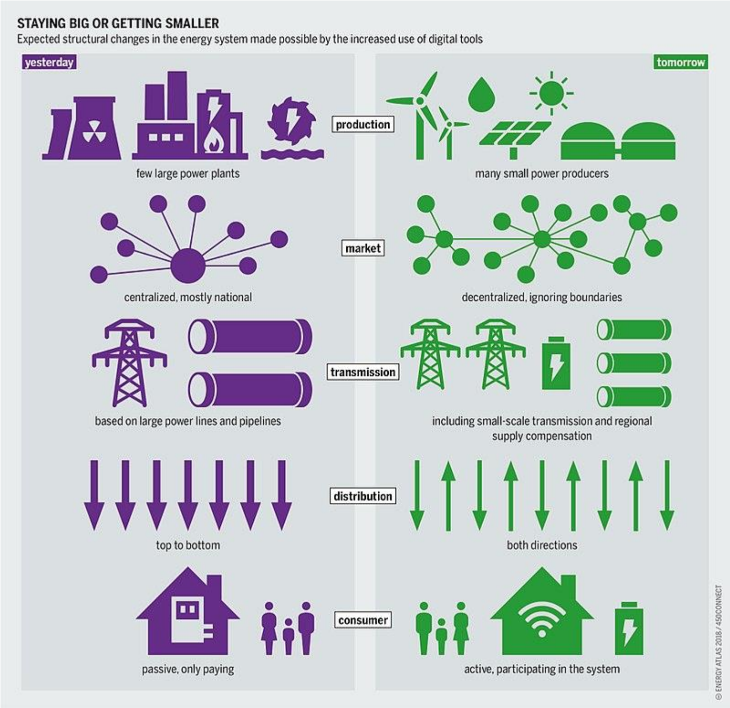


Image source: [Smart Enviroment] by David, March 2nd 2018. Pixabay License.

Use Cases — Energy Sector

Smart Grids:

- Decentralized smart power plants that are able to detect and dynamically react to changing energy demands
- Energy transmission networks which are capable of automatically optimize overall energy flows
- Smart homes which produce part of their required energy themselves
- Smart appliances and smart meters that are expected to help reducing the need for building new power plants



Use Cases — Health-Care Sector

The aim of the Internet of Things in the healthcare sector is to improve patients' health.

Improvement by (remote) monitoring patients' physiological data:

- Is the cornerstone of the medical Internet of Things
- Professional medical devices that are connected to the Internet could provide doctors with vital signs of patients and could even remotely give intensive care patients a shot of medicine

Improvement by ambient assisted living:

- Encompass technological systems comprised of sensors, smart objects, and smart devices
- Support people in need to remain largely autonomous
- Sensors could detect the fall of a senior citizen and alert an ambulance
- Stove could detect that is has been unsupervised and could turn itself off

Use Cases — Health Care Sector

[1]

[2]

- Records health-related data being readily available to doctors
- Regularly measures heart frequency
- Able to conduct electrocardiograms
- Alerts users if irregularities in their heart rate are detected
- Detects a fall and alerts an ambulance after a short period of time of not moving

Image source [1]: [Apple Watch] by Zziccardi, September 19th 2014. Public Domain.

Challenges of the Internet of Things — Data Flood

The rapidly increasing number of sensors create huge amounts of data. This data needs to be transmitted, processed and stored.

The requirements for the realization of the Internet of Things are entirely different from the requirements of our traditional Internet

- Currently data is transferred in large chunks of data
- The Internet is designed to guarantee the arrival of all requested data

In the Internet of Things, sensors and smart objects constantly send small pieces of information

- The majority of data will not be transferred in intervals of relatively large chunks of data, but transferred constantly in small bits of data

Challenges of the Internet of Things — Interoperability

Karlsruhe Institute of Technology

There are many different smart things from a number of different manufacturers. All these things are expected to communicate and even interact witch one another to realize their full potential.

Already today there are a variety of competing standards and protocols for the Internet of Things

- E.g., Z-Wave and ZigBee for smart home

Today many smart objects support multiple standards and protocols

- But there is a trend toward platformization and the creation of different ecosystems that do not work with each other
- This will become an even bigger challenge when considering the countless application scenarios for the industrial Internet of Things
- Different industries will have different objectives and requirements for their industrial Internet of Things

Challenges of the Internet of Things — Security and Privacy

Consider a smart watch and the medical Internet of Things, a fully connected smart home, a smart city where citizens every move is tracked to detect crimes or to optimize traffic flows.

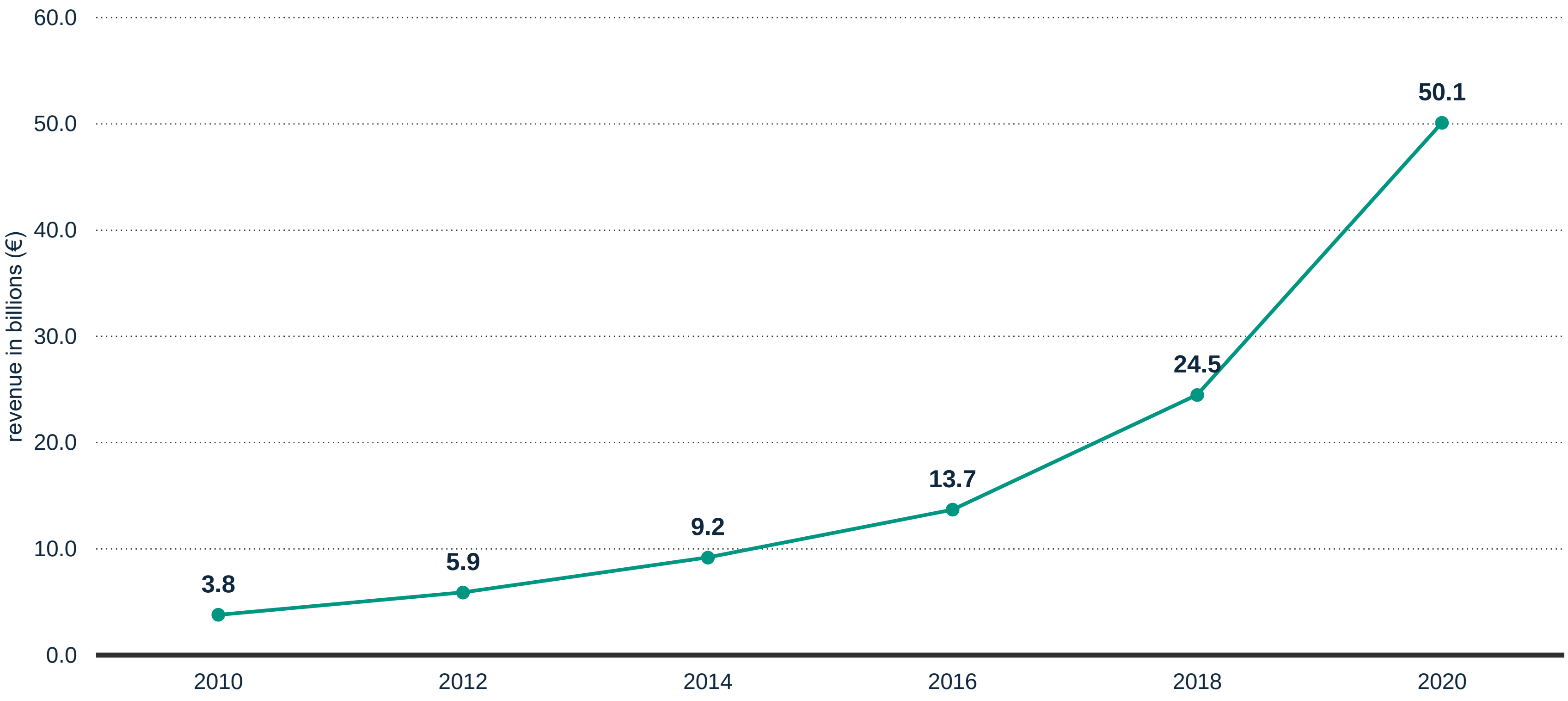
Security and privacy standards are crucial:

- The intended purpose itself might be benevolent, all this collected information can potentially also be used in an unethical or even compromising way that could harm individuals and alter our societies in an unfavourable way
- Only if security is ensured and if individuals are enabled to make informed decisions about who may use their data, when, and for what purpose, the Internet of Things will be able to fully unfold its potential for the benefit of everyone

Future of the Internet of Things

- We are still in an early stage of the Internet of Things
- More things are becoming connected in the next years
- We will see an overall growth of the number of available smart objects and devices
- More cities will launch efforts to become smart cities
- More industries will start to embrace the Internet of Things
- More workforce will be needed and new job opportunities will arise
- There will probably be more security incidents and privacy breaches

Estimated Revenue with IoT in Germany



Source: "Prognose zum Umsatz mit dem Internet der Dinge (IoT) in Deutschland von 2010 bis 2020" by Statista.

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Questions

Questions

Karlsruhe Institute of Technology

1. What is the Internet of Things and what are its nine essential characteristics?
2. What are common architectures for the Internet of Things and how do they describe the Internet of Things?
3. What are the four enabling technologies for the Internet of Things and how do they enable the Internet of Things?
4. What are the three core concepts of the Internet of Things?
5. What are typical application areas of the Internet of Things?
6. What are central challenges for the Internet of Things?

Further Reading

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