Internet of Things Security

Saad EL JAOUHARI

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Application design concepts	Business Model	Typical IoT Architecture Stack	Long Range protocols: 5G LoraWAN, Sigfox, LTE-M and NB-IoT	AIoT = AI + IoT	Unlicensed LPWAN	Security Functionalities
Developing an IoT application by the example (Node-Red, Rasberry Pi, Arduino, IDE, ...)		IoT Networks (PAN To WAN)		Blockchain		
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		Applications (Digital Twins, Smart building, Home Automation, ...)				

Recap module: Project

- Practical project → 6 supervised sessions

01

Introduction

What is computer security ?
IoT issues ?
Well-known IoT attacks

Introduction: what is security ?

- **Security**
  - **Oxford** The state of being free from danger or threat
  - **Collins** Security refers to all the measures that are taken to protect a place, or to ensure that only people with permission enter it or leave it.
- **Security is not safety**
  - **Security** is highly focused on the deliberate protection actions against malicious actions toward an individual, organization, or assets.
  - **Safety** consists in being sure that nothing goes wrong in absence of malicious person(s)

Introduction: what is information security ?

- **Information Security (Infosec)**:
  - **Definition**: Infosec refers to all the measures that are taken to protect information (data) from unauthorized access, use, disclosure, disruption, modification, or destruction.
  - **Information security** = **Computer security** + **Network security**

What is computer security ?

- Most developers and operators are concerned with **correctness and efficiency**:
  - A working software, website, blog, etc…
- **Security** is concerned with **preventing/protecting against undesired behavior**:
  - Considers an enemy/opponent/hacker/adversary who is actively and maliciously trying to *get around* any *protective measures* in place

What is computer security ?

- Kinds of undesired behaviors:
  - Stealing information: ~~confidentiality~~
    - Corporate secrets (product plans, source code, administrative documents, …)
    - Personal information (credit card numbers, SSN, …)
  - Modifying information or functionality : ~~integrity~~
    - Installing unwanted software (spyware, botnet client, …)
    - Destroying records (accounts, logs, plans, …)
  - Denying access: ~~availability~~
    - Unable to purchase products
    - Unable to access baking information

Defects and vulnerabilities

- Many breaches begin by exploiting a **vulnerability:**
  - This is a security-relevant **software defect** that can be exploited to provoke an undesired behavior
- A software **defect** is present when the software behaves incorrectly, (i.e., it fails to meet its requirements)
- Defect occur in the software's design and its implementation
  - A **flaw** is a defect In the design
  - A **bug** is a defect in the implementation

Considering Correctness

- The Flash vulnerability is an implementation **bug**
  - All software contain bugs. So what ?
- A normal user **never sees most bugs** and **works around them**
  - Most (post-deployment) bugs due to rare feature interaction of failure to handle edge cases
- Assessment: would be **too expensive** to fix every bug before deploying
  - Companies only **fix** the ones **mostly likely to affect** normal users

Considering Security

- Key difference: *an adversary is not a normal user*
- The **adversary will actively attempt to find defects** in rare features interactions and edge cases
  - For a typical user, (accidentally) finding a bug will result in a crash, which he will try to avoid
  - An adversary will work to find a bug that leaded to this crash and exploit it to achieve his goal

Considering Security

The main objective of computer security is to ensure security, by **eliminating bugs and design flows** and/or to make them **harder to exploit**

Introduction: What is IoT in a nutshell ?

No precise, consensual definition...

- **Internet of Things (one possible definition):**
  - **Network of devices** that are able to connect, interact and exchange data.

- **Standard devices**: desktops, laptops, smartphones, tablets, …

- But also, any **"traditional" object that contains a digital connectable device**: temperature and humidity sensors, domestic appliance, medical device, security camera, traffic light, ...

IoT is Security Critical

What is the difference between security of IoT and information security ?

Not that much, but…

Security is of critical importance for IoT

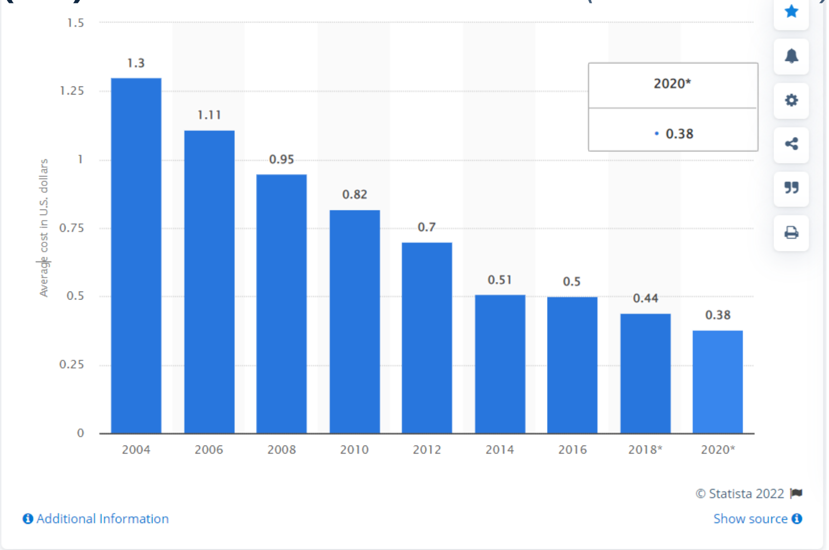
- Importance of communications (many protocols ! → BLE, Zigbee, Z-wave, NB-IoT, Lora, …)
- Huge number of connected devices (Heterogeneity !)
- IoT devices are used in critical systems (healthcare, industries, smart cars, …)
  - Failures may involve human, environmental, economical consequences

IoT is a Constrained System

IoT devices are often low-cost devices: constrained systems (< 1$!)

- Slow processor
- Small amount of RAM
- Low energy consumption
- Low network bandwidth capacity (and short range for some)

Average costs of industrial Internet of Things (IoT) sensors from 2004 to 2020 *(in U.S. dollars)*



Traditional security solutions cannot be (easily) applied to IoT

* https://www.statista.com/statistics/682846/vr-tethered-hmd-average-selling-price/

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A few Examples of IoT Security Issues

- **2016** possible to open and start a **car** by **hacking its keyless technology** (radio communication)
- **2016 :** DDoS (Distributed Denial of Service) attack (Mirai botnet) against the **DNS provider Dyn** by using **600 000 of connected devices** (mostly cameras) to put it out of order
- **2017**: IoT Goes Nuclear: Creating a **Zigbee** Chain Reaction

A few Examples of IoT Security Issues

- **2016** possible to open and start a **car** by **hacking its keyless technology** (radio communication)

Source: https://www.wired.com/2016/08/jeep-hackers-return-high-speed-steering-acceleration-hacks/
https://www.youtube.com/watch?time_continue=1&v=MK0SrxBC1xs&feature=emb_title&ab_channel=WIRED

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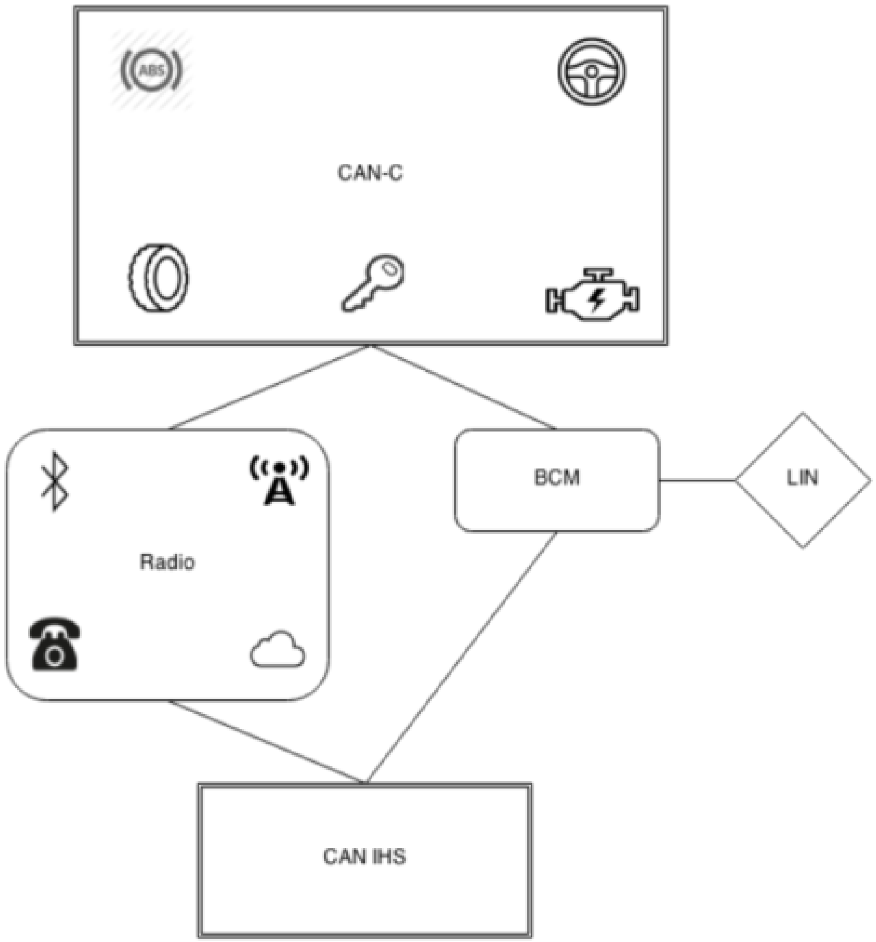

Figure: 2014 Jeep Cherokee architecture diagram

- CAN-C is the high-speed bus that connects the engine, brakes, airbags etc.
- CAN-IHS is a low-speed bus that connects the comfort systems like radio and climate controls.

* Miller, Charlie, and Chris Valasek. "Remote exploitation of an unaltered passenger vehicle." *Black Hat USA* 2015.S 91 (2015).

A few Examples of IoT Security Issues

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A few Examples of IoT Security Issues

- DDoS Attack in October 2016 → **Main Target**: DNS provider **Dyn**
  - Temporarily crippled several high-profile services such as **OVH, Dyn,** and **Krebs on Security** via massive distributed Denial of service attacks (DDoS)
  - DDoS attack was staged and launched from IoT devices using the Mirai malware
  - OVH reported that these attacks exceeded **1 Tbps** - the largest on public record
  - Mirai infected over **600,000** vulnerable IoT devices

- Mirai was designed for **two** main purposes:
  - Find and infect IoT devices to grow the botnet
  - Participate in DDoS attacks based on commands received by remote Command and Control (C&C) infrastructure

- Mirai operates in three stages:
  1. Infect the devices
  2. Protect itself
  3. Launch attack

A few Examples of IoT Security Issues

- **Stage 1: Infect the devices**
  - **Scan** for IoT devices that are accessible over the Internet
    - Primarily scans for ports **22, 23, 5747,** etc., that are open
    - Can be configured to scan for others
  - Once connected → **brute-forces** usernames and passwords to **login to the device**
  - Use the device to **scan networks** looking for more IoT devices

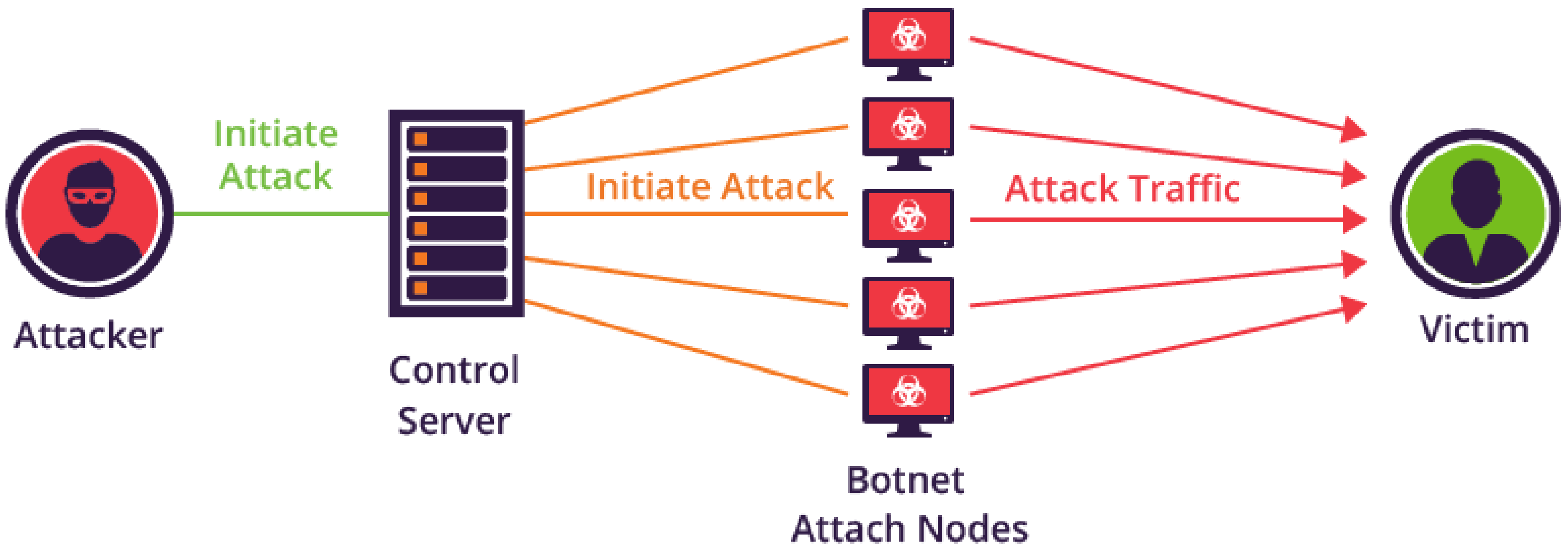
A few Examples of IoT Security Issues

- **Stage 2: Protect itself**
  - **Kill other process** running on infected device (SSH, Telnet, HTTP) to prevent owner from gaining remote access to device while infected
  - **Note:** Rebooting the device can <u>remove</u> the malware, but it can <u>become infected again</u>

- **Stage 3: Launch attack**
  - Infected device launches different types of attacks
  - HTTP floods, SYN floods, etc. → DDoS-based attacks

- ****Note**: Mirai contained a list of known networks in the U.S. to avoid attacking → U.S. Postal Service, Department of Defense

A few Examples of IoT Security Issues



https://www.imperva.com/blog/how-to-identify-a-mirai-style-ddos-attack/

A few Examples of IoT Security Issues

https://blog.cloudflare.com/inside-mirai-the-infamous-iot-botnet-a-retrospective-analysis/

A few Examples of IoT Security Issues

- **2017**: IoT Goes Nuclear: Creating a **Zigbee** Chain Reaction

- Connected Zigbee lightbulbs → Attack steps:
  1. **Target**: Philips Hue lamps using ZigBee wireless connectivity.
  2. Recover the AES-CCM Encryption keys using a side channel attack (Correlation Power Analysis (CPA))
  3. Create a malicious firmware update (a worm)
  4. Load it to a Philips Hue light.
  5. The worm spreads by jumping directly from one lamp to its neighbours, using their built-in ZigBee wireless connectivity and their physical proximity
  - Range 400m outdoor and 70m indoor

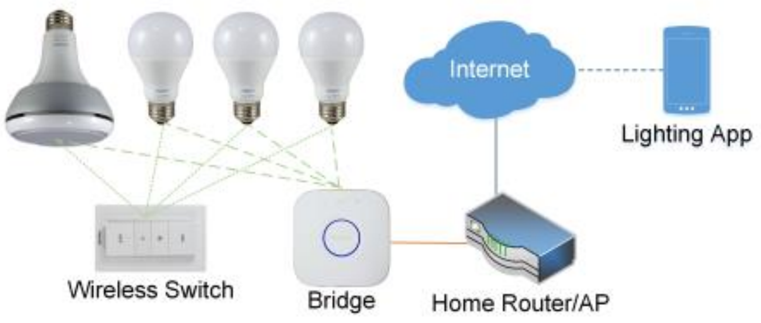


Figure 2. The ZLL architecture.


Figure 3. Philips Hue bridge (gateway), lamps, and wireless switch.

* Source image: [13]

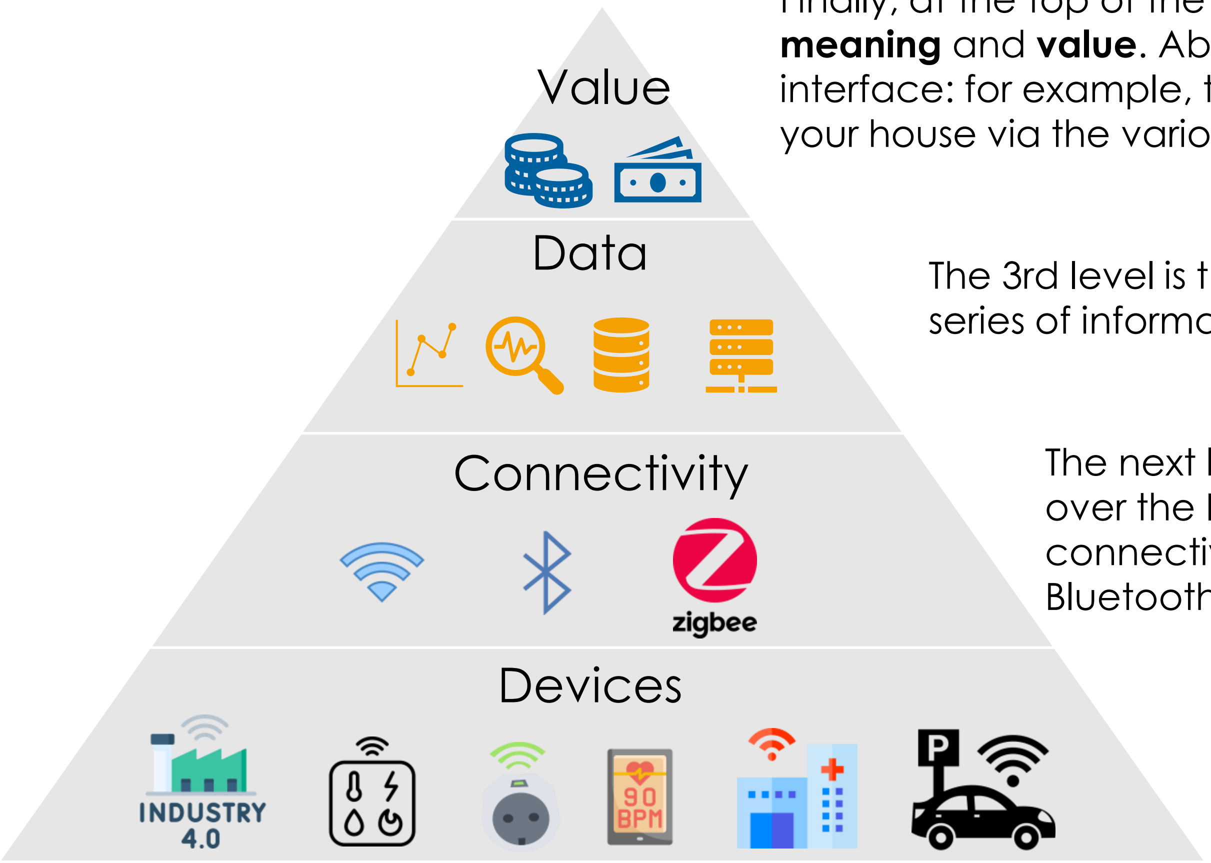
A few Examples of IoT Security Issues

Zigbee War Flying

Zigbee War Driving

https://www.youtube.com/watch?v=Ed1OjAuRARU&feature=emb_title&ab_channel=seyalr
https://www.youtube.com/watch?v=zcwz-lQtCwM&ab_channel=seyalr

IoT Architecture: global view



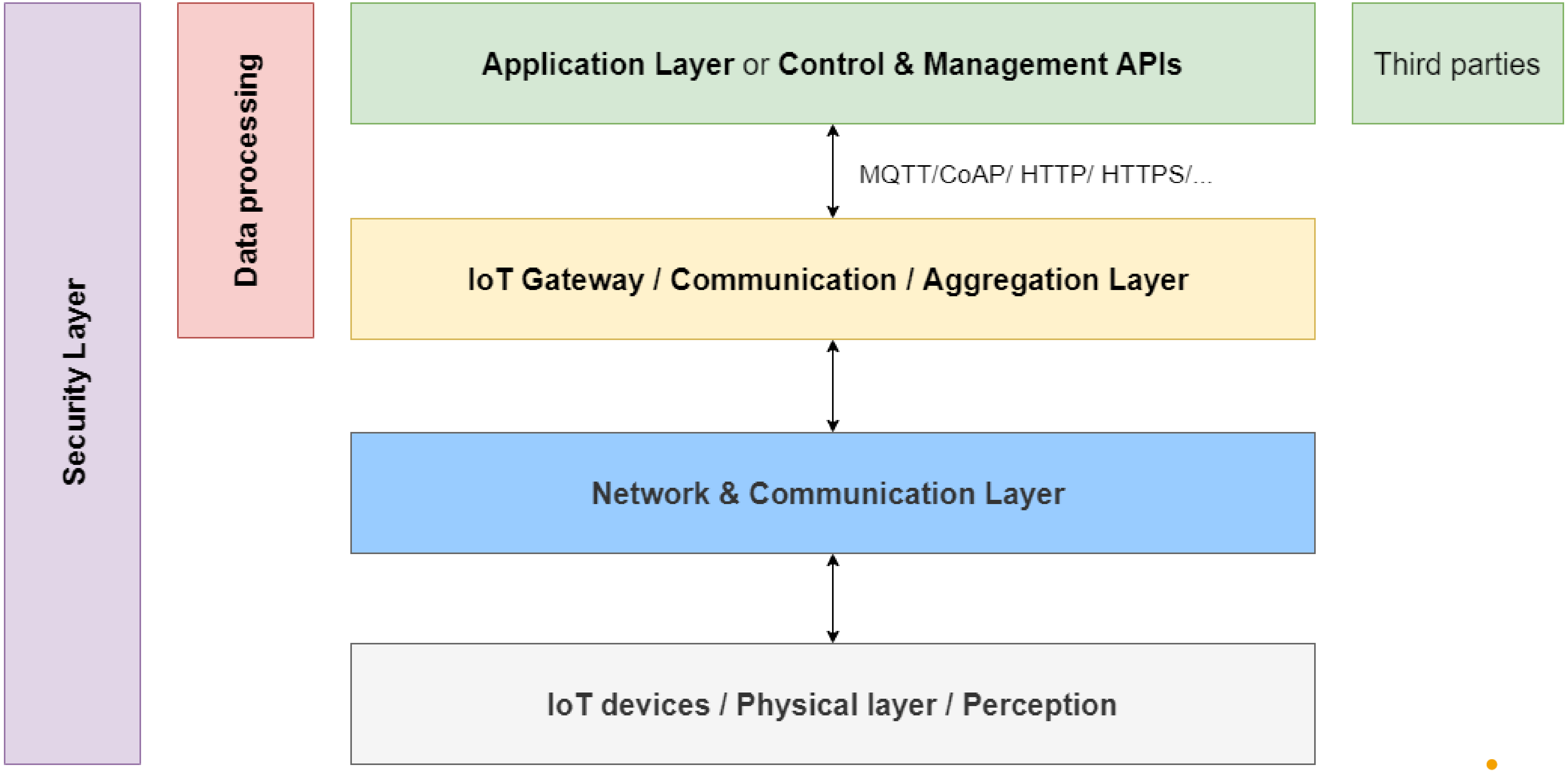
Finally, at the top of the pyramid, it is a matter of transforming this processed data to give it **meaning** and **value**. Above all, to be able to present it in an understandable and usable interface: for example, the application on your phone that communicates the temperature of your house via the various thermostats.

The 3rd level is the **data** level. The data arrives in its raw state. It is a series of information that must be sorted, analyzed and stored.

The next level is **connectivity**, i.e., how this captured data will be communicated over the Internet. You are probably already familiar with most of the different connectivity options: your home's WiFi, your phone's cellular network, your car's Bluetooth, etc.

The base of the pyramid is made up of **sensors** (**devices**), which capture and collect physical data from the environment. This can be humidity, temperature, presence, pressure...

IoT Architecture: global technical view



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Security: outline

Broad topic:

we will see most important features,

but we will not cover them in (too much) depth

- **Security Properties**
- **Security Threats**
- **Security Functionalities**

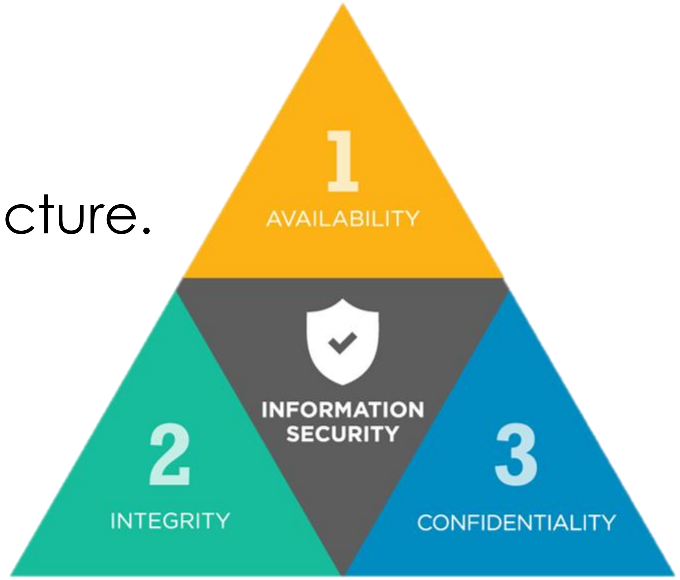
02

Main security concepts/properties

CIA

Main concepts
CIA

- **CIA** → Confidentiality Integrity and Availability
- Why ?
  - They are the **primary goals and objectives** of a security infrastructure.
  - Security **essentials**
  - Most important security **principles**
  - They are **interdependent**



Main concepts
CIA

- **Security controls** are typically evaluated based on the **respect of these principles**.
- A **complete security** solution should **adequately address each of these principles**
- **Vulnerabilities and risks** are also evaluated based on the **threat they pose against one or more of the CIA Triad principles**

Main concepts
Confidentiality

- Definition:
  - **The insurance of the protection of the secrecy of data, objects and resources.**
- Its main objectives:
  - **Prevent** or **minimize unauthorized access to data**
    - No one other than the legitimate recipient of a message receives it or is able to read it.
  - Provides means for **authorized users** to **access** and **interact with resources**

Main concepts
Confidentiality

- Some **attacks** that aim at violating this principle:
  - Capturing the network traffic
  - Stealing passwords
  - Social engineering
  - Port scanning
  - Shoulder surfing
  - Eavesdropping
  - Sniffing
  - Escalation of privileges
  - Etc.

Main concepts
Confidentiality

- Some security means to **guarantee confidentiality** includes, but not limited to:
  - Encryption of data
  - Strict access Control
  - Rigorous authentication procedures
  - Personal training
  - …

Main concepts
Confidentiality in IoT

- **In-device:** The data stored (if any) and the security keys need to be **safely stored** in the memory.
- **Device to Device**: **protecting** the **data exchanges** between IoT devices.
- **Device to Gateway**: **protecting** the **data exchanges** between the IoT device and the corresponding gateway.
- **Device to Cloud**: **protecting** the **data exchanges** between the IoT device and the cloud.
- **E.g.,**: via **data** or **traffic encryption**.

Main concepts
Integrity

- Definition:
  - **Is the concept of protecting the reliability and the correctness of the data.**
- Main objectives:
  - **Prevents unauthorized** subjects from **making modifications** on an object
  - **Prevents authorized** subjects from **making unauthorized modifications** (to avoid mistakes)
  - **Ensures** that the object remains **correct**, **unaltered** and **preserved** in most of the states of the object (data)

Main concepts

Integrity

- Some **attacks** that aim at **violating** this principle:
  - Viruses
  - Malwares
  - Errors in coding and applications
  - Man in the Middle
  - …

Main concepts

Integrity

- Some security means to **guarantee integrity** includes, but not limited to:
  - Encryption of data
  - Strict access Control
  - Rigorous authentication procedures
  - Data/Object Encryption
  - Using robust hash functions
  - Personal training
  - …

Main concepts
Integrity for IoT

- **Crowded frequency bands cause missed packets:**
  - Transmitting devices can **interfere** with nearby receiving devices.

- **Corrupted memory can lead to unexpected outcomes:**
  - Both flash and non-volatile memory can occasionally become corrupted.
  - **Unintended** or **intentionally** through malicious hardware hacking or malwares.
  - Regardless of the mechanism, it is imperative that microcontrollers are equipped with the necessary **integrity features** to identify when a device has been corrupted.
  - Once identified, the microcontroller can either **correct** the error or shut the device down, appropriately ensuring that the security of the wider system is not breached.

- **Sensor's data integrity:**
  - How to **guarantee** the integrity of the **data in transit** from the sensor to the end user ?

- In every stage of the IoT data life cycle from sensing and measuring, to interpreting and connecting the data, the quality and integrity of the information needs to be guaranteed. → E.g., via **hash function**

Main concepts
Availability

- Definition:
  - Authorized subject are granted **timely** and **uninterrupted** access to objects

- Its main objectives:
  - High level of **assurance** that the objects are **accessible to authorized subjects** and an acceptable level of performance
  - **Prevention** of Denial of Service (DoS)
  - Quick handling of **interruption** (**fault tolerance**)

Main concepts
Availability

- Some **attacks** that aim at **violating** this principle:
  - These include device failure
  - DoS attacks,
  - Object destruction
  - Communication interruptions or jamming
  - …

Main concepts
Availability

- Some security means to **guarantee availability** includes, but not limited to:
  - Providing redundancy mechanisms for critical systems
  - Maintaining reliable backups
  - Prevent data loss or destruction
  - Monitoring performance and network traffic
  - Using firewalls and IDS/IPS to prevent DoS/DDoS
  - Following a Business Continuity Planning (BCP) (in case of a disaster for instance)
  - Fault tolerance at the various levels of access/storage/security
  - Eliminating single points of failure (SPoF) to maintain availability of critical systems
  - …

Main concepts
Availability in IoT

- Ensuring that critical IoT devices are **always operational**
  - E.g., IoT monitoring sensors in healthcare or Industrial sensors
  - Quick detection and correction
  - Fault tolerance (redundant sensors !)

03

Security Threats

Taxonomy
Threat analysis

Security Threats
Definitions

- **Security Threat**: is anything that could cause **something bad** to an information system.
- **Attack**: consists in **intentionally** making **bad things** happening.
- **Vulnerability**: is a **weakness** that **enables an attack**.
- **Exploit**: is an **implementation of an attack**

Security Threats
Definitions

- A **threat** has the potential to exploit a vulnerability of the system to turn it into an attack
- A threat might or might not happen
- An attack may break (at least) one security property/concept
- The **consequence** of breaking security properties may be **huge** (even possibly destroying the system physically)
- An exploit typically uses (at least) one vulnerability

Security Threats
Taxonomy

- 9 main kinds of threats according to ENISA
  - **ENISA** = European Union Agency for Network and Information Security4
- During the reporting period (April 2020 to July 2021), the prime threats identified include:
  1. Ransomware;
  2. Malware;
  3. Cryptojacking;
  4. E-mail related threats; (e.g., phishing)
  5. Threats against data;
  6. Threats against availability and integrity;
  7. Disinformation – misinformation;
  8. Non-malicious threats;
  9. Supply-chain attacks

https://www.enisa.europa.eu/topics/threat-risk-management/threats-and-trends

Security Threats
Taxonomy

- Threats may be distinguished by:
  - Their **sources:**
    - Accidental or intentional, internal or external, low or high capacity
    - Depend on the context (e.g., a company with temporary workers using IoT objects connected to its servers might consider extra external sources)
  - Their **targets:**
    - Sensors, servers, databases, networks, software, users, ...
  - Their **operational modes:**
    - Modification of usage, overstepping of functional limits, deterioration, destruction, spying, ...

Security Threats
Taxonomy

- **Some threats related to IoT:**
  - Vulnerabilities
  - Malwares (ransomwares;)
  - Botnets
  - Denial of services (Threats against availability and integrity;)
  - Physical attacks (threats against data; Threats against availability and integrity;)
  - Information theft and unknown exposure (threats against data;)
  - Device mismanagement and misconfiguration
  - Lack of encryption (Threats against availability and integrity;)
  - Firmware updates Missing
  - …

Security Threats
Attacks

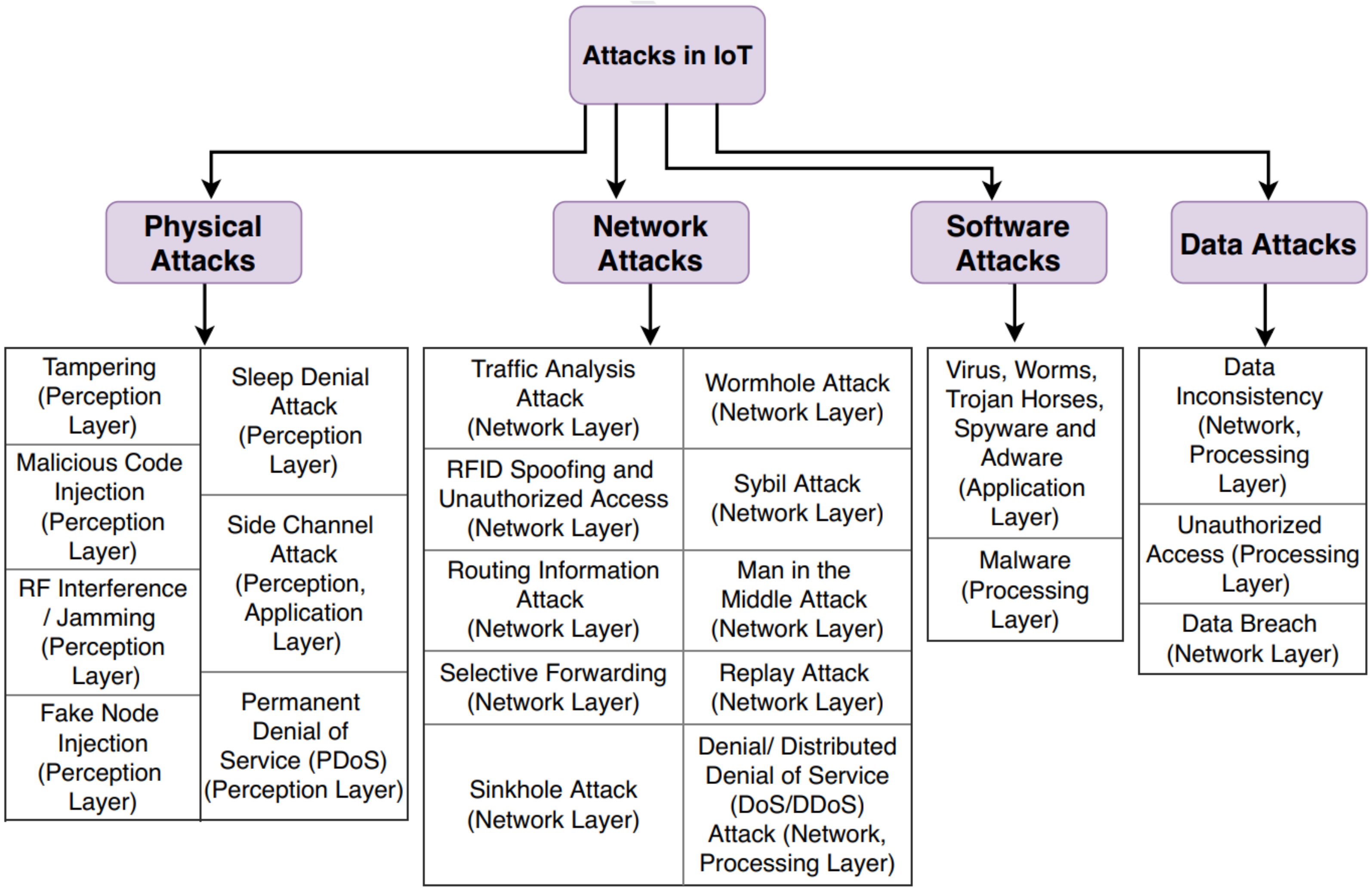


Figure 2: *Attacks in IoT*

* Source image: [9]

Security Threats
Attacks

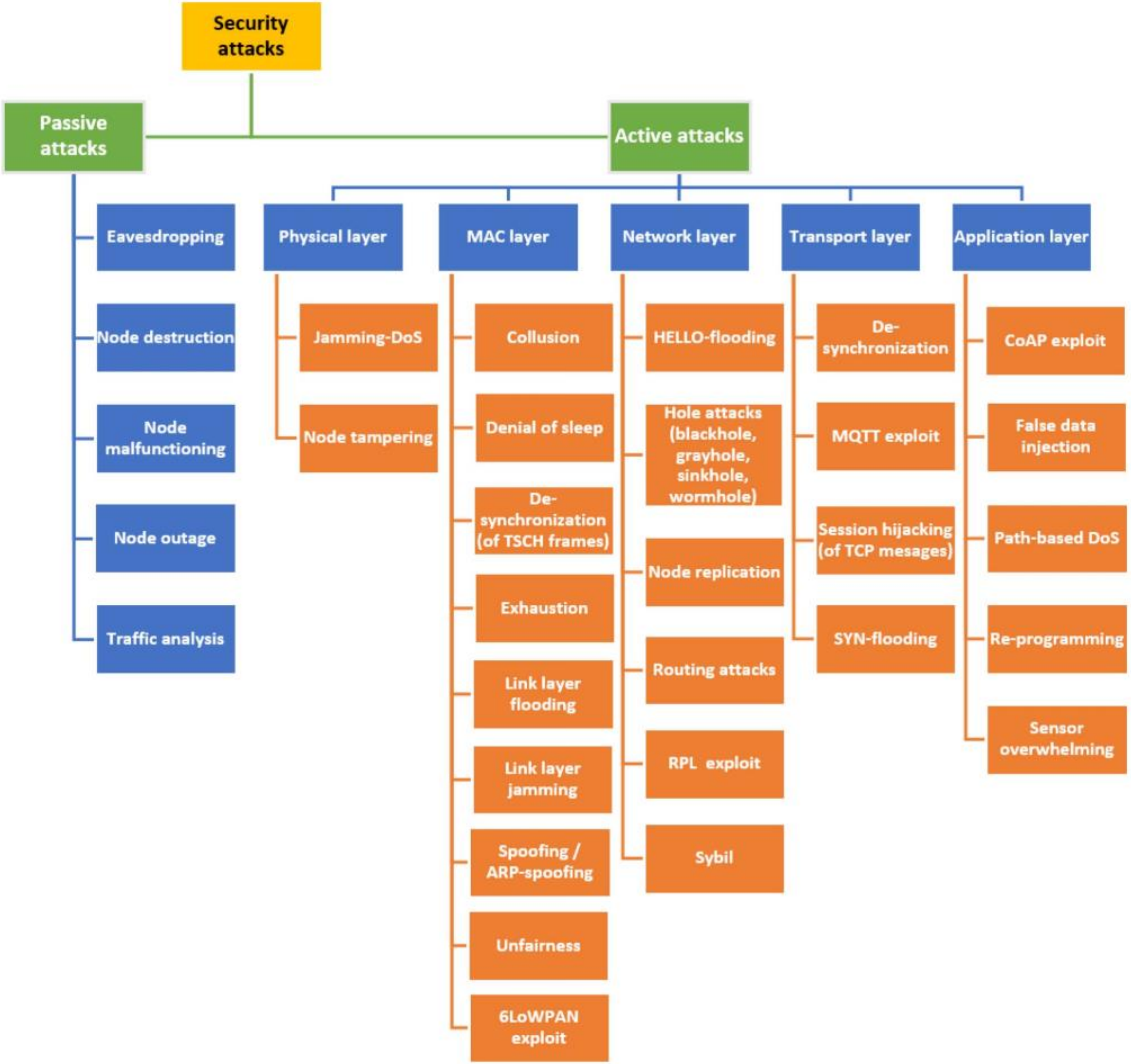


Fig. 3. Security attacks towards the WSNs and IoT - OSI stack protocol layered description.

* Source image: [10]

04

IoT and Smart Infrastructures

ENISA
Shodan

ENISA: Good practices for IoT and smart Infrastructures

- **ENISA**: European Union Agency For Cybersecurity

- **Smart infrastructure**, enabled by technologies like IoT, offer numerous of advantages bringing serious cost savings and efficiencies.

- These kinds of **data-driven environments**, fuelled by **connected devices** and network connectivity, become a **new attack surface for cyber threats**.

- **ENISA** develops **guidance** to **secure IoT and Smart Infrastructures** from cyber threats, by **highlighting good security practices** and proposing **recommendations** to operators, manufacturers and decision makers.

Source: https://www.enisa.europa.eu/topics/iot-and-smart-infrastructures

ENISA: Good practices for IoT and smart Infrastructures

- It provides also a Good practices for IoT and Smart Infrastructures **Tool**
- This tool intends to provide an aggregated view of the ENISA Good Practices for IoT and Smart Infrastructure that have been published the last years.
- It provides:
  - Baseline security IoT
  - Smart cars security
  - Smart hospitals security
  - Smart cities
  - Industry 4.0
  - Smart Airports

Source: https://www.enisa.europa.eu/topics/iot-and-smart-infrastructures/iot/good-practices-for-iot-and-smart-infrastructures-tool

Shodan

SHODAN

- Is a **search engine** for Internet-connected devices

- If a device is directly hooked up to the Internet, then Shodan queries it for various **publicly-available information**.
  - **Device name:** What your device calls itself online. For example, Samsung Galaxy S21.
  - **IP address:** A unique code assigned to each device, which allows the device to be identified by servers.
  - **Port #:** Which protocol your device uses to connect to the web.
  - **Organization:** Which business owns your "IP space". For example, your internet service provider, or the business you work for.
  - **Location:** Your country, city, county, or a variety of other geographic identifiers.

- The types of devices that are **indexed** can vary tremendously:
  - Baby monitors
  - Internet routers
  - Security cameras
  - Maritime satellites
  - Traffic light systems
  - Nuclear power plants
  - Etc.

https://www.shodan.io/

Shodan

- It allows to **search for very specific types of devices**
  - Can be used to **exploit vulnerabilities !**
  - To **protect yourself / your organization**

- **Be careful when using this tools:** you don't have the right to access unauthorized information (rules change from one country to another)

https://www.shodan.io/

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