Chapter 1/2

Things and IoT Application Domains

What you'll learn in this page

- **Understand** what things are and be able to identify things in IoT applications.
- **Illustrate** what smart objects are.
- **Describe** different application scenarios that benefit from IoT.

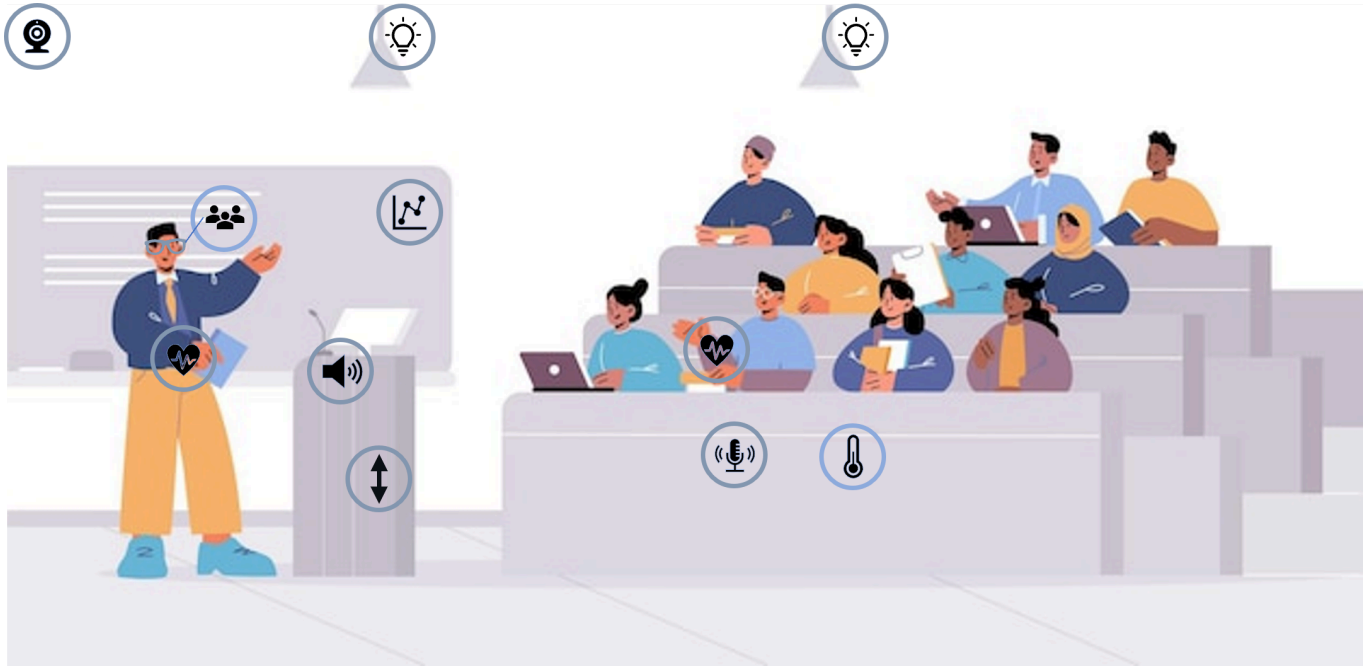
From the definitions given in the previous section, we can understand the Internet of Things as comprising of things that are connected and that can be used as a platform for developing services. Here "things" are effectively defined as objects that can be uniquely **identified**, **addressed**, and **tracked**, i.e., they are objects that have an identifier that can be used to separate them from other objects. In this section we introduce the breadth of IoT by giving examples of things and application areas for IoT. We also briefly discuss how things are constructed with a view to offering an early reference model that will be expanded on in the subsequent sections.

Things

While the first examples of "things" were everyday objects and household appliances that were given an identity and that were connected, nowadays a much broader range of "objects" can be converted into "things". Indeed, any object can be part of IoT as long it

satisfies the three key requirements: (1) it can be addressed; (2) it is connected; and (3) it can be used to build services. Below we highlight this by presenting examples of non-traditional objects that can be considered things.

Smart spaces are physical spaces (rooms, open office spaces, lobbies) that are connected and that integrate sensors or other computing technologies. Smart spaces have long been one of the popular domains for IoT. An early example of a smart space is the Random Hall Bathroom Server which allowed to monitor the occupancy status of bathrooms at a university student dormitory. In most cases the space itself might not be addressable as such and instead certain regions of the space would be covered with sensor-enabled connected devices that allow obtaining information from that part of the space. An example of a smart space in a campus environment is a smart classroom, illustrated in the figure below, that offers sensors to monitor the overall environment (e.g., air quality through CO2 levels, light intensity, and temperature), and the activity taking place (video cameras and microphones).



An example of a smart lecture hall with sensor-enabled interior design, e.g., height-adjustable podium, adaptive microphones, speakers, and lighting.

Animals can also be converted into things. While humans can naturally identify and address animals, computers can only achieve this if suitable computing equipment is placed on the animal. A common example is the use of low-power location trackers to monitor movements of migratory animals, such as birds, whales, or large mammals. This development has been significant for sciences, making it possible to analyse and track movements of animals over extended periods of time. However, animals as things are not limited to migratory animals as domestic pets and farm animals are also being monitored using IoT technology. For example, cows, pigs, and chickens can be monitored using collars that gather vital parameters to identify potential health or other issues and help to improve productivity. For pets, there also are smart collars but the focus of these

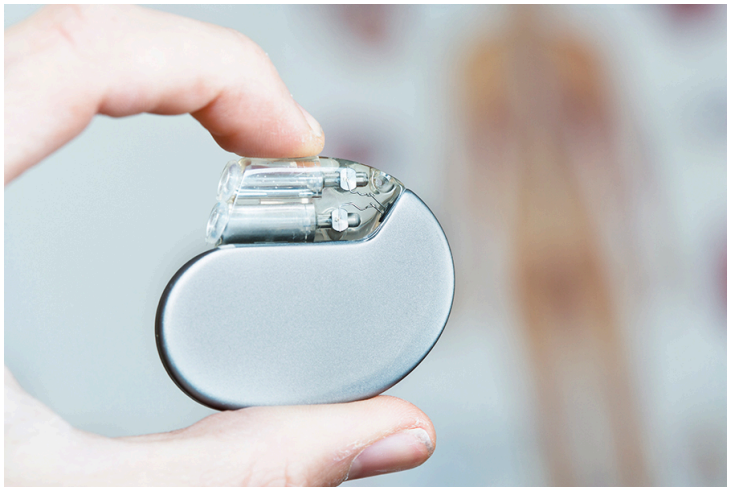
works is on providing a remote interface to interact with pets. Examples of IoT applications for animals are shown in the figure below.

Examples of IoT applications in tracking the location and the well-being of animals.

Textiles integrating sensors, networking and other technology are emerging as another field of IoT. This is particularly popular in sports tech which designs high-end sportswear that integrates sensors and networking. These gather analytical information that can be used to examine sports performance. Examples range from shoes integrating pressure sensors to shirts that include heart rate monitoring sensors together with location and movement tracking (i.e., accelerometers and gyroscopes). Naturally, connected smart textiles are not restricted to sport but come also in other forms, e.g., face masks that contain sensors and networking to provide feedback on ambient environment and home-use textiles for monitoring elderly people. Examples of IoT textiles are shown in the figure below.

Examples of sensor-integrated textiles.

Humans can also become part of the IoT through implantable devices. The most common examples originate from healthcare where implantable pacemakers and insulin pumps are actively used. As before, the key aspects are that the device has a unique identifier that allows addressing it, offers connectivity, and can be used to offer services. Note that not all implantable medical devices are necessarily things as only some offer wireless connectivity from the outside (which can be disabled for security reasons). As for the services they offer, this aspect relates to monitoring health conditions, offering diagnostics of the devices and providing statistics of when they have been active. An example of an implantable pacemaker is shown in the figure below. The circuit performs active monitoring of heart activity and regulates the heartbeat if necessary. Medical doctors can use a separate wireless interface to access information about heart activity during care visits.



A wireless pacemaker can contain an activity sensor, a battery, and a circuitry that sends electrical pulses to help regulate the heartbeat.
Image source: https://www.nhlbi.nih.gov/health/pacemakers

Consumer IoT devices are nowadays highly commonplace. A typical consumer IoT device consists of a stand-alone device that integrates sensors and a wireless interface and that can be interacted with through a smartphone application. Indeed, wearables and home appliances these days are interacted with through smartphone apps which offer a way to control parameters on these devices and provide a dashboard to examine information captured by the devices. The figure below shows a range of different consumer IoT devices, which are interacted with through smartphone apps. Compared to the early examples of IoT devices, such as the Coke vending machine, the basic structure is the same. The consumer device integrates sensors that provide the information that serves as the basis for implementing the services that are available, but in these examples, information is not accessed through the Internet rather than on a smartphone that is paired with the device. This highlights the shift in IoT over the years from information

that is accessible over the Internet to something that is accessible on a smartphone, laptop, tablet, or other device in proximity of the IoT device.

Variety of consumer IoT devices.

Crowdsensing is a technique where a set of individuals carry a smart / IoT device to collect, map, analyse, estimate, or infer any processes of common interest. Unlike the previous examples, which were "one-to-one", crowdsensing operates following a "many-to-one" model where multiple IoT devices collectively provide the information that a single service uses. Note that, in the case of crowdsensing, the human having the IoT device is not responsible for capturing information, but the IoT device collects the

information by itself. When humans are responsible for collecting and providing the required information, this is known as **crowdsourcing** instead of crowdsensing. Popular crowdsensing domains include environmental monitoring and mobility monitoring. The figure below shows an example where humans carry portable air quality monitors to obtain information about the air quality within the city, and taxicabs are equipped with GPS sensors to capture and monitor mobility within the city. These examples highlight how simple individual IoT devices can enable important services when enough devices connect to the same application.

Engaging individual IoT devices can enable crowd management and fine-grained air quality monitoring.

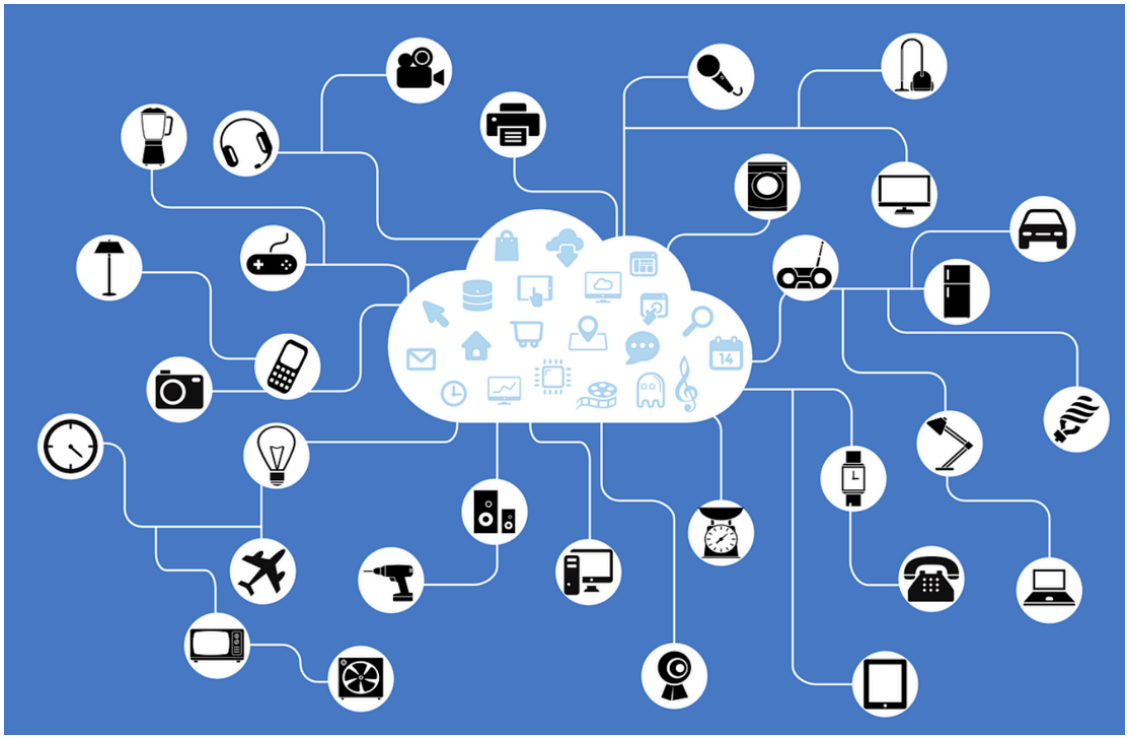
Smart Objects

Connected things, such as those introduced above, form the basic building block for developing Internet of Things applications. However, which components do the things comprise of? In the early days of IoT, most devices simply consisted of a sensor and a network interface whereas modern IoT devices combine multiple sensors, processing,

different networking interfaces, and even different user interfaces. One way to describe the things is to refer to them as **smart objects** which refers to an object that satisfies the following three criteria:

- Can **sense** information about its surroundings, i.e., integrates **sensors**.
- Can **send** and/or **receive** data remotely, i.e., integrates one or more **networking interfaces.**
- Can **perform** computational operations, i.e., integrates **control hardware** and **algorithms.**

Note that these requirements also pose additional, more implicit requirements. For example, operating the sensors and computing operations naturally requires that the smart object has access to a power source. Most definitions of **smart** devices also require that the devices be **programmable**. For the purposes of this course, we limit the definition of **smartness** of an object to cover **the integration of sensors and computing** though we generally expect smart devices to also be programmable. During the course, we consider smart objects as the basic building block on top of which IoT applications are built. We return to smart objects and the different functionalities they offer later during the course. Examples of the smart objects and connections between them are highlighted in the figure below.



Examples of smart objects.

Application Domains

Thus far we have examined a wide range of different connected things that form the basis of Internet of Things applications. We next highlight selected application domains for IoT. The aim is not to provide a comprehensive overview of all areas - indeed, IoT nowadays spans practically all domains - rather than provide examples that highlight the breadth of the modern Internet of Things. These examples also serve to highlight how within a single application domain a wide range of IoT devices, from low-end sensors to consumer devices and high-end commercial devices, can be used.

Agriculture: IoT is increasingly being adopted in practically all forms of industry to automatically monitor operations and to provide data that can then be used (by AI algorithms) to optimize the different operations. One of the fastest growing sectors has been agriculture where IoT has been used, e.g., to monitor soil conditions and to automate irrigation schedules through statically deployed networks. Similarly, smart collars and implantable sensor devices are used to monitor animal welfare, activity, location, and behavior with the aim of avoiding diseases, increasing animal welfare, and potentially also increase productivity. Another emerging topic is autonomous vehicles and drones, which can be used to automate certain operations, e.g., aerial drones have been used to deploy pesticides and self-driving or autonomous tractors can be used to support harvesting operations. Examples of the use of IoT technology in agriculture are highlighted in the figure below.

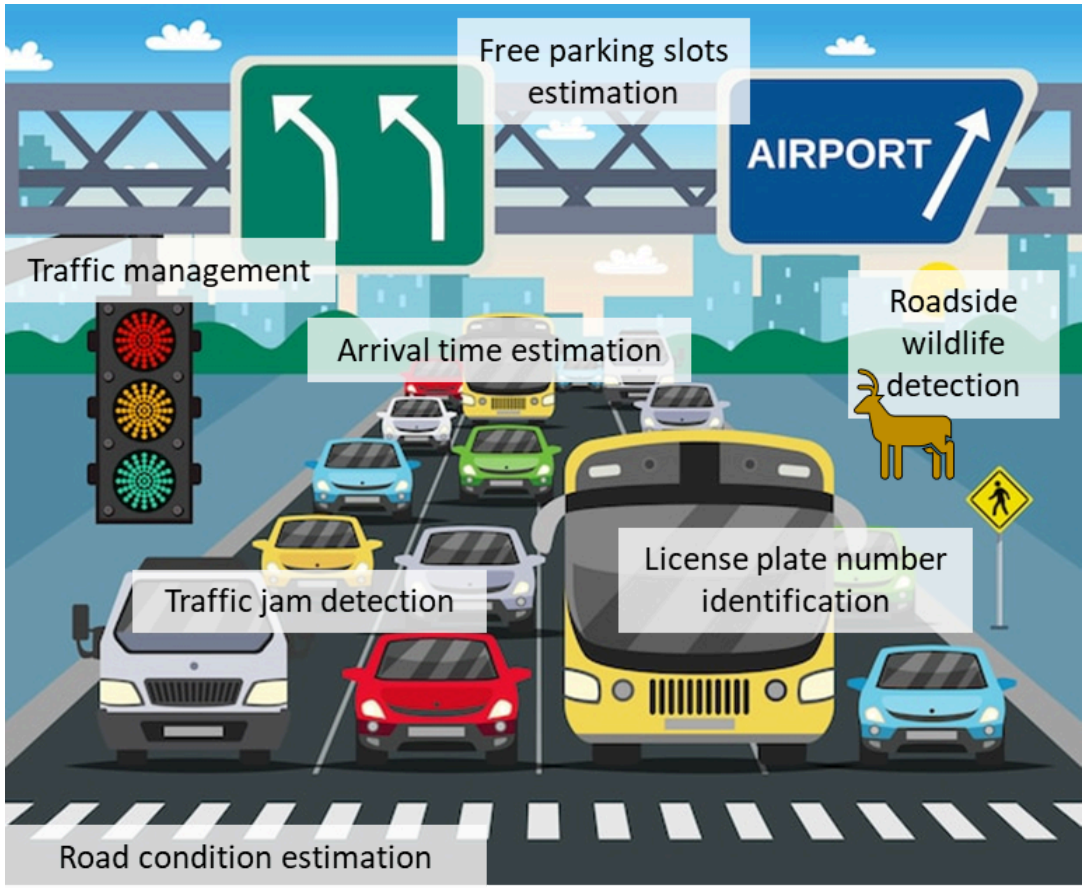
Harvesting operations can be supported by aerial drones and self-driving tractors.

Manufacturing and Industry: Modern manufacturing industry is increasingly taking advantage of IoT technology as part of their processes. Indeed, modern manufacturing machines integrate sensors that are used to monitor machine performance and condition. This information is then used to offer services such as fault warnings, predictive maintenance, error analysis, and feedback on overall productivity. The sensor data can also be used to offer additional services, e.g., to help train machine operators, or to analyse productivity of the overall production chain. A more recent development is the notion of digital twins, which attempts to create a virtual (or digital) equivalent of a physical object or a system, and to link the physical and virtual representations with each

other. IoT sensors offer the technology to monitor objects which provides the foundation for establishing a digital representation, and IoT devices also control and link the physical and digital representations so that changes in one representation are reflected in the other. Examples of the use of IoT and digital twins in manufacturing are illustrated in the figure below.

Human digital twins can be created and employed in manufacturing.

Traffic: Many malls, airports and other large-scale places nowadays integrate IoT-based monitoring systems to support finding parking spots. In the simplest case, these systems identify free parking spots (using proximity sensors) and use different lights to visualize the status of a spot, whereas recently vision technologies have reached a stage where automated registration plate number identification is used to detect entry and exit. The use of IoT in traffic is not limited to parking, however. Remote road locations can use roadside wildlife detection systems to warn drivers when wildlife is moving around (e.g., using tripwires and low-power communication). Buses, taxis, trams, trains etc. integrate connected sensors which are used to estimate arrival time to next station, as well as to identify problems in the traffic network, and there are even applications that use sensors on mobile phones to estimate road conditions. Some examples of traffic related IoT solutions are highlighted in the figure below.



IoT-based applications enable automation of traffic management and road safe measurements.

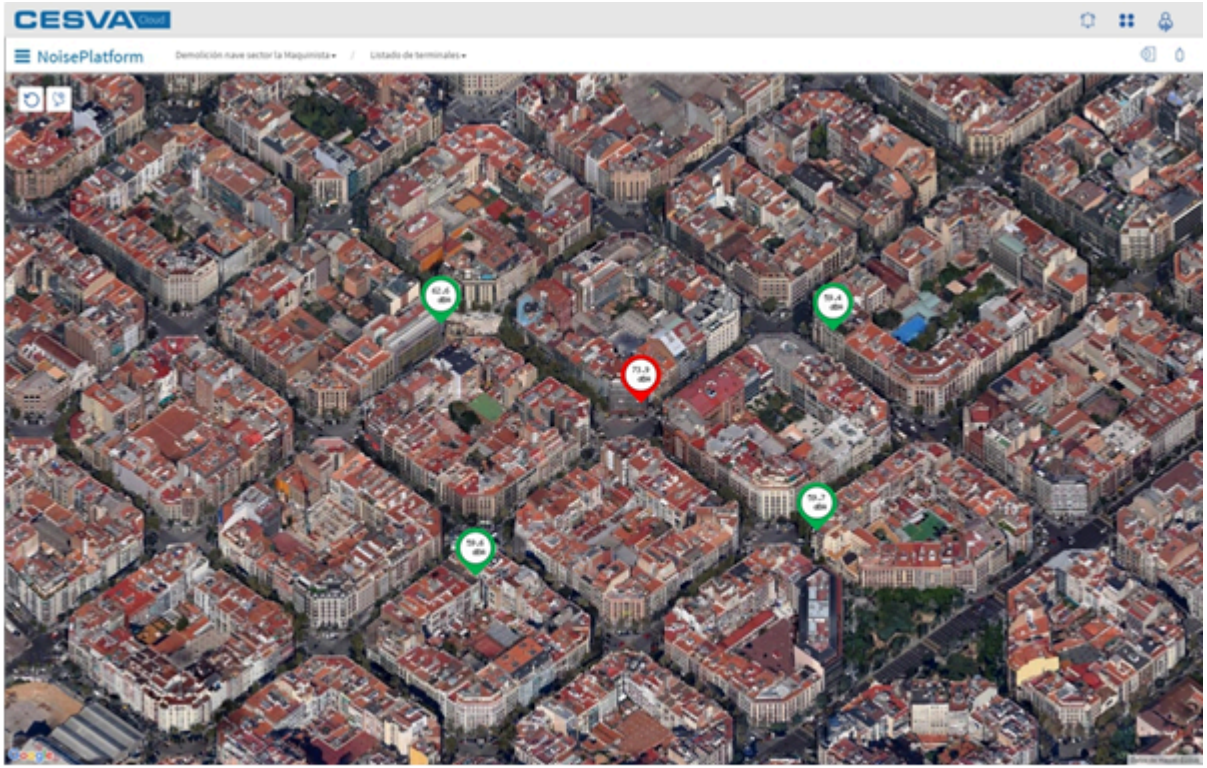
Buildings: Energy management in buildings is another common example from everyday life where IoT plays a key role. Buildings and other spaces (such as restrooms) can use motion-controlled lights to reduce excess energy use. Note that the motion control solution itself is not necessarily IoT, unless the system also integrates network interface that allows adjusting the parameters or obtaining feedback about the system. Nevertheless, these kinds of solutions are usually linked with the collection of energy statistics and integrated into a broader IoT-based building management system.

Intelligent HVAC (heating, ventilation, and air condition) is another popular example from the building domain which uses sensor data to monitor energy use, temperature, CO2 accumulation, or other parameters and to adjust the operations of the HVAC system with the aim of providing an optimal trade-off between living comfort and electricity use. As with the other application domains, IoT is not limited to monitoring buildings where people live in. Another example is building integrity monitoring which uses vibration and other sensors to provide insights about building integrity. Such solutions are increasingly common at historical sites (e.g., the Colosseum in Rome, Italy integrates structural integrity sensors to monitor impact of traffic and visitors), buildings with large visitor counts (e.g., Stadiums) and critical infrastructure such as bridges. Examples of the use of IoT in the building domain are shown in the figure below.

Source: https://theblogofcardigan.com/structural-health-monitoring-of-colosseum

IoT sensors are used for monitoring structural health of buildings.

Cities: Smart cities are one of the most often cited examples of application domains for IoT technology. The basic premise is that by integrating connected sensors and computing (i.e., smart objects) to the city, it becomes possible to monitor and optimize the operations of the city, to identify potential problems, as well as to understand potential issues the citizen is facing. A simple example is air quality monitoring which is nowadays adopted in every corner of the world. Indeed, from the Internet we can get information about the air quality of different regions and cities. Weather information is another related example, even if this information typically is provided through intermediaries that integrate the sensor data with weather models, unlike air quality information which is available more directly. There are related examples that focus simply on monitoring the state of the city, e.g., crowd density monitoring, noise pollution monitoring, or light pollution monitoring. Beyond monitoring, there are examples also related to optimization and control. For example, cities can use IoT to optimize garbage collection operations, manage and control water delivery or wastewater management systems, and adjust traffic lights for traffic congestion management. Examples of these are shown in the figure below.



Source: https://www.cesva.com/en/products/sensors-terminals/noiseplatform/

Online noise monitoring of cities using IoT sensors.

Electrical Grid: IoT technologies are not just used for consumer and business operations but even safety critical operations can take advantage of IoT. Note that in these applications the communication links usually are unidirectional (uplink) to avoid attackers gaining access to the system. One example of these fields is the **energy (smart) grid** which aims at using sensing and AI to monitor power flows and to manage production to match demand. Sensors can also offer information for diagnosing and localizing faults (e.g., because of storms or other natural disasters) and they offer flexibility that makes it easier to add and remove substations to the network. Modern

grids without exception rely on sensors as this also serves as the basis for dynamic pricing structures, such as those used by certain electricity pricing contracts. The figure below shows how IoT devices are used to implement modern smart electrical grids.

Source: https://www.cisco.com/c/en_in/solutions/industries/energy.html

IoT devices are used to monitor network state, diagnose, and localize faults of electrical grids.

Summary

- Things are objects that satisfy the three criteria for IoT: they can be addressed, they can connect to other devices or be connected by other devices, and they can be used

to develop services. Any object can be made into a thing by integrating necessary computing devices with the object.

- The Internet of Things is nowadays a broad field, and things range from animals and humans to machinery, and even rooms and other physical spaces.
- Things and IoT devices are nowadays used in every application domain. Recalling all domains is not important, but understanding the breadth of IoT domains and devices is, as this allows understanding how any domain can benefit from adopting IoT technology.

Exercises

Exercise:

1.2. Concepts

TRIES 2 POINTS 0/3

Instructions

Please choose the option(s) that are correct.

Which of the following apply for smart objects?

- Can send or receive data.
- Integrates sensors.
- Cannot perform any computations.

ⓘ Select all correct options.

Objects are "smart" if they

- can be programmed.
- can connect to other devices.
- integrate sensors and computing resources.

ⓘ Select all correct options.

Which of the following characteristics apply for things?

- They can be addressed.

They can be identified.

They are the same as smart objects.

Select all correct options.

Submit

Exercise:

1.2. Things and IoT technology

TRIES 2 POINTS 0/3

Which of the following options regarding modern airplanes are correct? Pick all that apply.

- Can be communicated with.
- Integrate many sensors.
- Can be seen as part of IoT.

ⓘ Select all correct options.

Which of the following application domains harnesses IoT technology?

- Shipbuilding
- Textile industry
- Banking

ⓘ Select all correct options.

Humans can be considered a thing in the IoT when

- they have implantable devices, such as implantable cardioverter defibrillators (ICD).

they have implantable devices, such as artificial joints or dental implants.

they carry portable devices, such as smart rings, to obtain information about personal parameters.

Select all correct options.

Submit

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