Internet of Things and Services

Service-oriented architectures

Internet of Things

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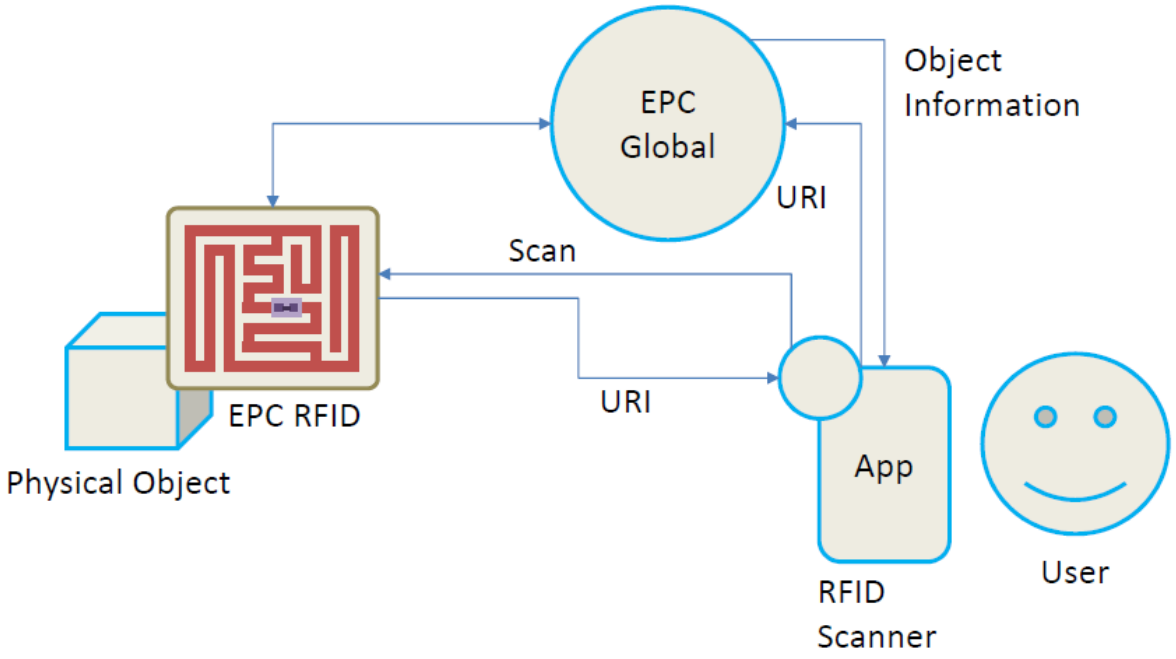
Internet of Things (IoT)

- IoT *allows people and things to be connected*
  - ***Anytime***, ***Anyplace***, *with* ***Anything*** *and* ***Anyone***, *ideally using* ***Any path/network*** *and* ***Any service***
  - European Research Cluster on IoT
    - http://www.internet-of-things-research.eu/

- **Internet of Things (IoT)** is the network of physical objects (devices, vehicles, buildings and other items embedded with microprocessor/memory, software, sensors, actuators, and network connectivity) that enables these objects to collect and exchange data.

History of IoT

- Kevin Ashton, The **Internet of Things** (MIT Auto-ID Center, 1999)
  - RFID (Radio-frequency identification)
  - EPC (Electronic Product Code) Global Network

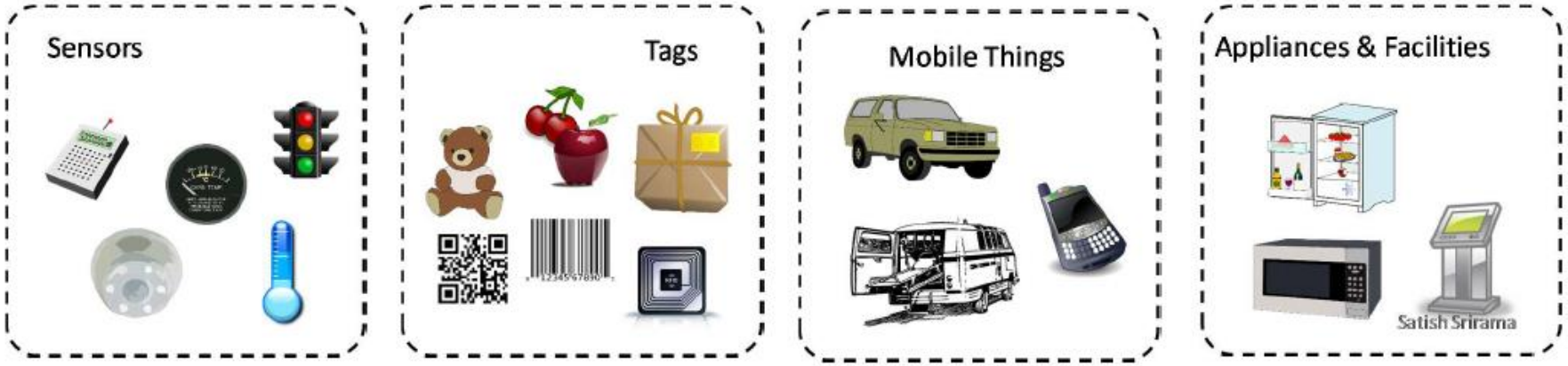


Related terms

- Cyber-Physical Systems (2006-)
  - Coined by National Science Foundation (U.S.)
  - Integrated embedded systems
  - Every physical thing embeds a networked "computer"
- Machine-to-Machine (M2M)
  - The root is much older than IoT (1970s)
  - Technologies to accelerate IoT

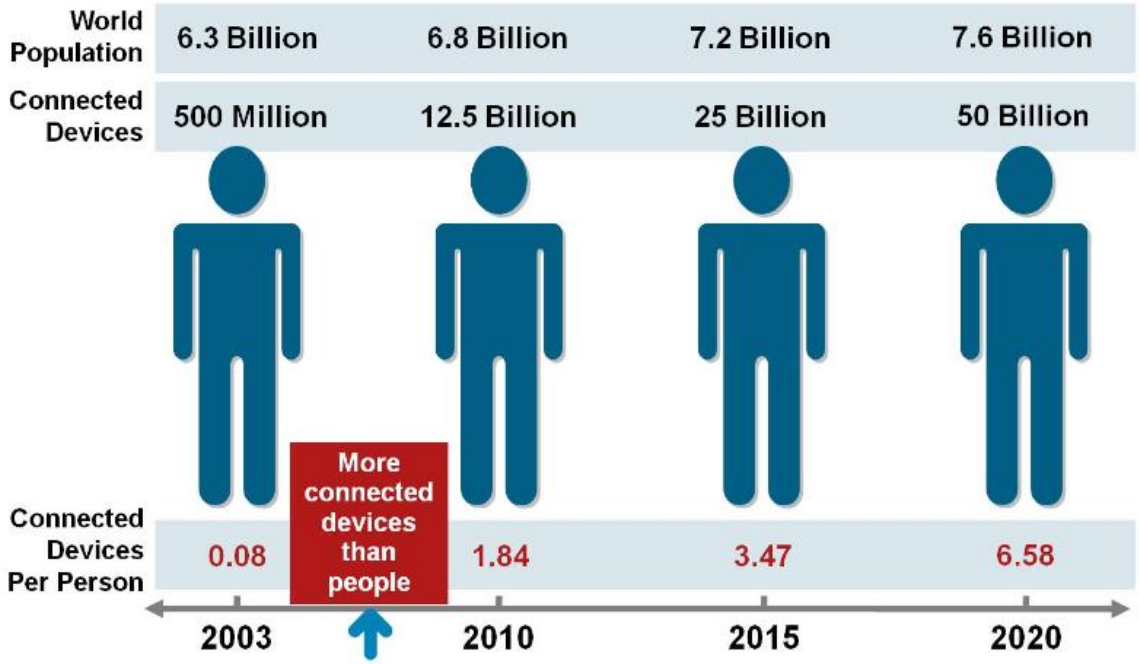
What is a *Thing?*

- Can be a person with a heart monitor implant
- A farm animal with a biochip transponder
- An automobile that has built-in sensors
- Other natural or man-made objects
- With a **unique identifier** and the ability to communicate over the internet, without requiring human interaction



Why IoT is so important?

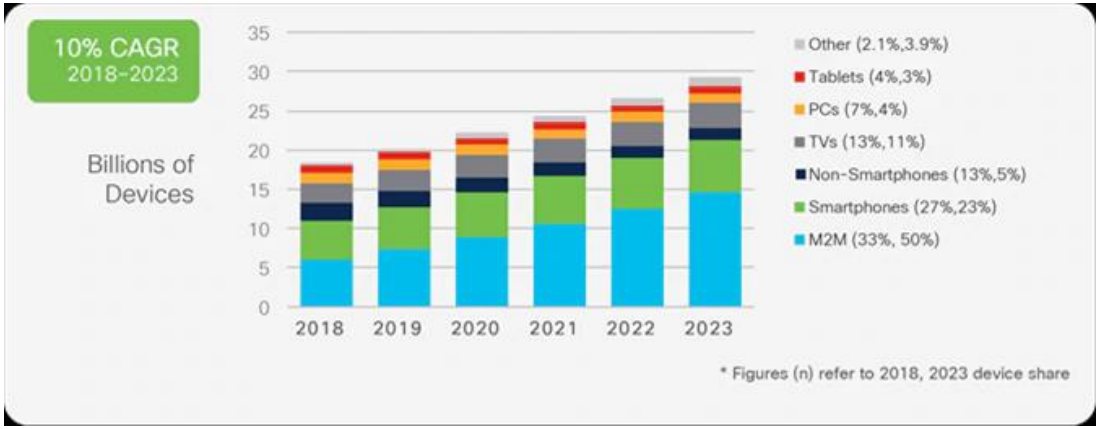
- More connected devices than people
- Recent predictions go up to 500 billion devices by 2030
- Cisco believes the market size will be $19 trillion by 2025



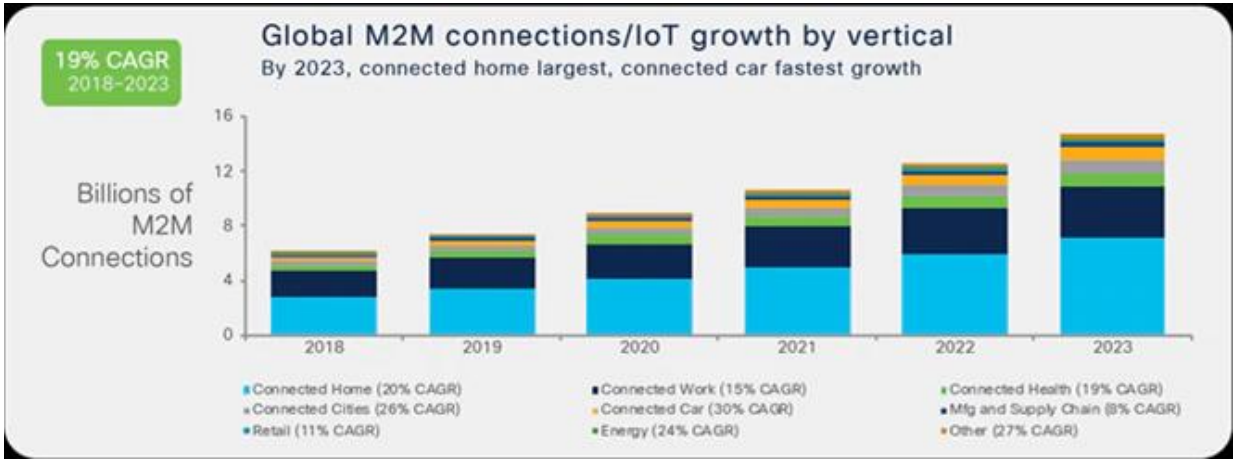
CISCO - The Internet of Things - How the Next Evolution of the Internet Is Changing Everything

Cisco Annual Internet Report (2018–2023)

- Global device and connection growth



- Global M2M connection growth by industries



Internet of Things

Internet of Everything

- The Internet of Everything (IoE) *"is bringing together **people**, **process**, **data**, and **things** to make networked connections more relevant and valuable than ever before-turning information into actions that create new capabilities, richer experiences, and unprecedented economic opportunity for businesses, individuals, and countries.", (Cisco, 2013)*
- IoE is **the intelligent connection of people, process, data and things.**
  - The Internet of Everything (IoE) describes a world where billions of objects have sensors to detect measure and assess their status; all connected over public or private networks using standard and proprietary protocols

IoT vs IoE

- The Internet of Things (IoT) is the network of physical objects accessed through the Internet.
  - These objects contain embedded technology to interact with internal states or the external environment.
  - In other words, when objects can sense and communicate, it changes how and where decisions are made, and who makes them.
- The Internet of Everything (IoE) with four pillars: people, process, data, and things builds on top of The Internet of Things (IoT) with one pillar: things.
  - In addition, IoE further advances the power of the Internet to improve business and industry outcomes, and ultimately make people's lives better by adding to the progress of IoT. (*Dave Evans, Chief Futurist Cisco Consulting Services).*

Pillars of IoE

- **People**: Connecting people in more relevant, valuable ways.
- **Data:** Converting data into intelligence to make better decisions.
- **Process:** Delivering the right information to the right person (or machine) at the right time.
- **Things:** Physical devices and objects connected to the Internet and each other for intelligent decision making; often called *Internet of Things (IoT).*

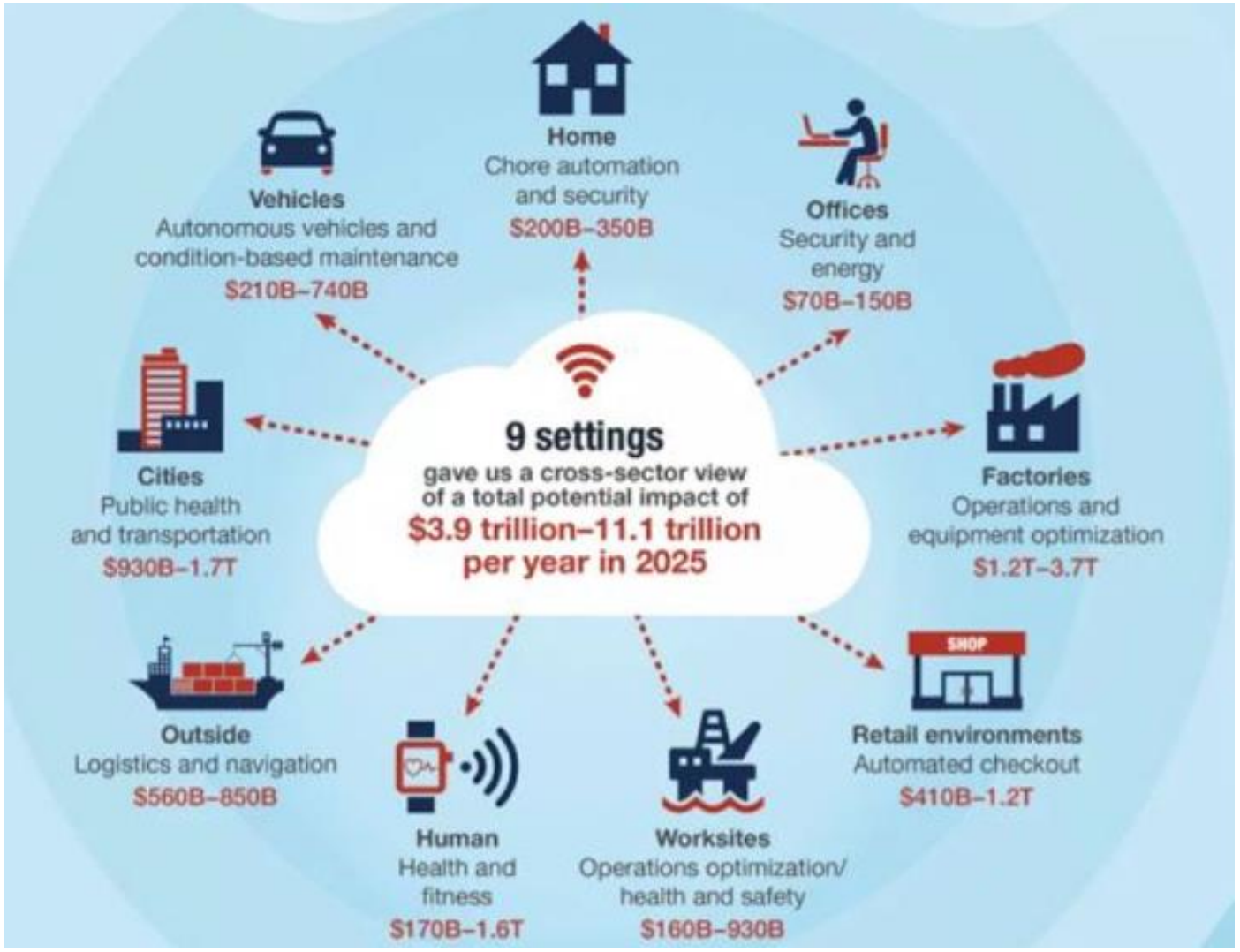
Internet of Everything

- The Internet of Everything will create tens of millions of new objects and sensors, all generating real-time data.
  - "**Data is money**," - Nick Jones, research vice president and distinguished analyst at Gartner.
  - "Businesses will need **Big Data** and **storage technologies** to collect, analyze and store the sheer volume of information. Furthermore, to turn data into money business and IT leaders will need decisions. As they won't have the time or the capacity to make all the decisions themselves they will need processing power."
- But as devices get more connected and collect more data, **privacy** and **security** concerns will increase too.
  - How companies decide to balance customer privacy with this wealth of IoE data will be critical.

IoT applications

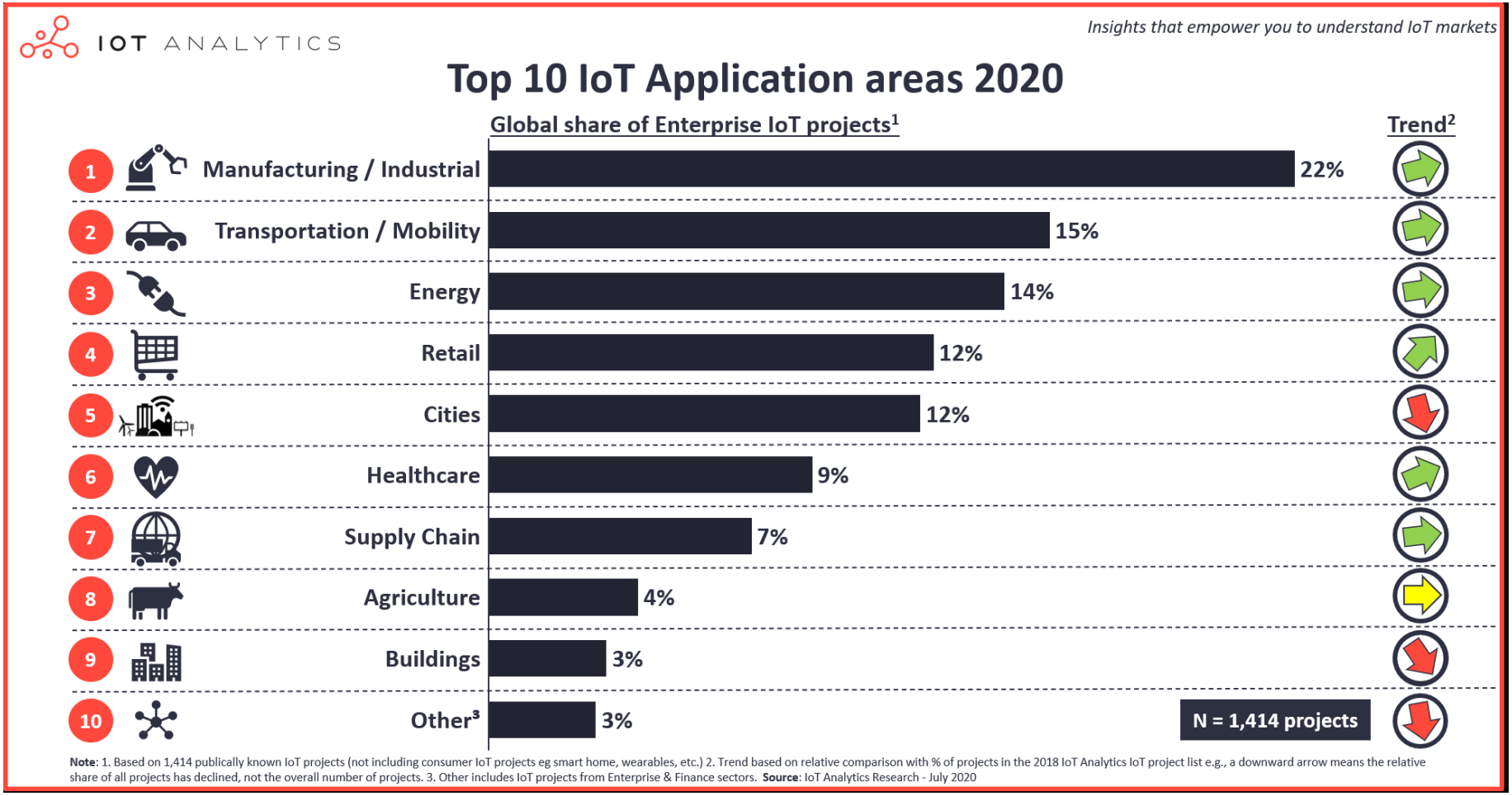
- Smart Home
- Smart Factory
- Smart City
- Smart Vehicles
- Smart Healthcare
- Smart Agriculture/ Farming
- Smart Environment
- Smart Utilities/Grid
- …

Endless opportunities for IoT



Source: McKinsey & Co

IoT applications

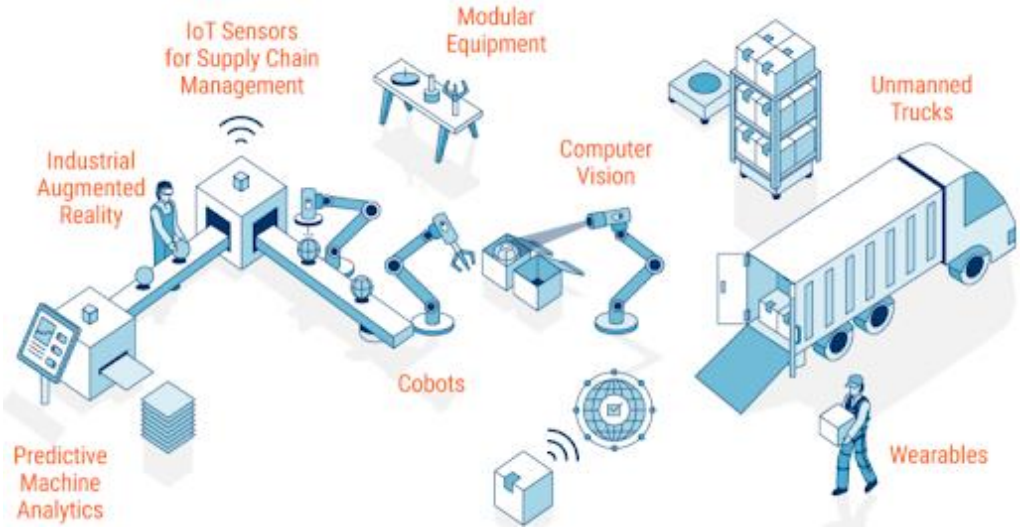


Smart Home

- Connected radiator/heater
- Connected air conditioner
- Connected camera
- Connected door
- Connected window
- Connected microwave
- Connected refrigerator
- Connected water boiler

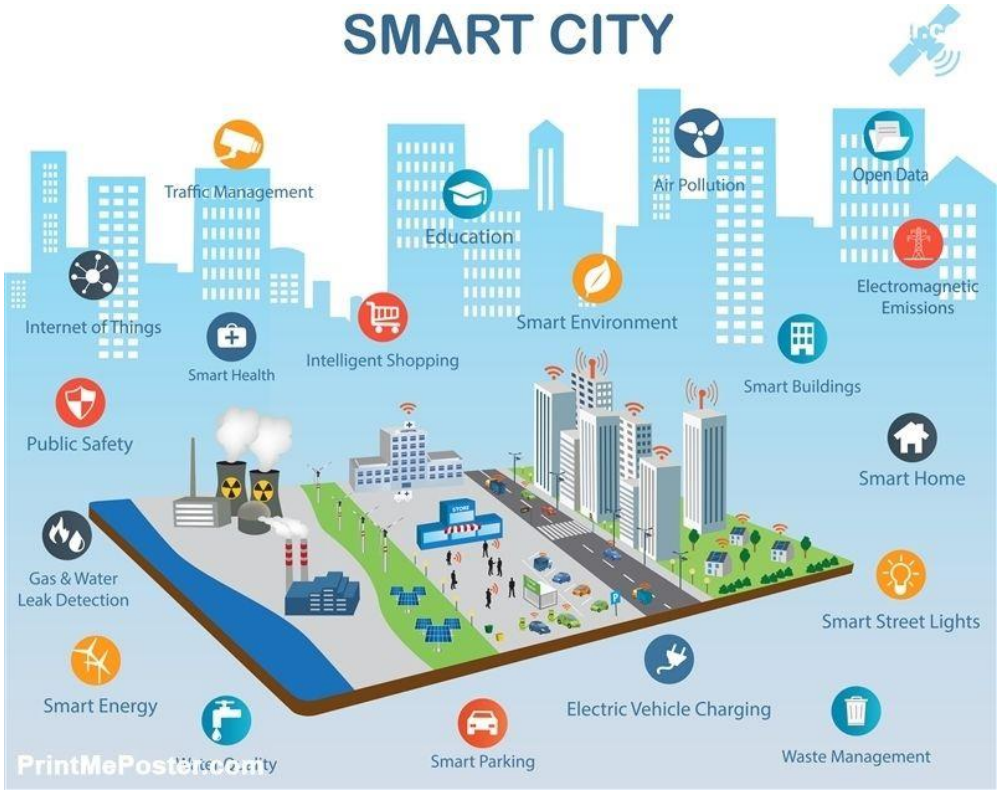
Smart Factory (Industry 4.0)

- Connected production line
- Connected warehouse
- Connected shipment and logistics
- Federated resource database
  - Knowing which manufacturer has parts in stock
  - Knowing how long it takes to import the parts
  - Knowing shipping time
- Predictive production & maintenance
  - Digital Twins



Smart City

- Connected government
- Connected utility
  - e.g. water, electricity, petrol, natural gas etc.
- Connected traffic control system
  - Smart traffic signals (auto-change based on traffic situation)
  - Communicable with smart vehicles
- Connected facility
- Connected public transportation and stations
  - Public security and safety control
  - Assisted travelling (personalized notification)
  - Bike sharing

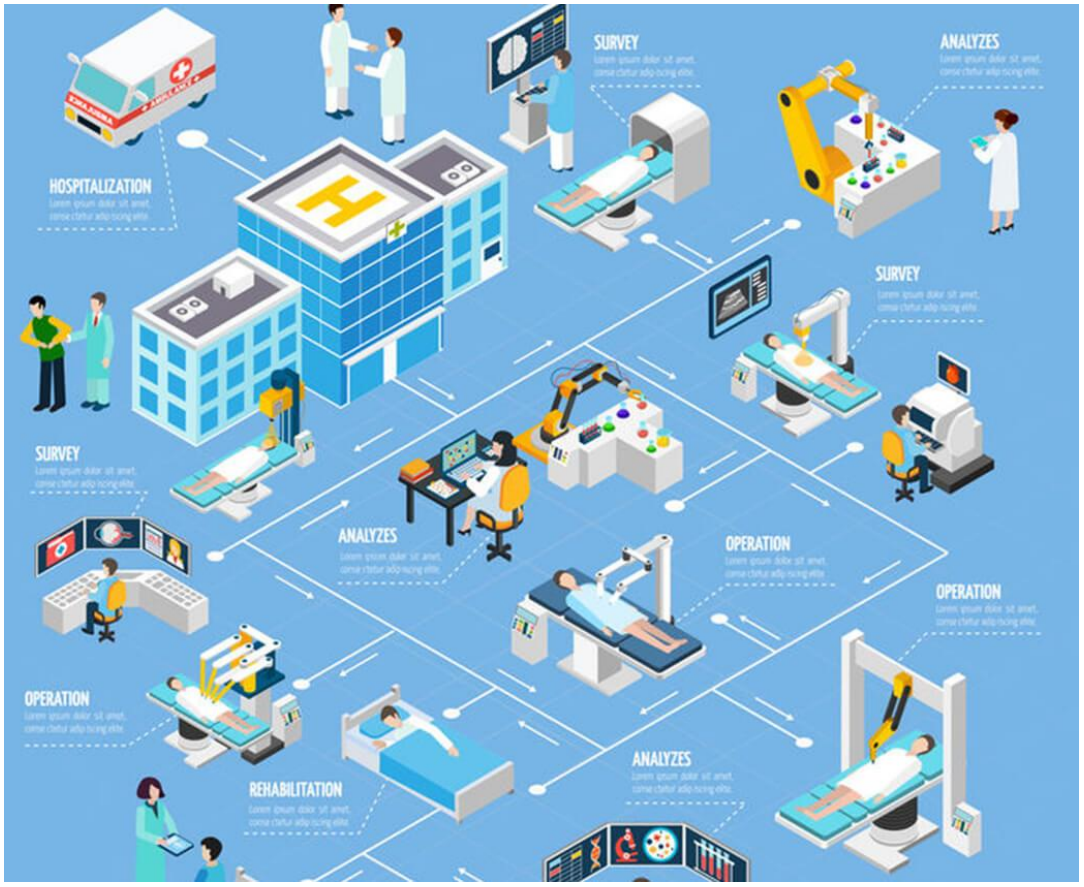


Smart Vehicles

- Connecting to manufacturer
  - Tracing conditions
  - Predicting states
  - Maintenance notification
- Connecting to Road-Side Units (RSUs)
  - Petrol/electricity stations
  - General services
  - Traffic system
- Connecting to proximal vehicles
  - Vehicle-to-Vehicle (V2V) network
  - Self- / assisted driving

Smart Healthcare

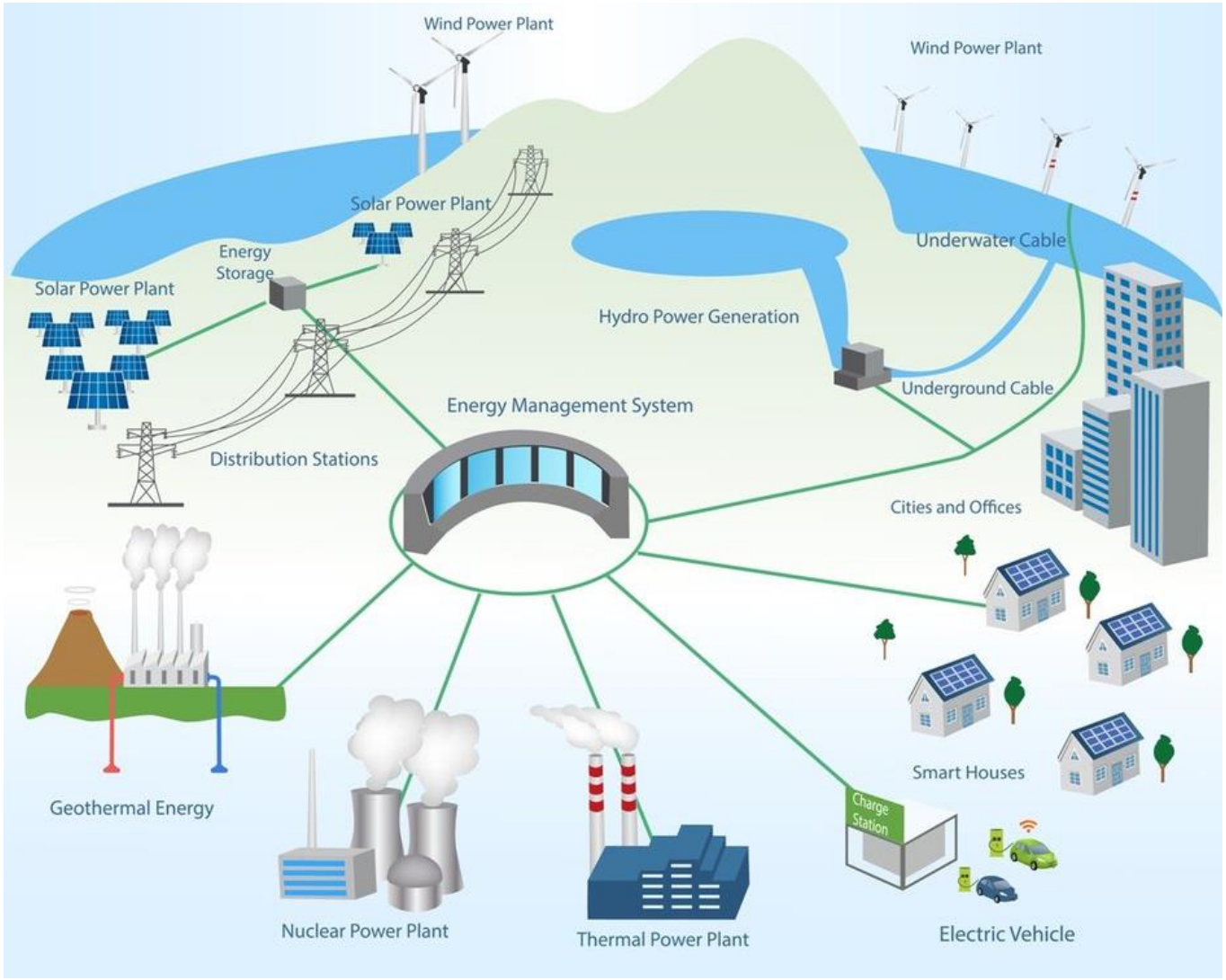
- Connected medicine
- Body sensor network
- Healthcare robot
- Healthcare-specific smart home
- Home-Hospital system



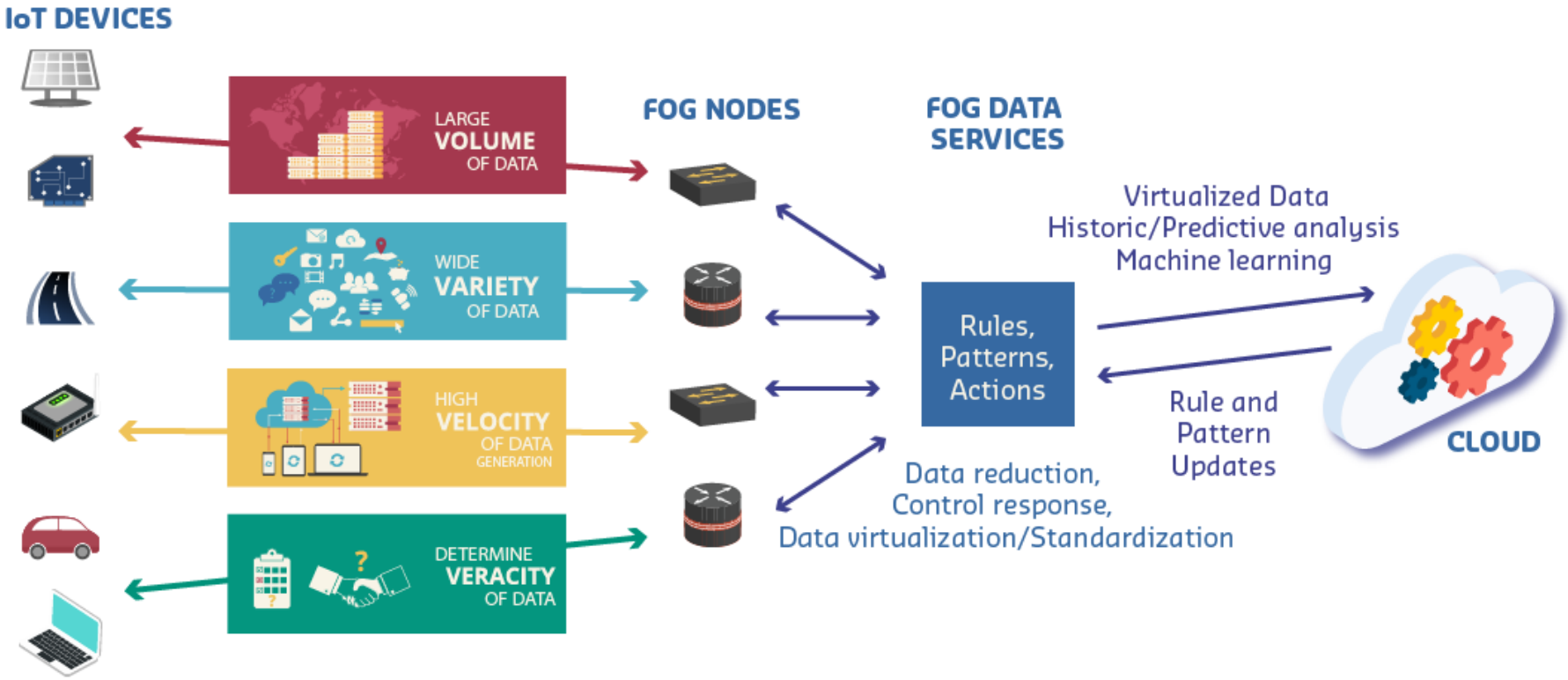
Smart Agriculture/Farming

- Connected Plants
- Connected Animals
- Connected Barn
- Connected Agricultural equipment
- Connected Packing and shipping
- Smart Monitoring/ control/planning

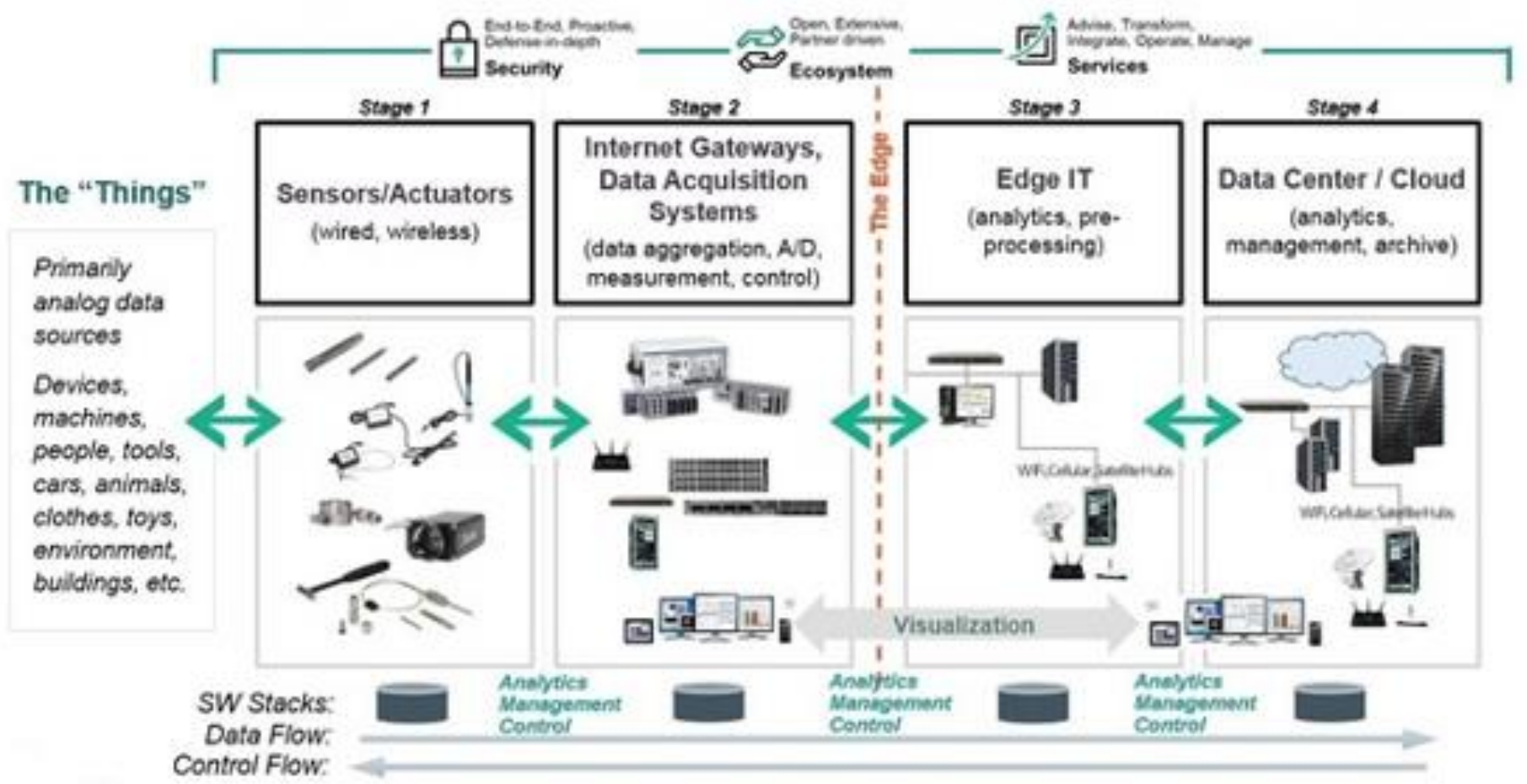
Smart Grid


Wind Power Plant
Wind Power Plant
Solar Power Plant
Energy Storage
Solar Power Plant
Underwater Cable
Hydro Power Generation
Underground Cable
Energy Management System
Distribution Stations
Cities and Offices
Smart Houses
Charge Station
Geothermal Energy
Nuclear Power Plant
Thermal Power Plant
Electric Vehicle

General IoT architecture

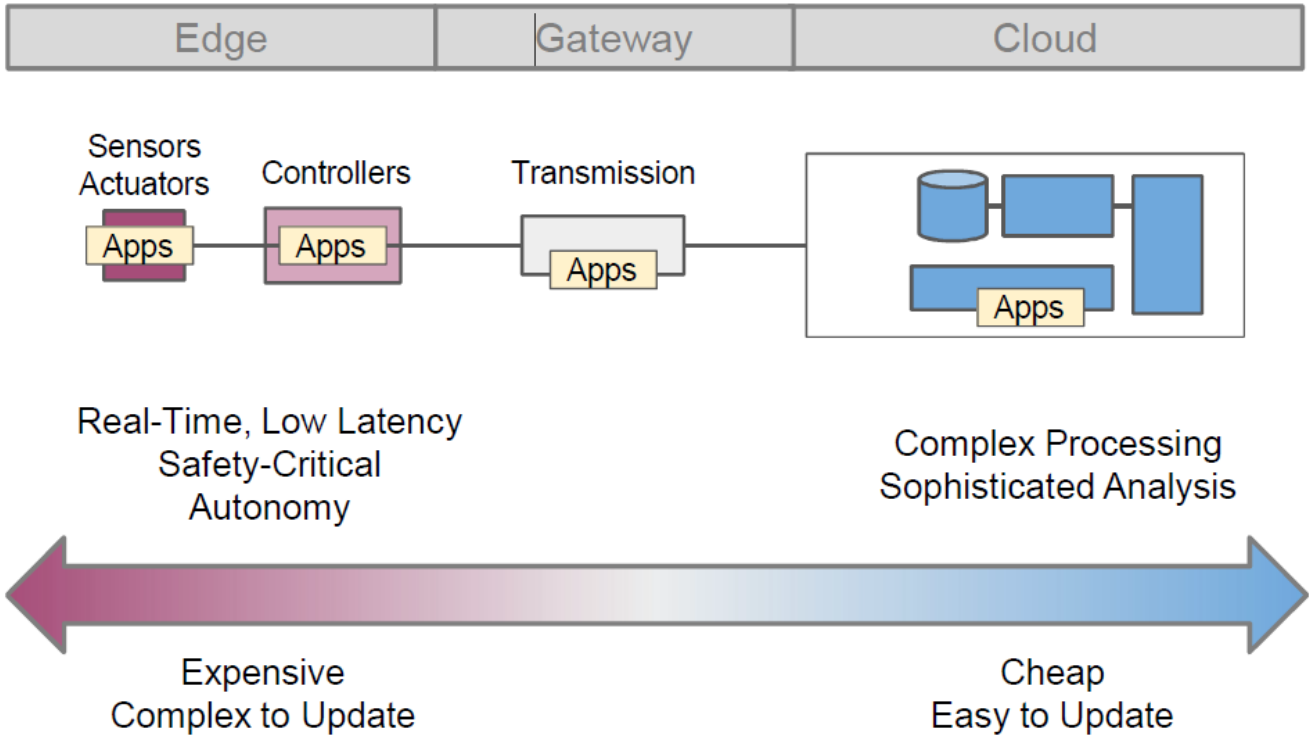


IoT architecture



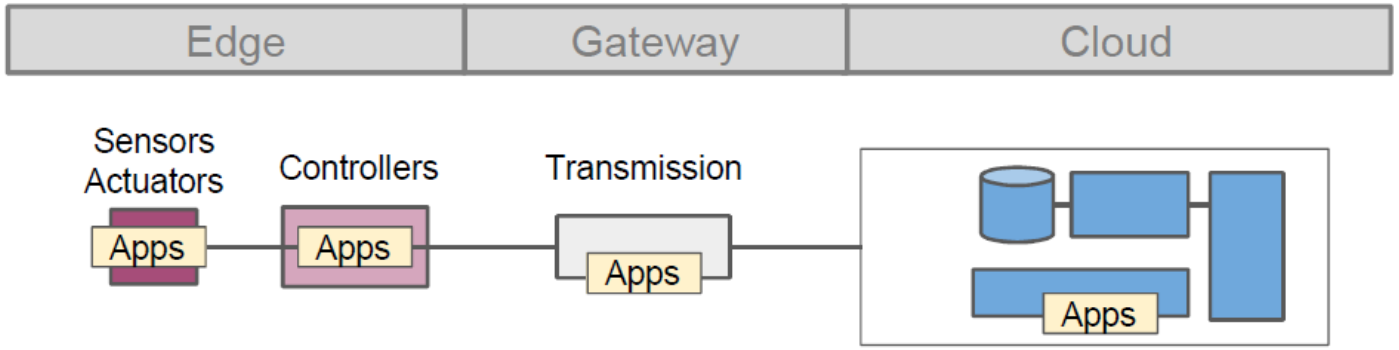
IoT application components

- Trade-offs in allocating IoT application components
  - Microservices, event-driven, reactive



IoT microservices

- A modular architecture of independently deployable units, microservices, enables and supports shifting application logic along the continuum
- Virtualization and containerization help achieving the desired deployment flexibility.
  - Vision: build once, deploy anywhere
- Yet flexible app deployability is often limited by different run-time platforms and architectures from edge to cloud



IoT Reference Model

- CISCO IoT Reference Model consists of 7 levels

Levels

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

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

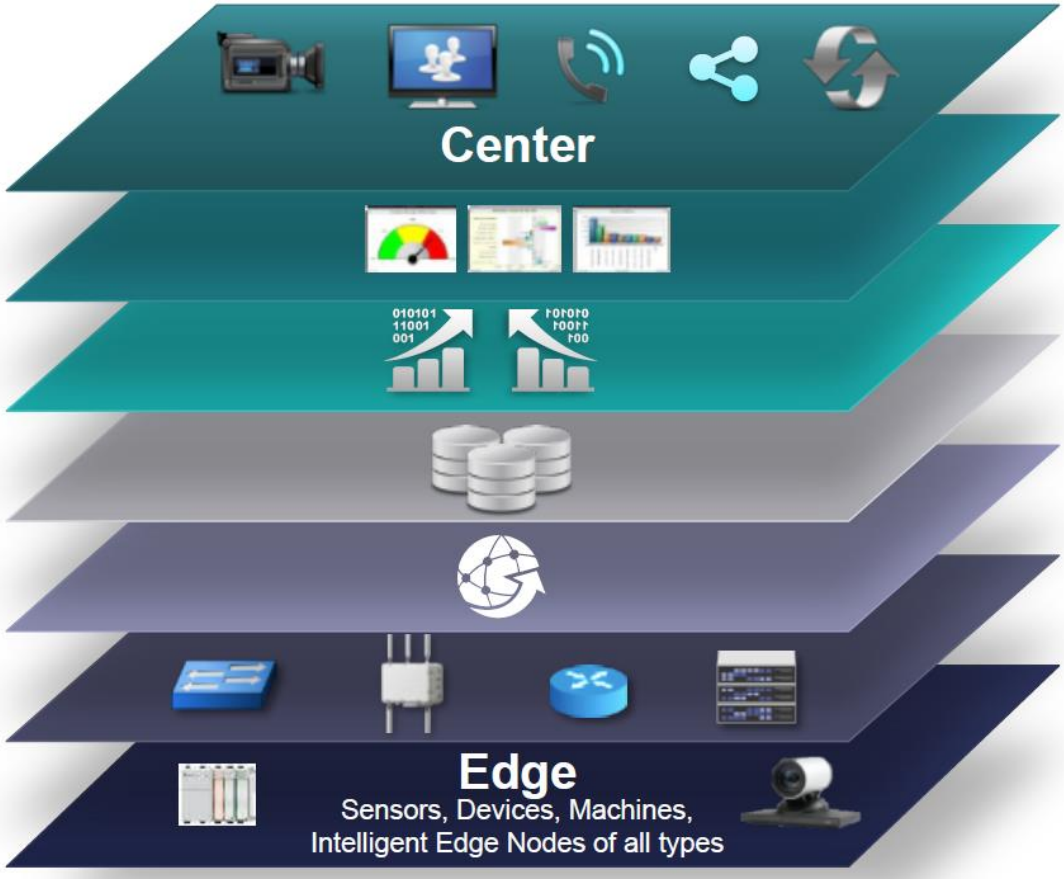
5 **Data Abstraction**
(Aggregation & Access)

4 **Data Accumulation**
(Storage)

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

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

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



Level 1: Physical Devices and Controllers

- These are the "things" in the IoT, and they include a wide range of endpoint devices that send and receive data

Level 2: Connectivity

- Communications and connectivity are concentrated in this level. The most important function of Level 2 is reliable, timely information transmission, that includes transmissions:
  - Between devices (Level 1) and the network
  - Across networks (east-west)
  - Between the network (Level 2) and low-level information processing occurring at Level 3

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

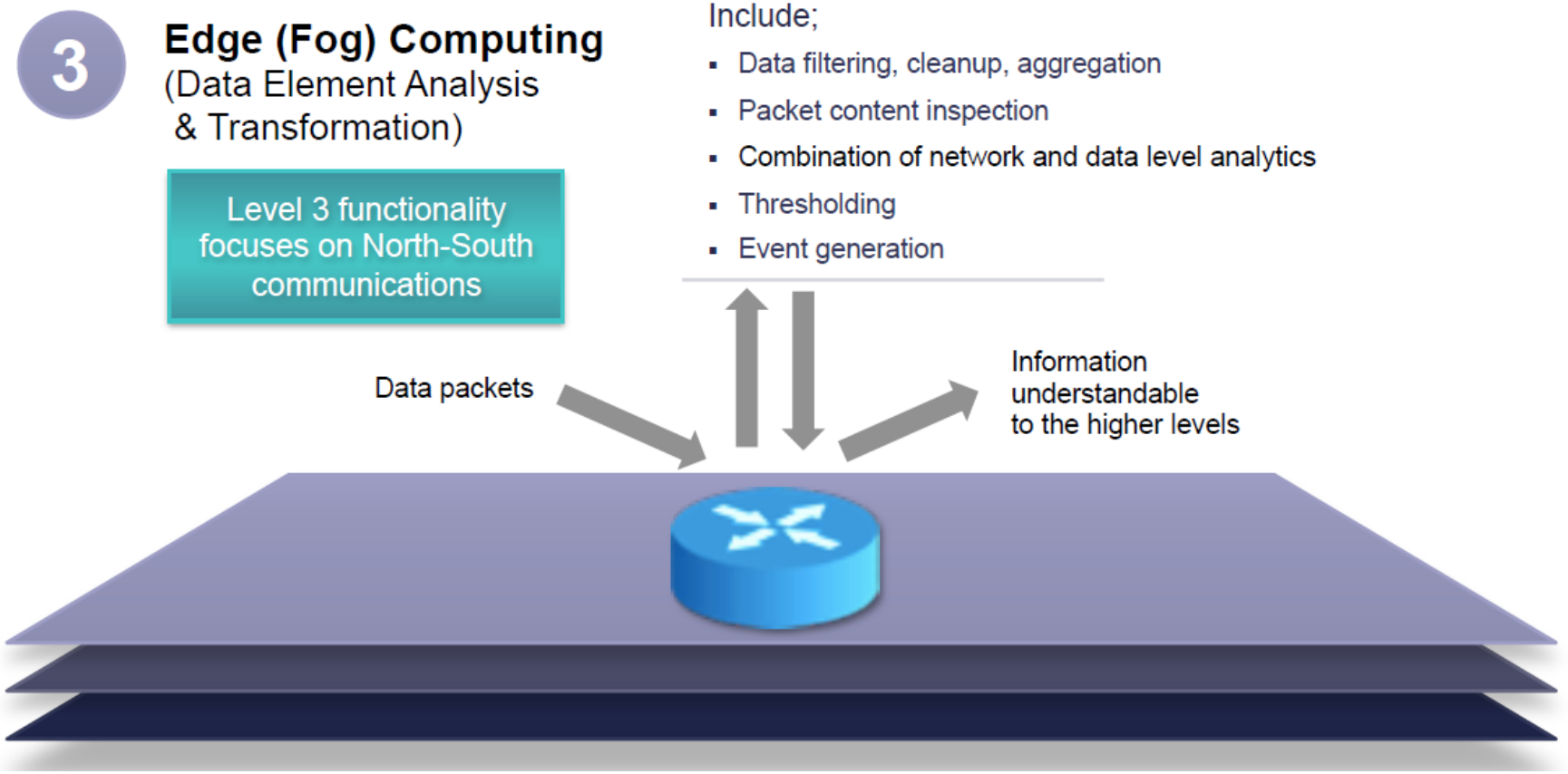
Level 2 functionality focuses on East-West communications

Connectivity includes:

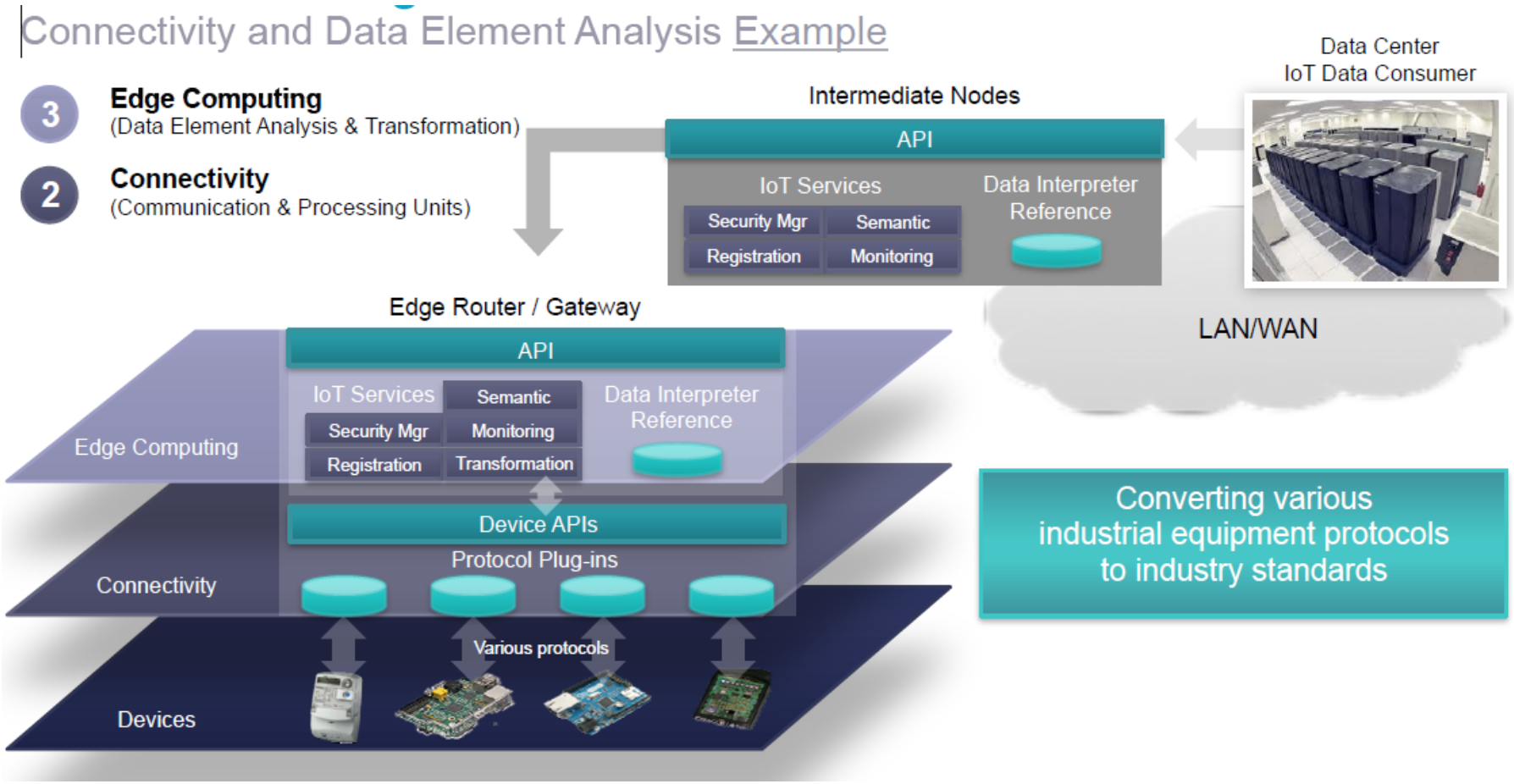
- Communicating with and between the Level 1 devices
- Reliable delivery across the network(s)
- Implementation of various protocols
- Switching and routing
- Translation between protocols
- Security at the network level
- (Self Learning) Networking Analytics

Level 3: Edge (Fog) Computing

- Focus on high-volume data processing, analysis and transformation.

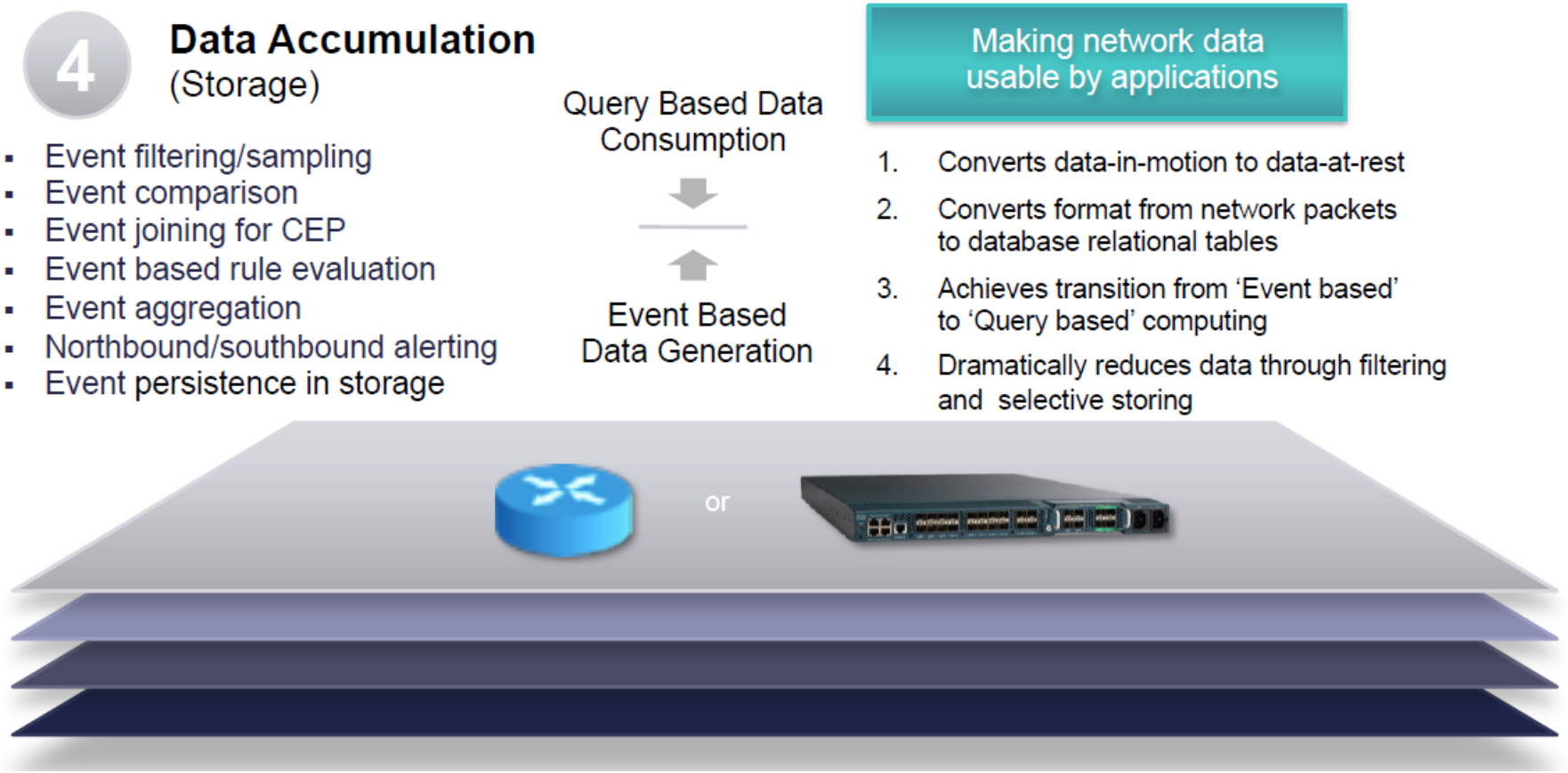


Connectivity and IoT Data Analysis



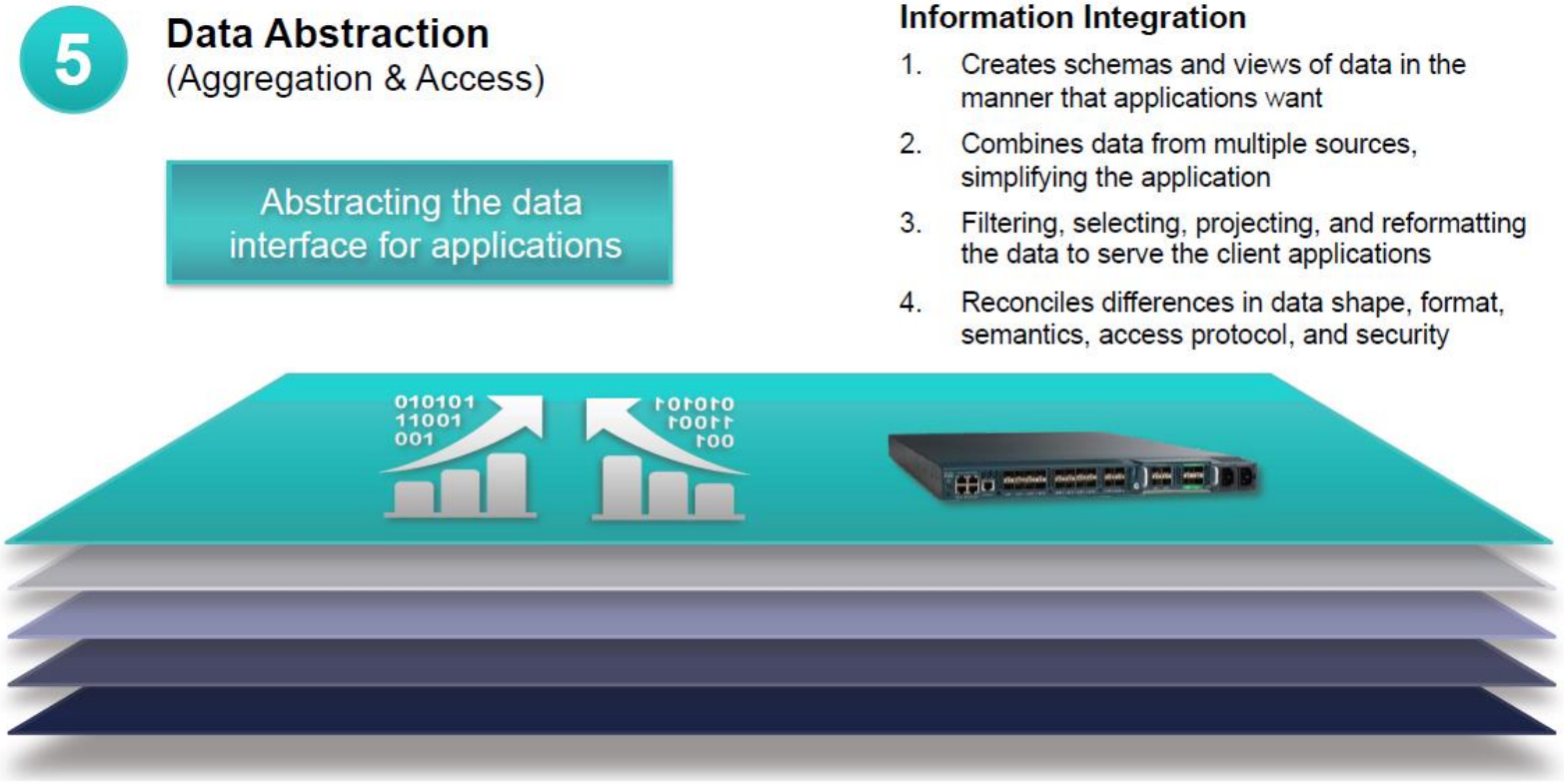
Level 4: Data Accumulation

- At Level 4, Data Accumulation, data in motion is converted to data at rest



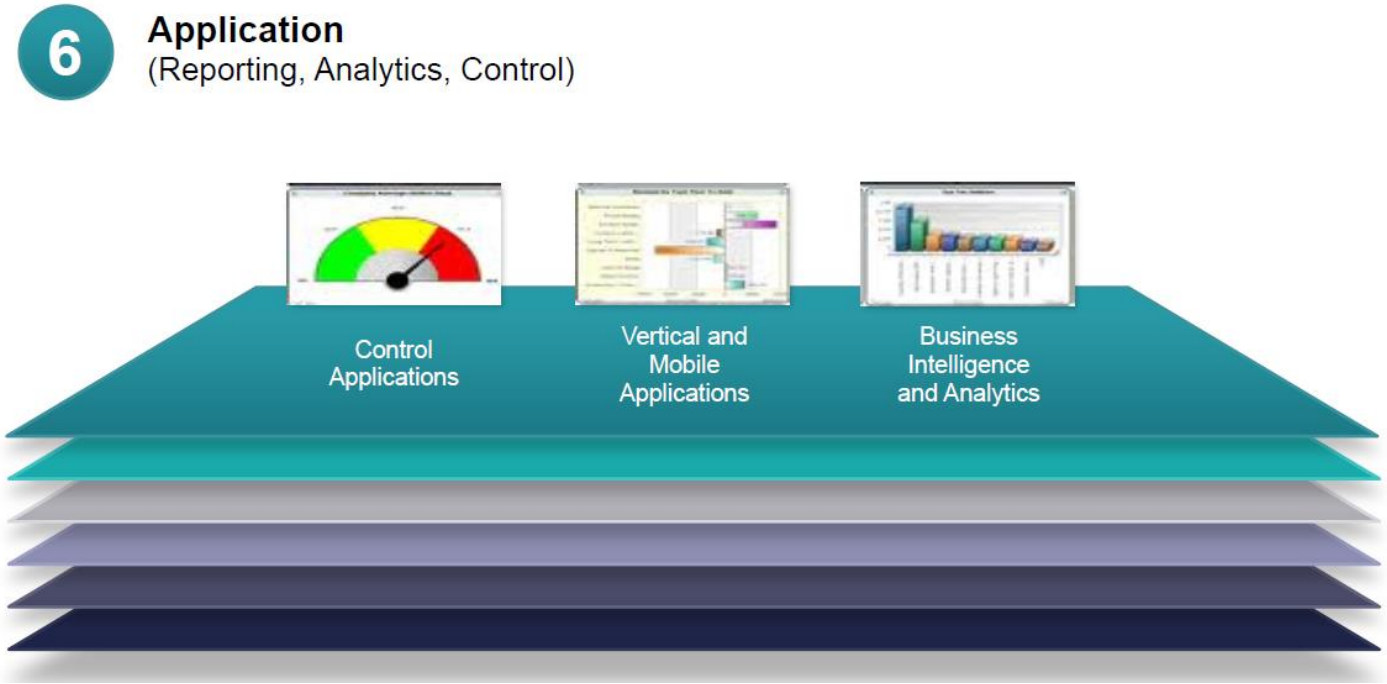
Level 5: Data Abstraction

- The data abstraction functions of Level 5 are focused on rendering data and its storage in ways that enable developing simpler, performance-enhanced applications.



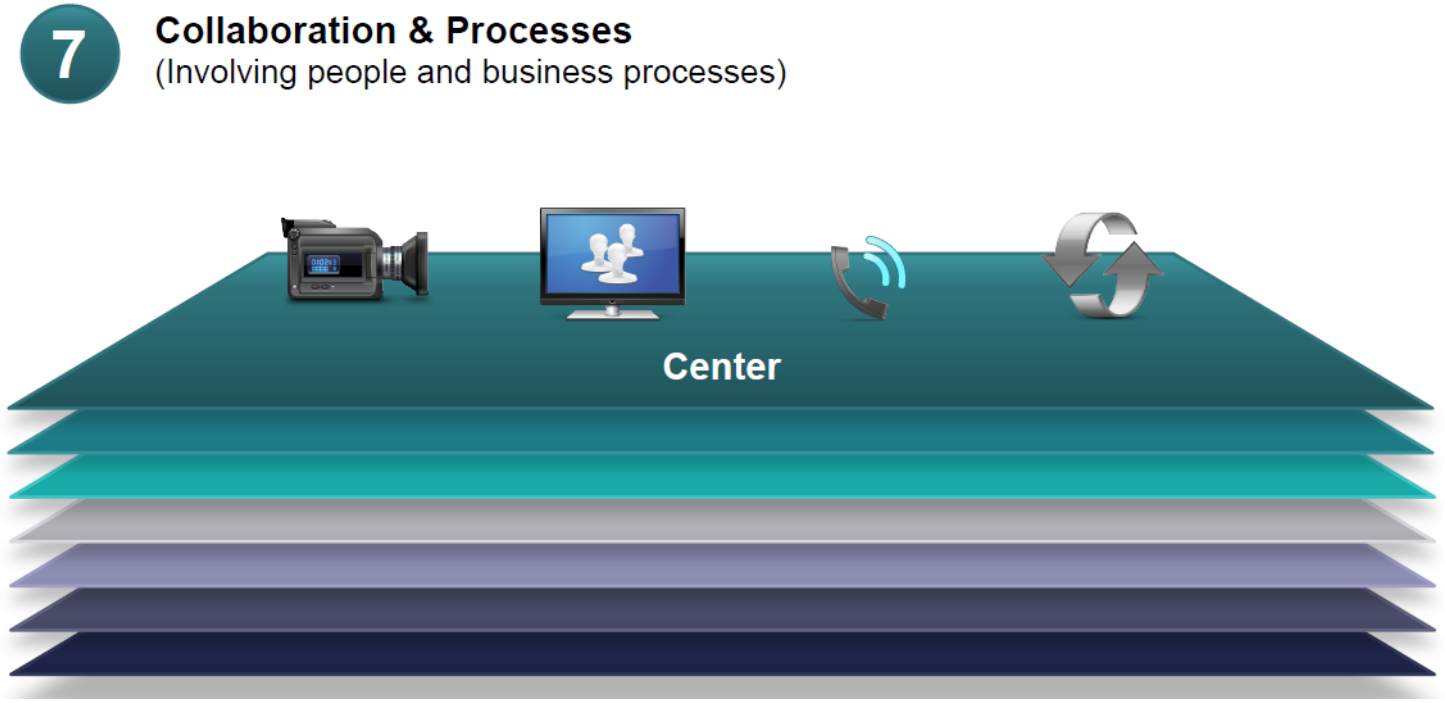
Level 6: Application

- Level 6 is the application level, where information interpretation occurs.
- Software at this level interacts with Level 5 and data at rest, so it does not have to operate at network speeds.



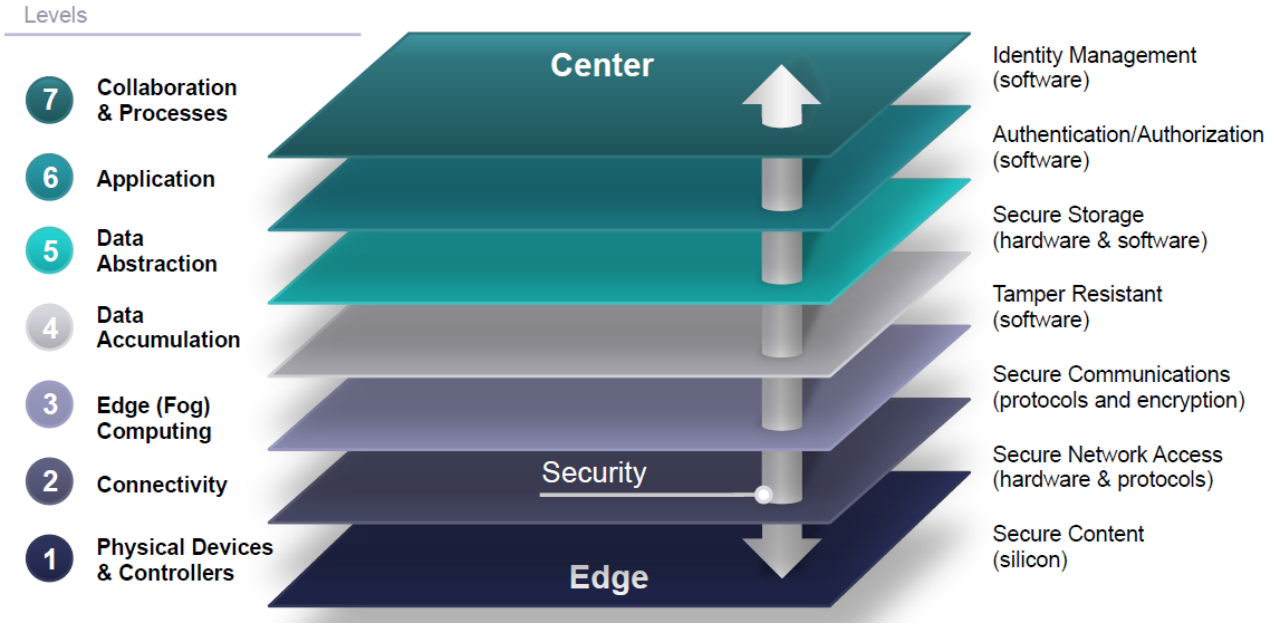
Level 7: Collaboration and Processes

- One of the main distinctions between the IoE and IoT is that IoE includes people and processes.
- This difference becomes particularly clear at Level 7: Collaboration and Processes



Security in the IoT

- Discussions of security for each level and for the movement of data between levels could fill a multitude of papers.
- For the purpose of the IoT Reference Model, security measures must:
  - Secure each device or system
  - Provide security for all processes at each level
  - Secure movement and communication between each level, whether north- or south-bound



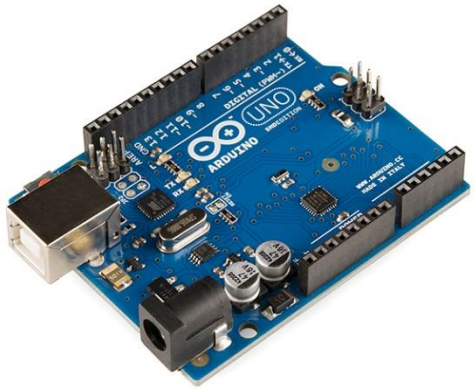
Internet of Things

Microcomputers/microcontrollers, sensors, actuators,…

IOT DEVICES - THINGS

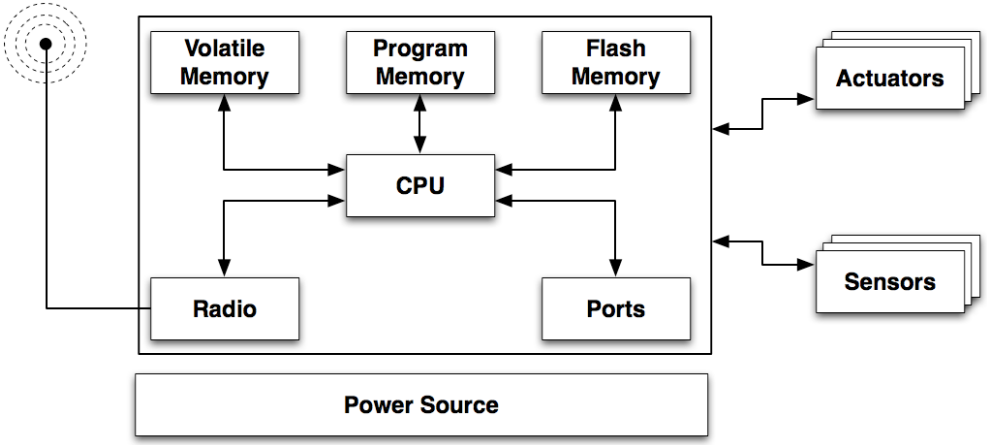
IoT sensing and smart devices

- IoT Devices
  - Sensors and actuators
  - Motion, temp, light, open/close, video, reading, power on/off/dimm etc.
- Communication protocols
  - Wireless and wired
  - Protocols such as ZigBee, Z-Wave, Wi-Fi/Wi-Fi Direct, Bluetooth etc.
  - Network congestion is a challenge
- Arduino & Raspberry PI
  - For rapid prototyping



IoT device architecture

- Energy
  - Devices are battery-powered, meant to operate unmanned for a long period of time
  - Communication is typically the biggest energy drain
  - Duty cycle is critical: nodes need to "sleep" for most of the time
- Reliability
  - Wireless link quality fluctuates based on environment
  - The topology changes as the WSN operates!
  - Nodes are often deployed in a "hostile" environment
  - The application/network must self-organize and self-adapt!



Sensors & actuators

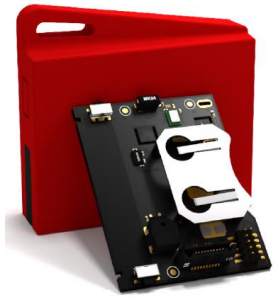
- Measure values
- Send raw data
- Low power

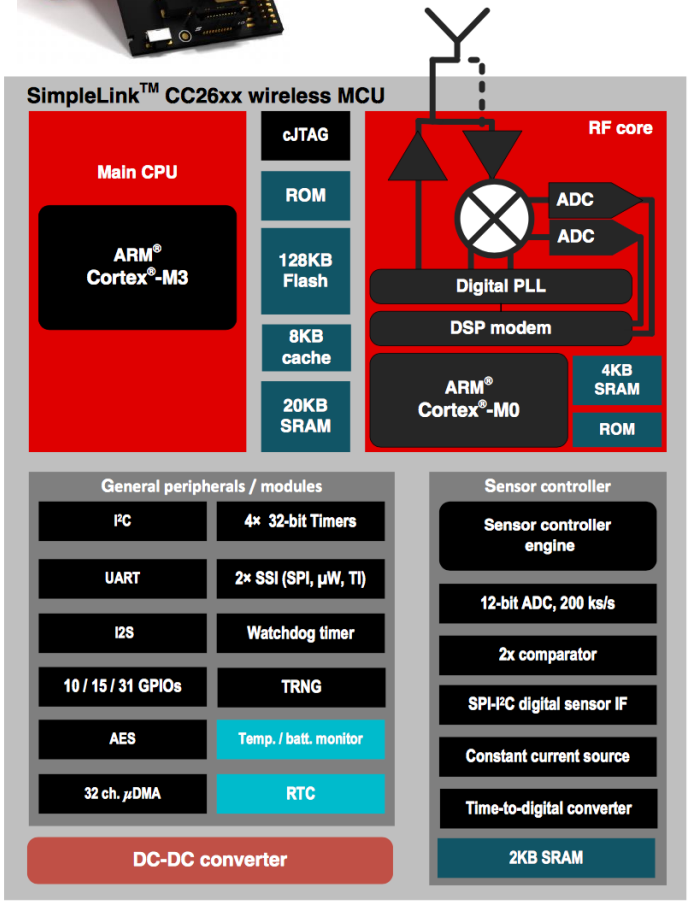
Early platforms: Example

- TI MSP 430
  - 16 bit RISC @8 MHz
  - 10 KB RAM
  - 48 KB code
- Chipcon CC2420 radio
  - IEEE 802.15.4 compliant
  - On-board antenna
- External 1MB flash chip
- Temperature, light, and humidity sensors built-in
- Cost at the time of massive production: ~80 EUR

Current platforms: Example

- CC2650 System-on-Chipv(SoC)
  - 32 bit ARM Cortex M3 @48MHz
  - 20 KB RAM
  - 128 KB code
- Radio
  - Multi-standard: IEEE 802.15.4,vBluetooth LE, 6LowPAN
  - On-board antenna
- Ambient temp, IR temp, humidity, light, acceleration, magnetometer, pressure, gyro, microphone, reed
- Cost at the time of massive production: ~29 EUR



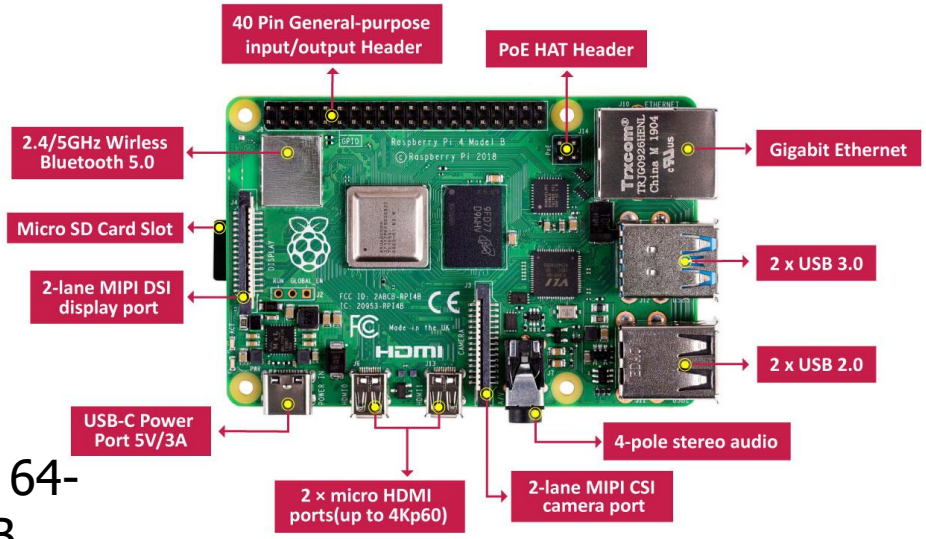


IoT Operating systems

- IoT OSs are crucially different from mainstream ones
  - RIOT, FreeRTOS, Contiki-NG, Zephyr, Mbed, Android Things, Mynewt, Windows 10 IoT Core, …
- They essentially provide basic run-time support for application programs
- Key functionality
  - Drivers and hardware abstraction layer
  - Concurrency support
  - Networking stack
  - Developer tools
- Programs are cross-compiled and linked with the OS
  - Looks more like a library then real OS
- Resulting binary deployed onto the node

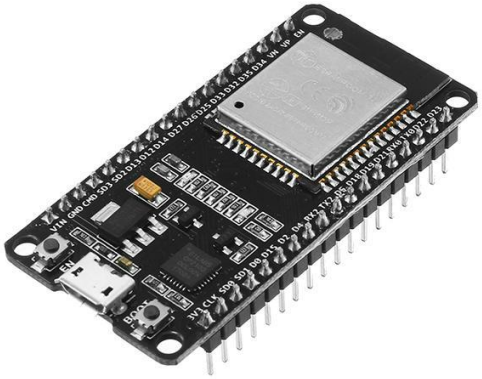
Microcontrolers & microcomputers

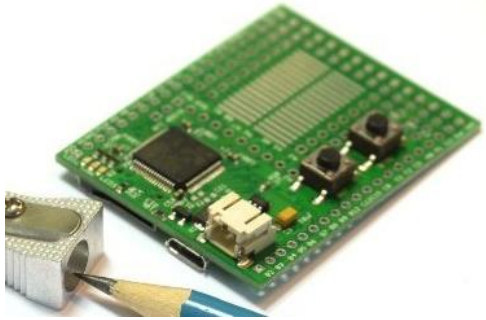
- Arduino
  - Small programmable device
  - Easy connectable
  - Open source
  - Has a simple to use software
  - Arduino Uno
    - Microchip ATmega328P, SRAM: 2KB, Flash: 32KB, EEPROM: 1KB
- Raspberry Pi
  - Runs Linux (Raspbian)
  - More software oriented programming
  - Full Networking System
  - Raspberry Pi 4 Model B
    - Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz, 1GB/2GB/4GB LPDDR4 SDRAM



Microcontrolers & microcomputers

- Espressif Systems
  - ESP8266, ESP32
- Particle
  - Argon, Boron, Photon, Elec
- Espruino
- Intel
  - Galileo, Edison
- Beaglebone
  - Blue, Black, AI, Green
- UDOO
  - Bolt, Neo, X86
- Parallella



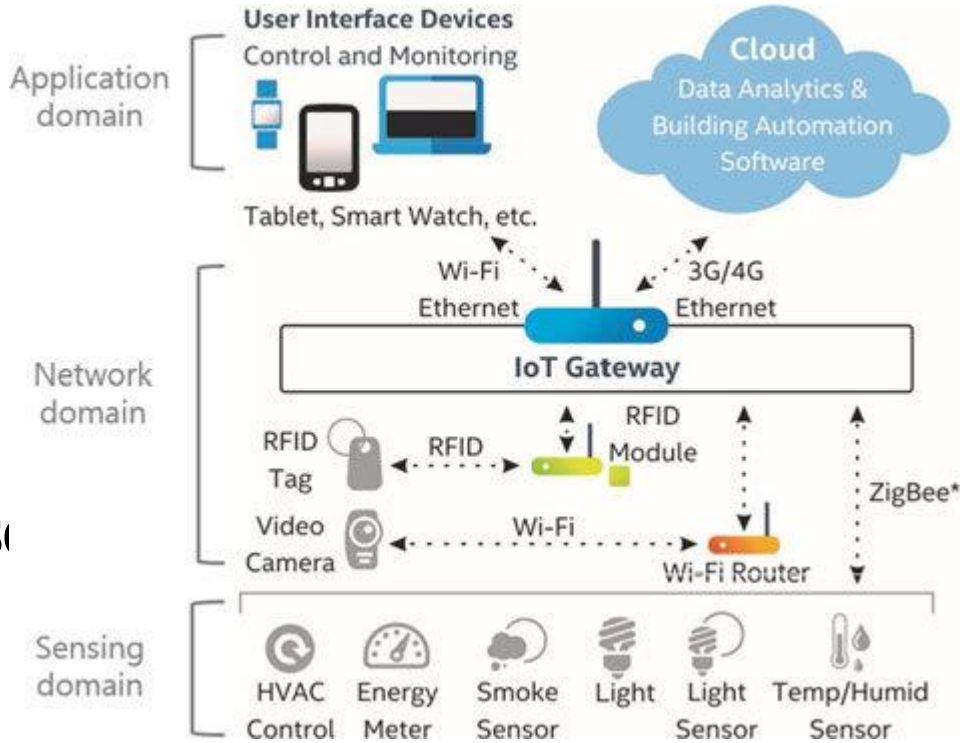


Edge computing

- Local processing, storage and analytics
- Get data from sensors, process, store & analyse, and send some data to the fog/cloud
- IoT Gateway
  - Gateway Protocols
    - 6LoWPAN
    - LoRaWAN / SigFox / NBIoT
    - BLE
  - Internet Protocols
    - CoAP
    - MQTT
    - AMQP
    - HTTP
    - XMPP

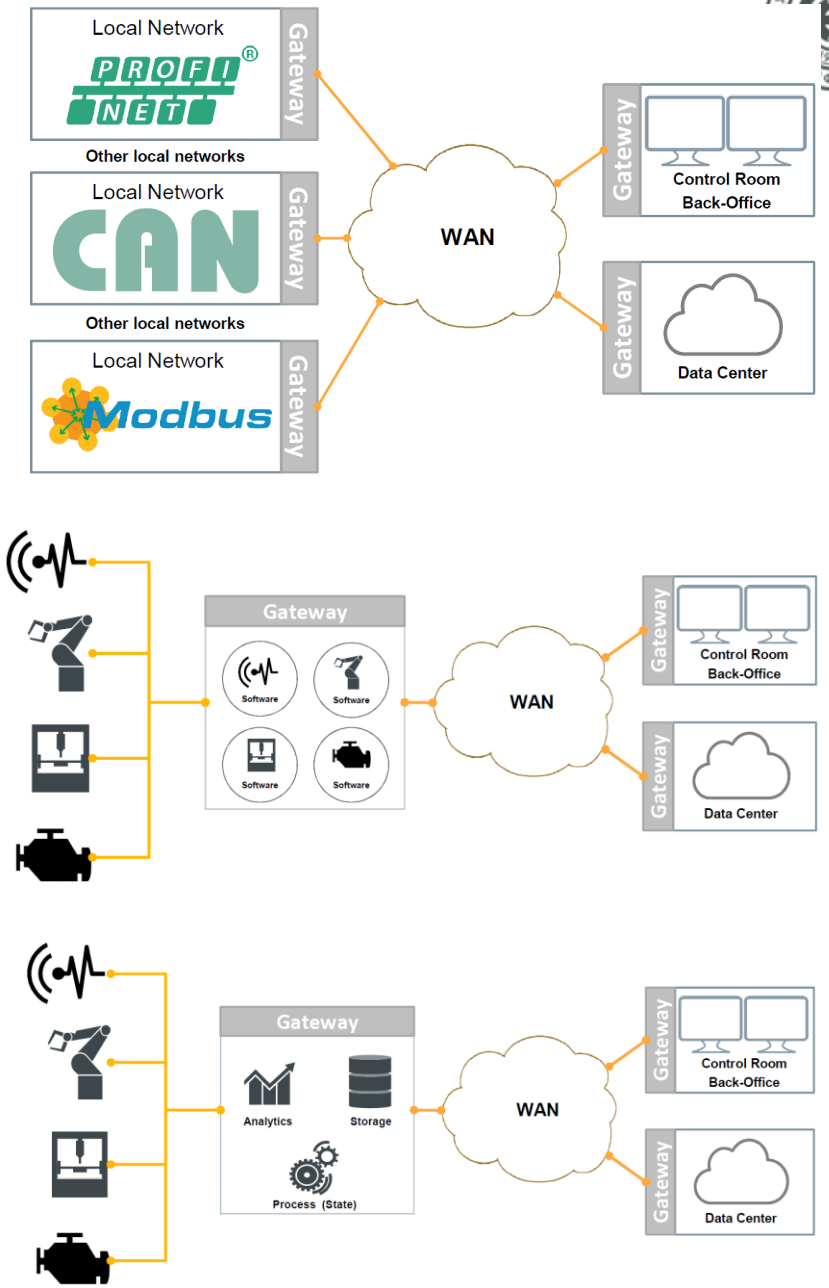
IoT Gateway

- Primarily deals with the sensor data acquisition and provisioning
- Embedded processing saves the communication latencies
- Predictive analytics
  - Collect data only occasionally
- Mobile/smart phones can als participate as Gateways
  - This brings in the scope of mobile web services and mobile cloud services for IoT



IoT Gateway

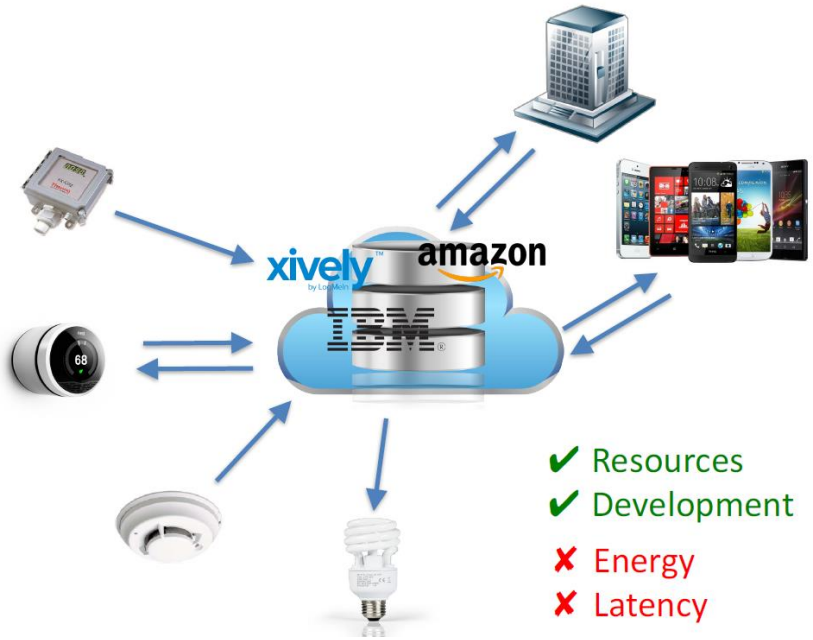
- Bridging of separated communication networks, including protocol adaptation
- Acting as a proxy to connect dumb things to the IoT, making them intelligent
- Providing common management, processing and analytics services to things close to the field



Cloud-centric IoT

- Cloud Processing and Storage
- Aggregate Data
- Big Data Storage
- Analytics and inferences

Pros and Cons of cloud-centric IoT



IoT platforms

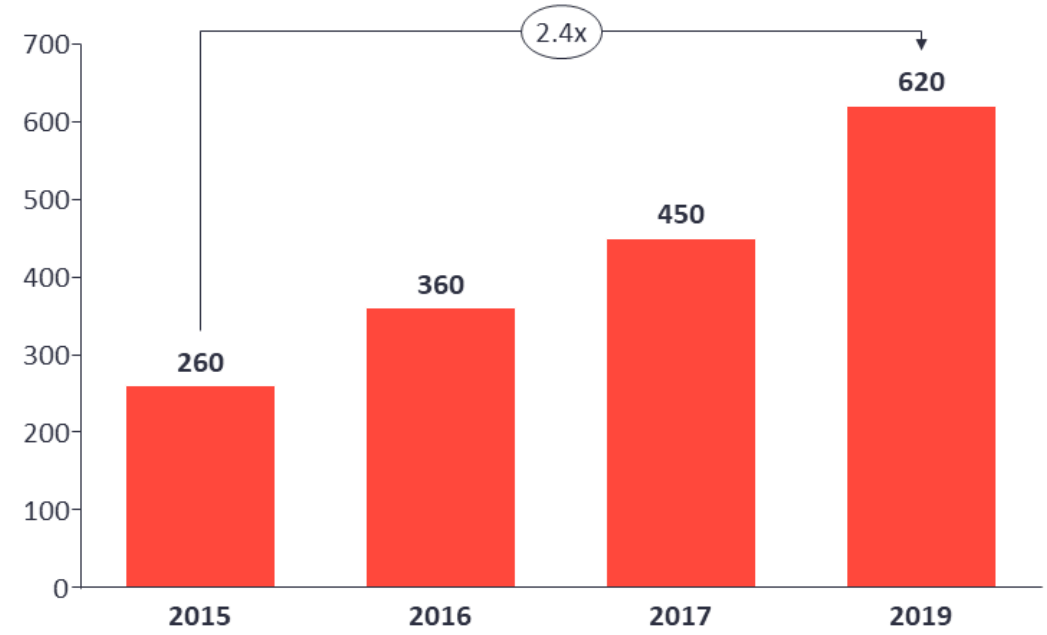
Database of 600+ IoT Platforms

Insights that empower you to understand IoT market

IOT ANALYTICS
MARKET INSIGHTS FOR THE INTERNET OF THINGS

Number of publicly known "IoT Platforms" (2015-2019)

Number of publicly known "IoT Platforms" (IoT Analytics Research)



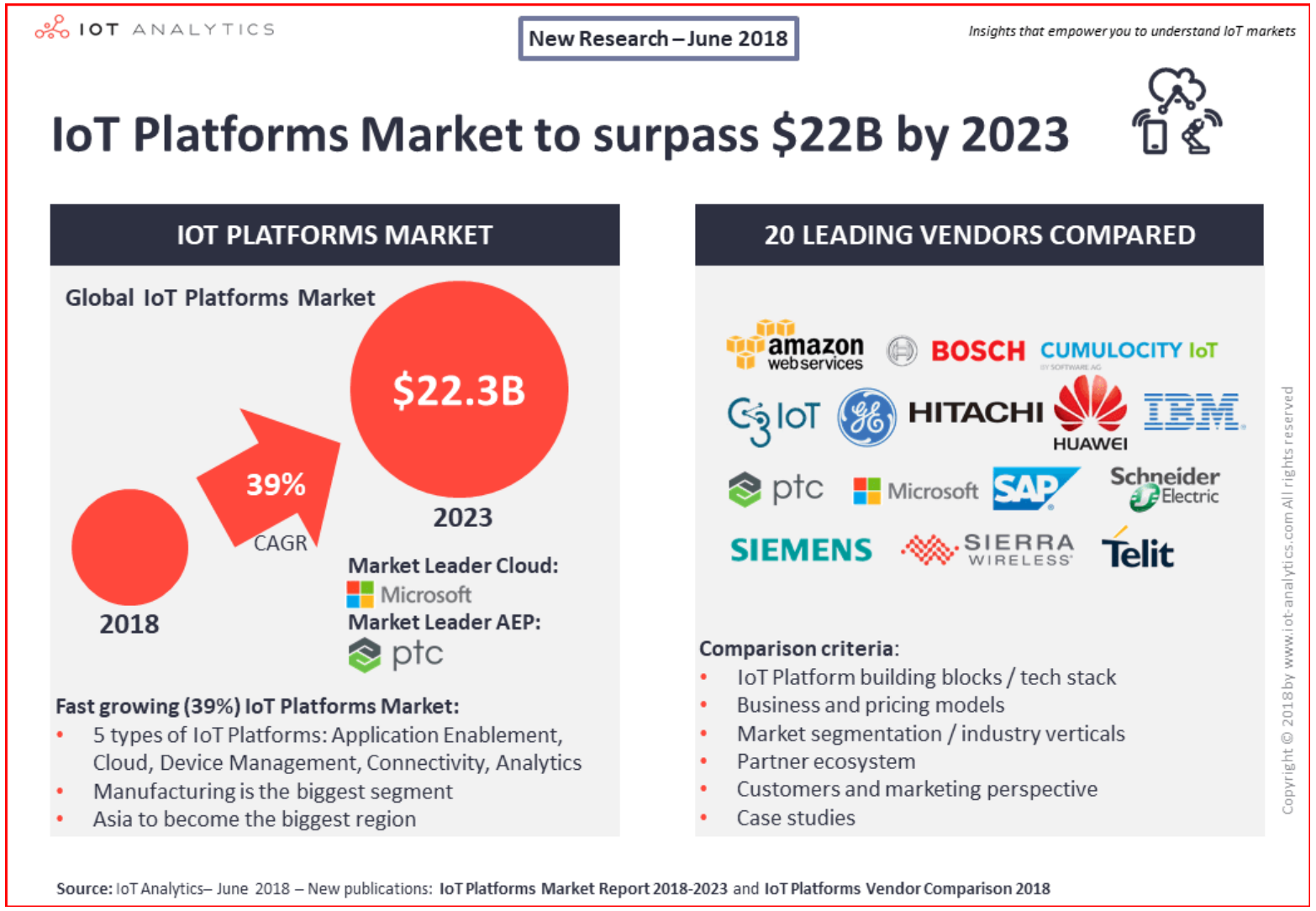
40+ example providers

Source(s): IoT Analytics Research

IoT Platforms Competitive Landscape & Database 2020

IOT ANALYTICS

IoT platforms



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  - Chapter 1: IoT and Edge Computing Definition and Use Cases
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- The Internet of Things Reference Model – CISCO 2014
  - http://cdn.iotwf.com/resources/71/IoT_Reference_Model_White_Paper_June_4_2014.pdf

- Internet of Everything - https://ioe.org/