Internet of Things

Introduction and Basic Concepts

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Amirkabir University of Technology

Contents

- Basic Concepts
- Ecosystem
  - Things
  - Platform
  - Networks
  - Applications and Verticals
- Architecture
- Challenges
- Business and Market Opportunities
- Trends

Mostly adopted from IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

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What is IoT?

- "IoT" term was first introduced by Kevin Ashton in 1999.
- **Kevin Ashton:**
  - If we had computers that knew everything there was to know about things—using data they gathered without any help from us—we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best. We need to empower computers with their own means of gathering information, so they can see, hear and smell the world for themselves.

* Internet of Things Challenges, Advances, and Applications, CRC Press, 2018

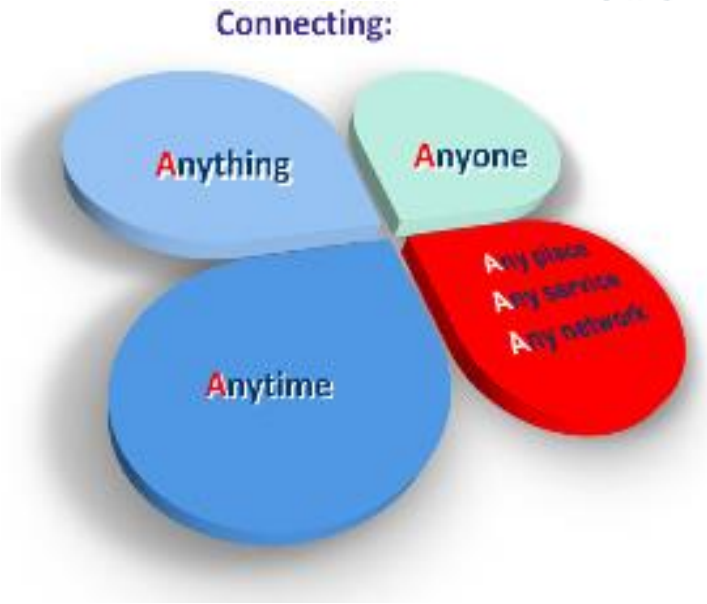
What is IoT?

- **ITU-T, 2012**
  - Internet of things (IoT): *A* global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

* Internet of Things Challenges, Advances, and Applications, CRC Press, 2018

What is IoT?

- **IERC, 2014**
  - A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.



* Internet of Things Challenges, Advances, and Applications, CRC Press, 2018
* http://www.internet-of-things-research.eu/about_iot.htm

What is IoT?

- **ISO/IEC, 2015**
  - An infrastructure of interconnected objects, people, systems, and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react.

* Internet of Things Challenges, Advances, and Applications, CRC Press, 2018

What is IoT?

- **IEEE IoT, 2015**
  - An IoT is a network that connects uniquely identifiable 'Things' to the Internet. Through the exploitation of unique identification and sensing, information about the 'Thing' can be collected and the state of the 'Thing' can be changed from anywhere, anytime, by anything."

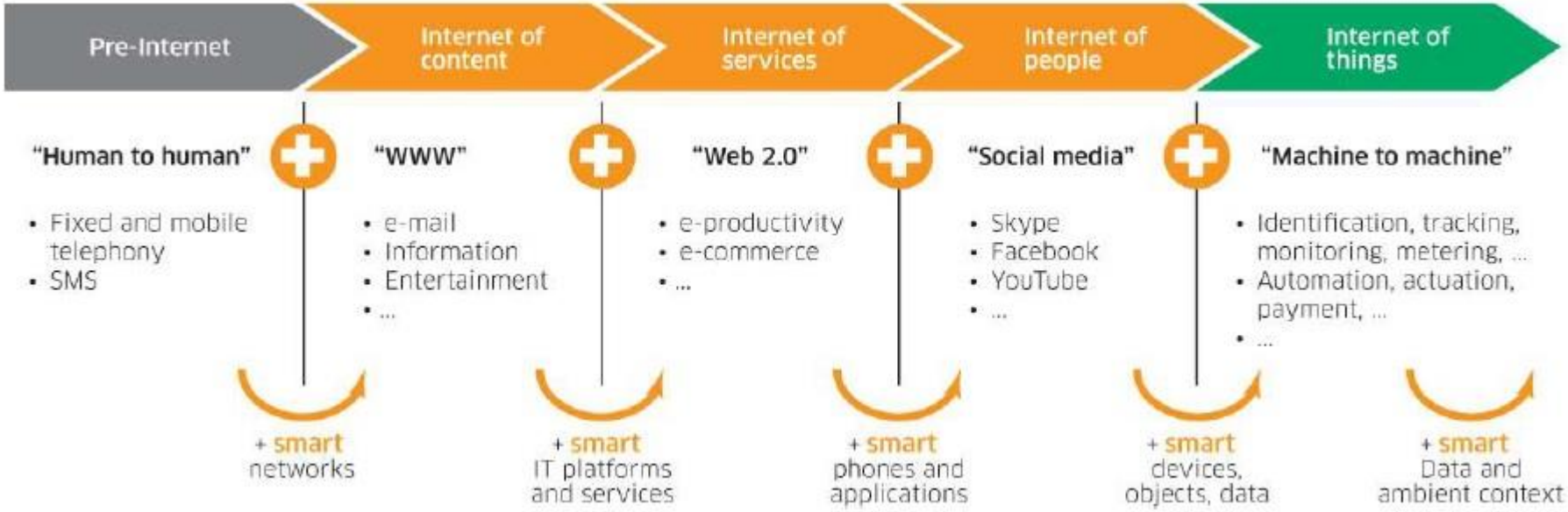
* Internet of Things Challenges, Advances, and Applications, CRC Press, 2018

What is IoT?

- IoT is a world of interconnected things which are capable of sensing, actuating, and communicating among themselves and with the environment (i.e.,smart things or smart objects) while providing the ability to share information and act in parts autonomously to real/physical world events and by triggering processes and creating services with or without direct human intervention.

* Internet of Things A to Z : Technologies and Applications, IEEE Press, 2018

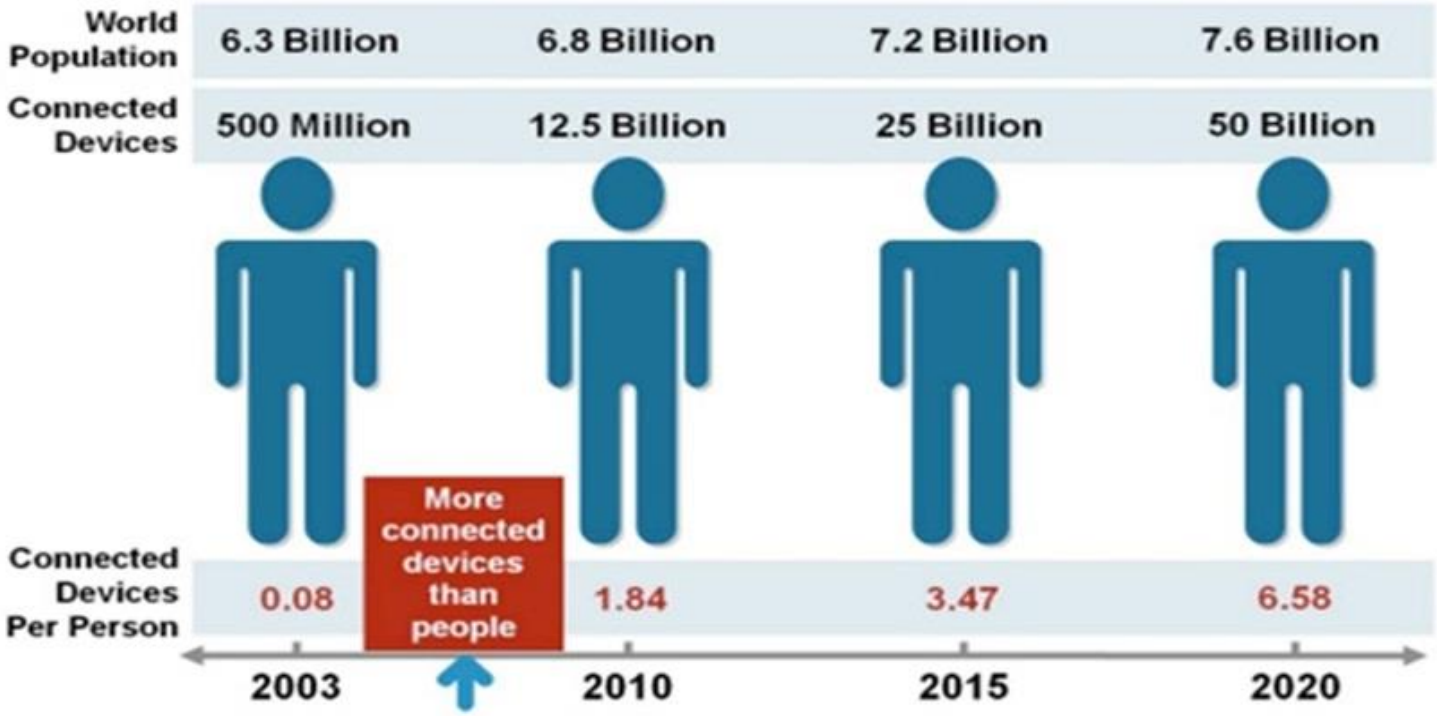
History of IoT



* Lecture, Internet of Things: An Introduction, Tecnico Ulisboa, 2018

The number of connected devices:

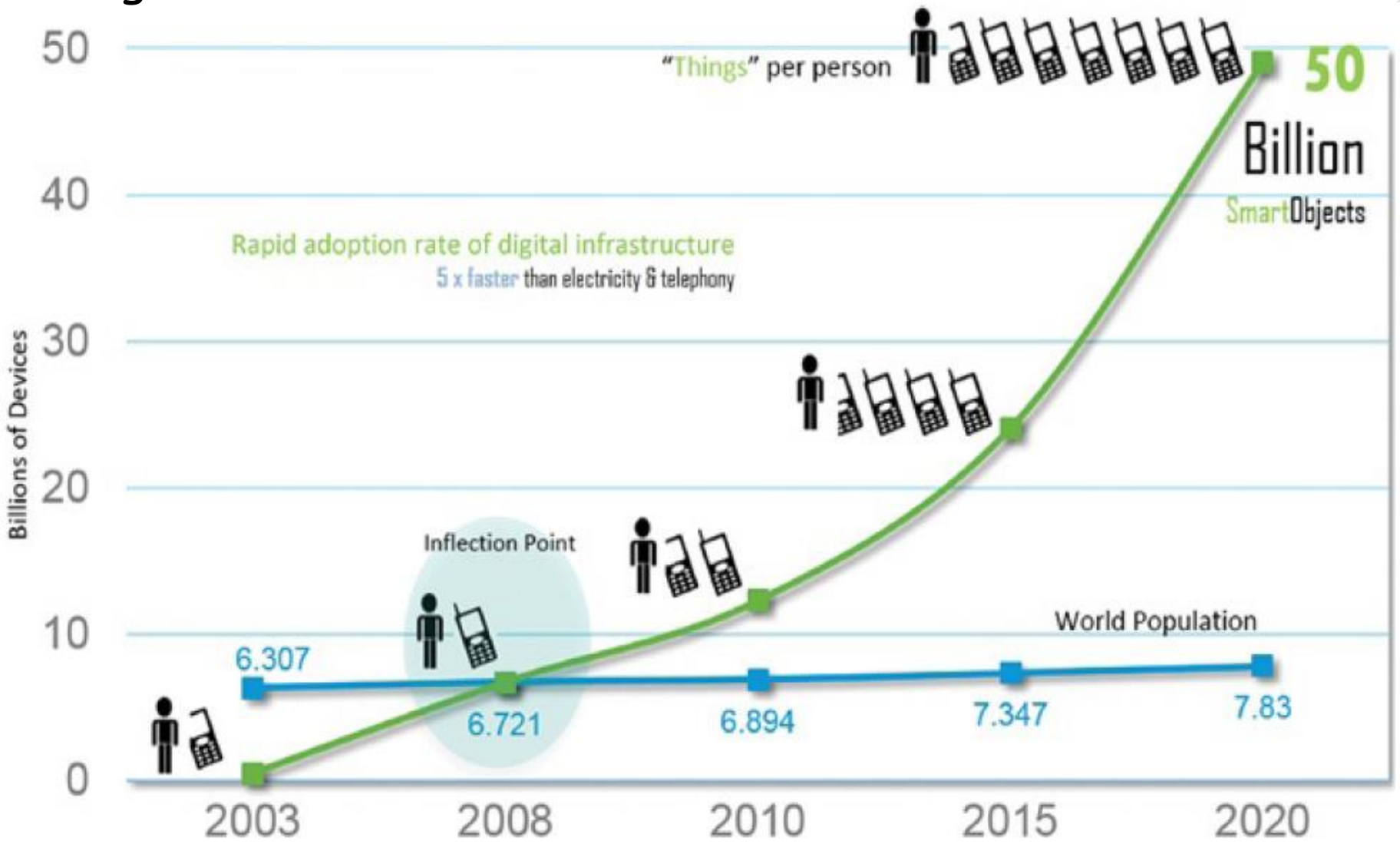
- Devices connected to the internet exceed the number of people



* http://blueapp.io/blog/a-brief-history-of-iot/
* Cisco IBSG, April 2011

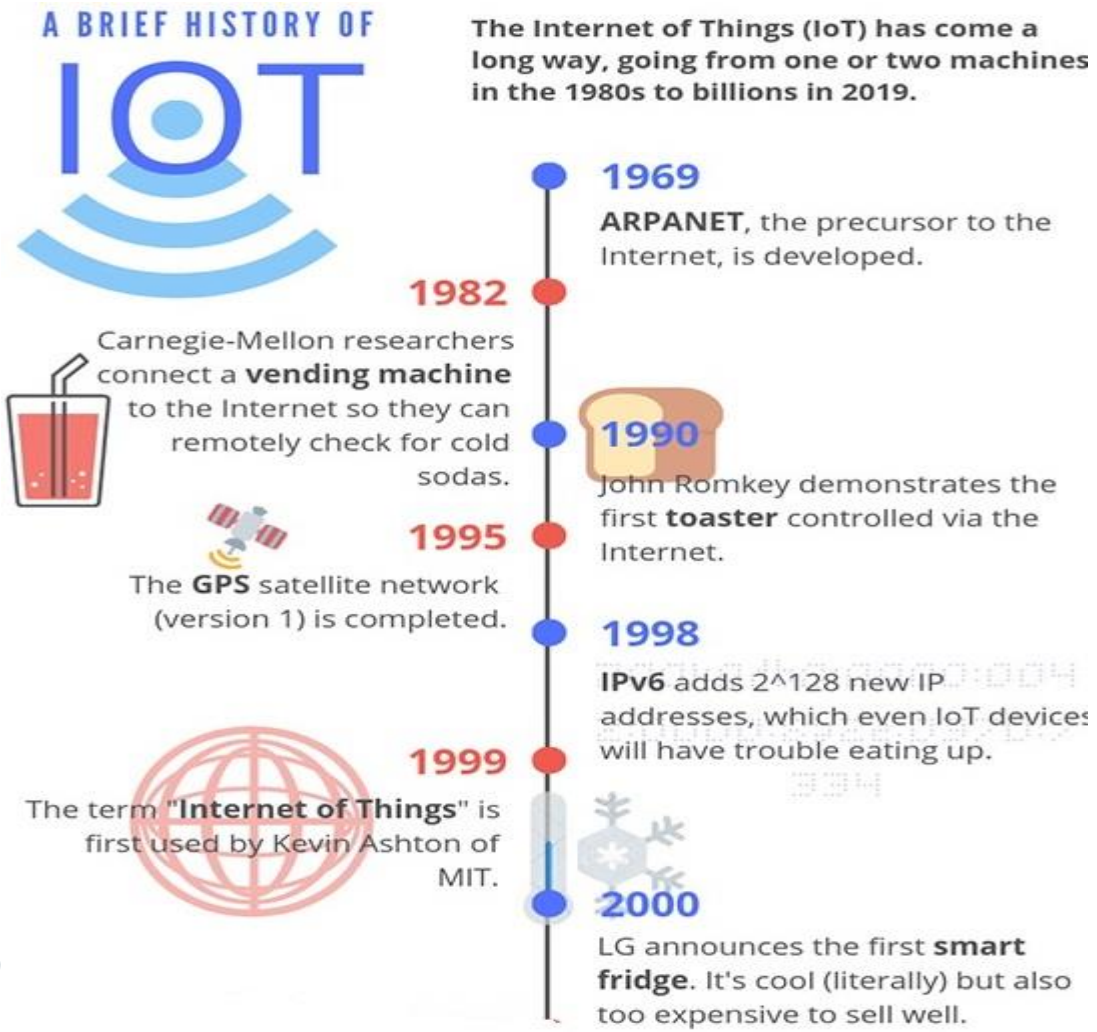
IoT Impact

- Growing the number of connected devices to 50 billion in 2020.



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

History of IoT



* https://www.iottechtrends.com/history-of-iot/

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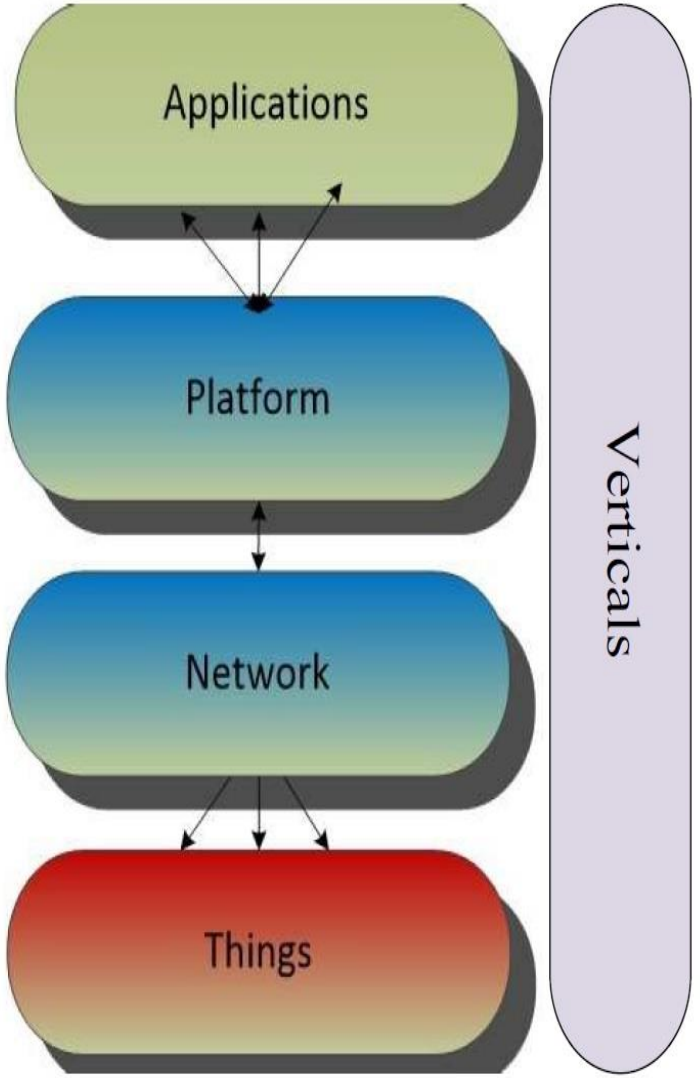
IoT Ecosystem

- Things:
  - sensors and actuators
- Network:
  - communication technologies
- Platform:
  - security, process modeling and device management, data stream and information management, integration of information access mechanisms
- Applications:
  - making decisions, data analytics



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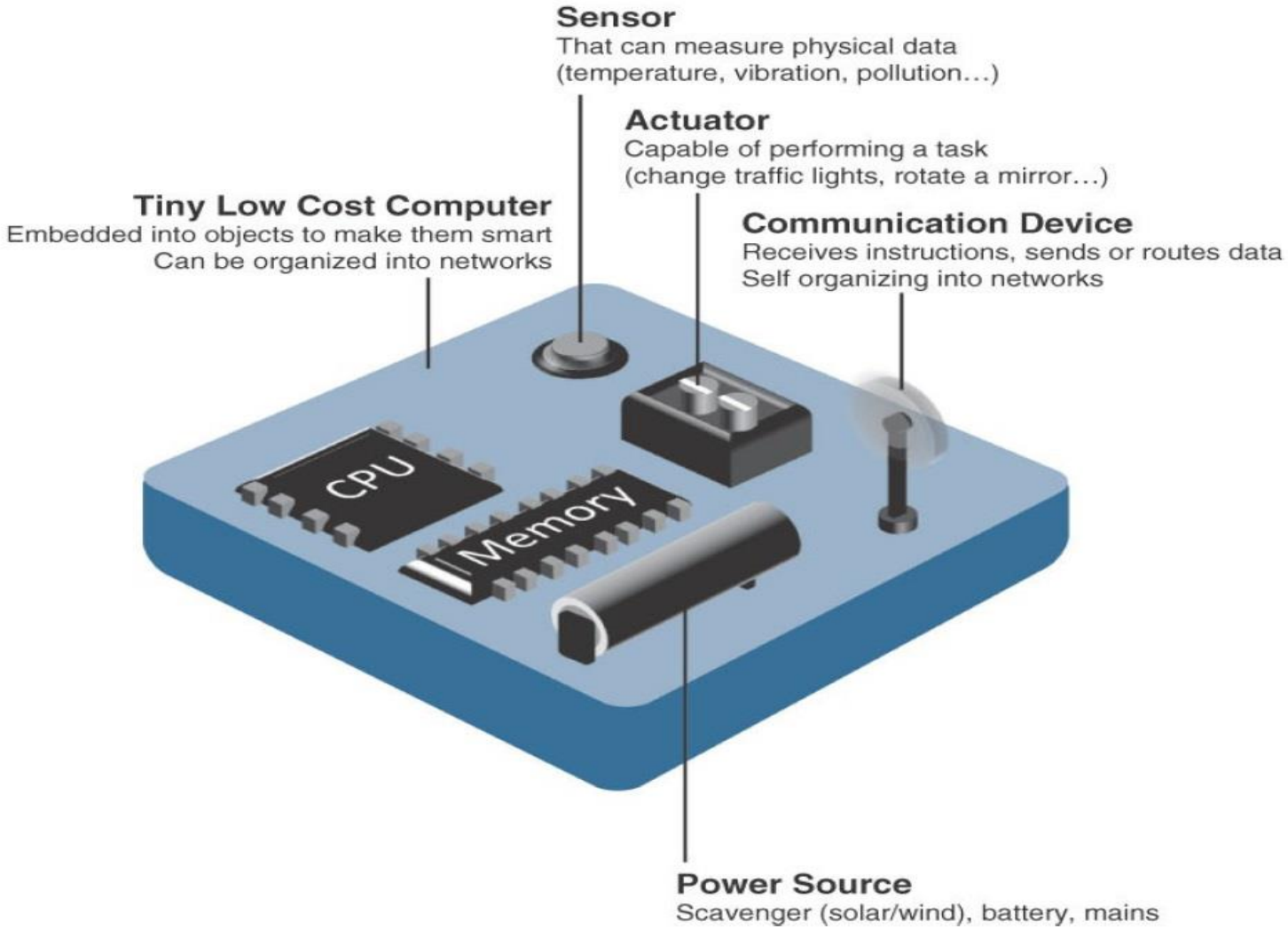
What are Things?

- Smart objects or Things are any physical objects that contain embedded technology to sense and/or interact with their environment in a meaningful way by being interconnected and enabling communication among themselves or an external agent.
- Things are
  - Sensors
  - Actuators

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

What are Things?

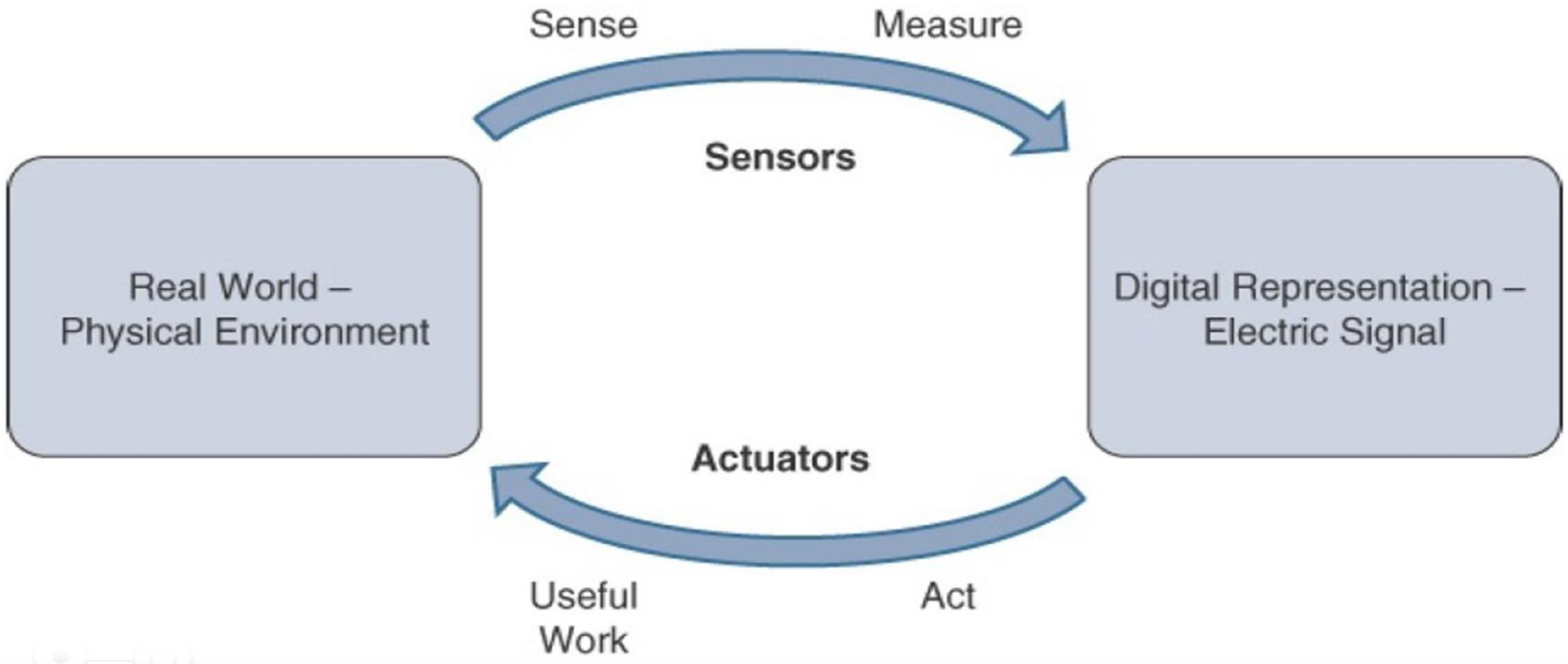
- Sensors
- Actuators



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

What are Things?

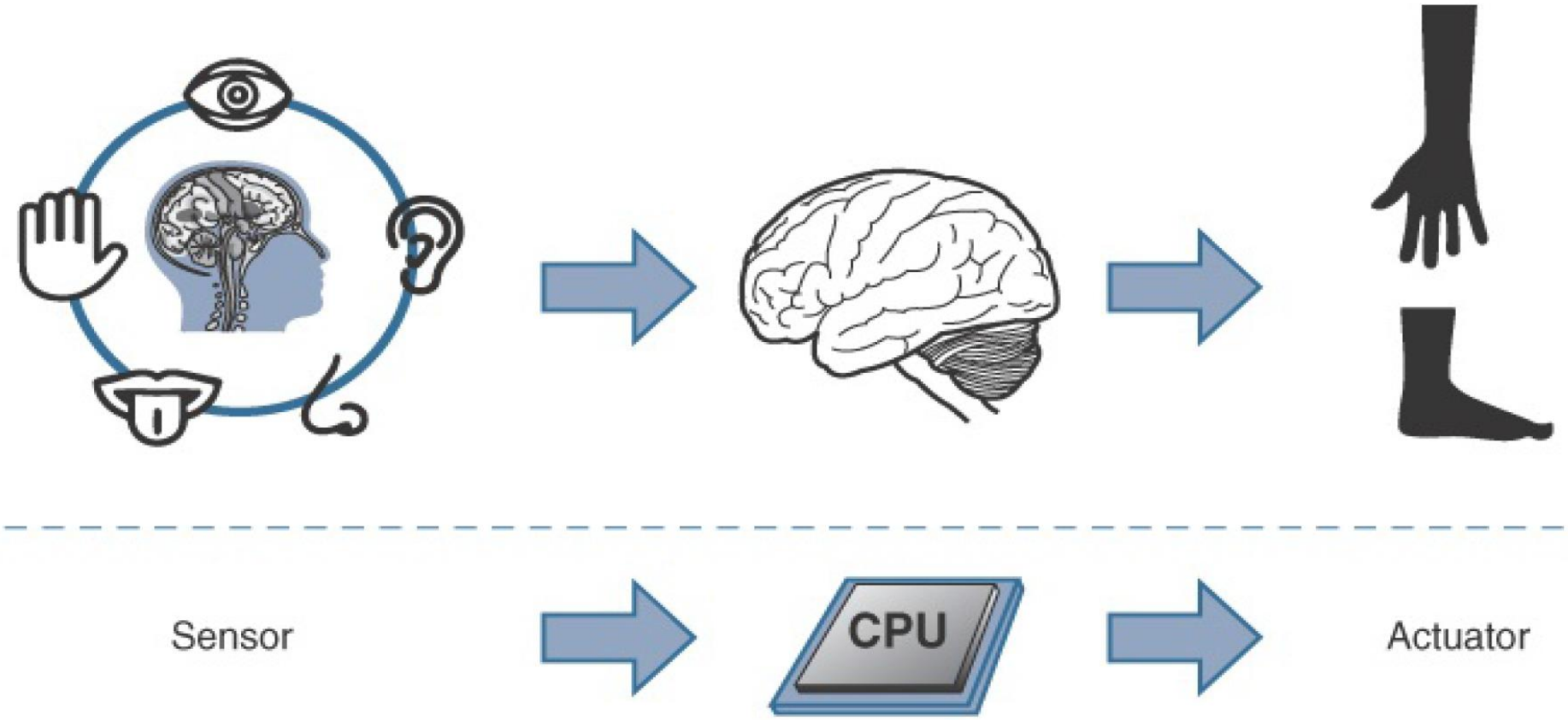
- How Sensors and Actuators Interact with the Physical World



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

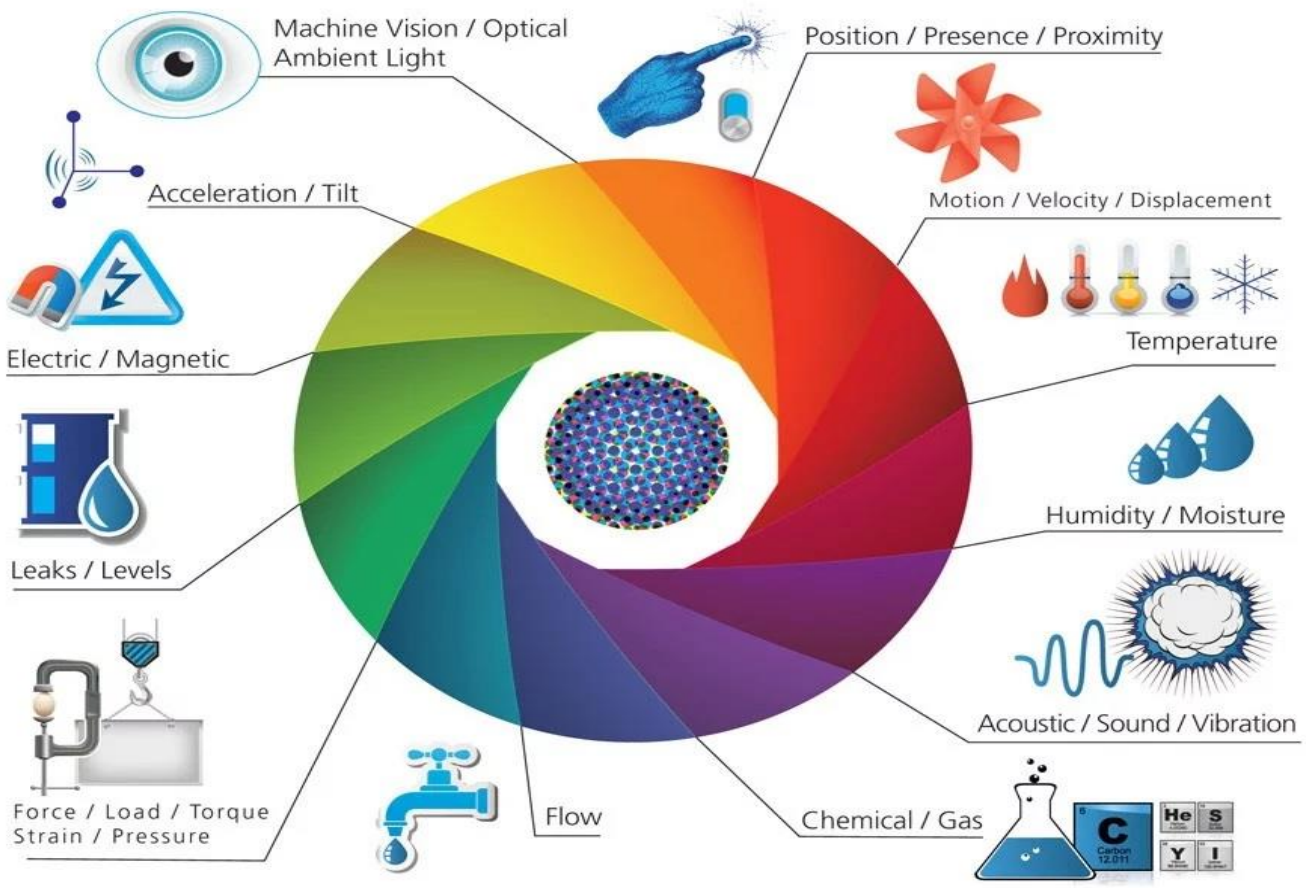
What are Things?

- Comparison of Sensors and Actuators Functionality with Humans



What are Things?

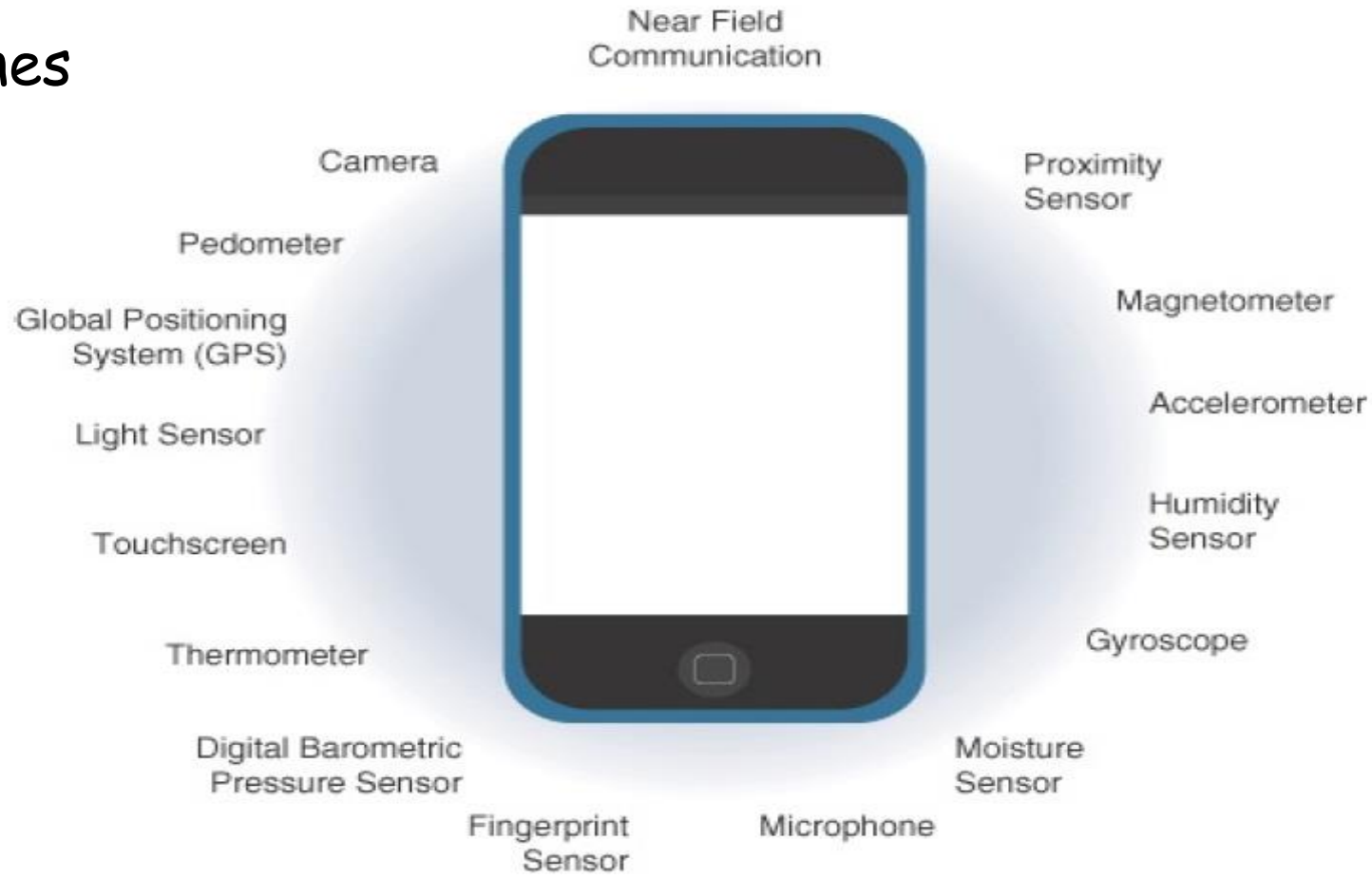
- Sensors and Actuators



* https://www.postscapes.com/iot-sensors-actuators

What are Things?

- Sensors in smart phones



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Sensors

- Measures some physical quantity and converts it into a digital representation.

- That digital representation is typically passed to another device for transformation into useful data that can be consumed by intelligent devices or humans.

- Sensors can be readily embedded in any physical objects that are easily connected to the Internet by wired or wireless networks.

- Because these connected host physical objects with multidimensional sensing capabilities communicate with each other and external systems, they can interpret their environment and make intelligent decisions.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

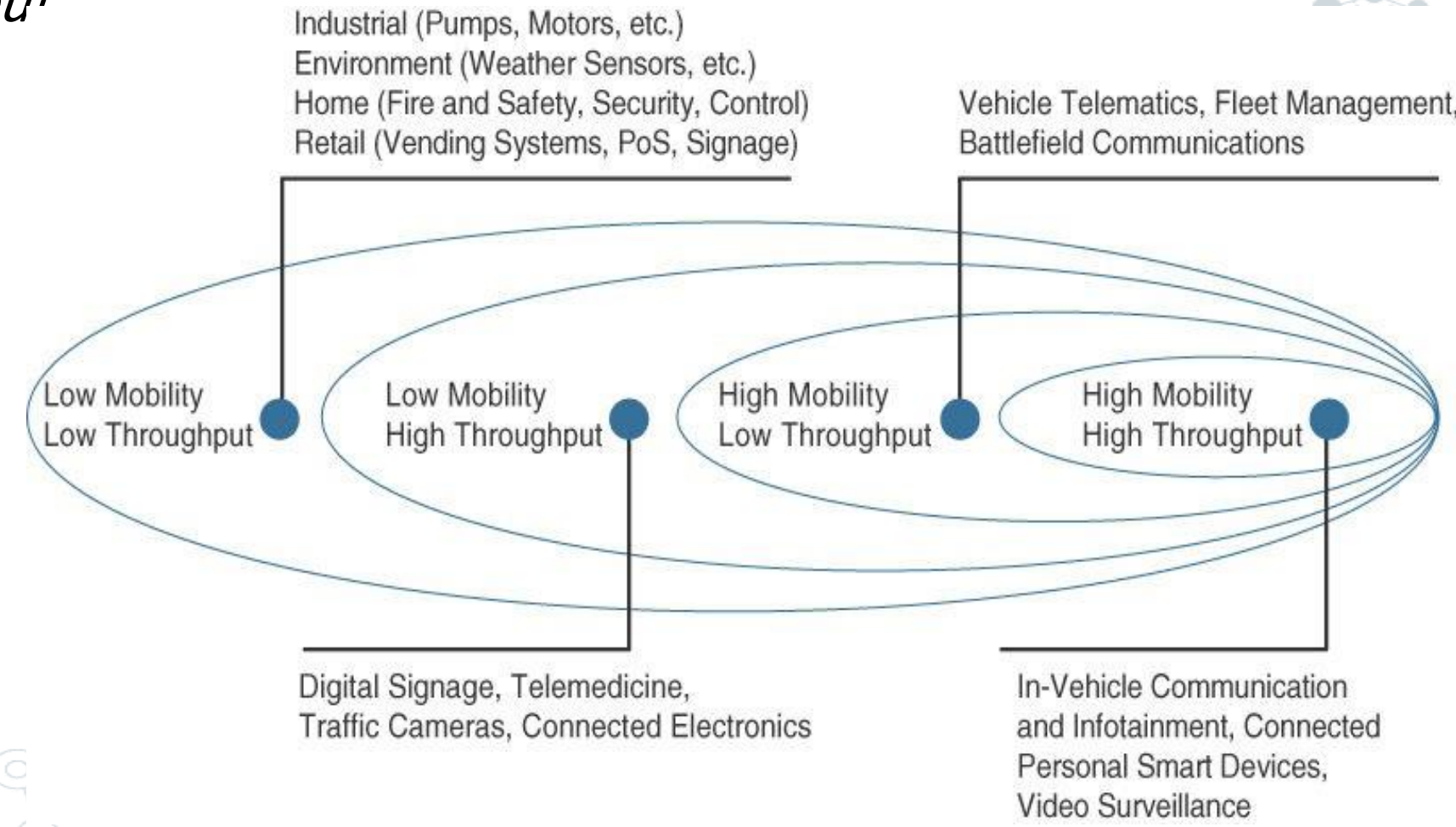
Sensors

- Different types of sensors
  - Active or passive
  - Invasive or non-invasive
  - Contact or no-contact
  - Absolute or relative
  - Area of application
  - How sensors measure
  - What sensors measure

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Sensors

Example of Sensor Applications Based on Mobility and Throughput



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Actuators

- Actuators receive some type of control signal (commonly an electric signal or digital command) that triggers a physical effect, usually some type of motion, force, and so on.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Actuators

- Different types of actuators
  - Type of motion
  - Power
  - Binary or continuous
  - Area of application
  - Type of energy

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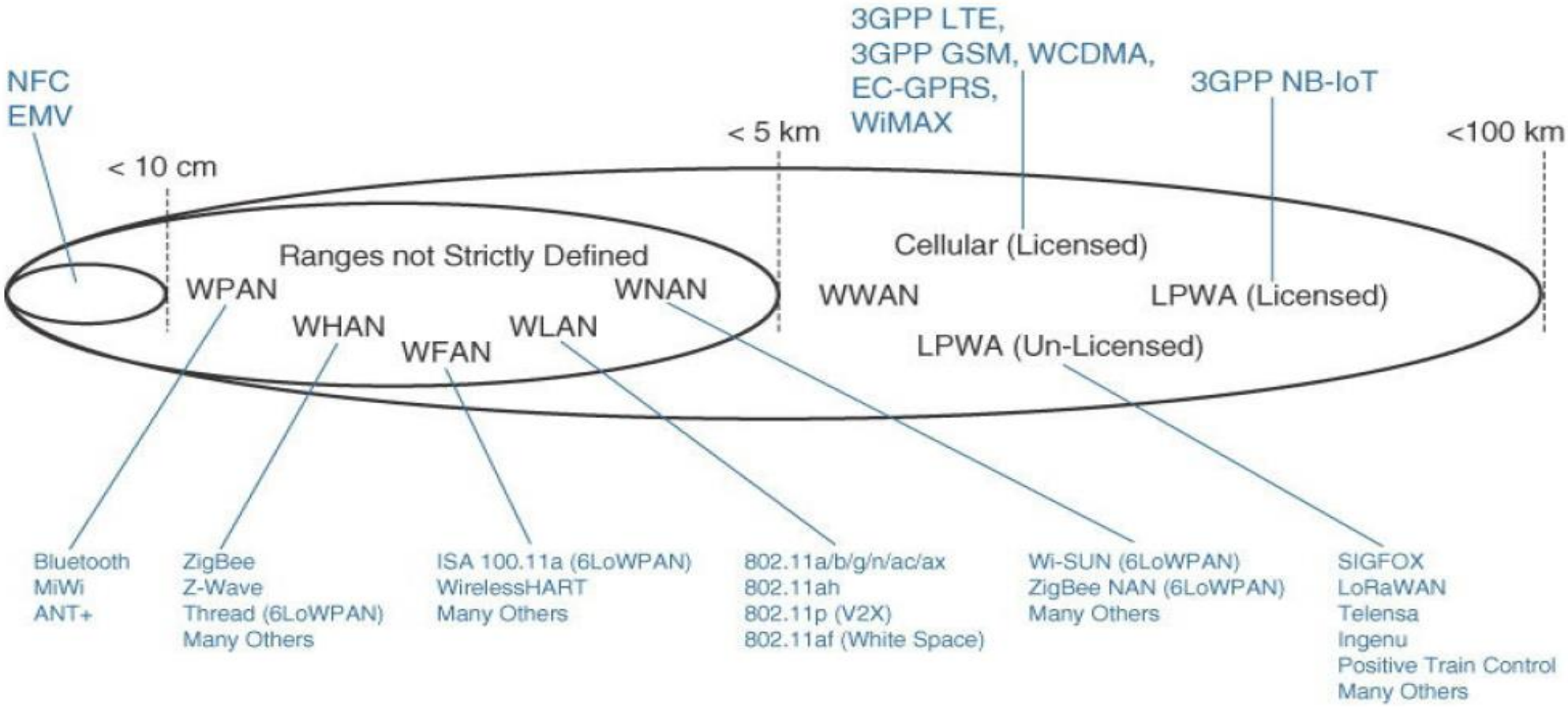
IoT Networks

- Having determined the the smart object and its required transmission capabilities (transmission range, data volume and frequency, sensor density and mobility), you are ready to connect the object and communicate.
- A first step in designing an IoT network is to examine the requirements in terms of mobility and data transmission (how much data, how often, how long, how much power).
- IoT Network is the communication domain for the IoT devices and endpoints.
- It includes the devices themselves and the communications network that links them.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

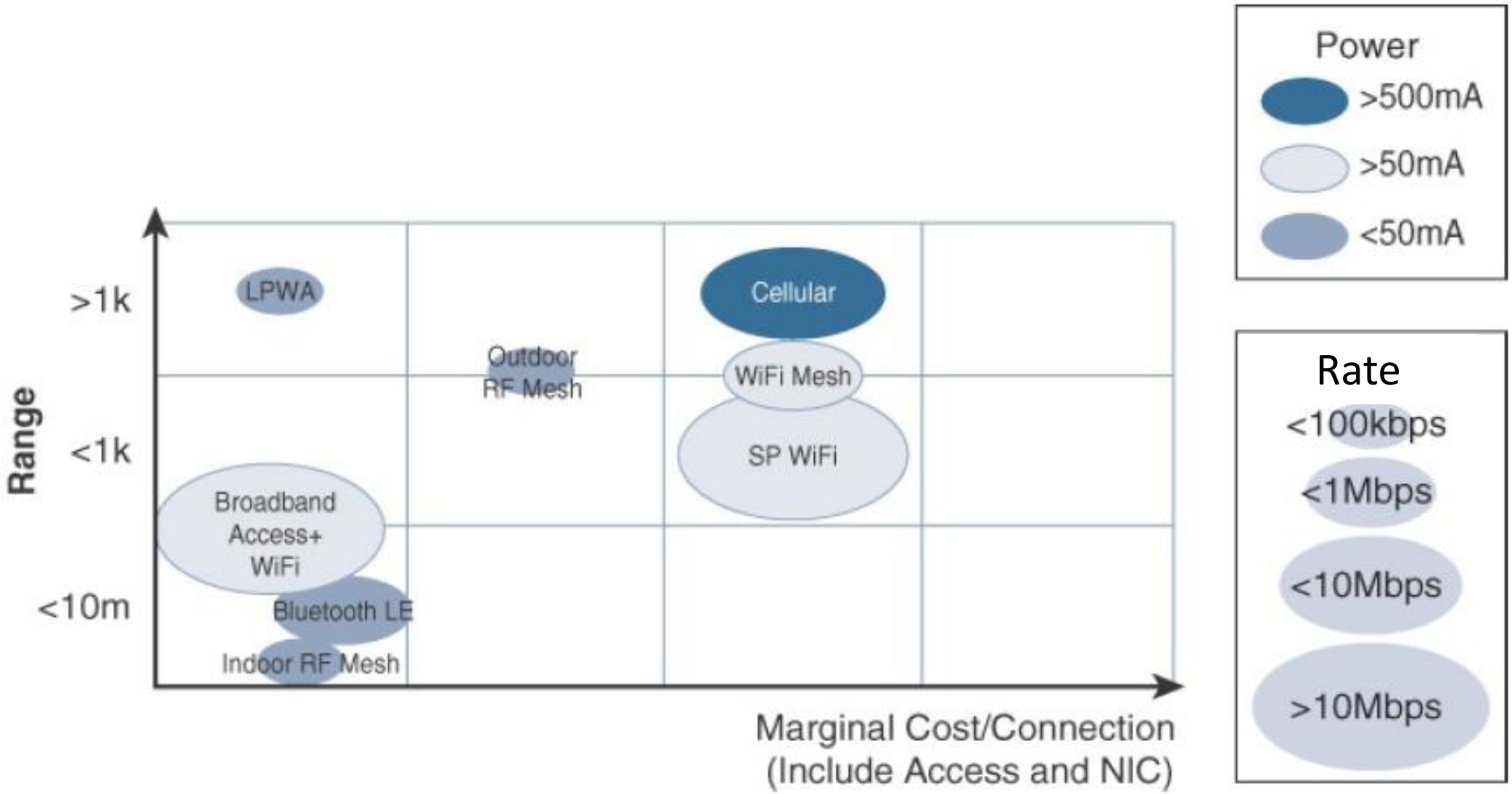
Access Technologies and Distances



WPAN: Wireless Personal Area Network
WHAN: Wireless Home Area Network
WFAN: Wireless Field (or Factory) Area Network
WLAN: Wireless Local Area Network

WNAN: Wireless Neighborhood Area Network
WWAN: Wireless Wide Area Network
LPWA: Low Power Wide Area

Comparison Between Common Last-Mile Technologies in Terms of Range Versus Power and Rate



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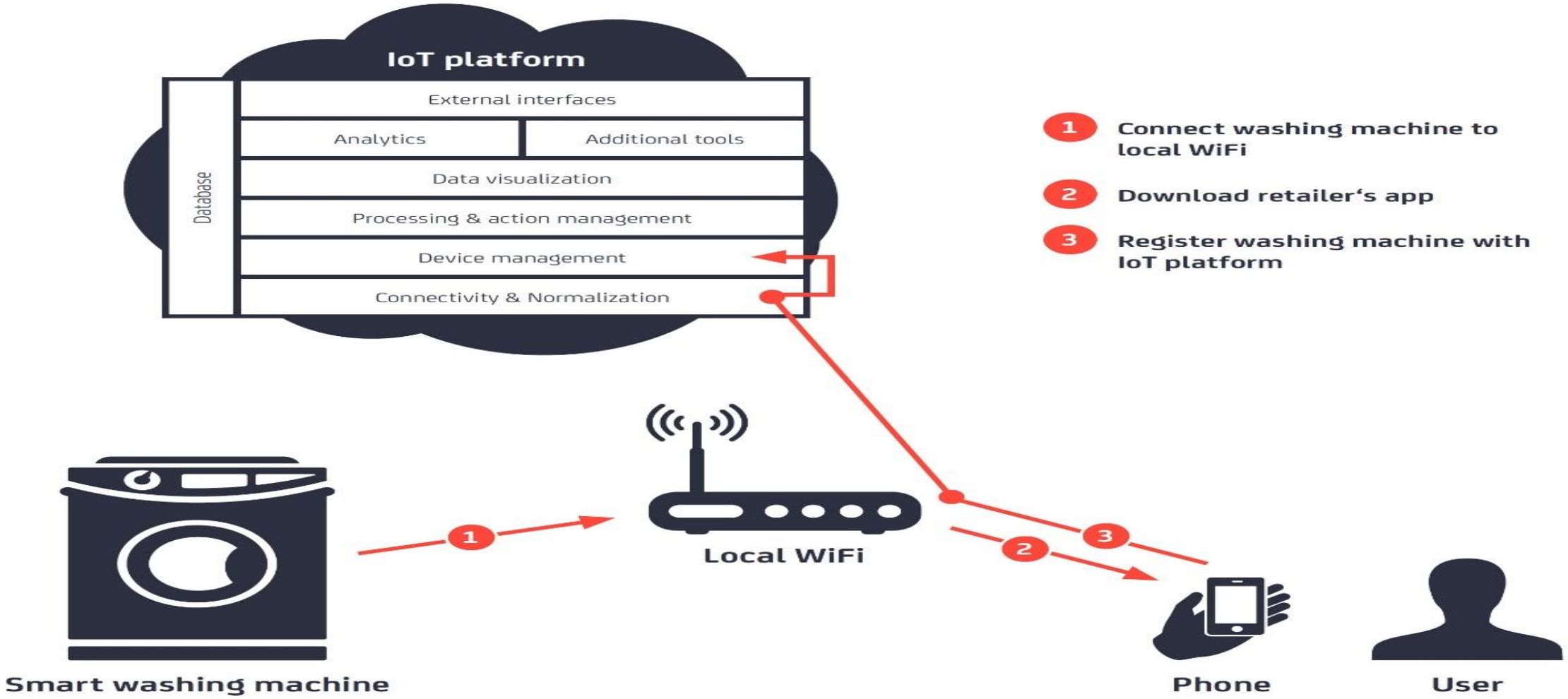
IoT Platforms

- IoT platforms are the central piece in the Internet of Things architecture that connect the real and the virtual worlds and enable communication between objects.
- In its most simple form, an IoT platform is just about enabling connectivity between objects.
- In a more sophisticated form, the platform consists of a variety of important building blocks:
  - Connectivity and normalization,
  - device management,
  - database,
  - processing and action management,
  - analytics,
  - visualization,
  - additional tools, and
  - external interfaces

* IoT Platforms, IoT Analytics, 2015

IoT Platforms



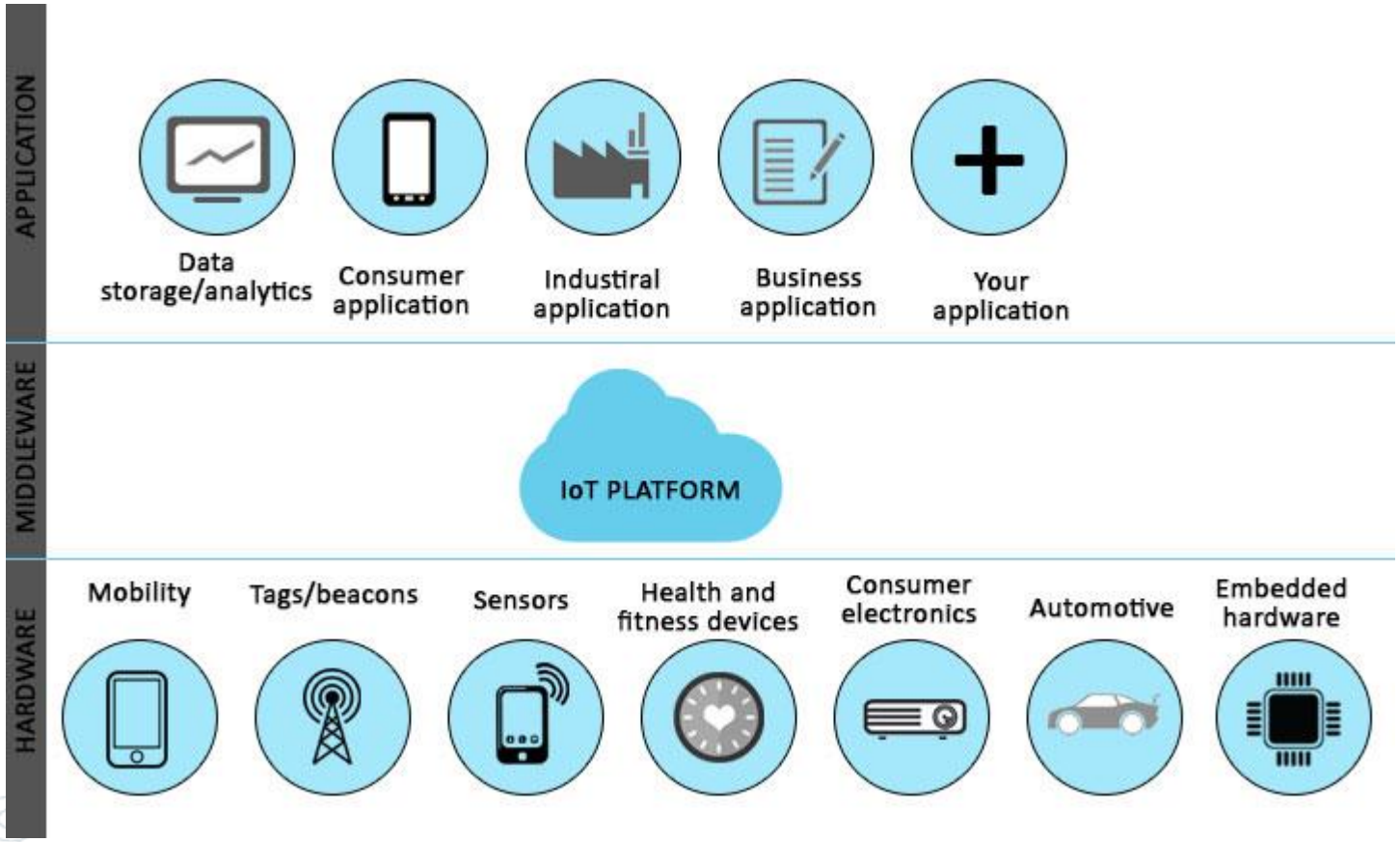
* IoT Platforms, IoT Analytics, 2015

IoT Platforms

- An IoT platform is an end-to-end software framework.
- It's the glue that pulls together information from sensors, devices, networks, and software that work together to unlock valuable, actionable data.
- A platform should have the ability to:
  - manage devices
  - allow remote connections to all relevant objects or devices
  - collect and manage data and help you define business rules
  - enable analytics and visualization
  - integrate with IT and cloud services

* https://www.business.att.com/learn/research-reports/whats-an-iot-platform-and-what-role-does-it-play.html

IoT Platforms



* https://www.educba.com/iot-platform/

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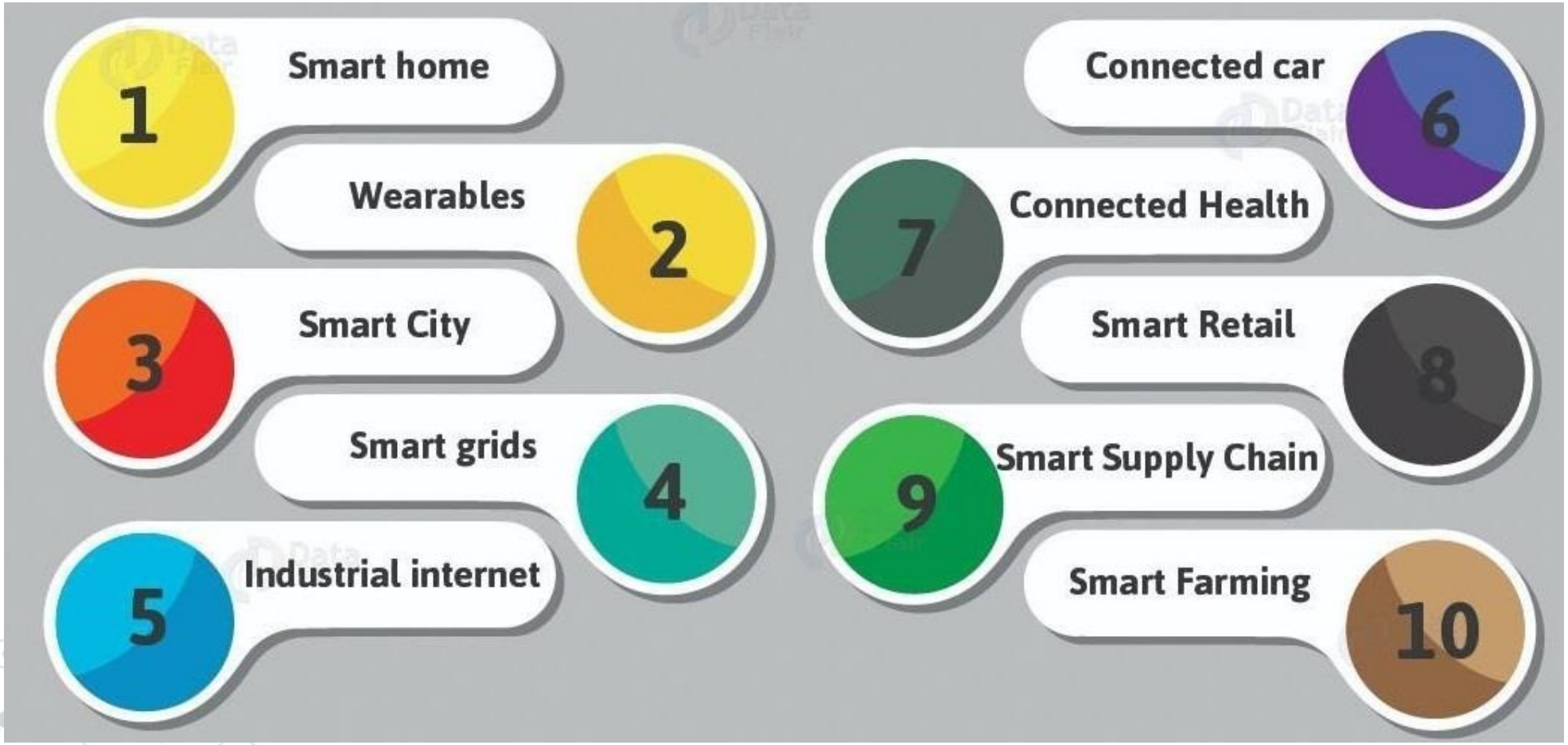
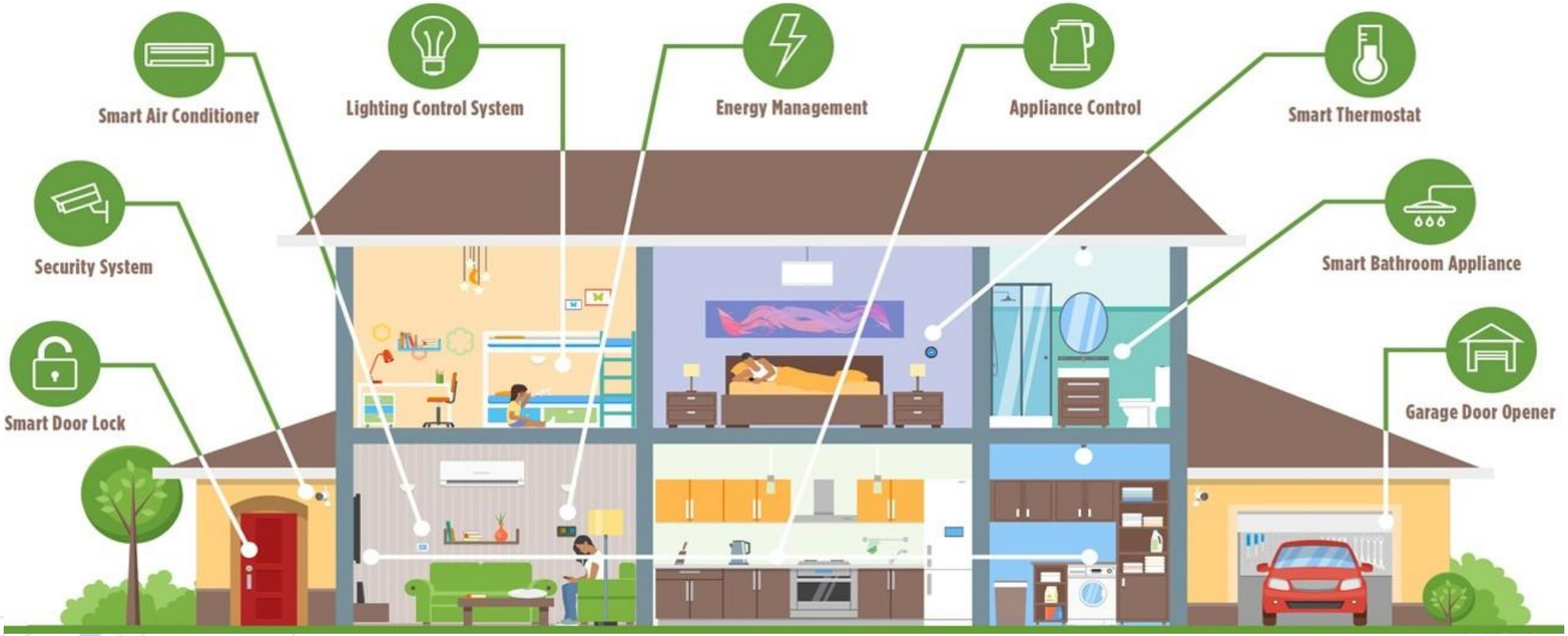
IoT Applications and Verticals



* https://www.meee-services.com/category/artificial-intelligence/

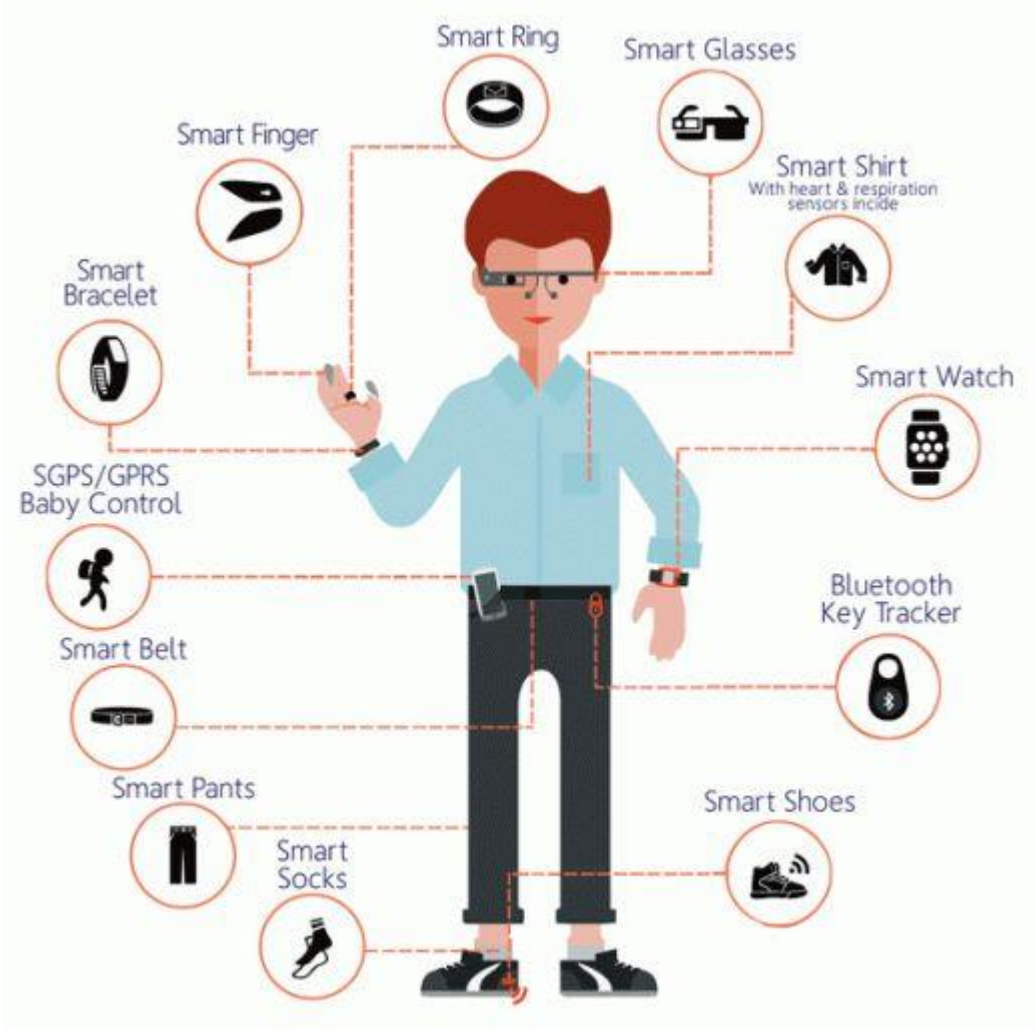
IoT Applications and Verticals- Smart Home

Smart Home



* https://www.bluebonnetelectric.coop/Community/News/articles/2016/Magazine-Stories/HOME,-SMART-HOME-Trends-in-residential-technology

IoT Applications and Verticals- Smart Wearables



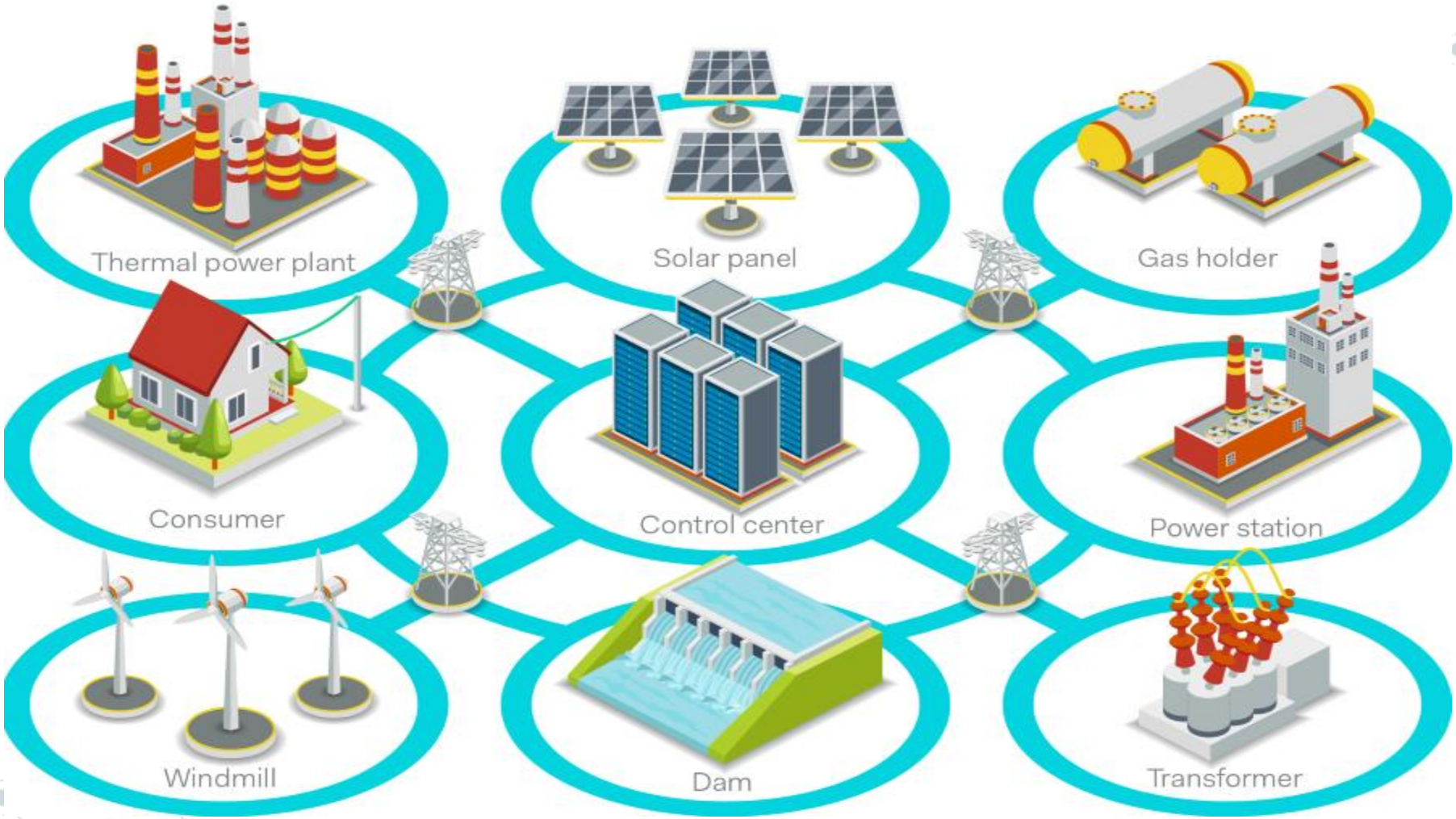
* https://www.quora.com/Why-the-boom-of-wearable-devices

IoT Applications and Verticals- Smart City

Smart City

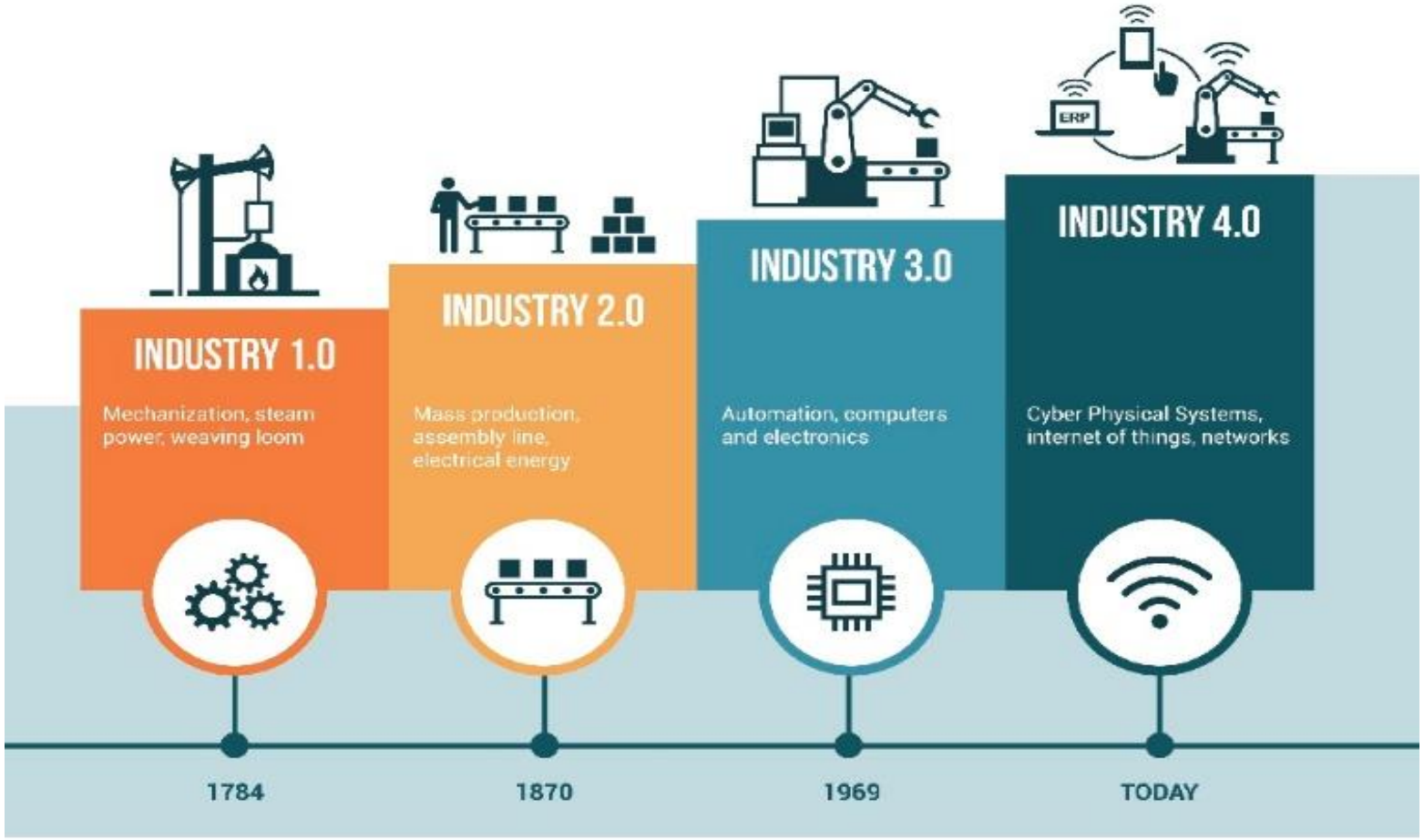
* https://www.ifpenergiesnouvelles.com/article/smart-city-energy-challenges-facing-sustainable-cities

IoT Applications and Verticals- Smart Grid



* https://www.powerelectronicsnews.com/technology/is-your-smart-grid-secured

IoT Applications and Verticals- Industrial IoT

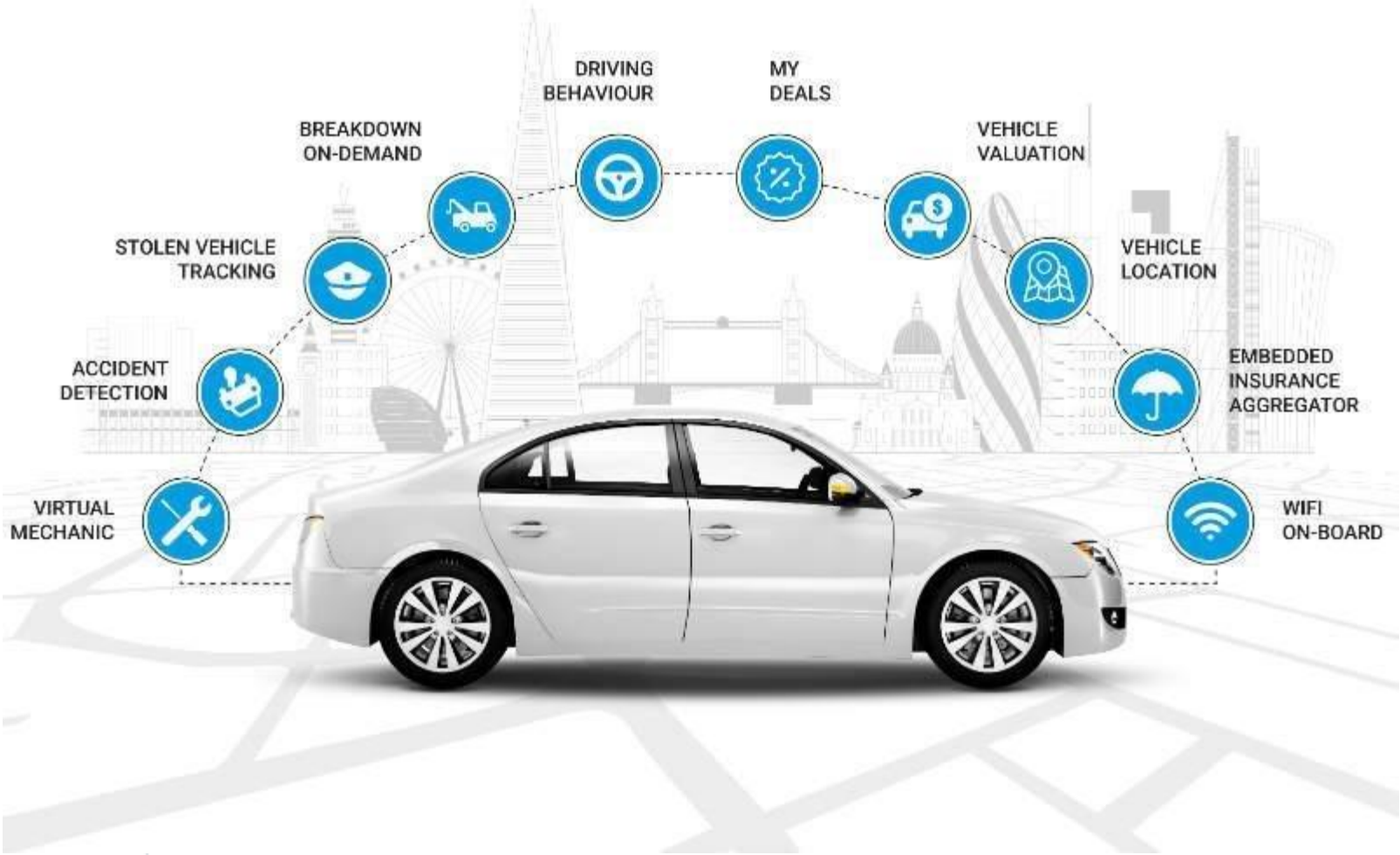


* https://www.seekmomentum.com/blog/page/3

IoT Applications and Verticals- Smart Transportation

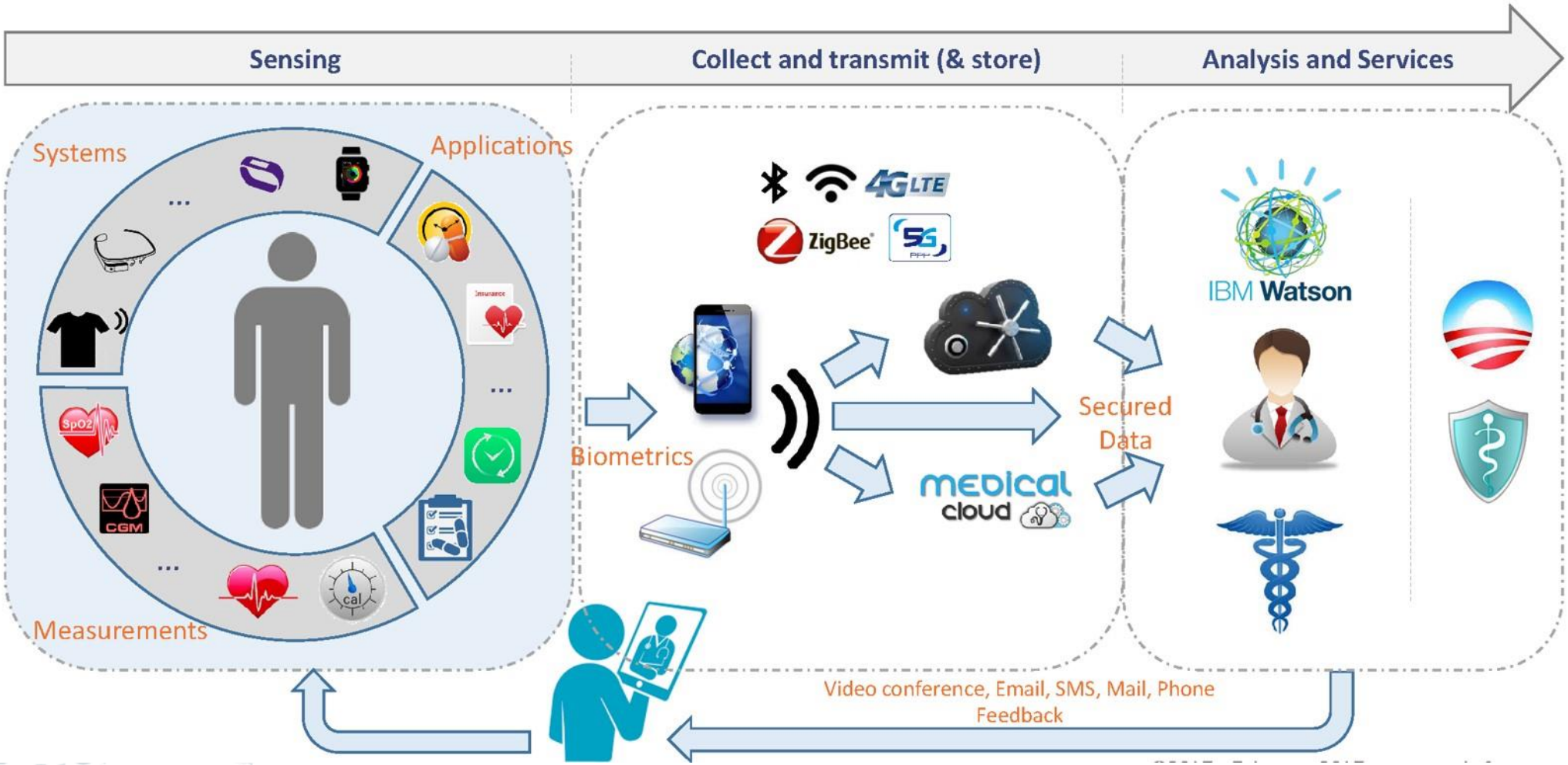
* https://www.sentinelassam.com/editorial/intelligent-transportation-system-and-smart-city-4/

IoT Applications and Verticals- Connected Car



* https://www.researchgate.net/figure/Function-of-connected-car_fig1_323258412

IoT Applications and Verticals- Connected Health

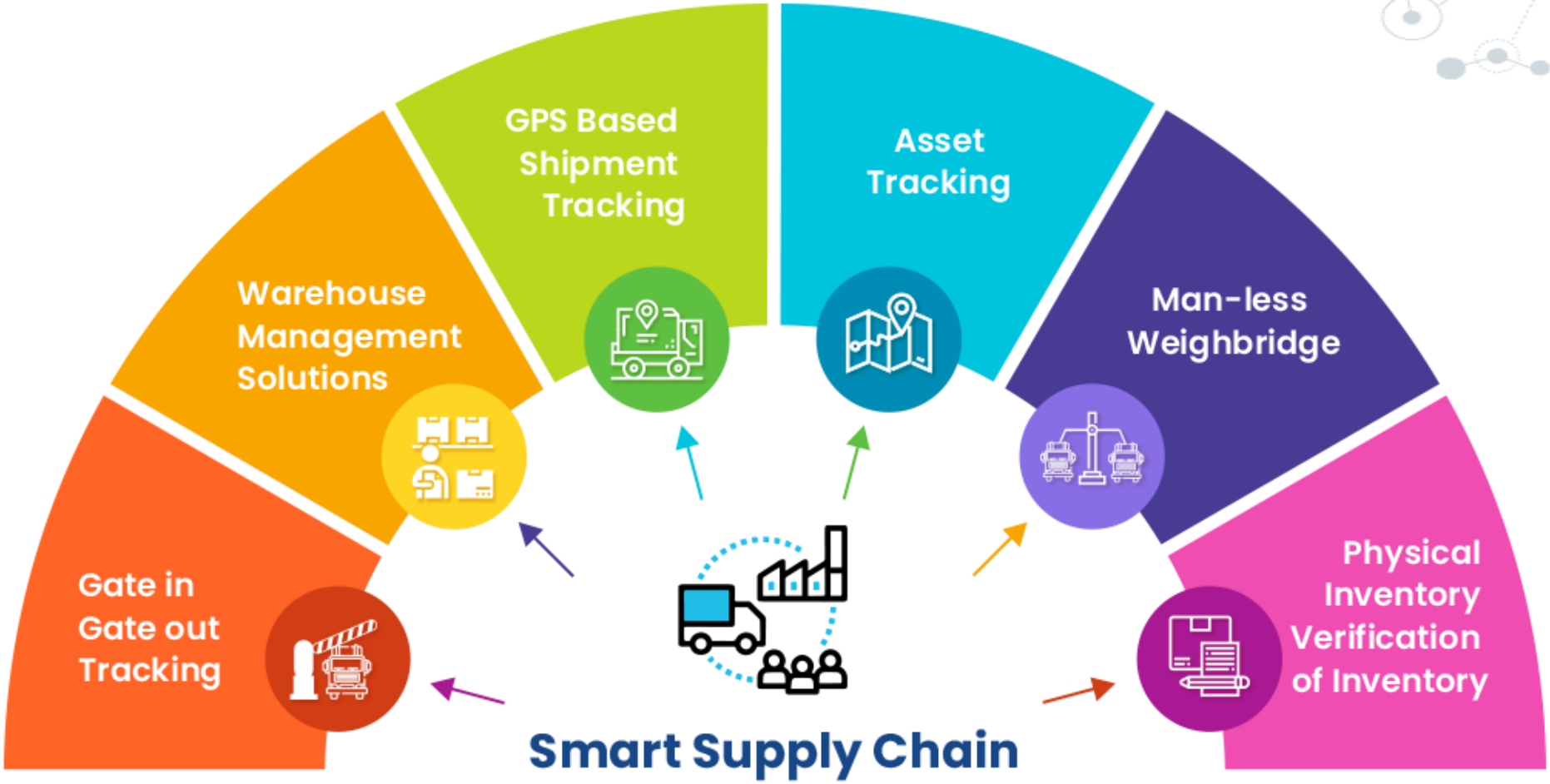


* http://www.yole.fr/IoT_Seminar_Yole_FraunhoferEMFT.aspx

IoT Applications and Verticals- Smart Retail

* https://tmrblog.com/smart-retail-systems-market-iot-influence-the-future-of-retail-store/

IoT Applications and Verticals- Smart Supply Chain



* https://www.ecubix.com/smart-supply-chain-solutions/

IoT Applications and Verticals- Smart Farming

* https://stock.adobe.com/images

Convergence of information technology (IT) and operational technology (OT)

- Until recently, IT and OT have for the most part lived in separate worlds
- IT supports connections to the Internet along with related data and technology systems and is focused on the secure flow of data across an organization.
- OT monitors and controls devices and processes on physical operational systems. These systems include assembly lines, utility distribution networks, production facilities, roadway systems, and many more.

Comparing OT And IT

Criterion	Industrial OT Network	Enterprise IT Network
Operational focus	Keep the business operating 24x7	Manage the computers, data, and employee communication system in a secure way
Priorities	1. Availability 2. Integrity 3. Security	1. Security 2. Integrity 3. Availability
Types of data	Monitoring, control, and supervisory data	Voice, video, transactional, and bulk data
Security	Controlled physical access to devices	Devices and users authenticated to the network
Implication of failure	OT network disruption directly impacts business	Can be business impacting, depending on industry, but workarounds may be possible
Network upgrades (software or hardware)	Only during operational maintenance windows	Often requires an outage window when workers are not onsite; impact can be mitigated
Security vulnerability	Low: OT networks are isolated and often use proprietary protocols	High: continual patching of hosts is required, and the network is connected to Internet and requires vigilant protection

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IoT Challenges

- Scalability
- Security
- Privacy
- Big Data and Data Analytics
- Interoperability

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IoT Challenges (cont'd)

- Scalability
  - The IPv4 address space has reached exhaustion and is unable to meet IoT's scalability requirements.
  - For IoT scale can be met only by IPv6.
- Security
- Privacy
- Big Data and Data Analytics
- Interoperability

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IoT Challenges (cont'd)

- Scalability
- Security
  - With more "things" connected with other "things" and people security is an increasingly complex issue for IoT.
  - Threat surface is greatly expanded and if device gets hacked, its connectivity is a major concern.
  - A Compromised device can serve as a launching point to attack other devices and systems.
- Privacy
- Big Data and Data Analytics
- Interoperability

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IoT Challenges (cont'd)

- Scalability
- Security
- Privacy
  - A sensor become more prolific in every day lives, the data what they gather will be specific to individuals and their activities.
  - For Businesses, the data has monetary value.
  - Organization discusses about who owns the data and how individuals can control whether it is shared and with whom.
- Big Data and Data Analytics
- Interoperability

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IoT Challenges (cont'd)

- Scalability
- Security
- Privacy
- Big Data and Data Analytics
  - IoT and large number of sensors are going to trigger deluge of data that must be handled.
  - This data will provide critical information and insights if it can be processed in an efficient manner.
  - Challenge is evaluating massive amounts of data arriving from different sources in various forms and doing so in a timely manner.
- Interoperability

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IoT Challenges (cont'd)

- Scalability
- Security
- Privacy
- Big Data and Data Analytics
- Interoperability
  - As with nascent technology, various protocols and architectures are jockeying for market share and standardizations within IoT.
  - Some of these protocols and architectures are based on proprietary elements and others are open.
  - Recently IoT Standards are helping minimize this problem, but there are often various protocols and implementations available for IoT networks.

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IoT Architectural Drivers

Challenge	Description	IoT Architectural Change Required
Scale	The massive scale of IoT end-points (sensors) is far beyond that of typical IT networks.	The IPv4 address space has reached exhaustion and is unable to meet IoT's scalability requirements. Scale can be met only by using IPv6. IT networks continue to use IPv4 through features like Network Address Translation (NAT).
Security	IoT devices, especially those on wireless sensor networks (WSNs), are often physically exposed to the world.	Security is required at every level of the IoT network. Every IoT endpoint node on the network must be part of the overall security strategy and must support device-level authentication and link encryption. It must also be easy to deploy with some type of a zero-touch deployment model.
Devices and networks constrained by power, CPU, memory, and link speed	Due to the massive scale and longer distances, the networks are often constrained, lossy, and capable of supporting only minimal data rates (tens of bps to hundreds of Kbps).	New last-mile wireless technologies are needed to support constrained IoT devices over long distances. The network is also constrained, meaning modifications need to be made to traditional network-layer transport mechanisms.

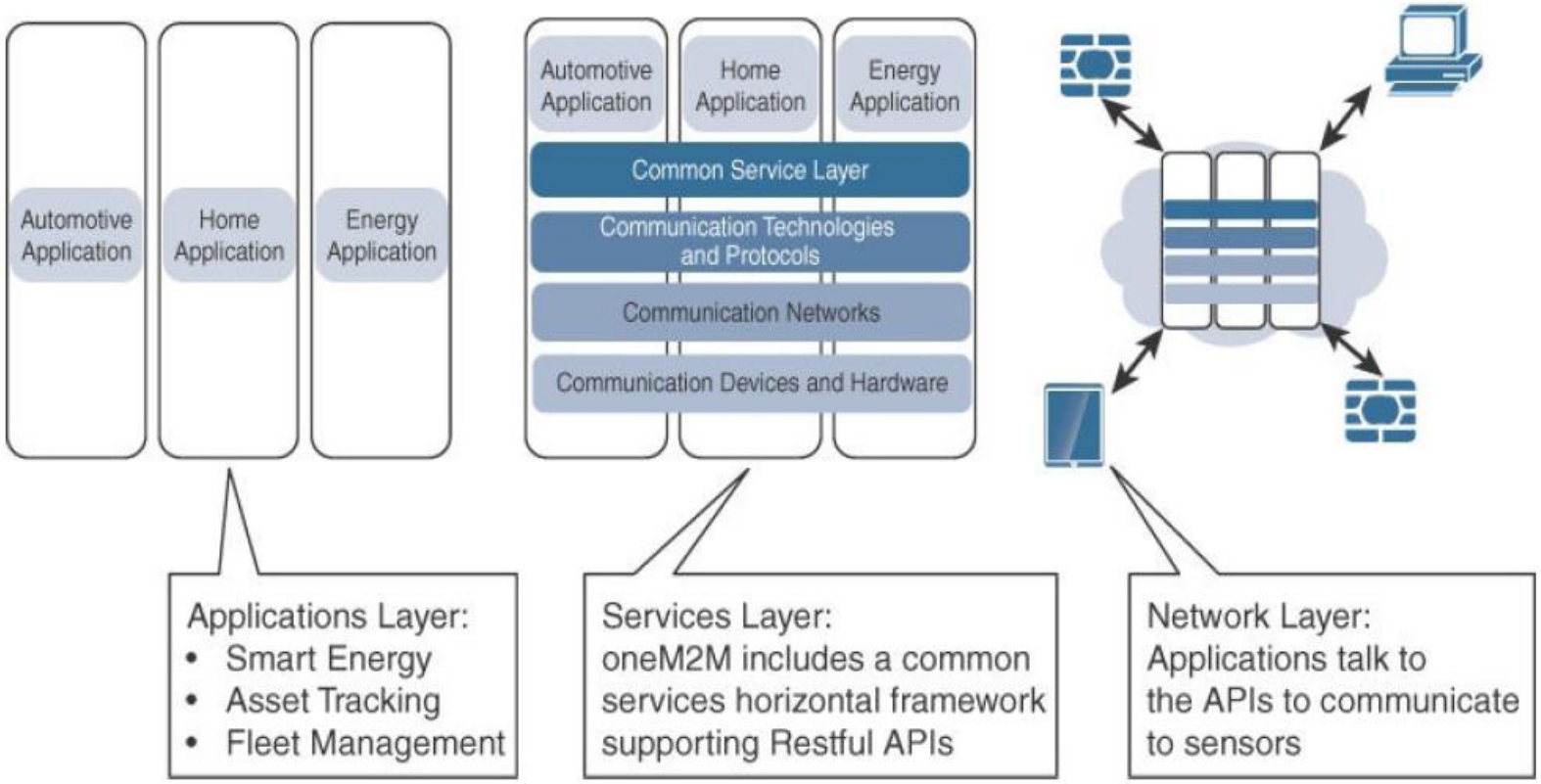
IoT Architectural Drivers (cont.)

The massive volume of data generated	The sensors generate a massive amount of data on a daily basis, causing network bottlenecks and slow analytics in the cloud.	Data analytics capabilities need to be distributed throughout the IoT network, from the edge to the cloud. In traditional IT networks, analytics and applications typically run only in the cloud.
Support for legacy devices	An IoT network often comprises a collection of modern, IP-capable endpoints as well as legacy, non-IP devices that rely on serial or proprietary protocols.	Digital transformation is a long process that may take many years, and IoT networks need to support protocol translation and/or tunneling mechanisms to support legacy protocols over standards-based protocols, such as Ethernet and IP.
The need for data to be analyzed in real time	Whereas traditional IT networks perform scheduled batch processing of data, IoT data needs to be analyzed and responded to in real-time.	Analytics software needs to be positioned closer to the edge and should support real-time streaming analytics. Traditional IT analytics software (such as relational databases or even Hadoop), are better suited to batch-level analytics that occur after the fact.

IoT Architectures

- Two of the best-known architectures are those supported by
  - oneM2M by European Telecommunications Standards Institute (ETSI) in 2008
  - IoT World Forum (IoTWF) led by CISCO, IBM, and others in 2014

The Main Elements of the oneM2M IoT Architecture



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The IoT World Forum (IoTWF) Standardized Architecture

Levels

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

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

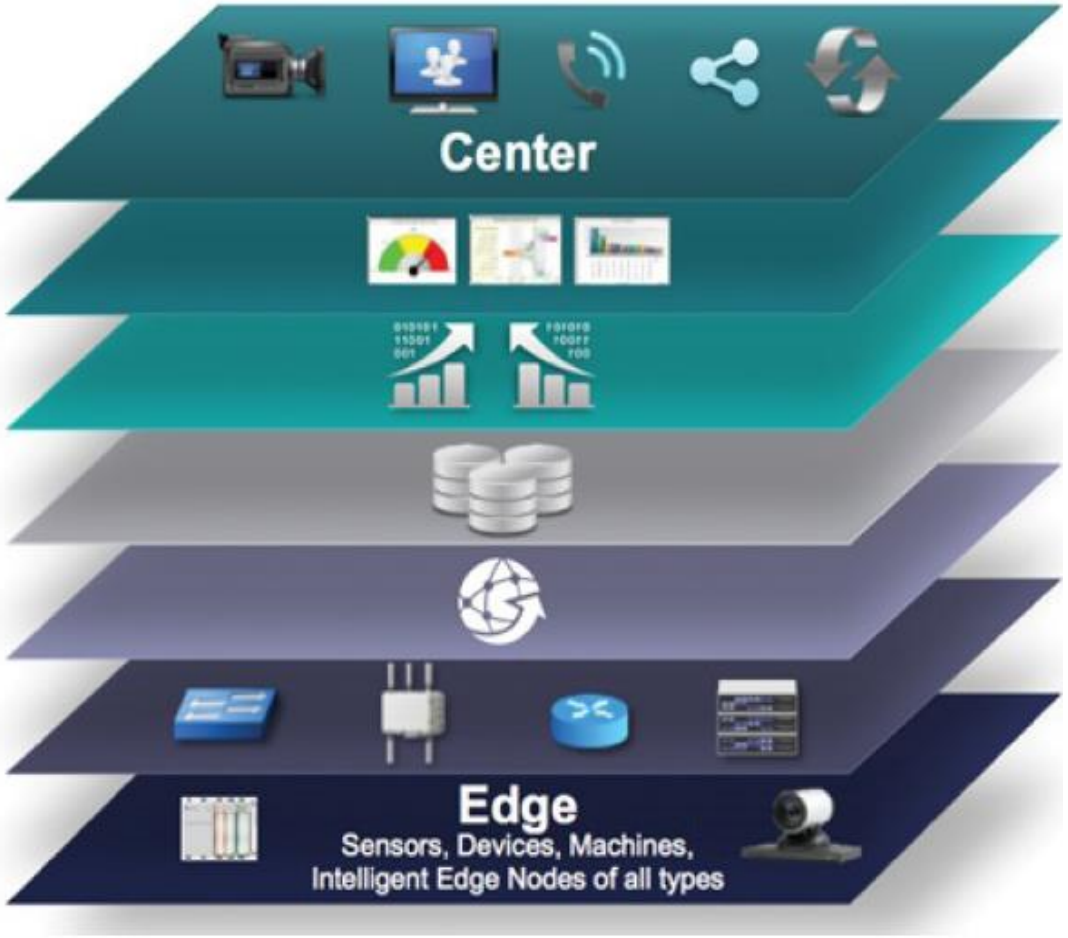
5 **Data Abstraction**
(Aggregation & Access)

4 **Data Accumulation**
(Storage)

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

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

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

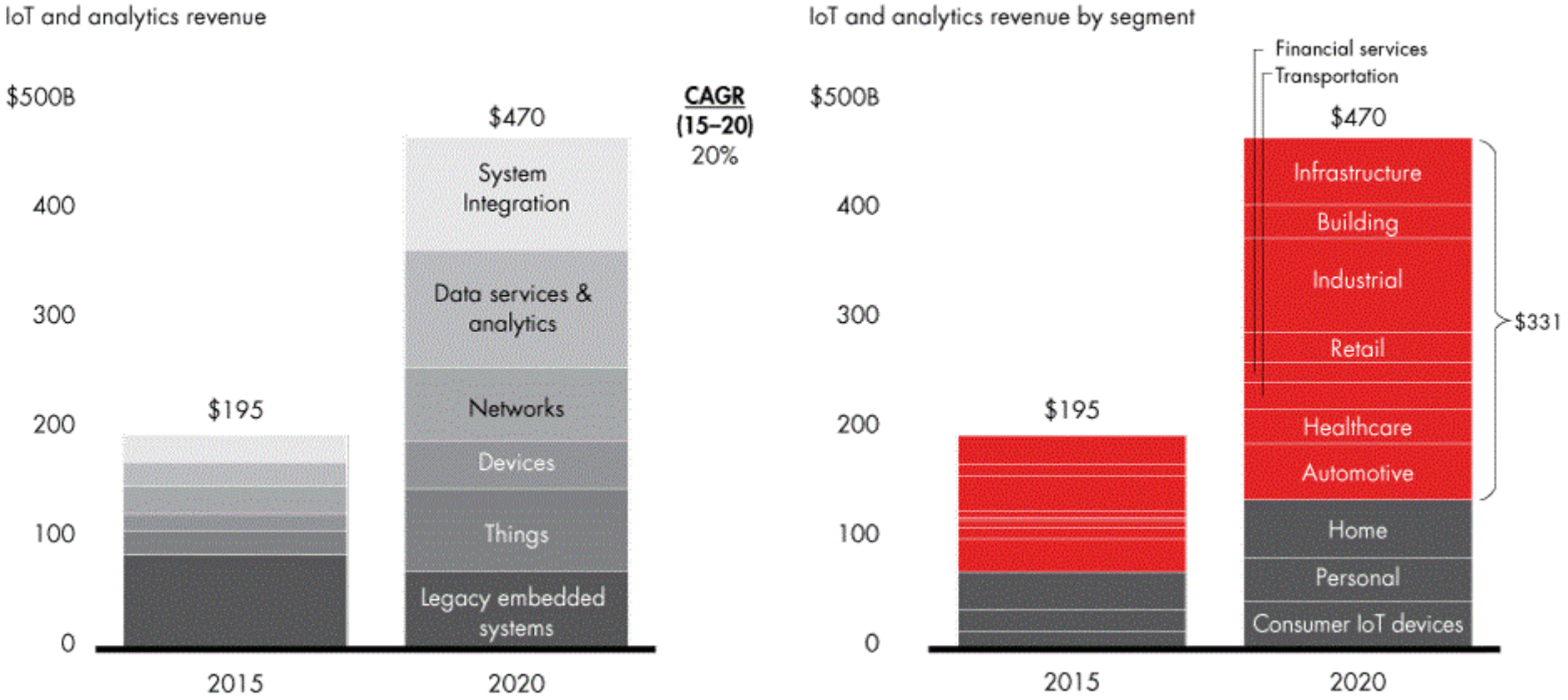


* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Contents

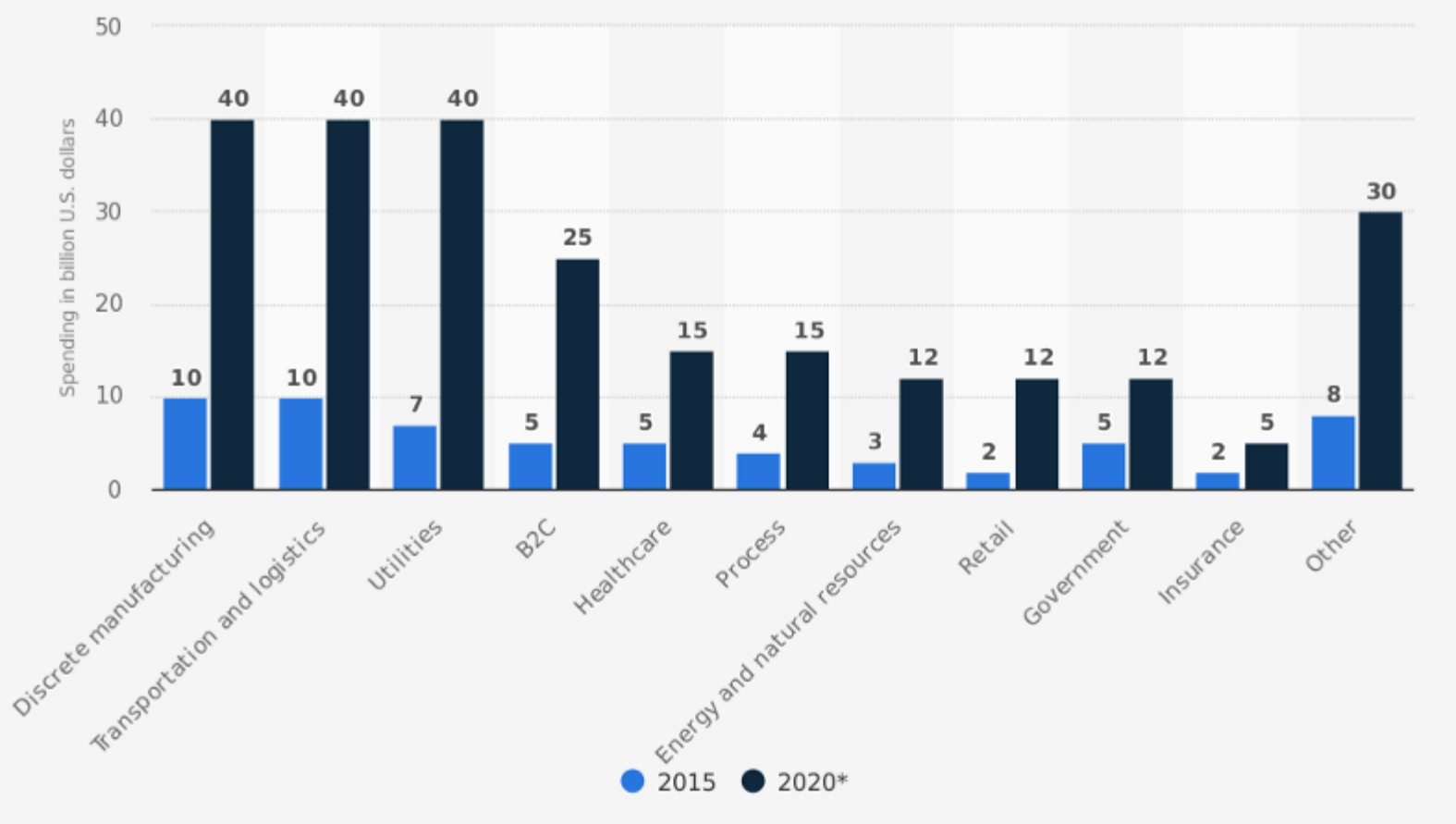
- Basic Concepts and History
- Ecosystem
  - Things
  - Platform
  - Networks
  - Applications and Verticals
- Architecture
- Challenges
- Business and Market Opportunities
- Trends

IoT Business and Market Opportunities



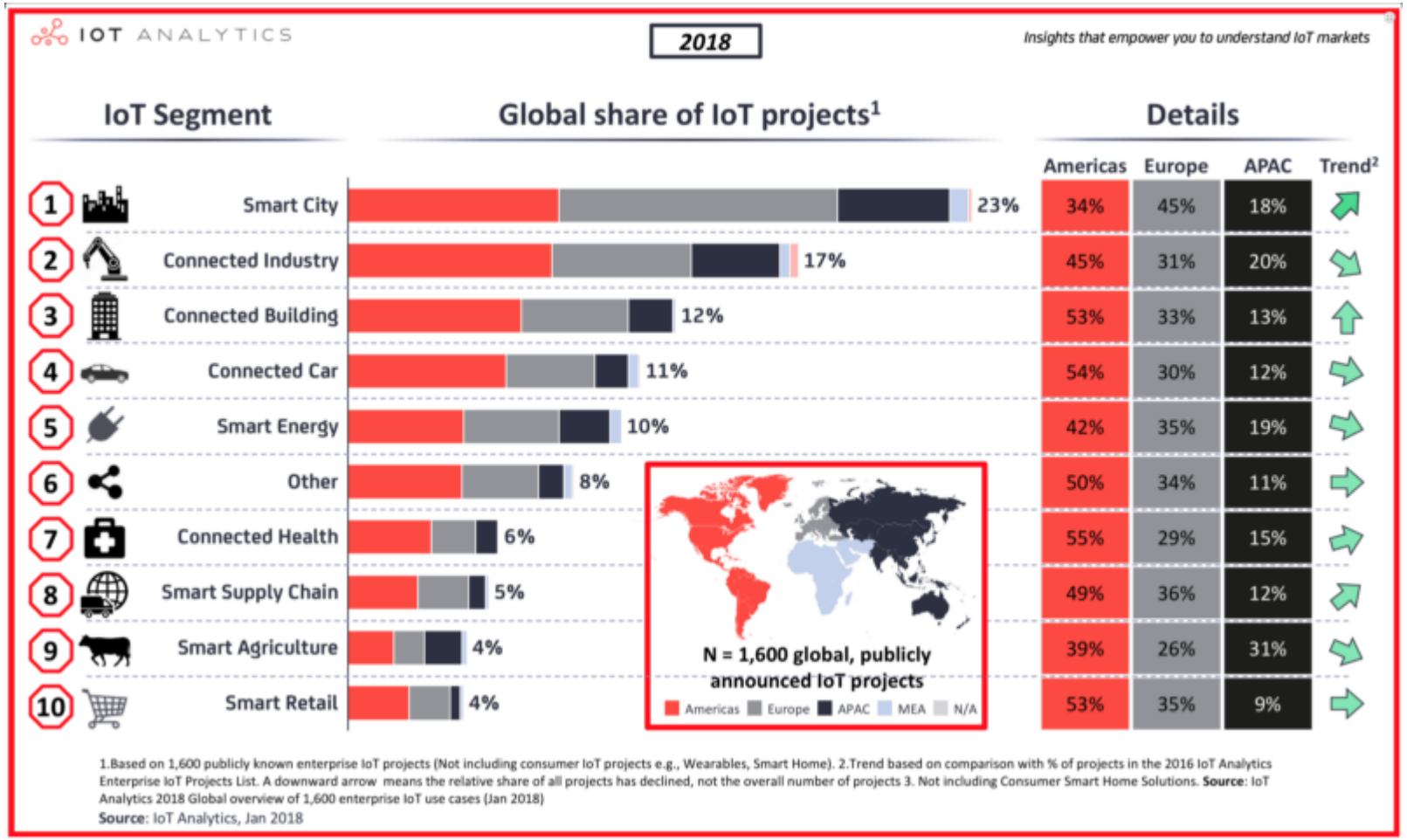
* https://towardsdatascience.com/internet-of-things-booming-15-trillion-market-88fde1da2113

IoT Business and Market Opportunities



* https://discoperi.com/iot_devices_market/

IoT Business and Market Opportunities



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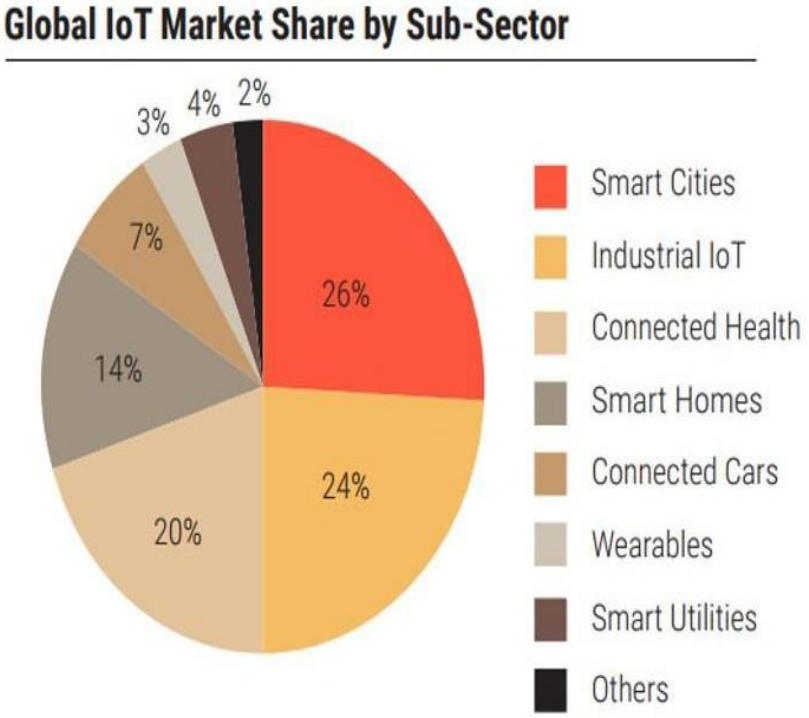
IoT Business and Market Opportunities



* https://dreamziot.com/the-upcoming-iot-market/

IoT- Products

Kasa Smart Wi-Fi LED Bulb with Multicolour
$29.99

Google Nest Learning Thermostat
$249

All-new Echo (3rd Gen)- Smart speaker with Alexa
$89.99

August Smart Lock
$ 220

IoT- Products

Rachio 3, Smart Sprinkler Controller
$229.99

Aladin home, A magic lamp designed for comfort at home
49,50 €/month

MyMDband, Medical Bracelet
$99.99

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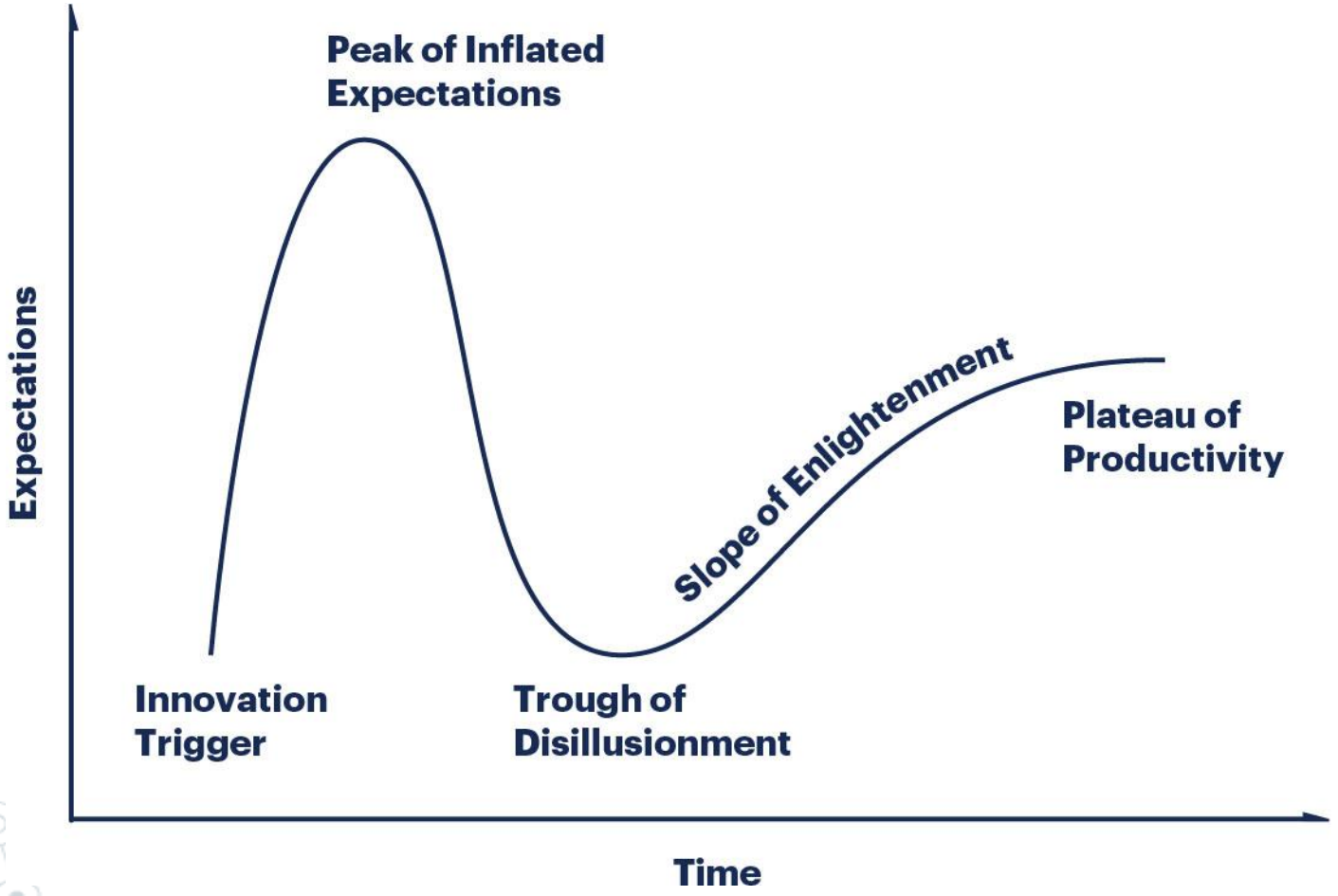
IoT Trends

1. Artificial Intelligence
2. Social, Legal, and Ethical IoT
3. Infonomics and Data Broking
4. The Shift from Intelligent Edge to Intelligent Mesh
5. IoT Governance
6. Sensor Innovation
7. Trusted Hardware and Operating System
8. Novel IoT User Experiences
9. Silicon Chip Innovation
10. New Wireless Networking Technologies for IoT

* https://www.gartner.com/en/newsroom/press-releases/2018-11-07-gartner-identifies-top-10-strategic-iot-technologies-and-trends

IoT Trends



*https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

Hype Cycle: five key phases of a technology's life cycle.

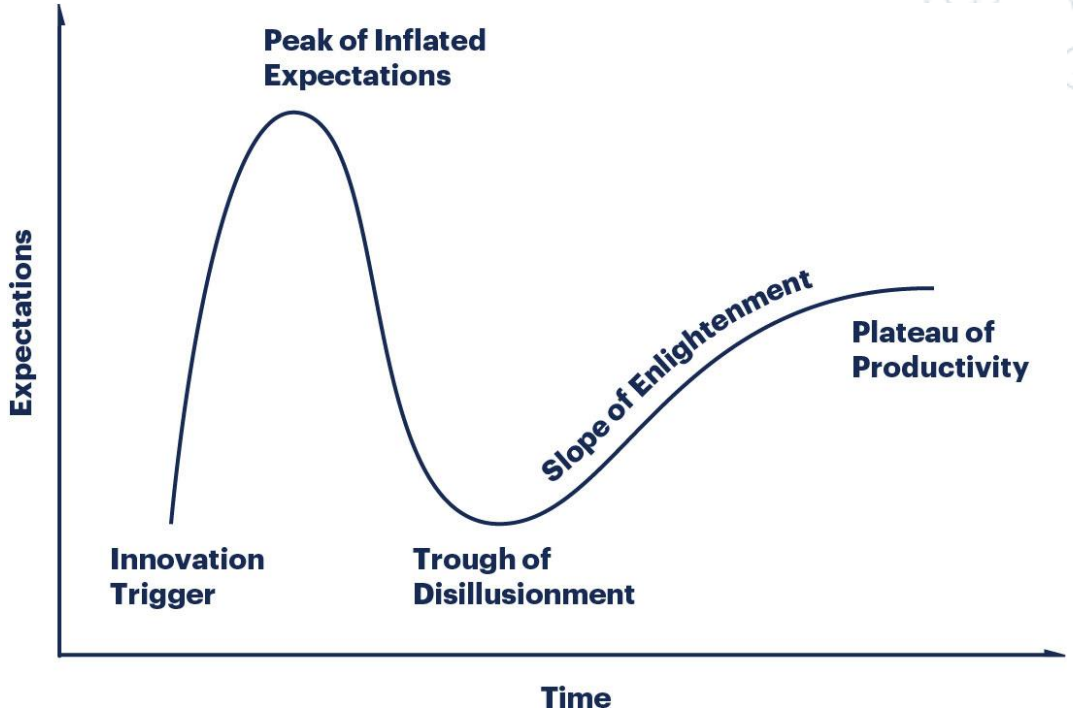
- **Innovation Trigger:** A potential technology breakthrough kicks things off. Early proof-of-concept stories and media interest trigger significant publicity. Often no usable products exist and commercial viability is unproven.

- **Peak of Inflated Expectations:** Early publicity produces a number of success stories — often accompanied by scores of failures. Some companies take action; many do not.

- **Trough of Disillusionment:** Interest wanes as experiments and implementations fail to deliver. Producers of the technology shake out or fail. Investments continue only if the surviving providers improve their products to the satisfaction of early adopters.

- **Slope of Enlightenment:** More instances of how the technology can benefit the enterprise start to crystallize and become more widely understood. Second- and third-generation products appear from technology providers. More enterprises fund pilots; conservative companies remain cautious.

- **Plateau of Productivity:** Mainstream adoption starts to take off. Criteria for assessing provider viability are more clearly defined. The technology's broad market applicability and relevance are clearly paying off.

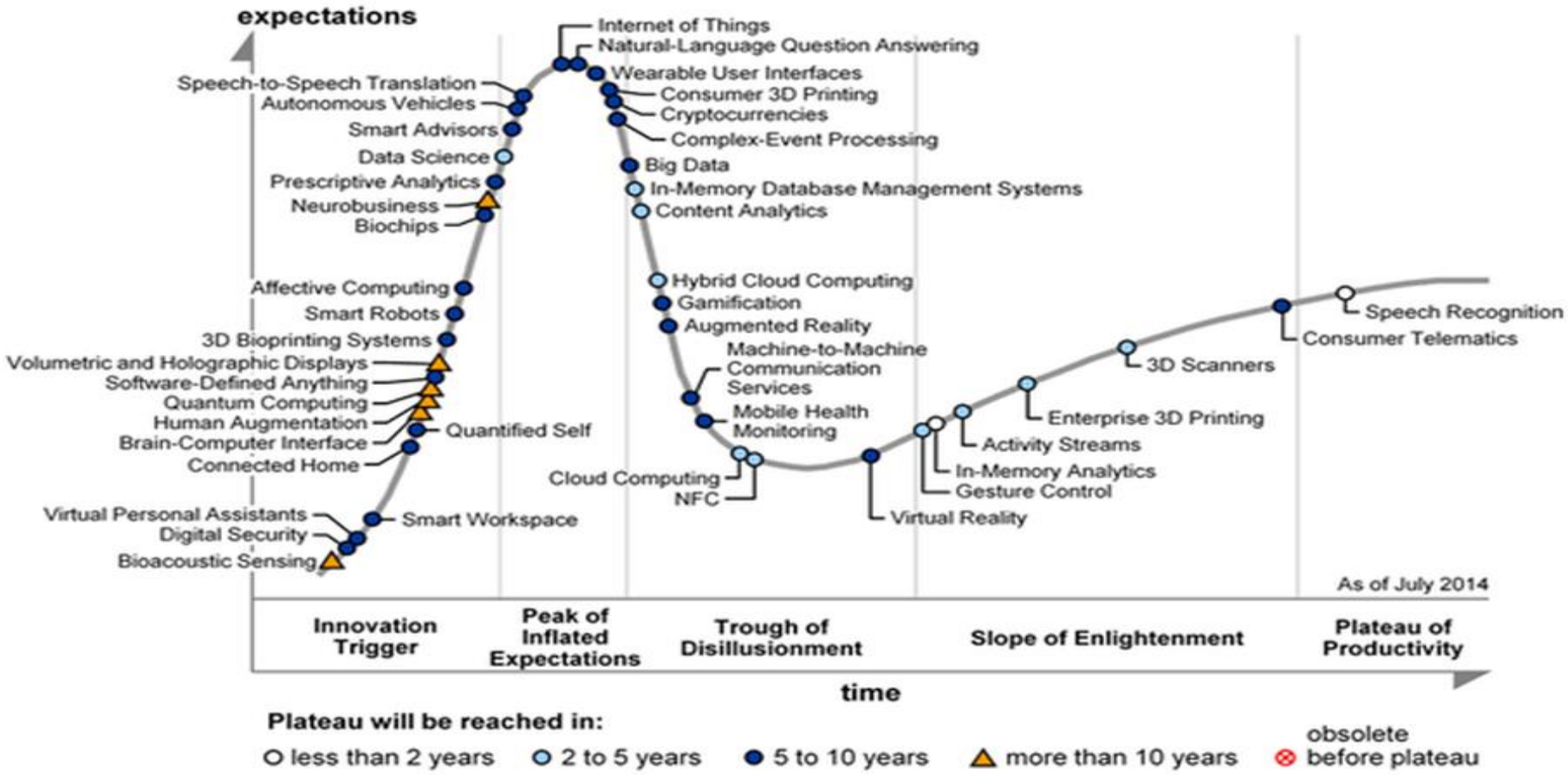


*https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

IoT Trends

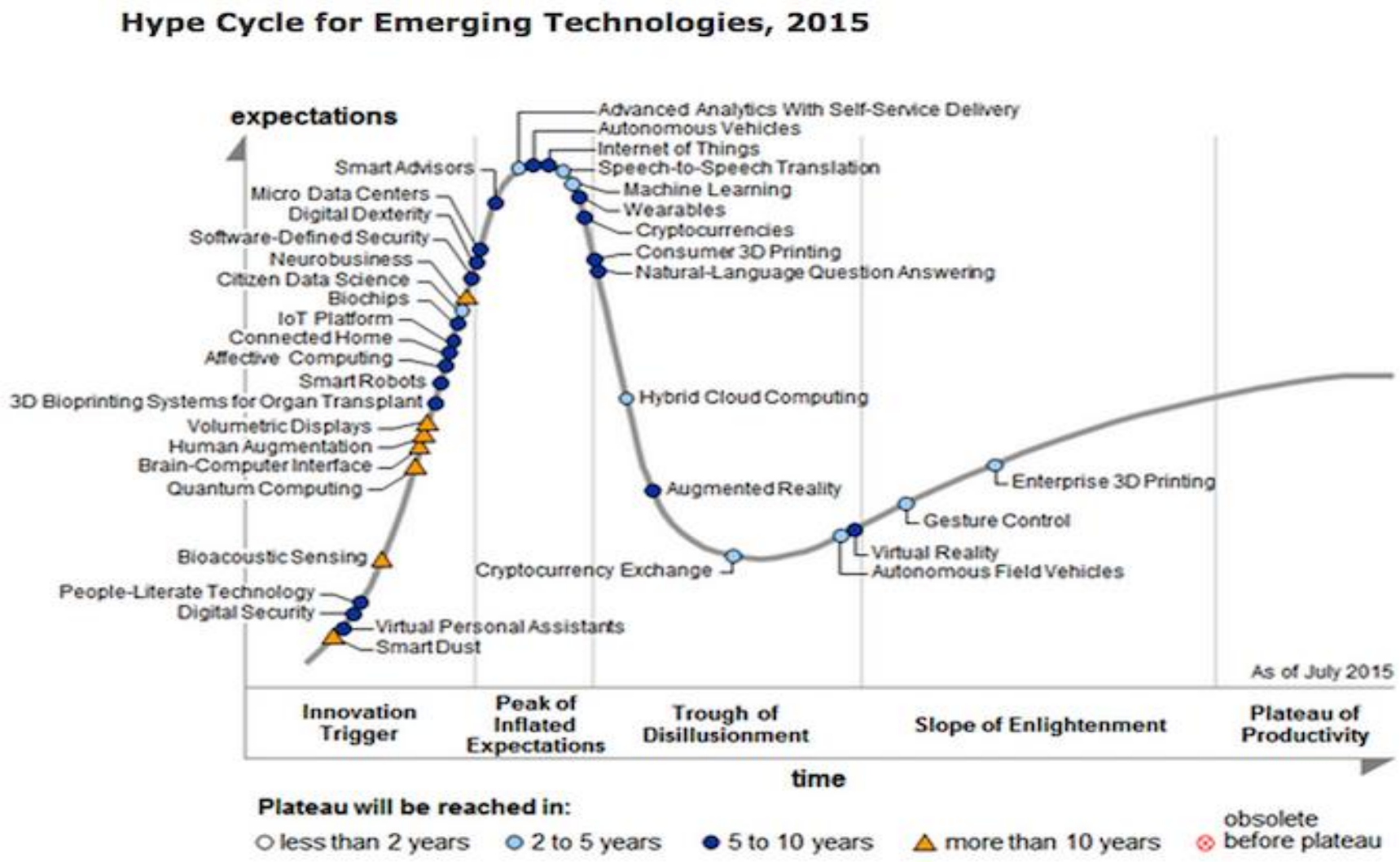
Gartner

Gartner Hype Cycle for Emerging Technologies, 2014



* https://ga...

IoT Trends



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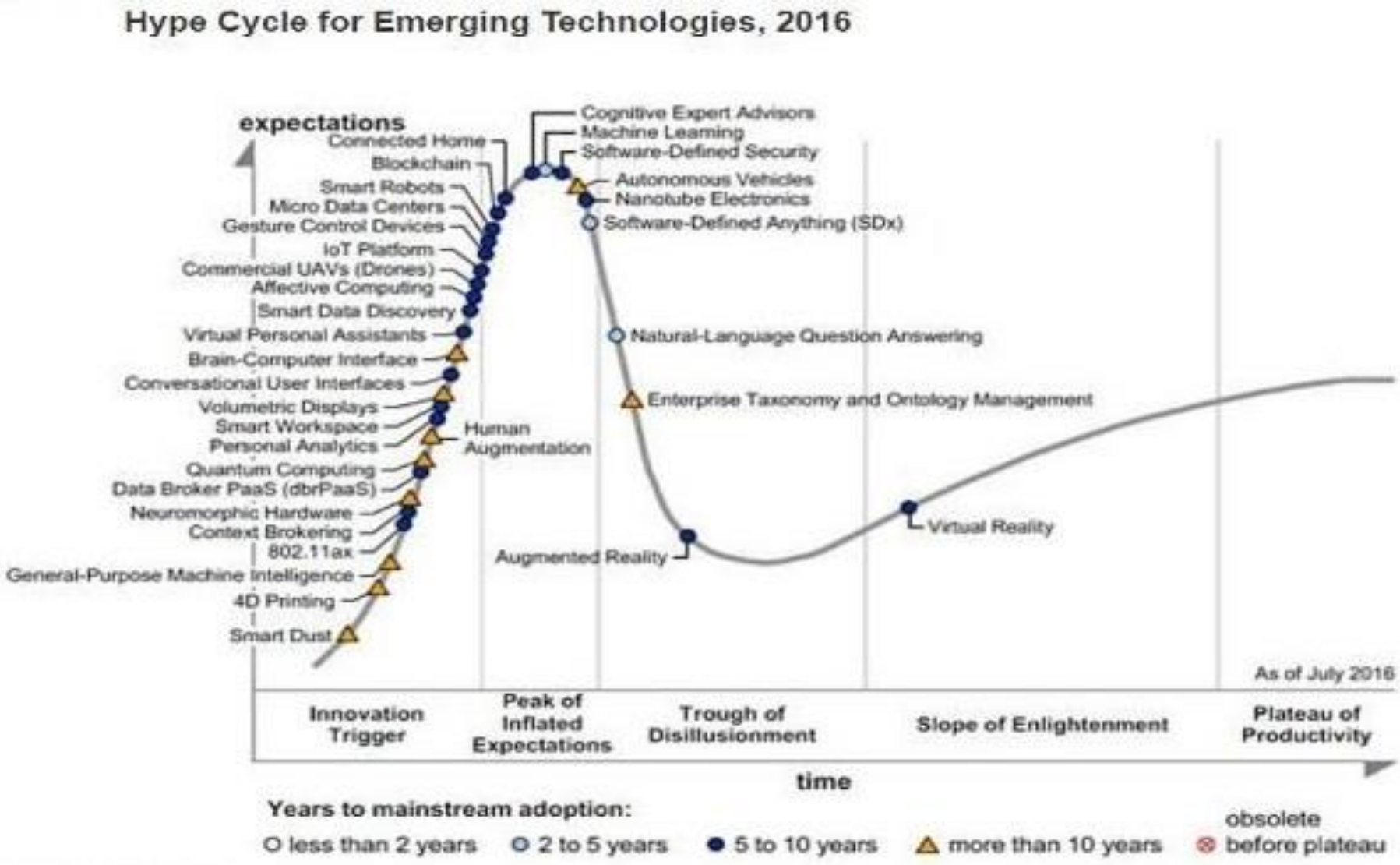
IoT Trends



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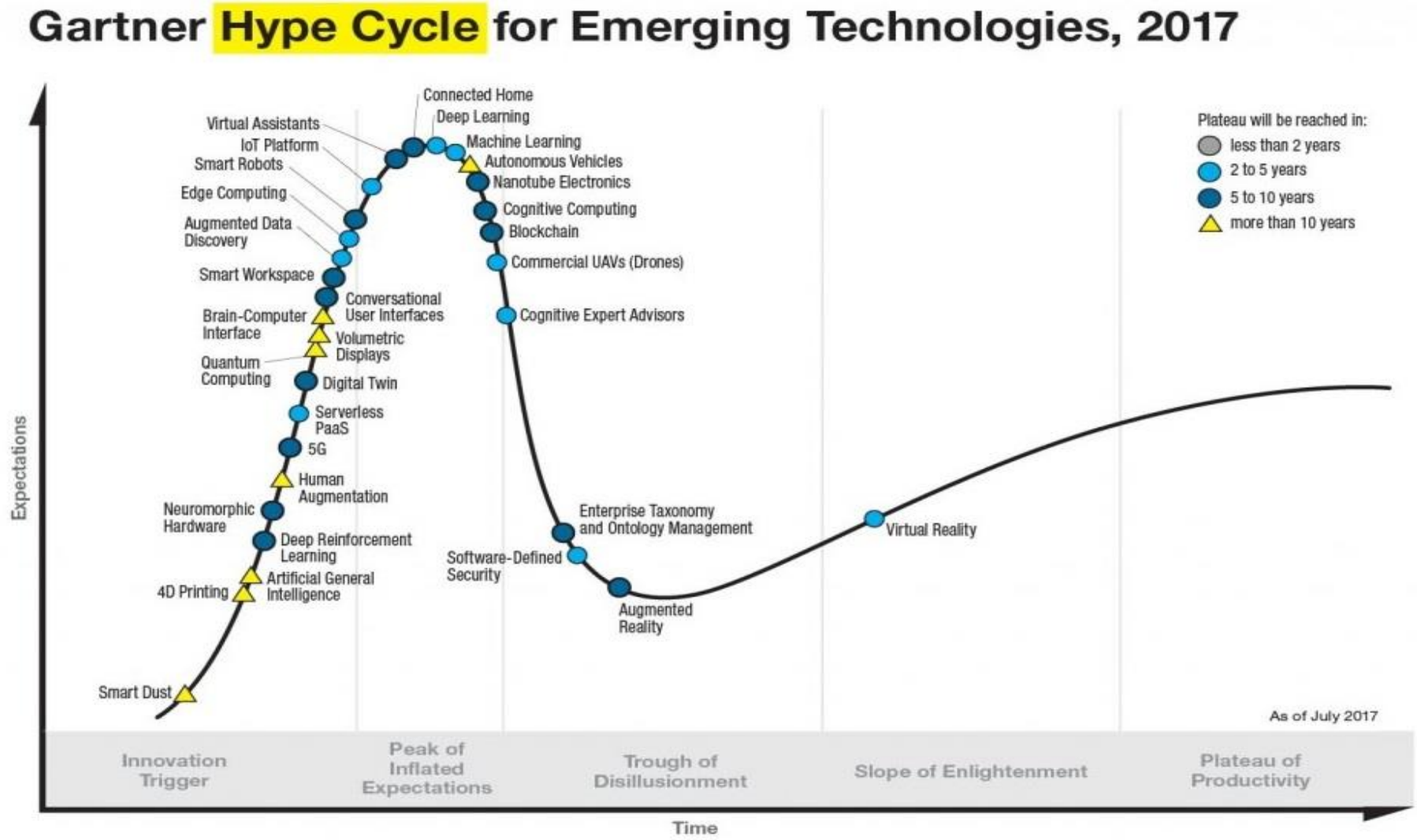

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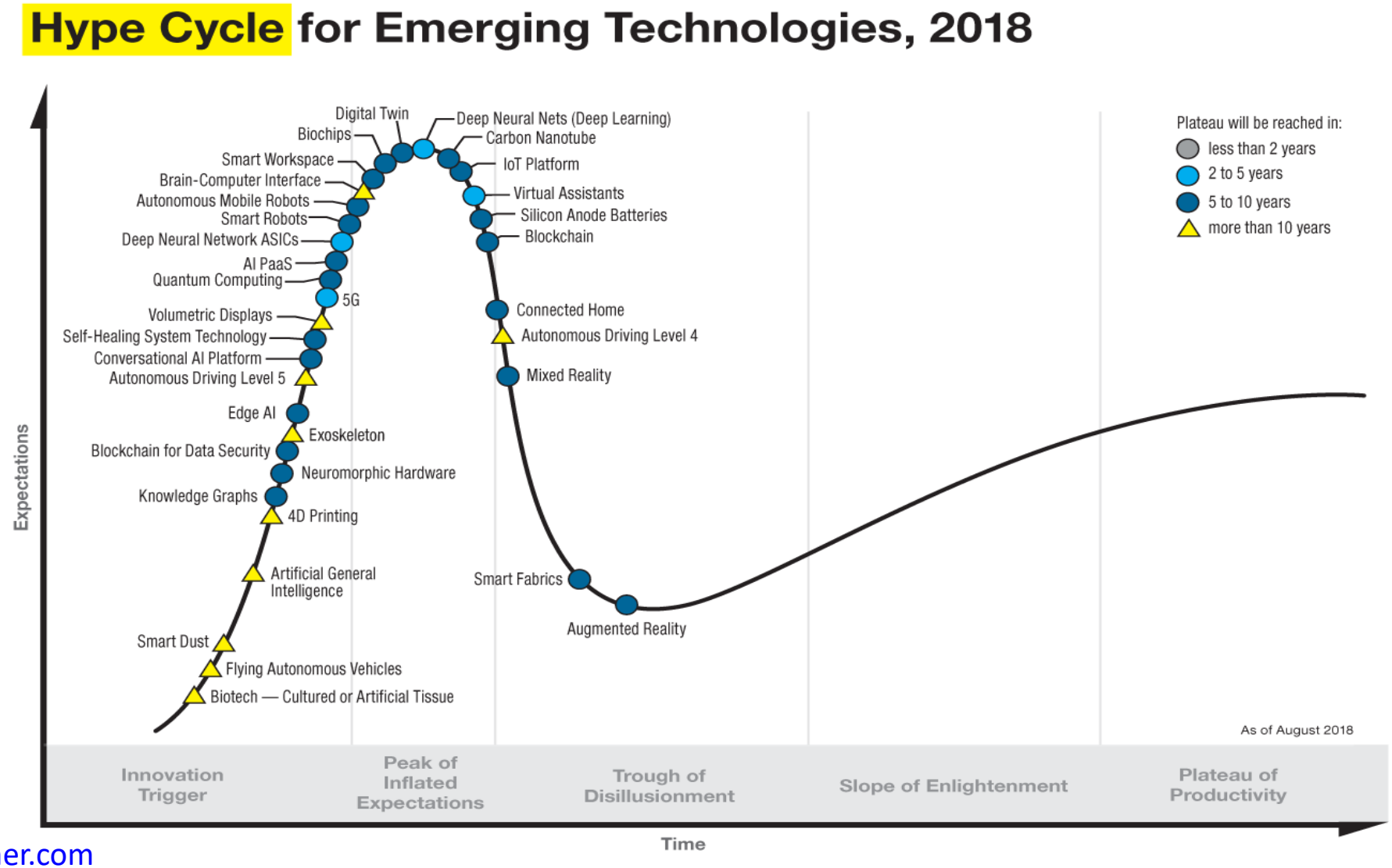

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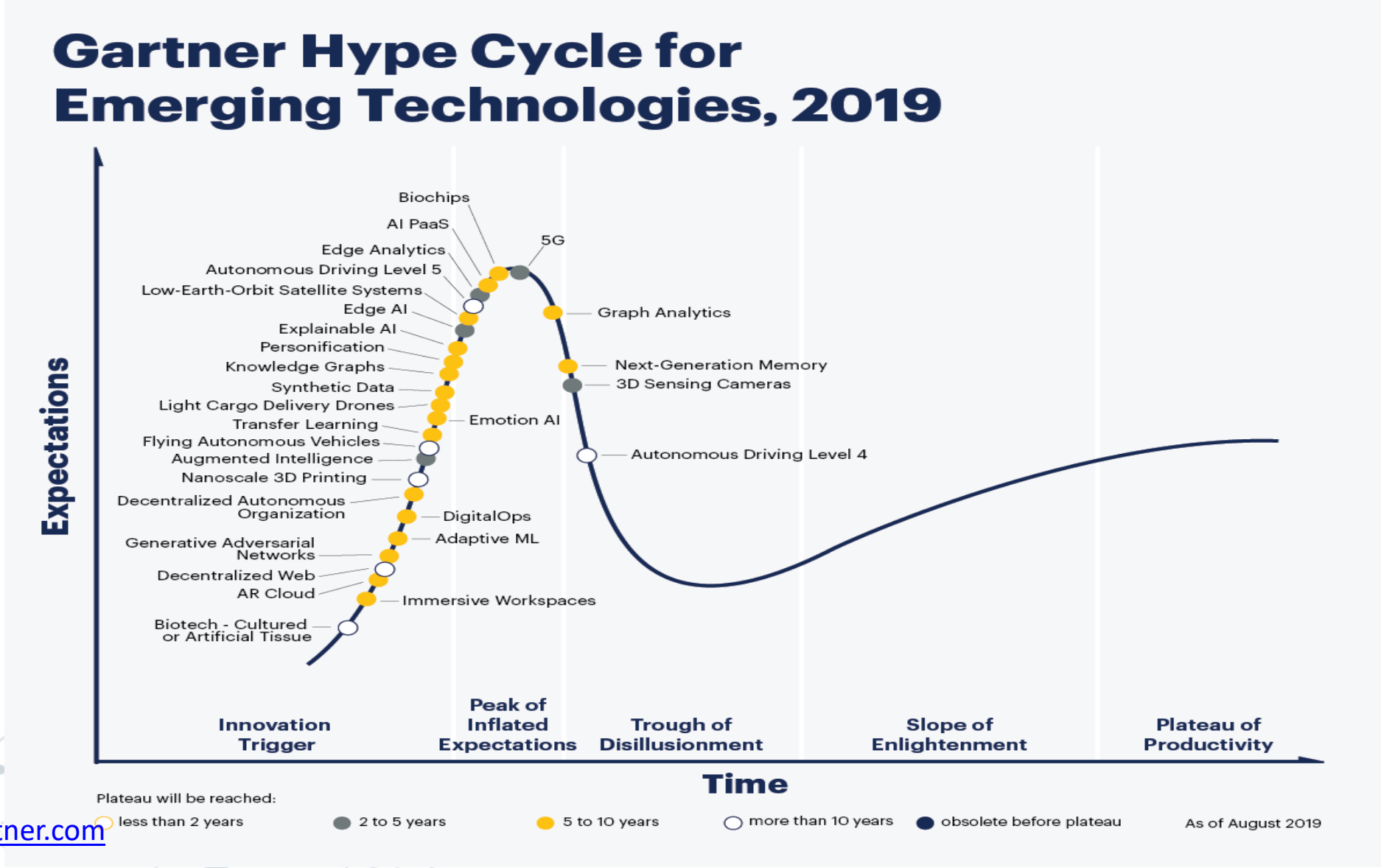

* https://gartner.com

Next Lecture

- An overview of
  - Electronic
  - Microcontrollers
  - Things (sensors and actuators)
  - gateways