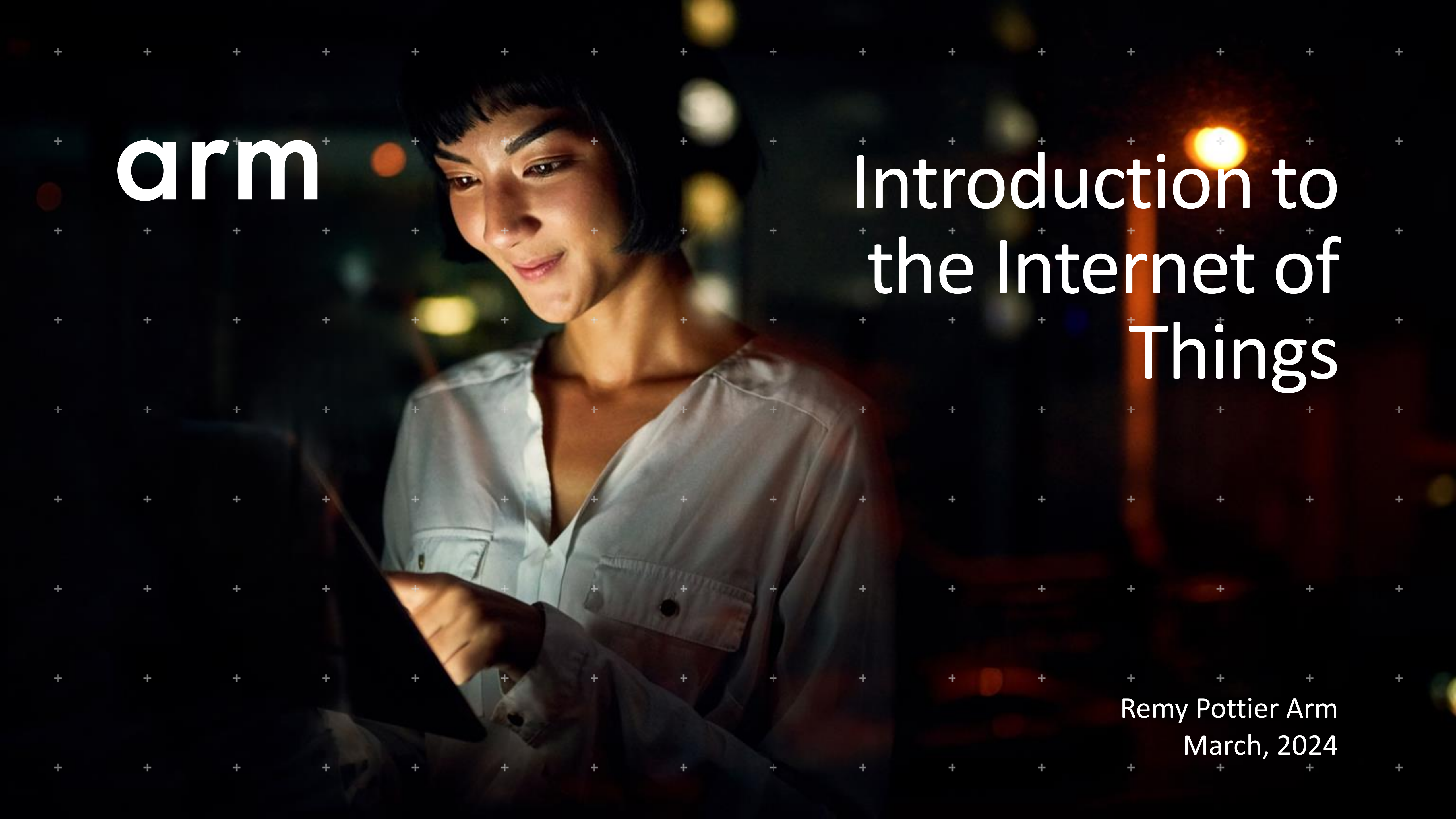

Introduction to the Internet of Things

Remy Pottier Arm
March, 2024

Syllabus

This module introduces the Internet of Things (IoT) technology, covering

- The meaning of IoT
- A brief history of IoT
- Technologies that enable the IoT paradigm
- The technical challenges facing IoT ecosystems
- Opportunities and potential applications

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What is IoT?

Internet of Things (IoT) refers to a large ecosystem of devices and smart objects that can gather, exchange, and act on information over networking infrastructure.

These “things” include:

- Smart Home Devices, e.g., washing machines, fridges, kettles, vacuum cleaners, light bulbs, thermostats, door locks, and video cameras
- Civil engineering structures, e.g., bridges and railways
- Wearable devices, e.g., smart watches, smart glasses, rings, and clothes
- Industrial devices, e.g., robotic systems, industrial equipment
- Biomedical devices, e.g., pacemakers, blood pressure monitors, digital pills
- And conceivably any THING in the world

How does an object become part of the IoT family?

Objects that make up the IoT typically have the following properties:

- They incorporate computing hardware with small form-factor
- Have (multiple) sensing and/or actuation capabilities
- Often have low-power consumption and can be battery-powered
- Usually transmit and receive information wirelessly
- They are connected to the Internet and may be uniquely addressable
- Their functionality can be (re)programmed (e.g. FOTA)
- May be able to operate autonomously without human interaction

The history of IoT

1988

Mark Weiser (Xerox PARC) – Ubiquitous Computing

"…hundreds of wireless computing devices per person per office, of all scales […] This is different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere. […] its highest ideal is to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it."

Weiser, M. (1988). What Ubiquitous Computing Isn't.

The history of IoT

1988 **1999-2002**

Neil Gershenfeld (MIT Media Lab)

"in retrospect it looks like the rapid growth of the World Wide Web may have been just the trigger charge that is now setting off the real explosion, as things start to use the Net."

Kevin Ashton (Auto-ID @ MIT) – Internet of Things

"We need an internet for things, a standardized way for computers to understand the real world."

Ghershenfeld, N. (1999). When Things Start to Think.

Forbes (2002). The internet of things.

The history of IoT

1988 **1999-2002** **2005**

International Telecommunications Union (ITU) Internet Report: The Internet of Things

“always on communications, in which new ubiquitous technologies (such as radio-frequency identification and sensors) promise a world of networked and interconnected devices (e.g. fridge, television, vehicle, garage door, etc.) that provide relevant content and information whatever the location of the user – heralding the dawn of a new era, one in which the internet (of data and people) acquires a new dimension to become an Internet of Things.”

ITU (2005). ITU Internet Reports 2005: The Internet of Things.

The history of IoT

1988 | 1999-2002 | 2005 | 2009

European Commission,
IoT — An action plan for Europe

"network of interconnected objects, from books to cars, from electrical appliances to food [...]. These objects will sometimes have their own Internet Protocol addresses, be embedded in complex systems and use sensors to obtain information from their environment [...] and/or use actuators to interact with it."

Commission of the European Communities (2009). Internet of Things — An action plan for Europe

The history of IoT

1988 1999-2002 2005 2009 2012 2016

Cisco and the "IoE- Internet of Everything"

"The Internet of Everything (IoE) brings together people, processes, 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."

Arm coins "The route to a trillion devices"

"IoT technology is becoming more affordable every day, driven by innovations in semiconductor technology, cloud computing, and mobile connectivity. This trend of cost reduction is driving exponential growth in IoT. ARM believes that we are entering a new era of computing. We expect that a trillion new IoT devices will be produced between now and 2035."

Evans, D. (2012). The Internet of Everything: How More Relevant and Valuable Connections Will Change the World

At ARM TechCon 2016, CEO Simon Segars discussed how he sees billions of devices scaling to trillions as IoT applications proliferate.

Technologies that enable IoT

Mobile computing:

Faster, cheaper, low-power processors and devices (e.g., smartphones and tablets)

Improved manufacturing technologies

Smaller computing hardware

Big data and the cloud:

Cloud-computing services to process data from sensors

Technologies that enable IoT

Better batteries:

E.g., lithium-ion polymer – more energy storage, rapid charging

Faster and more diverse standardized connectivity options:

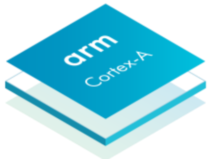
Short-range (Bluetooth, Zigbee), medium-range (Wi-Fi, cellular), and long-range (LoRa, SigFox)

Development resources:

APIs and protocols (REST, MQTT), language-independent data formats (e.g., JSON), development communities (Mbed)

Technologies that enable IoT

Mobile computing



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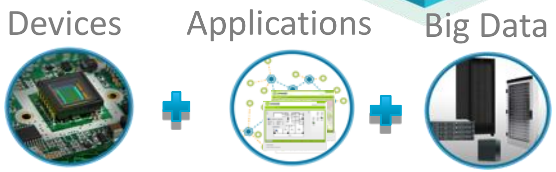
IoT

Reduce cost of manufacturing

Little devices and more sensors/Big data and the cloud



IEEE 802.15.4

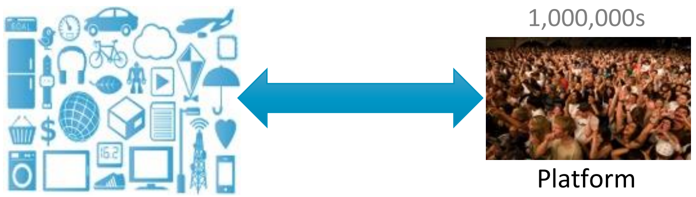
Wi Fi

LTE

Bluetooth® SMART

ZigBee

Networking standards that enable scalability

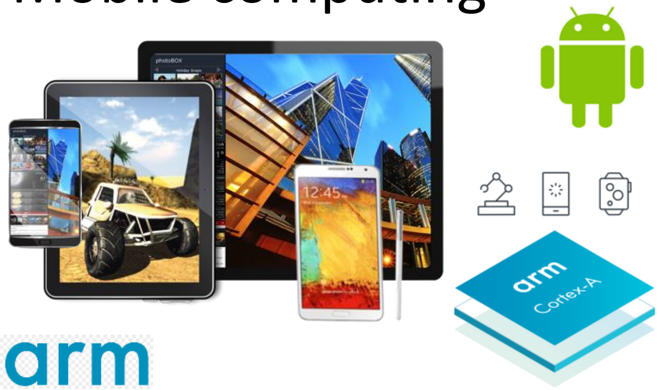


Cloud and community-based development

arm

Technologies that enable IoT

Mobile computing



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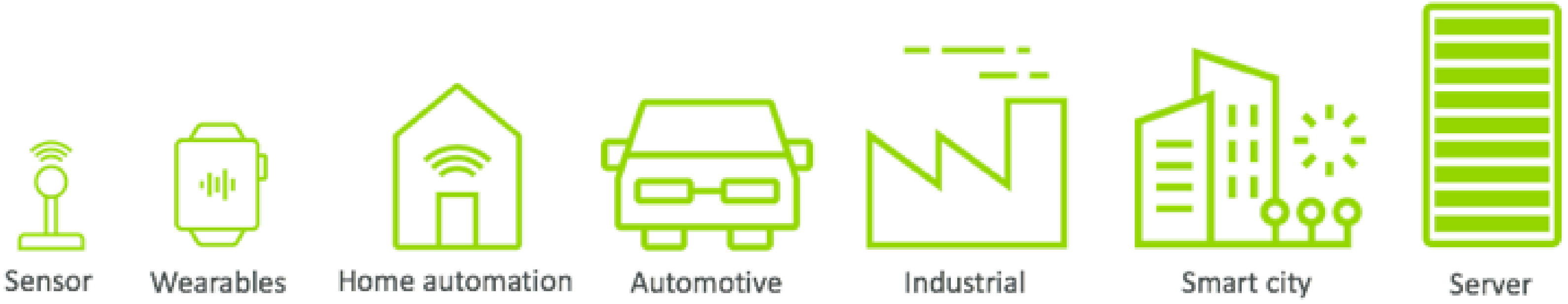
CORTEX®

IoT

The Arm architecture across IoT: From sensor to server

- Arm Cortex-A family
  - Application processors for feature-rich operating systems (OSes) and 3rd party applications
- Arm Cortex-R family
  - Embedded processors for real-time signal processing and control applications
- Arm Cortex-M family
  - Microcontroller-oriented processors application specific or system on chip (Soc) applications



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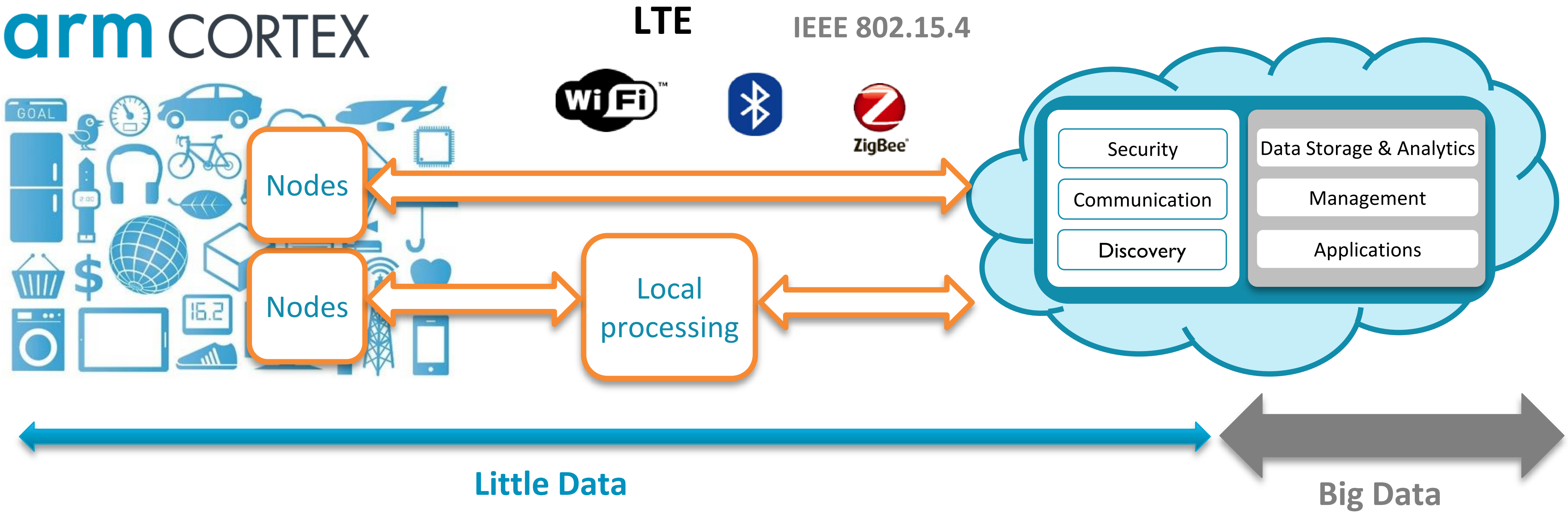
Little devices and sensing (little data)



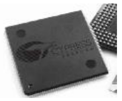
Arm Cortex-M: Enabling little devices

➢ 60B

Arm cortex-M chips shipped to date worldwide

Nordic Semi nRF52833
Bluetooth 5.1 & Zigbee
Arm Cortex-M4 Processor

Silicon Labs EFR32MG21
Multiprotocol wireless SoC
Arm Cortex-M33 Processor



Cypress CYW43438
WiFi + Bluetooth 4.2
Arm Cortex-M3 Processor

NXP K32
Industrial and IoT applications
Arm Cortex-M0+/M4 Processor

Dialog Semiconductor DA14585
Bluetooth 5.0 SoC w/Audio
Arm Cortex-M0 Processor

TI CC2650
BT/ZigBee/6LoWPAN
Arm Cortex-M3/M0 Processor

Wearable

Fitbit - 18M devices sold in 2018

Wearable

7,645 backers pledged $822,869

Airpower - Wearbuds

Toys

Anki

Embedded Java

MICROEJ

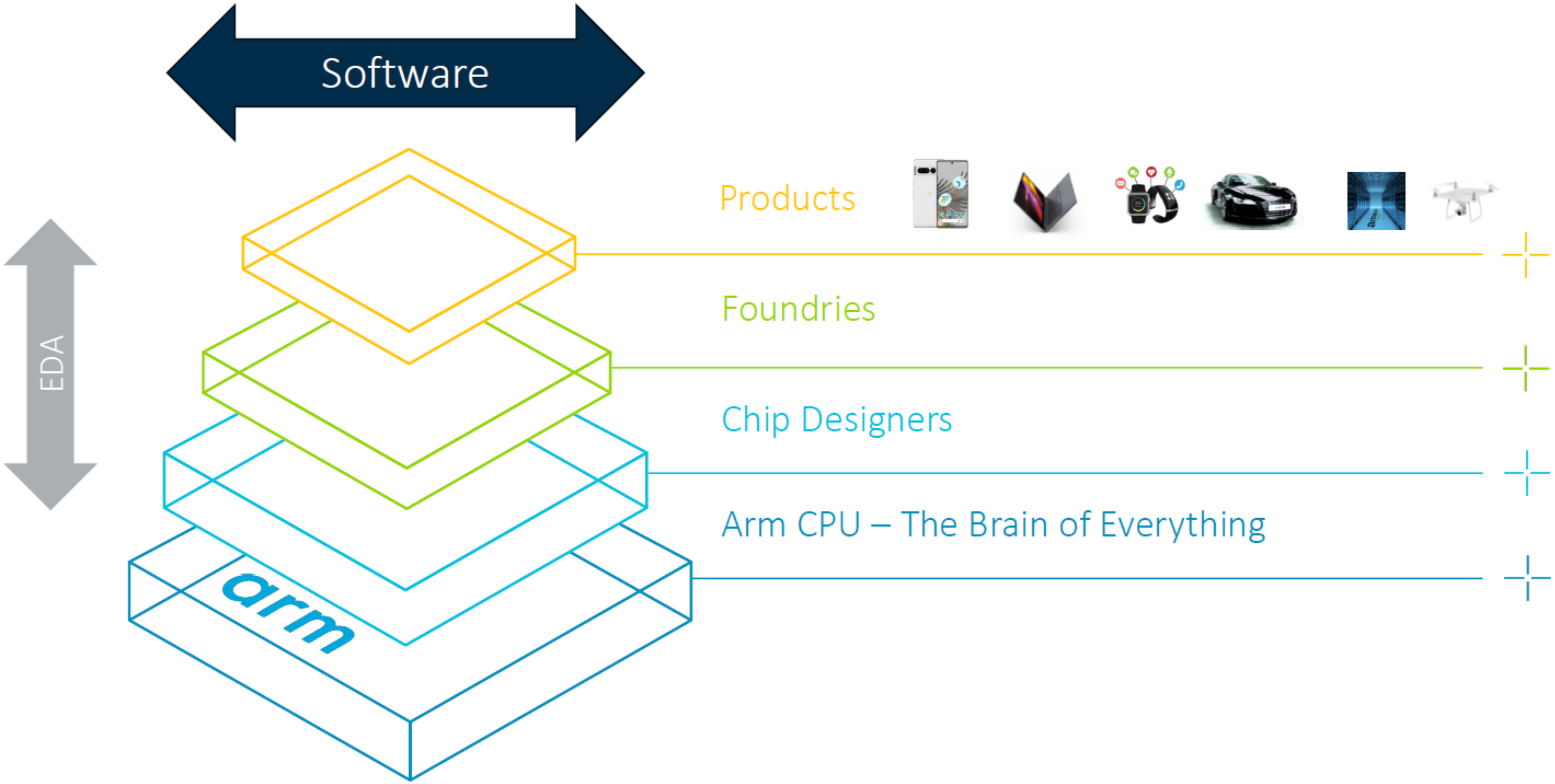
Technologies that enable IoT

Reduce cost of manufacturing

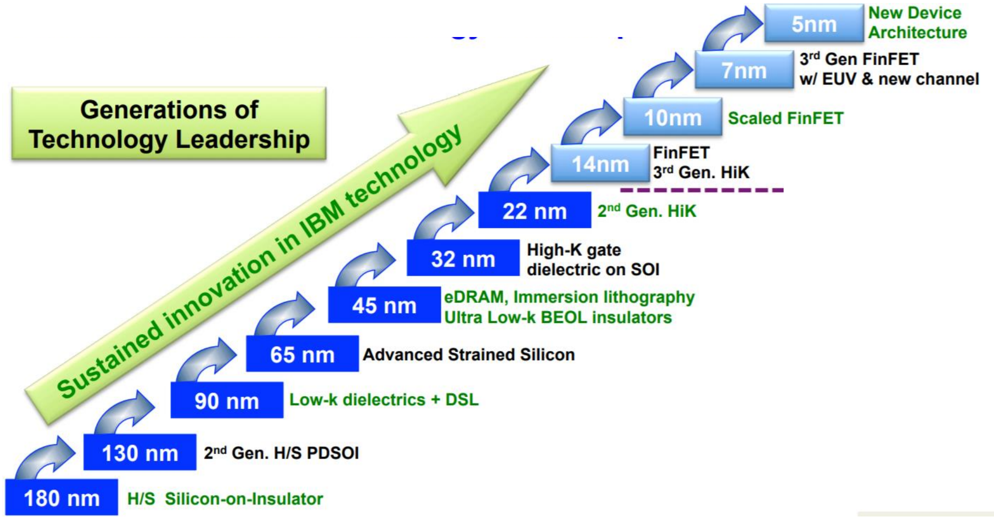
Little devices and more sensors/Big data and the cloud

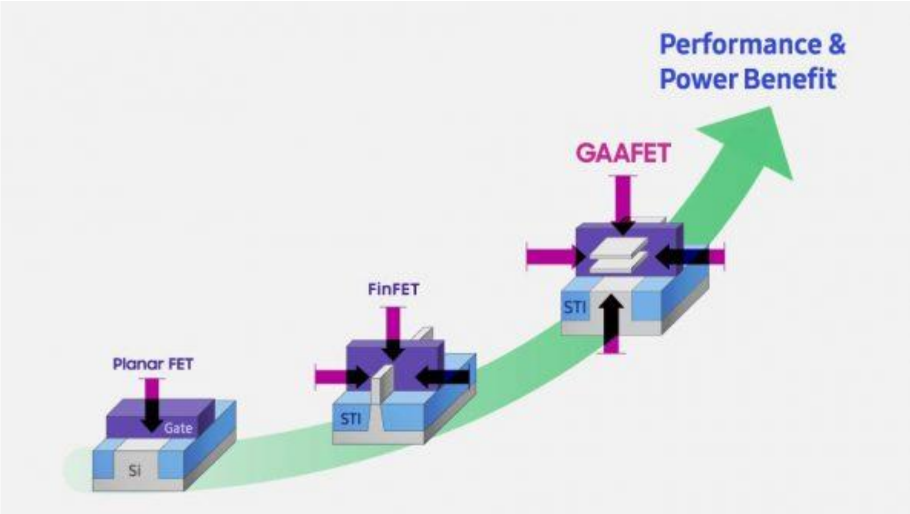
Devices Applications Big Data

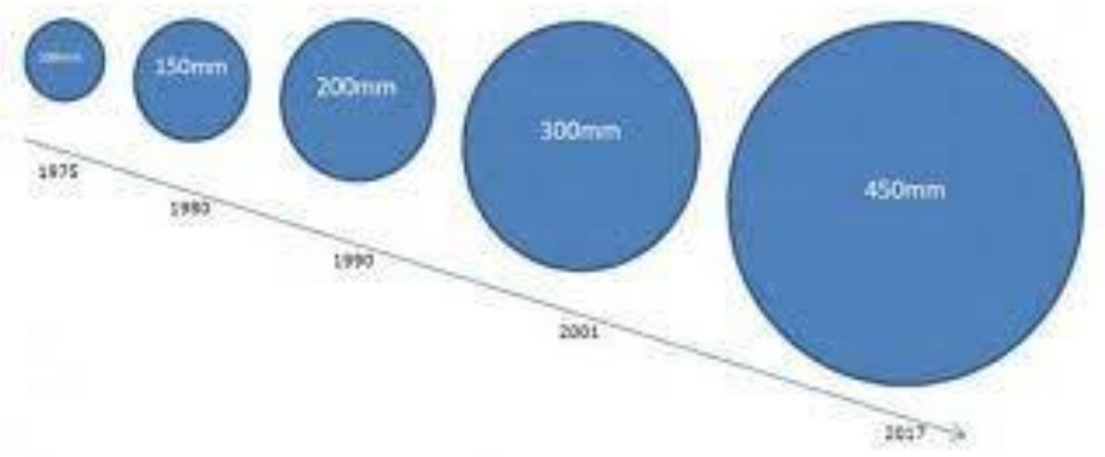
The Foundation of the Semiconductor Industry



Technology evolution







Technologies that enable IoT

IoT

IEEE 802.15.4

Wi-Fi

LTE

Bluetooth SMART

ZigBee

Networking standards that enable scalability

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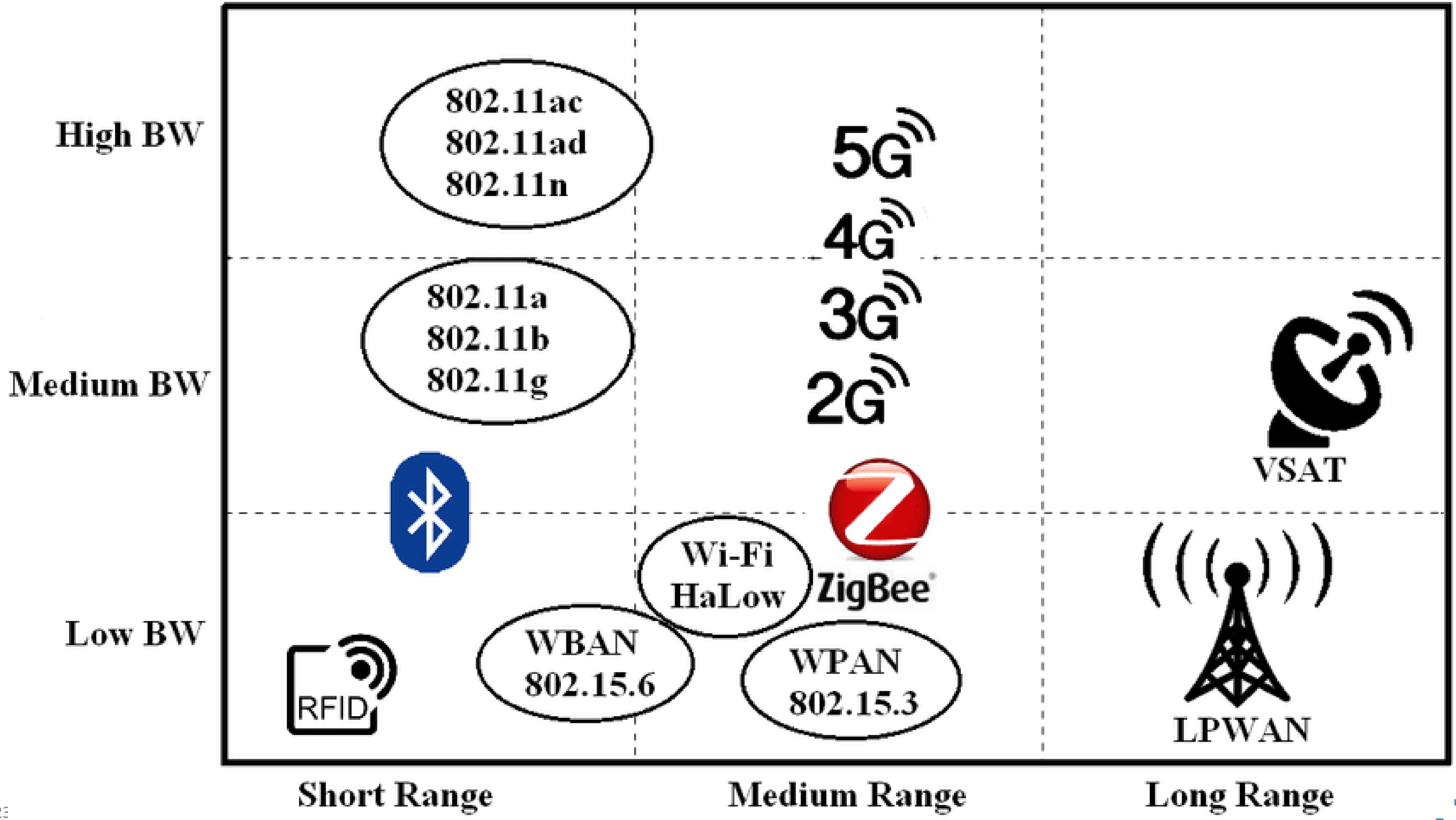
Bluetooth Low Energy (BLE) connectivity

- Ultra low power, designed to run with coin cells, e.g., 10mW
- Short range communication, e.g., < 100 meters
- Powering small IoT devices, e.g., wearables
- Proximity sensing/inventory tracking (BLE beacons)
- Many-to-many communications (mesh networking), e.g. building automation

Bluetooth® SMART

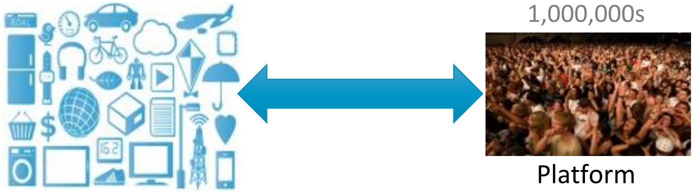
Wi-Fi connectivity

- Longer communication range
- Uses unlicensed spectrum and simple decentralized channel access protocol → easy to deploy
- Higher throughput supported
- Particularly suitable for devices with less stringent power constraints, e.g., smart home appliances
- Power-saving mode (PSM) also defined to save energy in battery-powered devices


High BW
Medium BW
Low BW
802.11ac
802.11ad
802.11n
802.11a
802.11b
802.11g
5G
4G
3G
2G
VSAT
Wi-Fi
HaLow
ZigBee
RFID
WBAN
802.15.6
WPAN
802.15.3
LPWAN
Short Range
Medium Range
Long Range

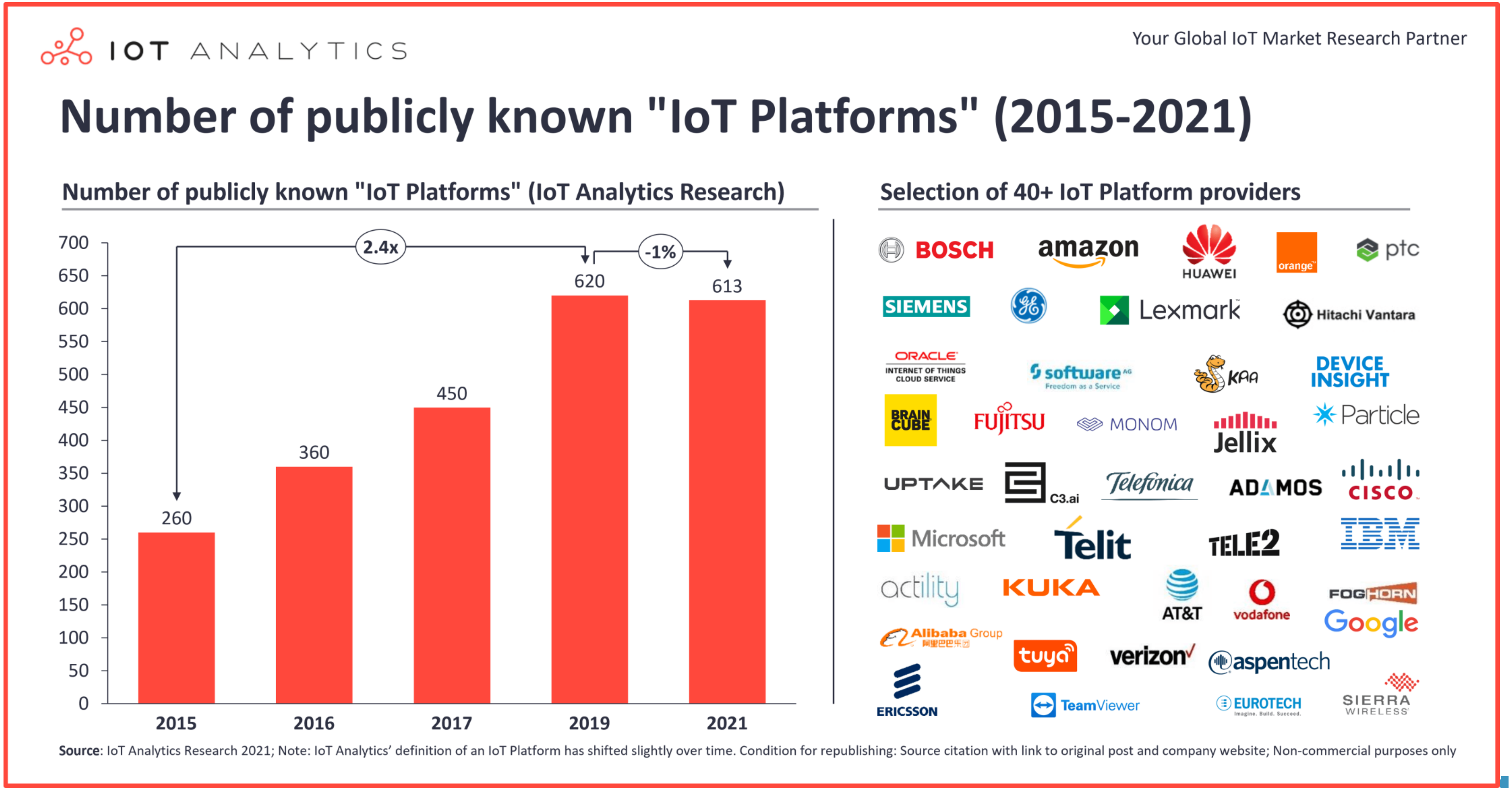
Technologies that enable IoT

IoT



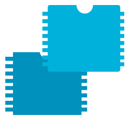
Cloud and community-based development

IoT platforms



Cloud and community-based development

Accelerating IoT deployment



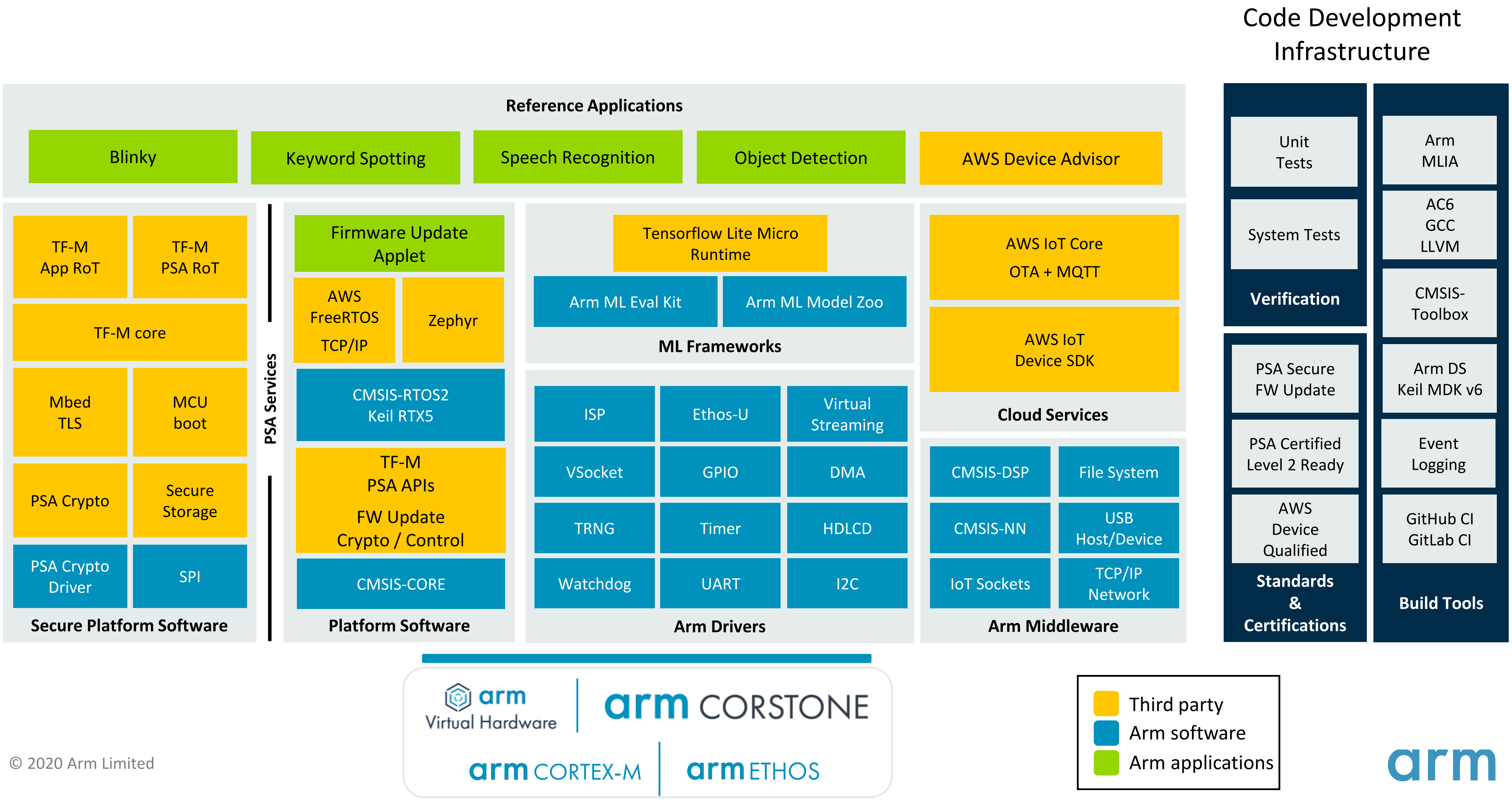
MCUs

Radios

Sensors

- Rapid, professional IoT device development
  - An open source platform and libraries for Cortex -M microcontrollers
- Mix and match essential components for your product design
  - Microcontrollers, radios, sensors, and software stacks
  - Bluetooth, 802.15.4/6LoWPAN, WiFi, and cellular
- Simplify integration with cloud services
  - Integration with IoT platforms
  - Embedded agents and APIs for cloud services

Software Overview

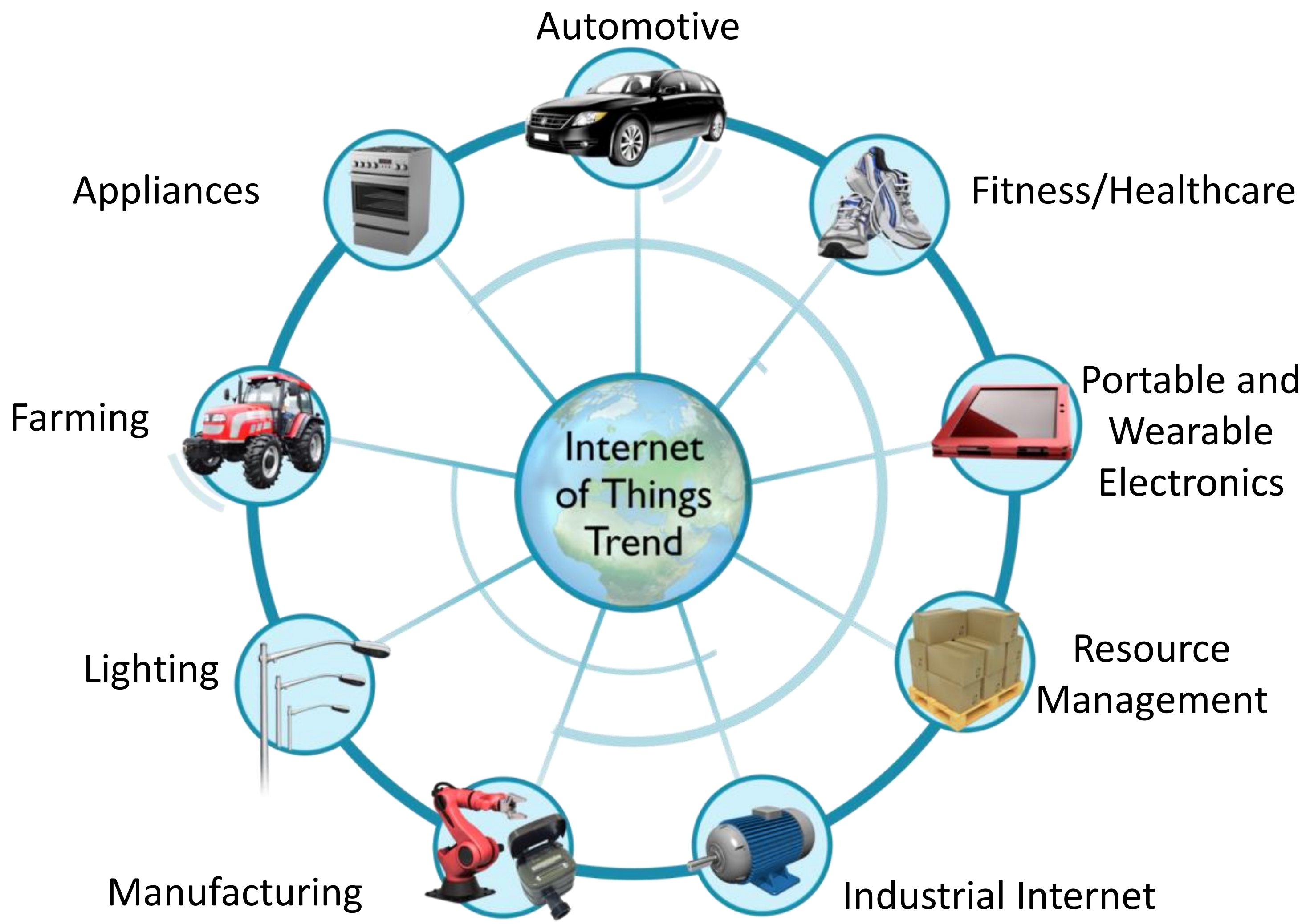


Challenges facing IoT

Interconnecting many devices that exchange (big) data can be challenging

- Better hardware and code that runs efficiently.
- Ensuring energy efficient operation.
- Data management
- Device management
- Ensuring reliable connectivity and scalability.
- Guaranteeing secure operation and data confidentiality
- Developing easy to use products and services
- Complying with regulations

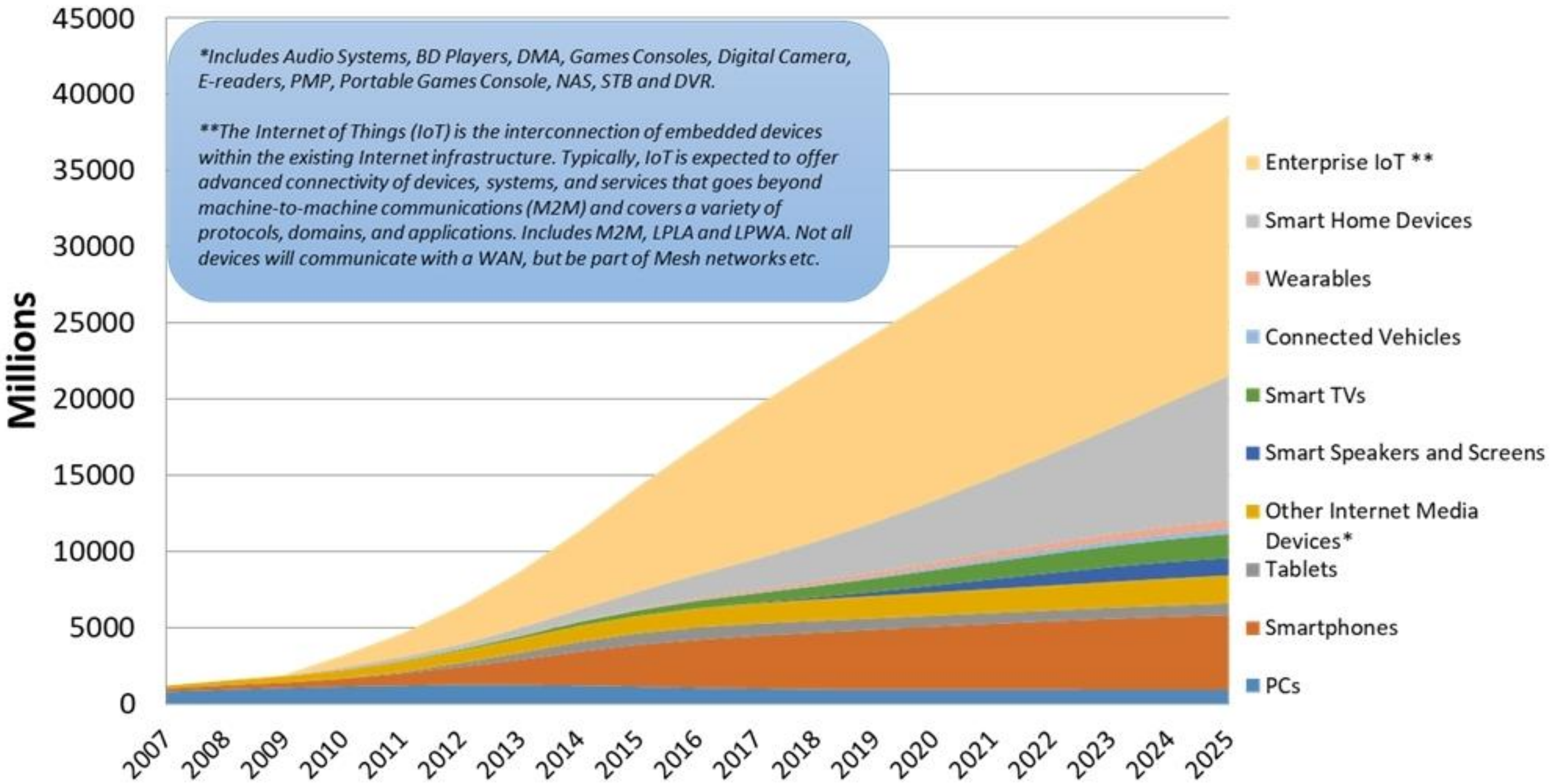
Opportunities



Application domains

- **Industry** (manufacturing, transportation, agriculture)
- **Consumer** (smart homes, appliances, assisted living)
- **Wearables** (healthcare, fitness, productivity)

Scale and diversity of IoT is very different to mobile



Source – Strategy Analytics research services, May 2019: IoT Strategies, Connected Home Devices, Connected Computing Devices, Wireless Smartphone Strategies, Wearable Device Ecosystem, Smart Home Strategies

IoT in the home

15 devices per person expected by 2030

Benefits

- Lower home carbon footprint (thermostats, smart metering, smart lighting)
- Personalization (voice-controlled personal assistants, access control)
- Increased comfort (appliances automation, assisted living robotics)
- Safety (smart cameras, smart locks)

Risks

- Communication is wireless and therefore potentially subject to abuse
- Control via software running on phone (app) – risk of malware and privileges abuse
- Hijacking and weaponization (e.g., Mirai botnet)

Others modules

Module	Contents
IoT System Architectures and Standards	• Key considerations for IoT systems • Cloud vs. Edge vs. Fog • IoT standards
Introduction to Embedded Systems	• What is an embedded system? • Examples of embedded systems • Features of embedded systems • Embedded systems programming
Hardware Platforms for IoT	• What is a hardware platform? • Types of memory • Power saving techniques • Types of sensors