Internet of Things as an Ecosystem for Innovation

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Outline

- Introduction
- Architectures & standardisation
- IoT Protocols and technologies
  - Link layer: WLAN, Bluetooth/BLE/5.0, ZigBee, LoRa, LTE-MTC
  - Network: 6loWPAN, MESH, ID-based routing, BloomFilters
  - Application: CoAP, MQTT,
  - Service discovery, composition and management
  - Inter-operability (Web of Things)
- Development platforms & testbeds
  - FIWARE, ..
  - Fed4FIRE,...
- Survey of research activities

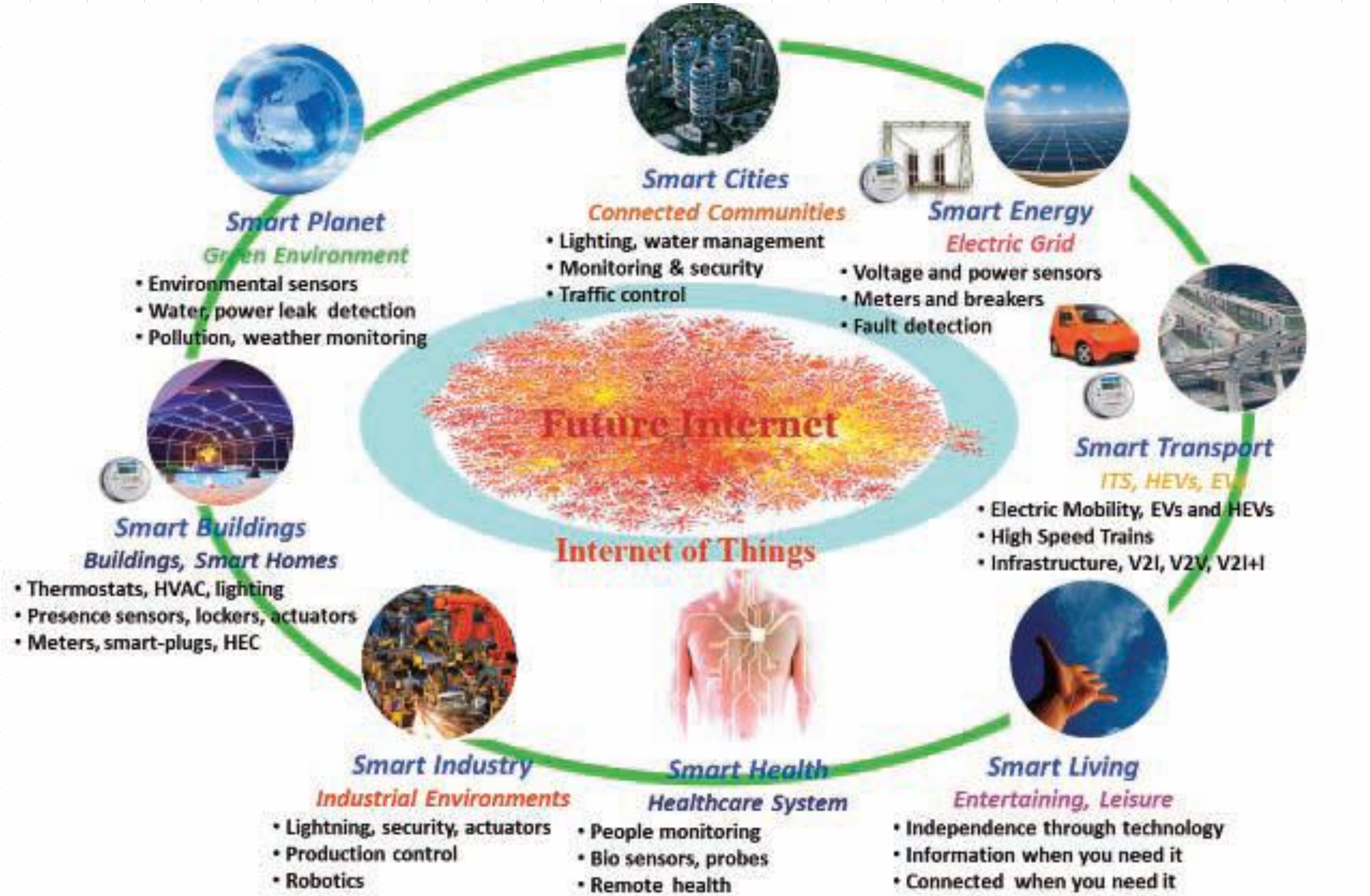
Introduction (1)

- **What is „Internet of Things (IoT) ?**
- **enables the objects** in our environment **to become active participants,** i.e., they share information with other members of the network or with any other stakeholder and they are capable of recognizing events and changes in their surroundings and of acting and reacting autonomously in an appropriate manner.

- **create a smart world**, where the real, digital and the virtual are converging to create smart environments that make energy, transport, cities, industry and many other areas more intelligent.

Introduction (2)

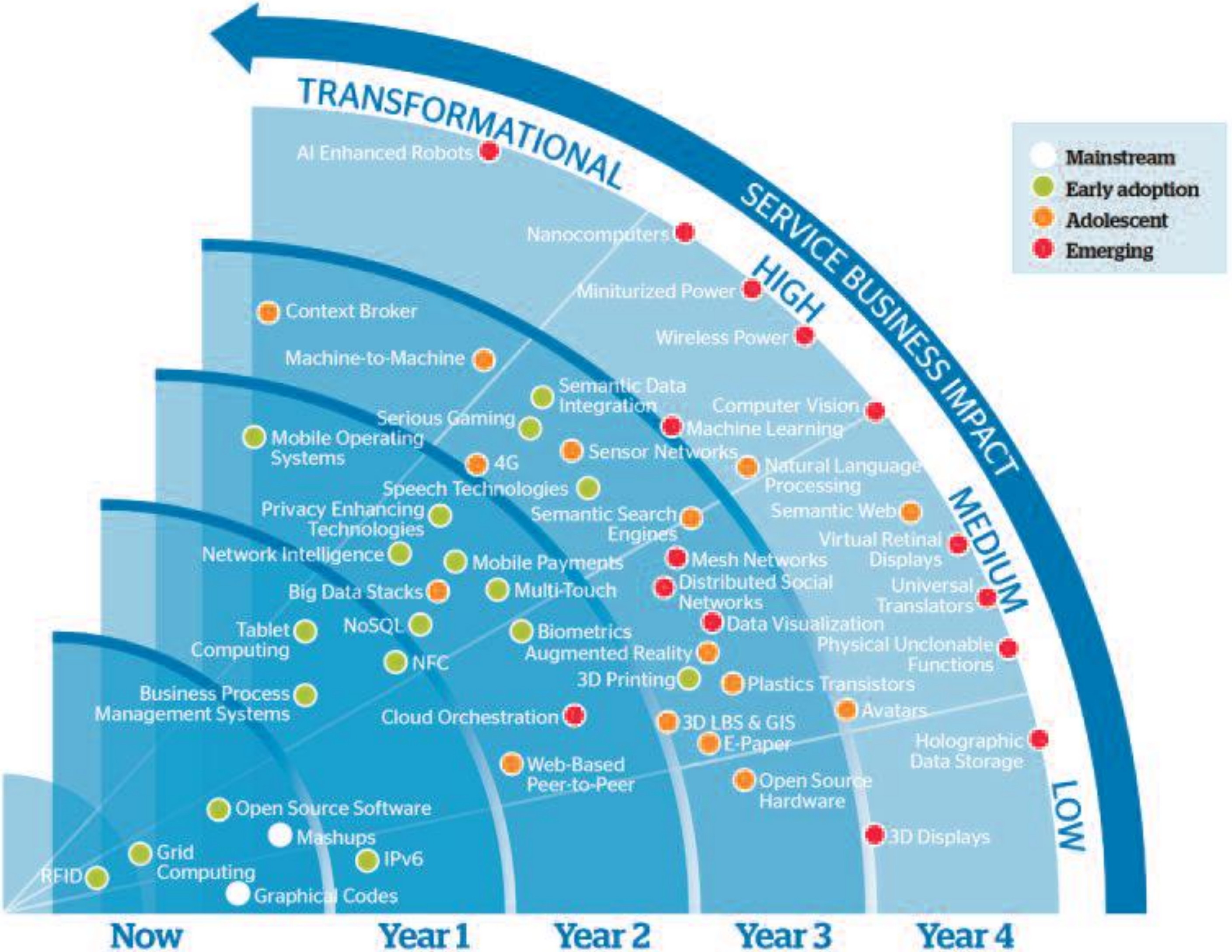
IoT Smart Environments and Applications



Enabling technologies of IoT

- Communication standards:
  - WLAN, BLE, LoRa, ZigBee, LTE-MTC, …
  - New "light" protocols: 6LoWPAN, COAP, Mesh, context routing,
  - IPv6 – address space
- Mobile Internet
  - Ubiquitous smart devices
- Semantic processing -addressing, routing, composition..
- Big Data
- Cloud/Edge Computing
- M2M
- …

Enabling technologies of IoT



2016 Enabling Information Technologies Radar

IoT challenges (1)

1. **Architecture:**
   - development and refinement of structural reference frameworks for the arrangement of physical and logical hard– and software components, including questions of object identification, virtualisation and decentralisation; also ensuring interoperability across application sectors – for huge number of devices.
2. **Interfaces:**
   - integration of multi-modal interface approaches for enabling interaction between heterogeneous devices

IoT challenges (2)

3. **Smart sensors:**
   - integration of sensing and reasoning capabilities into networked and energy-harvesting devices.

4. **Security, Trust and Privacy**
   - development of mechanisms and frameworks (by design) for ensuring that all users in business and private contexts trust the applications and maintain a certain power of control on their data across the full data and information life cycle.

IoT challenges (3)

5. **Software and middleware platforms:**
   - support for analysis and processing of data flows from sensing devices and a high quantity of object instances, complemented with event filtering and management capabilities and including complexity management considerations.
6. **Business models:**
   - a sound exploitation of the IoT business potential is still missing and new business models for the existing incumbents but also new and innovative players need to be developed.

IoT challenges (4)

8. Testing and Standardization:

- current IoT dispositions are still ongoing and effects on mass deployments need to be much better understood. Testing and large-scale pilots are absolutely crucial and should also lead subsequently to standardization for ensuring interoperability and reducing complexity.

IoT challenges (5)

9. **Societal and ethical implications:**
   - the IoT has already started to change our lives virtually but questions about the physical and logical usage coupled with considerations of needs for privacy, inclusiveness of the society and evolution of social behaviour remain very valid and only partly addressed.
   - IoT Governance: often misunderstood, IoT Governance is, in particular about the governance of the Things and their context of usage rather than Internet aspects. New models, mechanisms and frameworks covering legal aspects too are necessary for guaranteeing proper trust, identity and liability management.

IoT challenges (6)

11. **International and multidisciplinary cooperation:**
    - IoT is a truly global subject which shows interesting application cases in different parts of the world. Moreover, as it will only work if a certain level of interoperability is maintained, a common understanding among the different nations involved is pivotal.
    - Integration of results from other disciplines: basic ICT, robotics, nanotechnology, biomedicine and cognitive sciences provide a rich source of inspiration and applications for developing the Internet of things further on.

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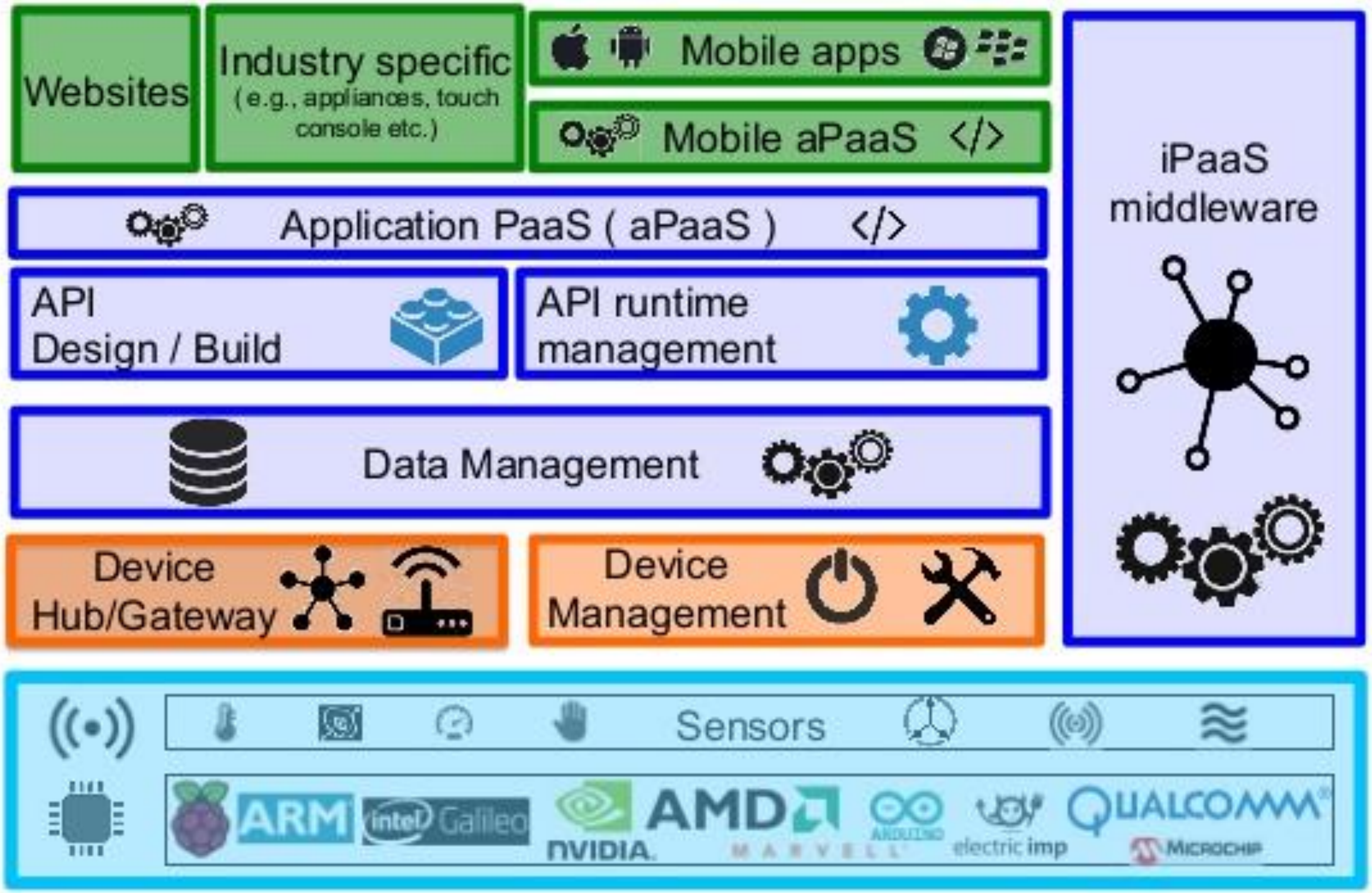
IoT Architecture (1)

- IoT is a complex ecosystem



Source: MuleSoft

IoT Architecture (2)

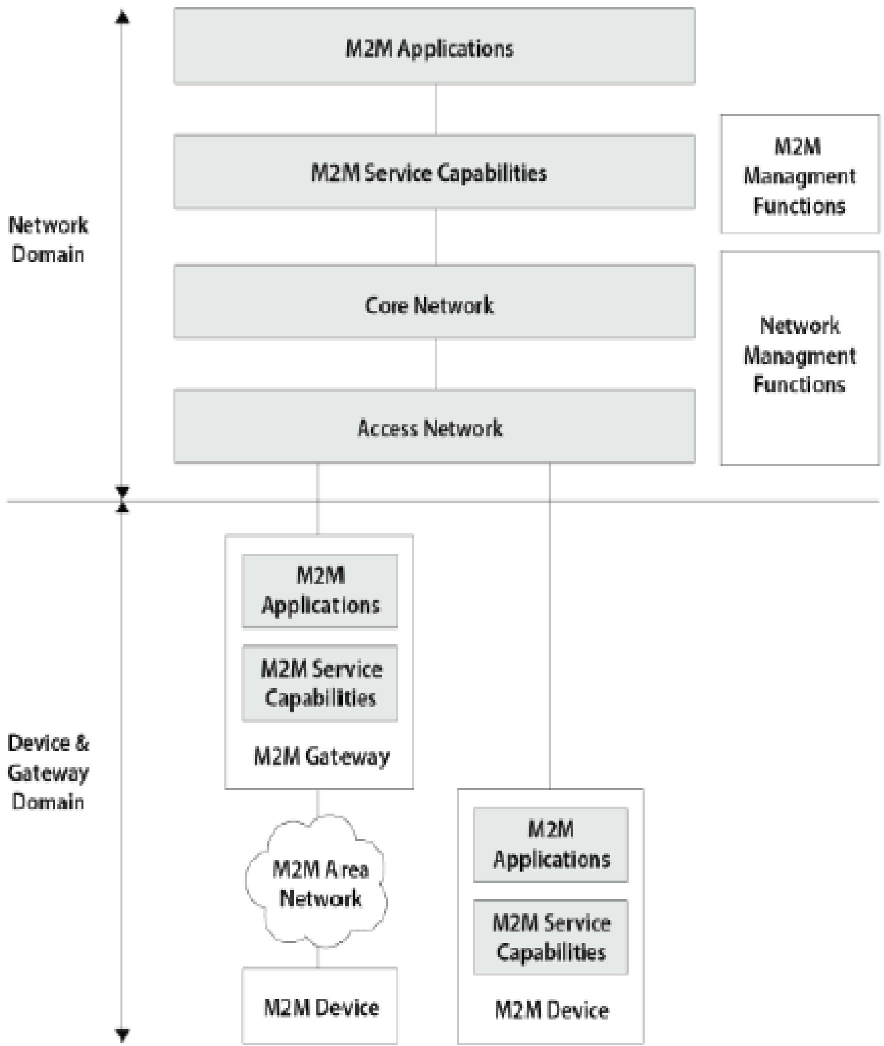
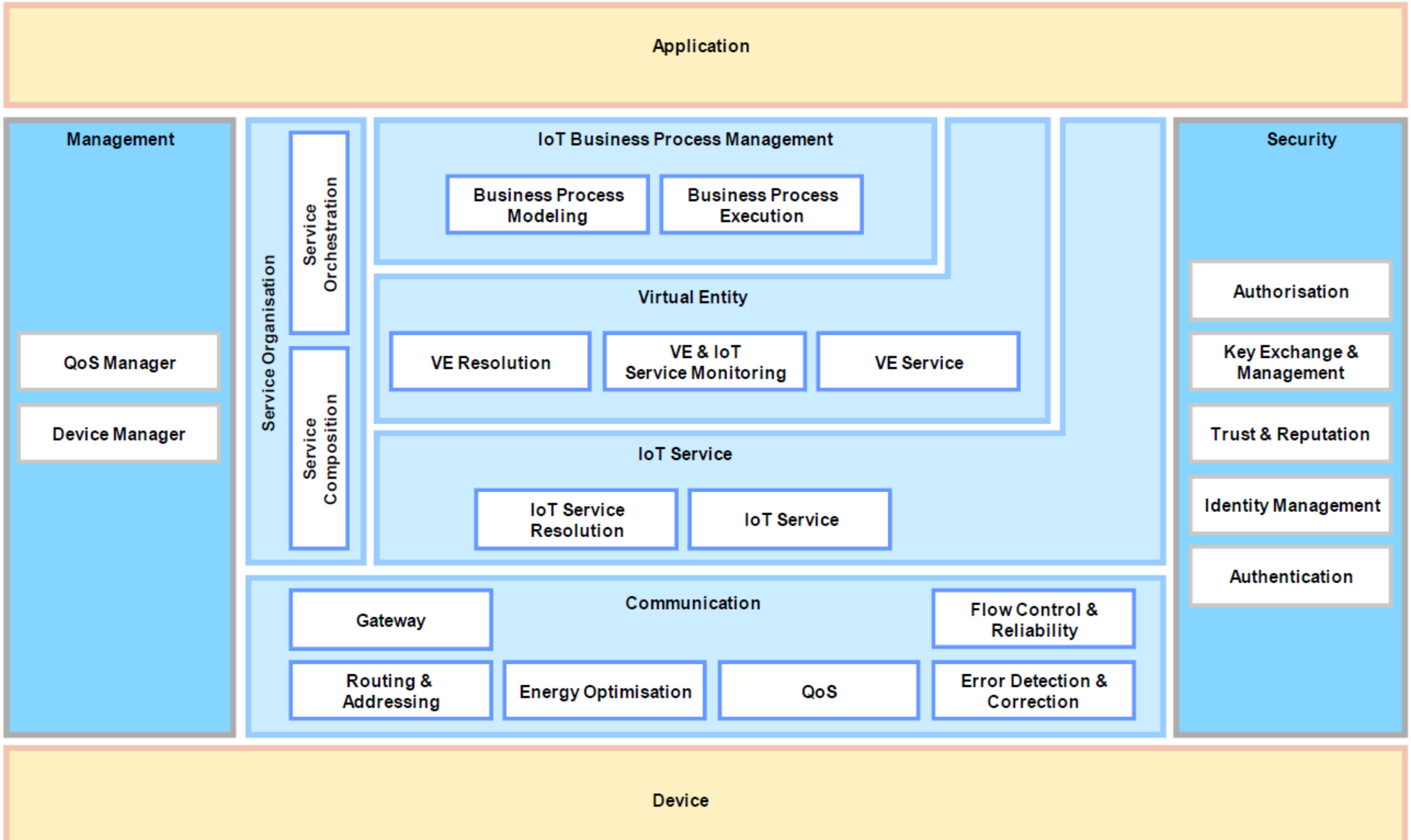


Figure 1: ETSI M2M top-level architecture

- ETSI architecture
  - Device & gateway domain
    - gathering data & communication
  - Network domina
    - processing data & applications (logic)

IoT Architecture (3)

- IoT-A Vision of IoT functionalities



Standardisation (1)

- „The concept of connecting any object to the Internet could be one of the biggest standardization challenges and the success of the IoT is dependent on the development of interoperable global standards."
  - IoT communication – most advanced
  - IoT service, orchestration, platforms etc... – some initiatives, e.g. smartM2M (oneM2M), IEEE P2413 WG, …
  - IoT Interoperability..

Standardisation (2)

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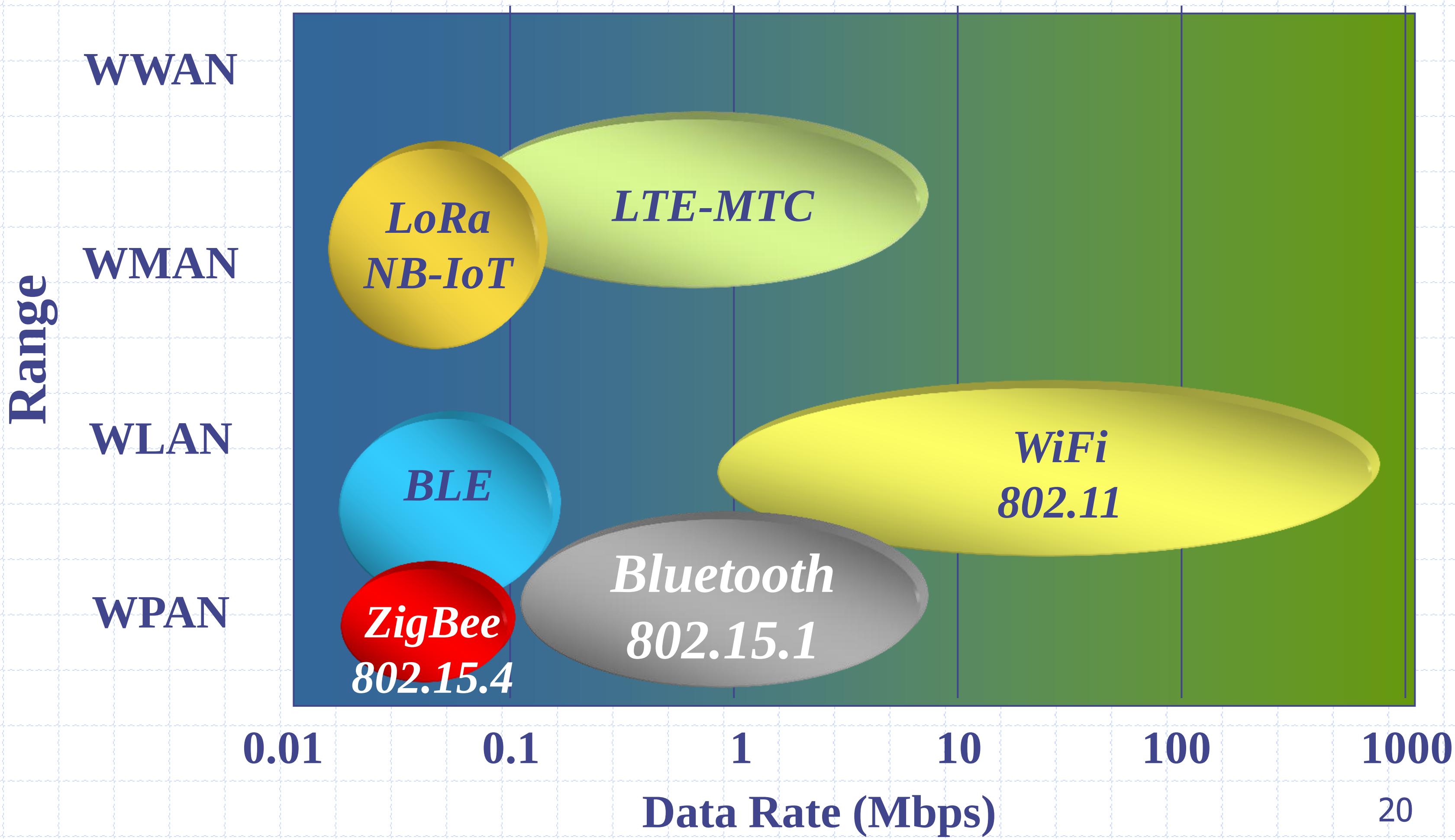
IoT Communication (1)

- Many standards exist: different purposes & properties

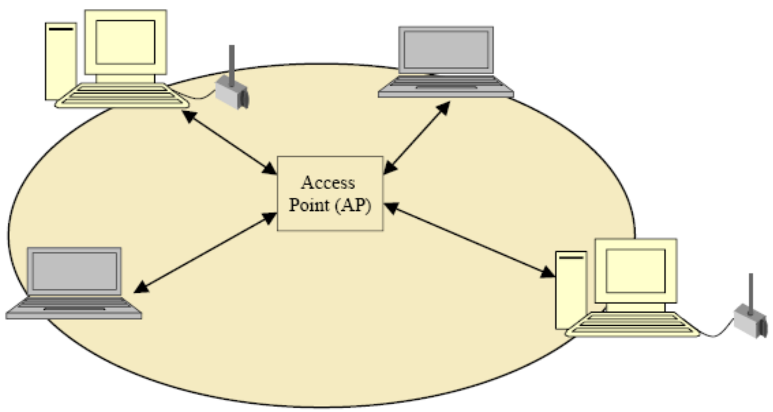


WLAN (WiFi) (1)

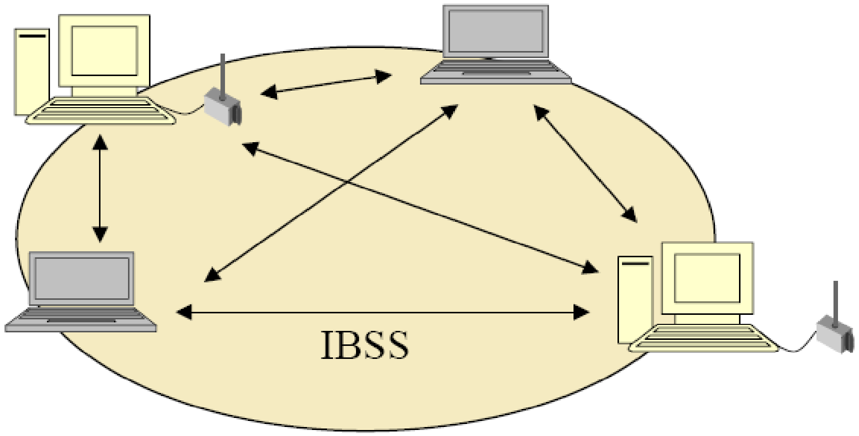
- Wireless Local Area Network (WLAN)
  - IEEE 802.11 with many, many extentions
- Objective:
  - Access to Internet, communication between ad hoc devices
  - Medium cost devices
- Frequency band:
  - 2.4 Ghz - 802.11, 802.11b, 802.11g
  - 5 Ghz - 802.11a, 802.11n, 802.11ac
  - 60 Ghz – 802.11ad
- Physical data rate:
  - 1Mbps - 7 Gbps
- Range:
  - < 100m
- Features: standardised (many extensions), matured (but new extensions are in progress), widely deployed, significant energy consumption

WLAN (WiFi) (2)

- Scenarios:



Infrastructure BSS



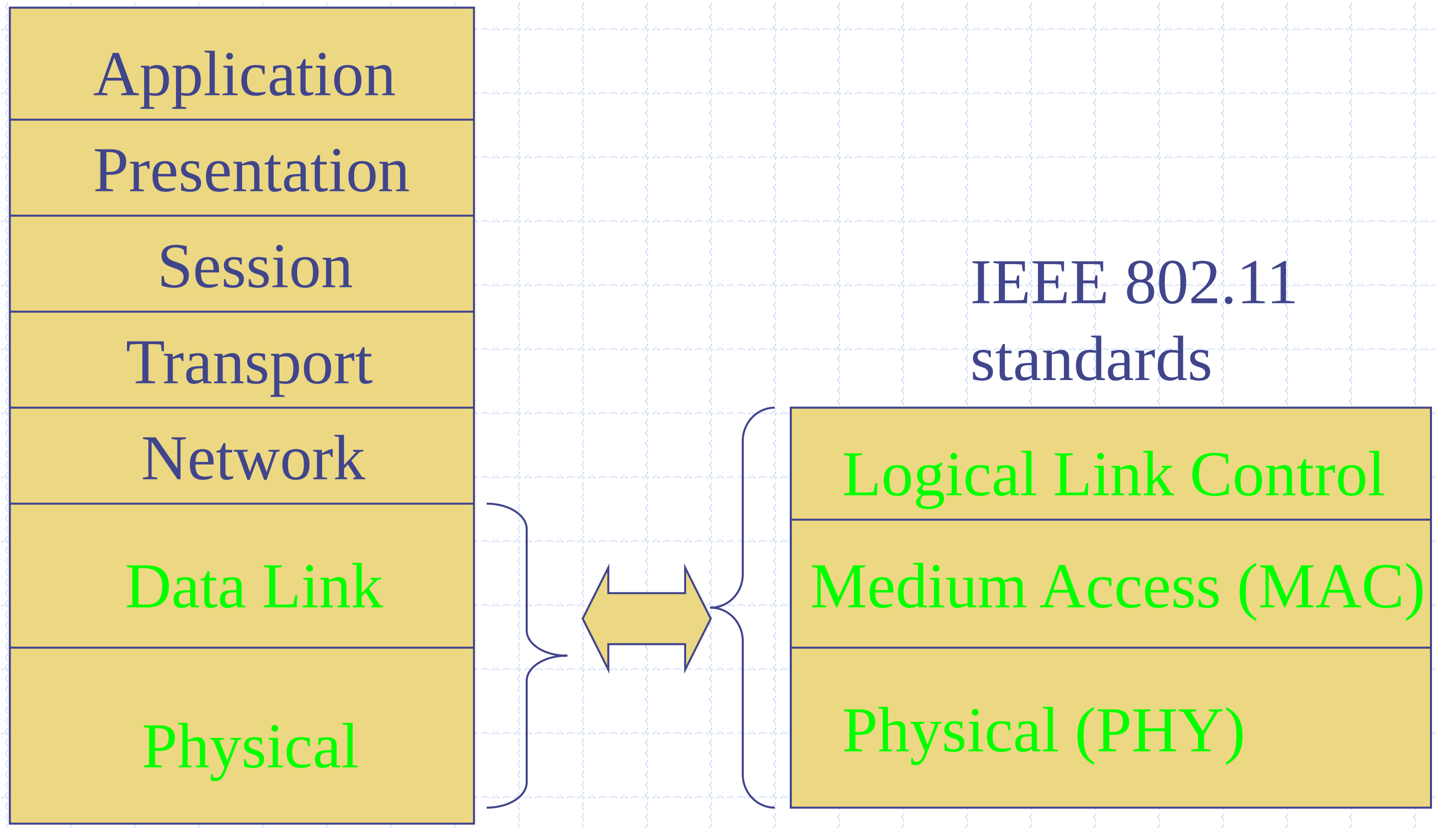
Independent BSS (ad hoc)

WLAN (WiFi) (3)

- Architecture – compliant with IEEE 802.x family

ISO
OSI
7-layer
model

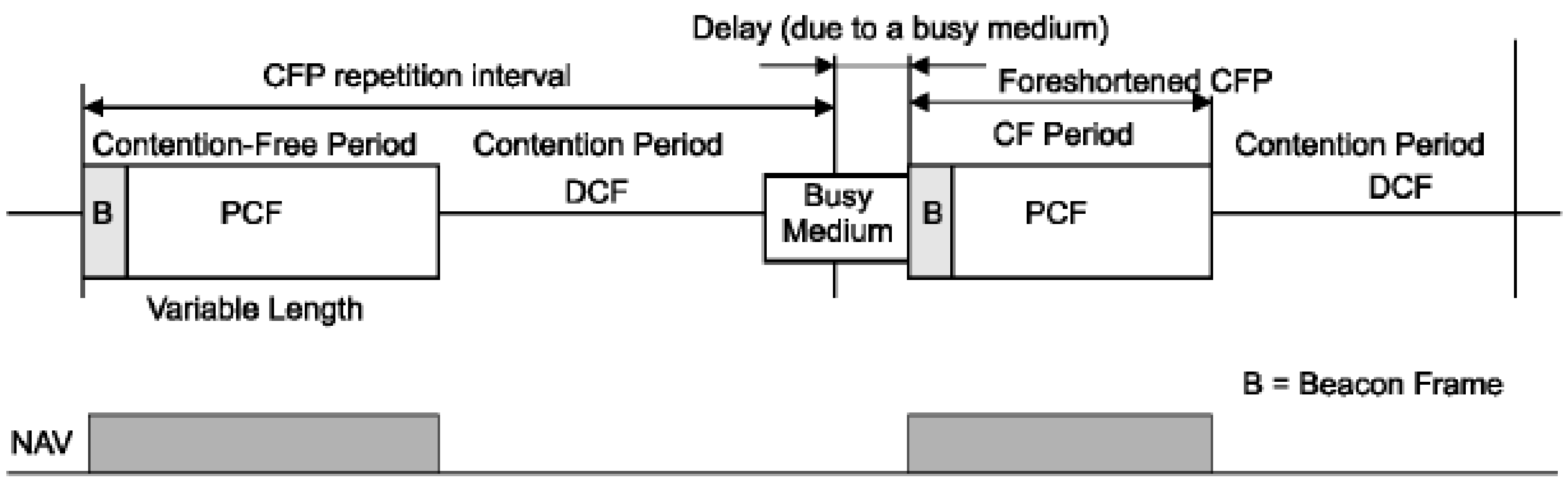
IEEE 802.11
standards



WLAN (WiFi) (4)

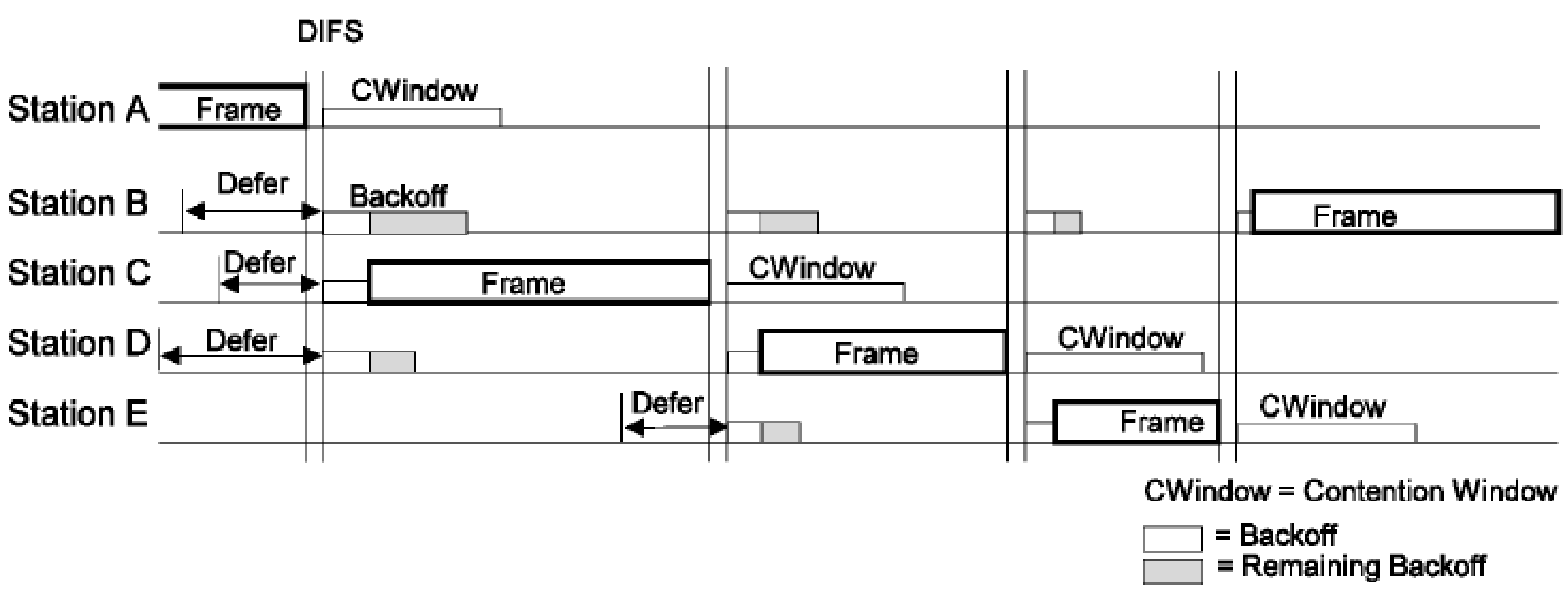
Medium Access Control Protocol - 2 modes:

- Contention based (DFC/EDCA) – CSMA/CA based, where collisions may occur
- Contention free (PFC/HCCA) – pulling based, transmission fully controlled by access point – no collision



WLAN (WiFi) (5)

- CSMA/CA uses simple rules:
  - listen before talk - wait for free channel
  - wait random backoff time to avoid collisions
  - if collision happen - double Contention Window (CW) to reduce collision probability



WLAN (WiFi) (6)

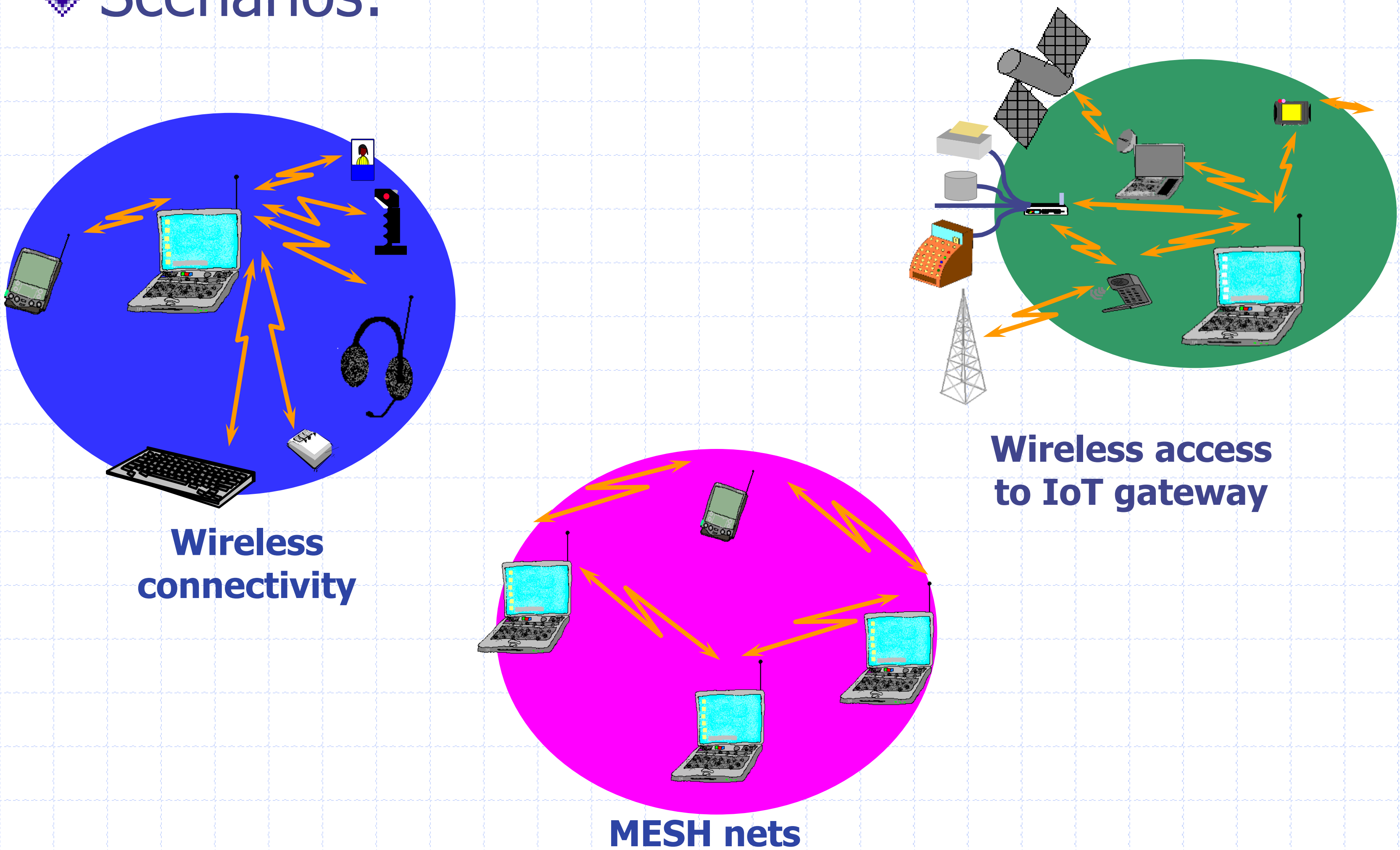
- CSMA/CA modelling - > @ lab session

Bluetooth (1)

- Wireless Personal Area Network (WPAN)
  - IEEE 802.15.1 (originally by IEEE, now is standardised by BSIG)
- Objective:
  - Short range communication between ad hoc devices
  - Low cost devices
- Frequency band: 2.4 GHz, 79 channels, each 1MHz
- Topology:
  - Star with centralised controller
- Data rates:
  - 0.72 – 24 Mbit/s
- Range:
  - < 1m, < **10m**, <100m
- Features: standardised, matured, widely available (many vendors), large energy consumption

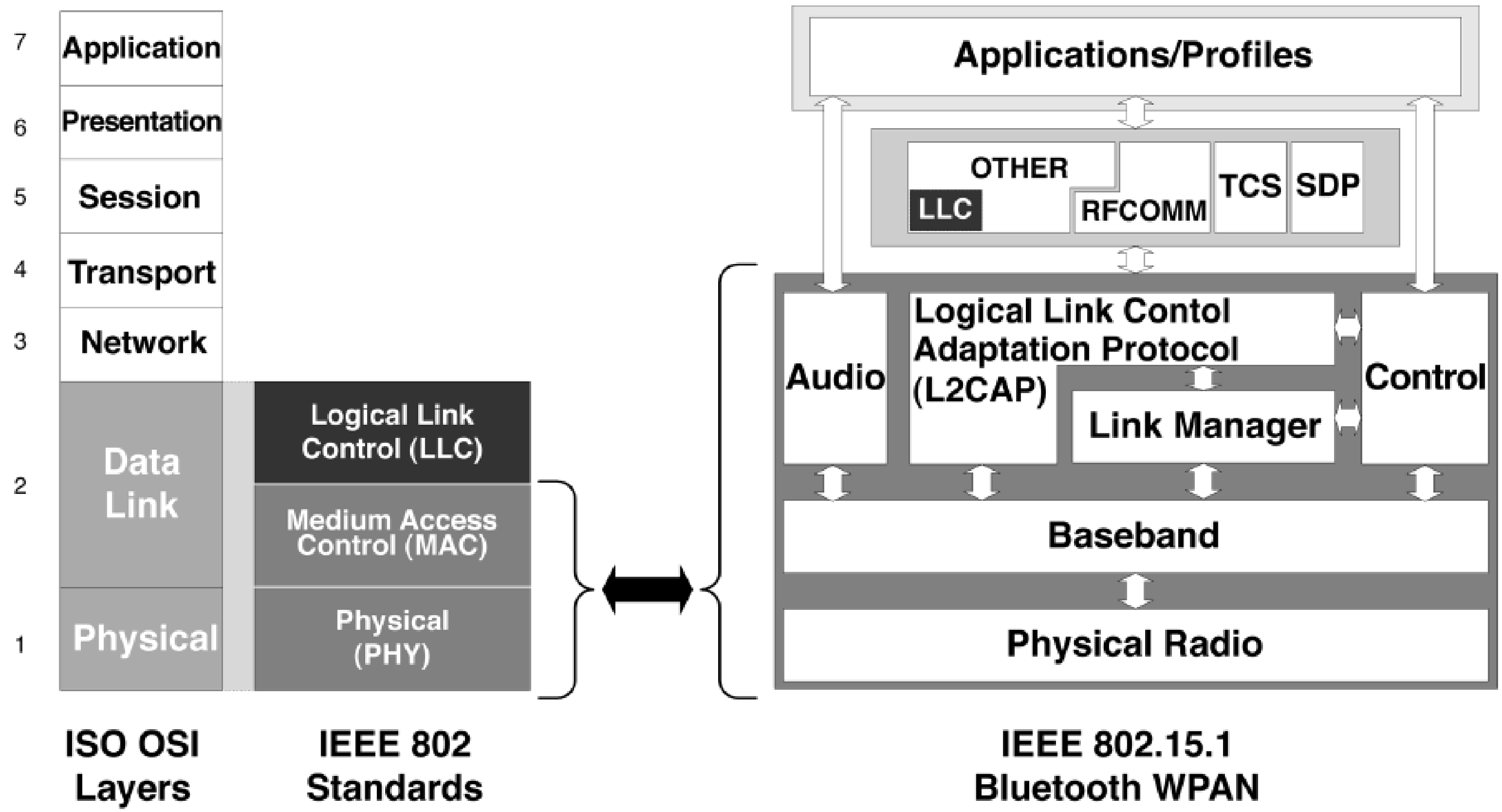
Bluetooth (2)

- Scenarios:



Bluetooth (3)

- Architecture – compliant with IEEE 802.x family



Bluetooth (4)

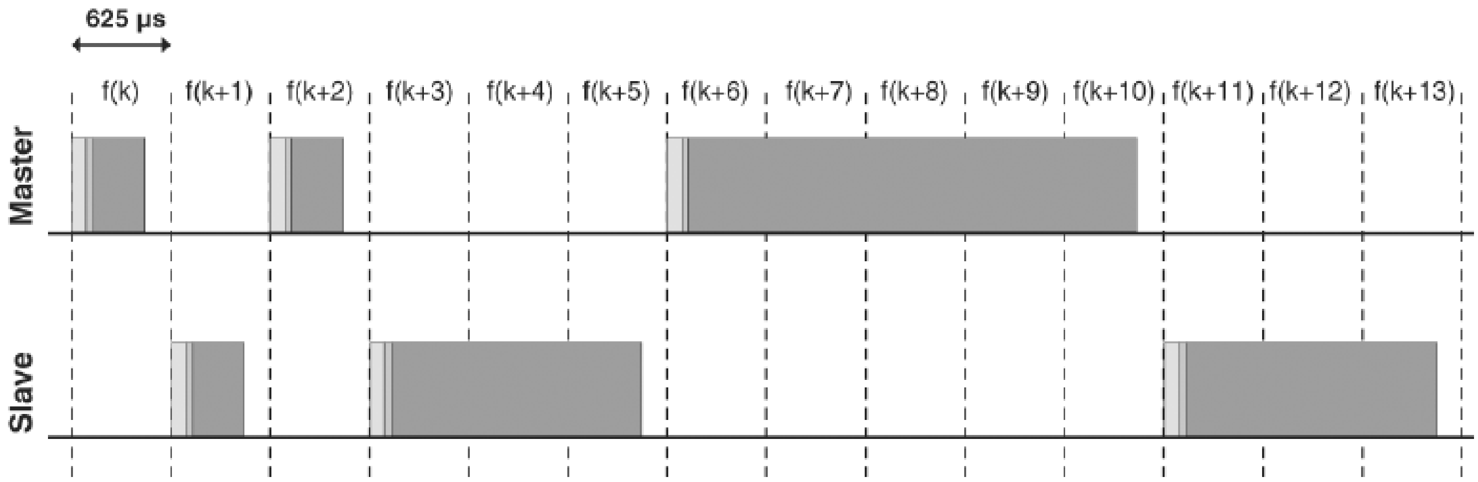
Physical layer

- Frequency band 2.402 – 2.480 GHz
  - 79 channel each 1 MHz
- Frequency Hopping Spread Spectrum
  - 1600 hops /s, managed by master node
- Modulation:
  - GFSK (Gaussian Frequency Shift Keying) – 0.72/1 Mbit/s
  - π/4 DQPSK (Diferential Quadrature Phase Shift Keying) – 2 Mbit/s
  - 8 DPSK (Diferential Phase Shift Keying) – 3 Mbit/s
- Output Power
  - Class 1: 100mW (zasięg <100m)
  - Class 2: 2.5mW (zasięg <10m)
  - Class 3: 1mW (zasięg <1m)

Bluetooth (5)

Medium Access Control Protocol

- TDMA based with TDD and centralised control (no collisions)
- Transmission in time slots (0.625 ms), data frame (max 340B) can occupy up to 5 slots
  - master station starts transmission in even slots
  - slave stations start transmission in odd slots
- Merges together circuit switching (audio streamaing) and packet switching - with QoS guaranties

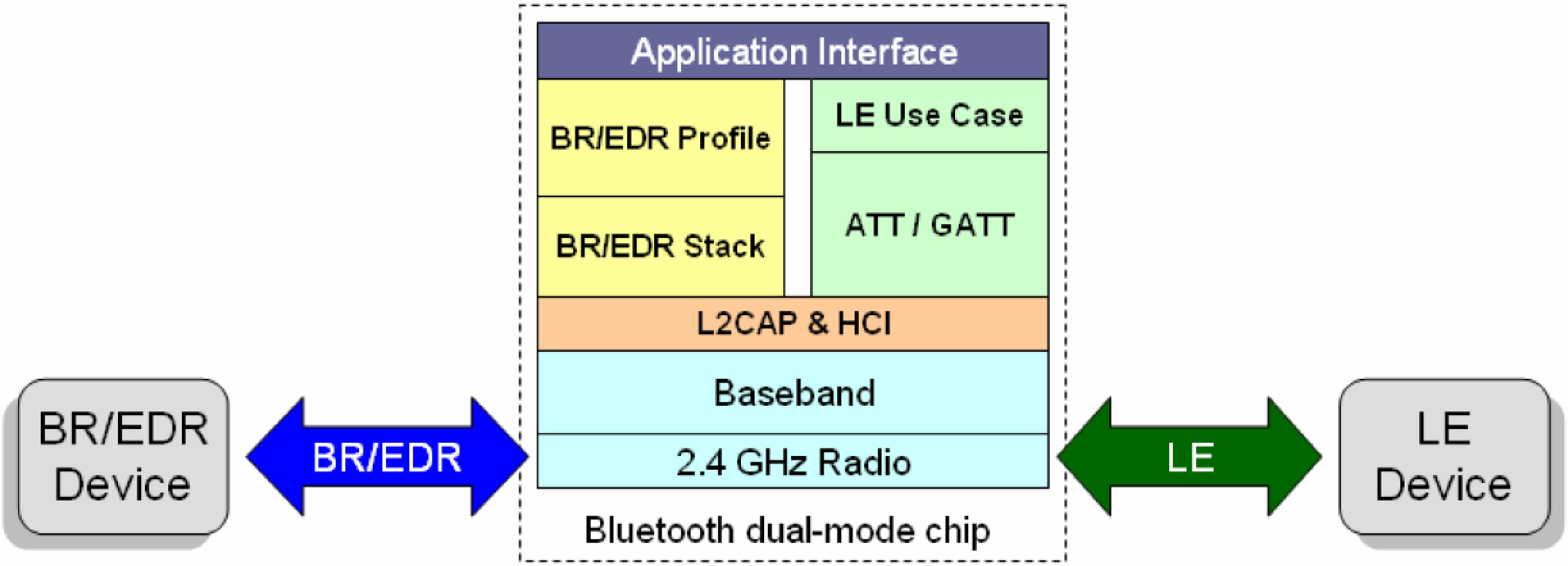


Bluetooth Low Energy (BLE) (1)

- Extension of Bluetooth - new mode which is not backward compatible
  - Defined in Bluetooth - 4.0 (2010), 4.1 (2013), and 5.0 (2016), MESH (2017)
- Objective:
  - Designed to send sporadically small packets (opposed to streaming)
    - Connect->transmit->disconnect->sleep
  - Low power consumption (15mA peak transmit, 1uA sleep)
    - Devices supplied by coin cells, e.g. CR 2032
  - Low cost devices (< 1$)
- Frequency band:
  - IMS - 2.4 GHz, 40 channels each 2MHz
- Data rates:
  - < 260 kbps
- Range:
  - < 10m, **<100m**, <200m
- Features: well standardised, emerging, becomes widely available (many vendors) but not fully compliant, very small energy

Bluetooth Low Energy (BLE) (2)

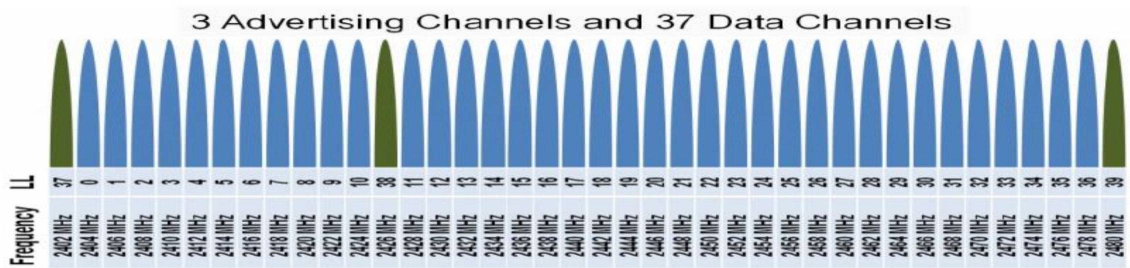
- Architecture – standalone or dual mode



Bluetooth Low Energy (BLE) (3)

Physical layer

- Frequency band 2.402 – 2.480 GHz
  - 40 channels each 2 MHz

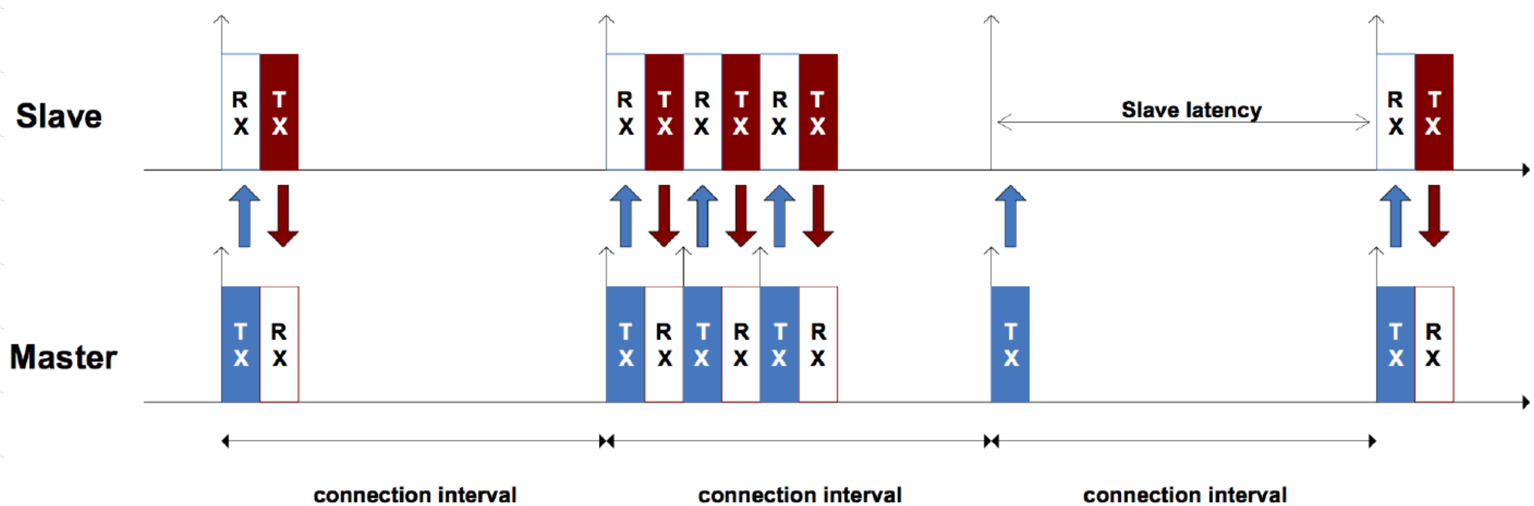


- Robust Adaptive Frequency Hopping – can coexist with WiFi
- Modulation: GFSK (Gaussian Frequency Shift Keying) – 1-2 Mbit/s
- Output Power
  - from -20dBm, up to +10 dBm (or more BLE 5.0 Long Range)
- Receiver sensitivity
  - > -70 dBm

Bluetooth Low Energy (BLE) (4)

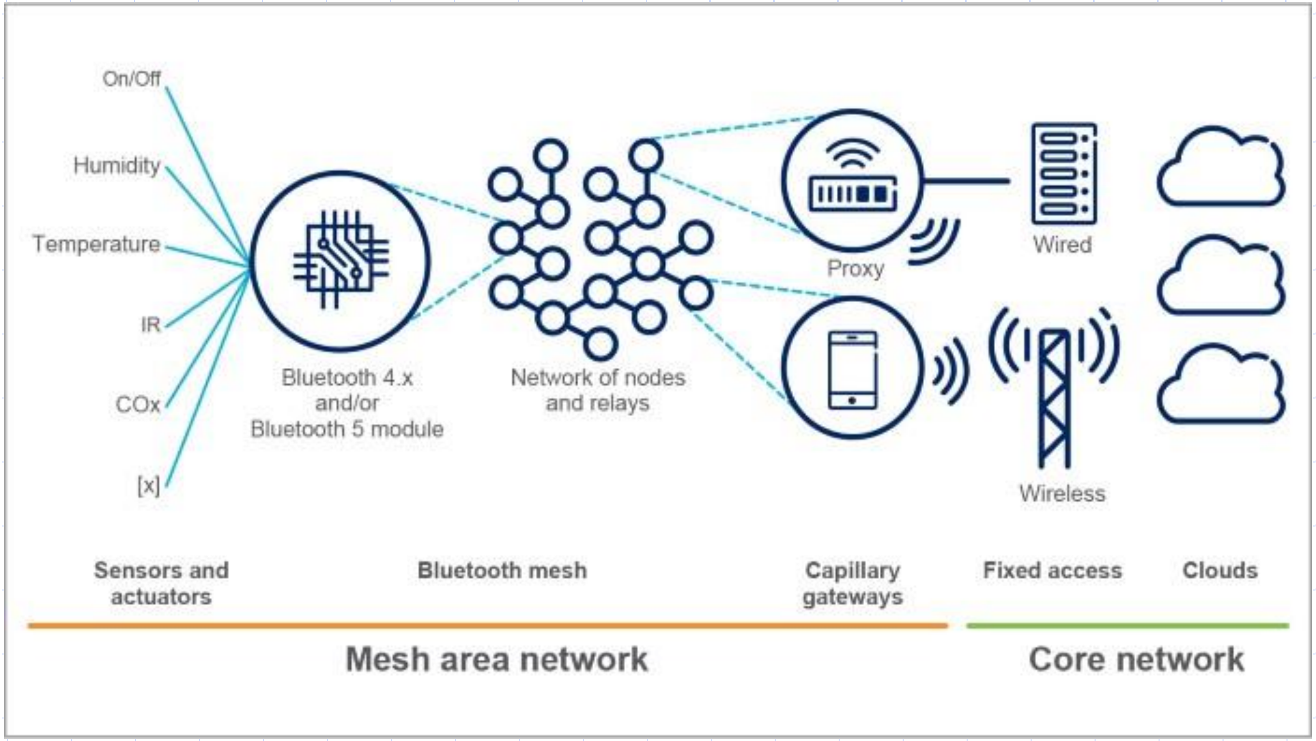
Medium Access Control Protocol

- TDMA based with TDD and centralised control (no collisions)
- Max payload size: data - 22B, advertisement - 39 B.
- Master STA: determines when slaves listen, invites slave, determines frequency hopping, initiate transmission
- Slave STA: responses to master requests
- Low connection time <3ms



Bluetooth Low Energy (BLE) (5)

- Bluetooth MESH Profile (July 2017)
  - publish/subscribe rules
  - flooding with restricted relaying
  - power saving with "friendship"

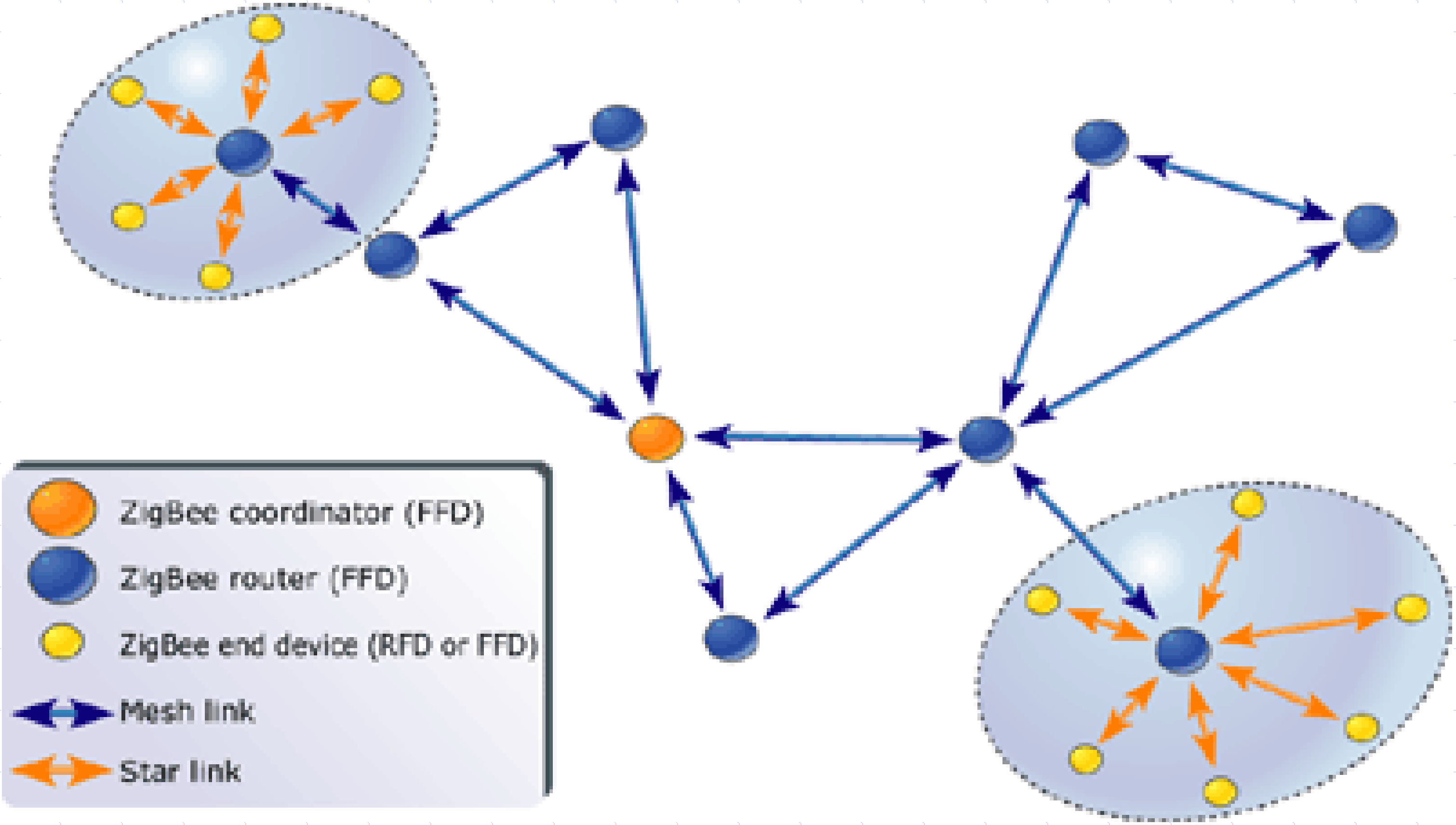


ZigBee (1)

- Wireless Personal Area Network (WPAN)
  - IEEE 802.15.4 - fully compliant with IEEE 802.x family
- Objective:
  - Control and Sensor Networks
  - Small data packets (up to 127B)
  - Low cost devices
- Frequency band:
  - IMS - 2.4 GHz, <250 kbps
  - 868 MHz (Europe) – 20 kbps
  - 915 MHz (US) – 40 kbps
- Range:
  - < 1m, <100m
- Features: standardised (2005), matured, available (many vendors), moderate energy consumption, support for mesh

ZigBee (2)

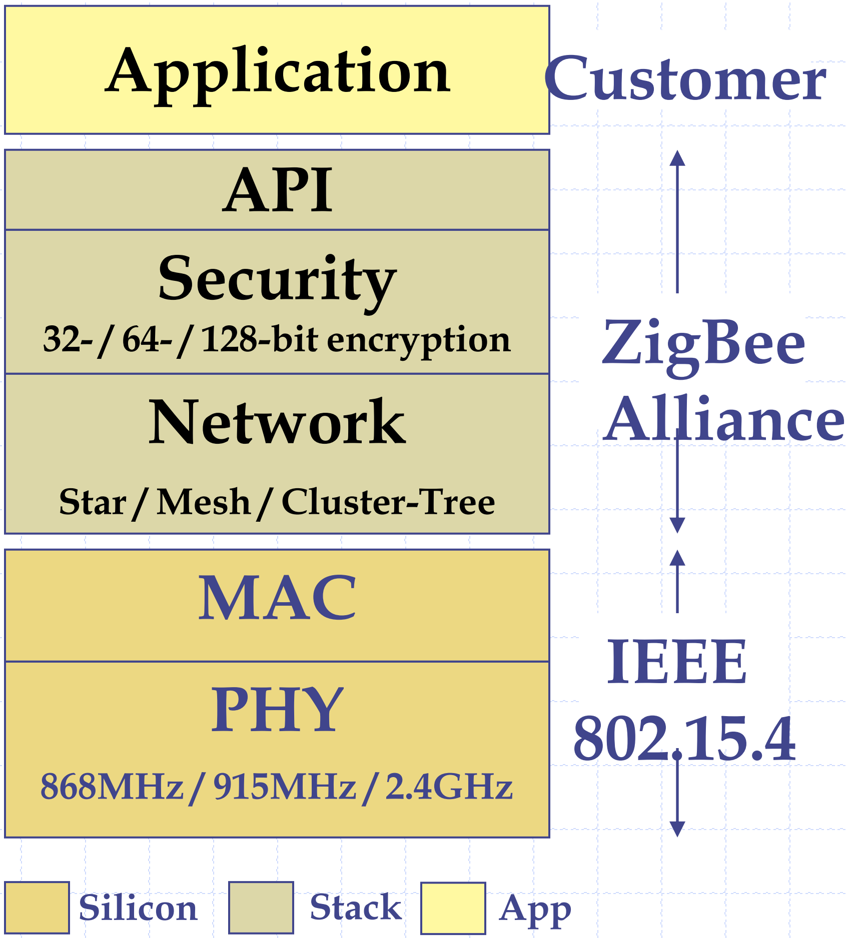
- Scenario:



Source: http://www.embedded.com/shared/printableArticle.jhtml?articleID=52600868

ZigBee (2)

- Architecture



ZigBee Alliance

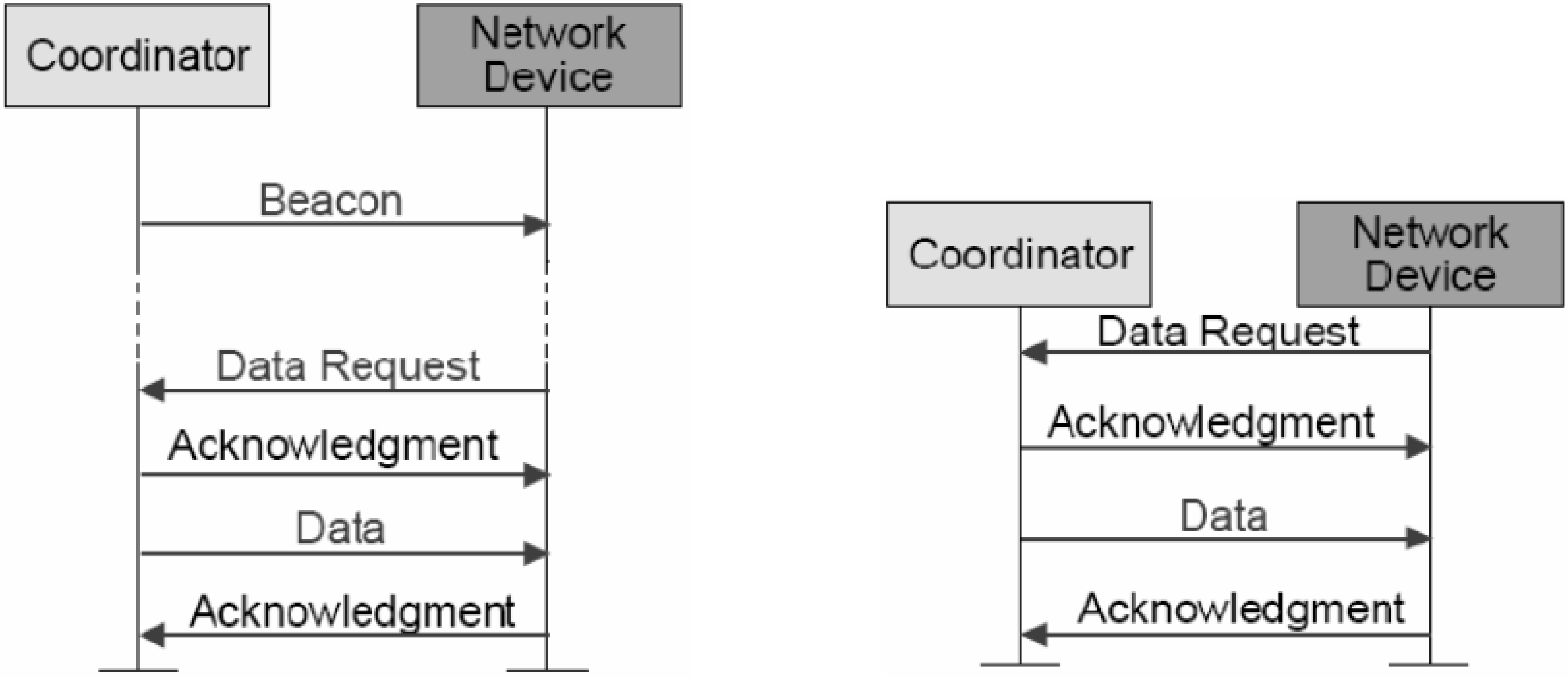
- “the software”
- Network, Security & Application layers
- Brand management

IEEE 802.15.4

- “the hardware”
- Physical & Media Access Control layers

ZigBee (3)

Medium Access Control Protocol



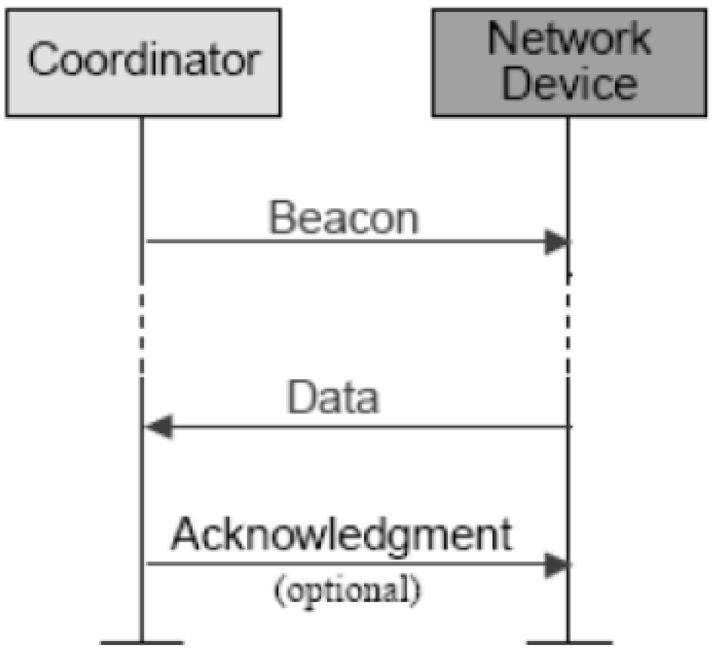
(a) Beacon-enabled network

(b) Nonbeacon-enabled network

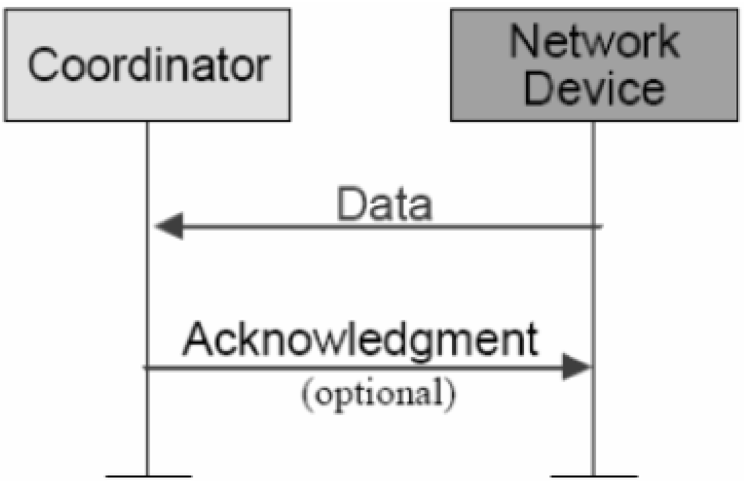
ZigBee (4)

Medium Access Control Protocol

- Examples



(a) Beacon-enabled network

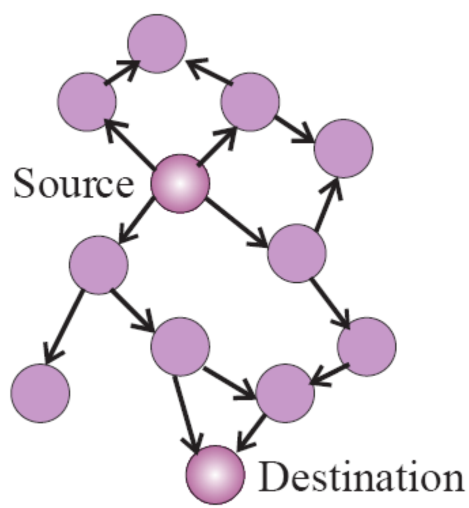


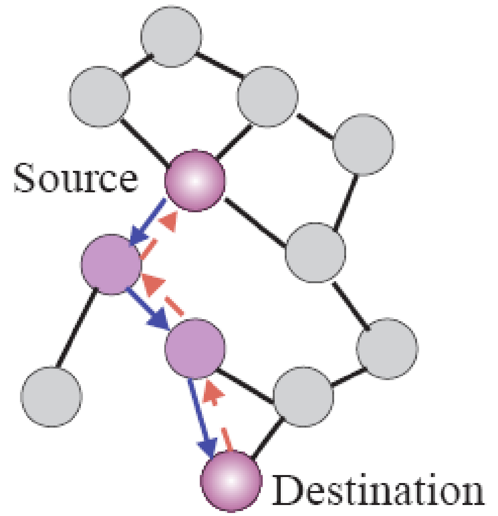
(b) Nonbeacon-enabled network

ZigBee (5)

MESH network

- Uses AODV (Ad hoc On-Demand Distance Vector)
  - Routes are creating “on demand”
  - Route discovery follows “flooding search”



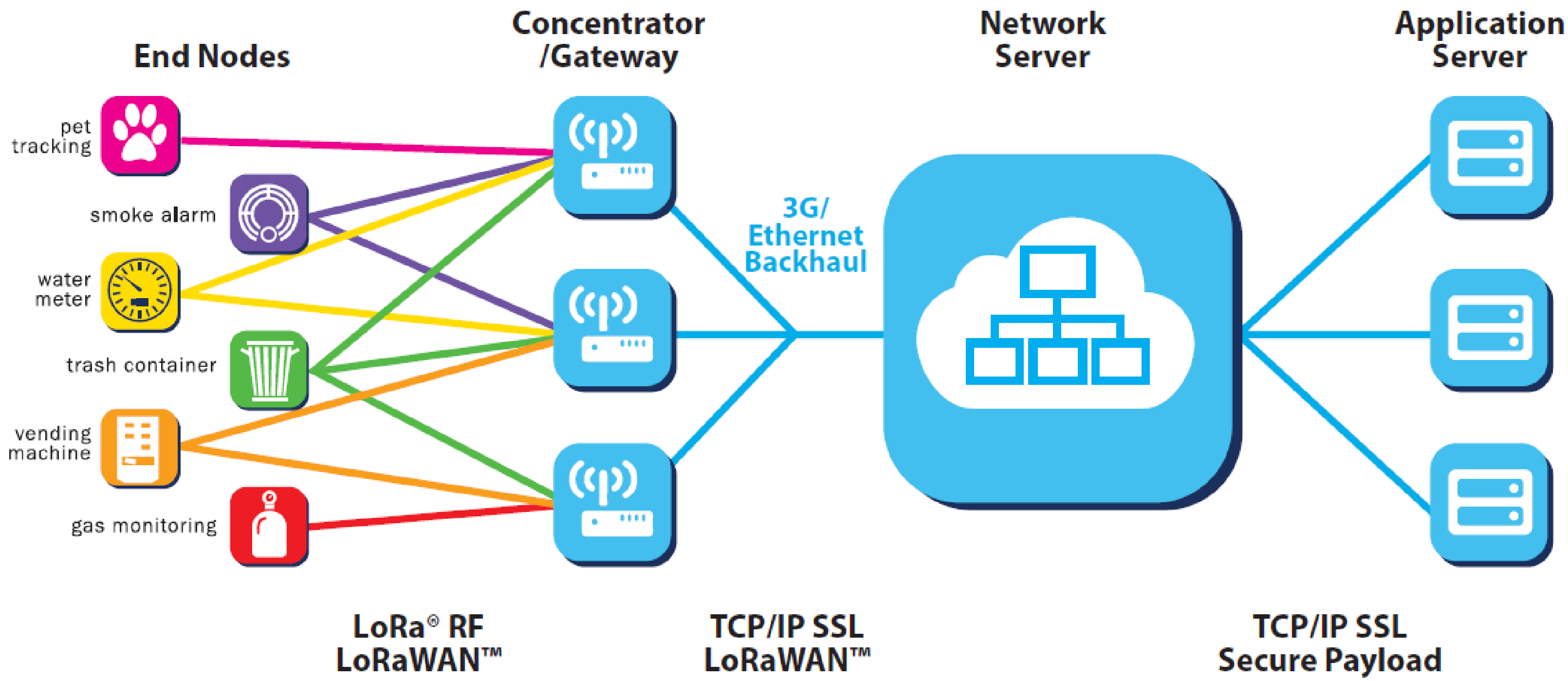


LoRa (1)

- Low–Power Wide-Area Networks (LPWAN)
  - Proprietary solution by Semtech
- Objective:
  - Long range communication to IoT devices
  - Low rate
- Frequency bands:
  - 433 MHz and 868 MHz (Europe) and 915 MHz (North America)
- Data rates:
  - 0.3 – 50 kbps
- Range:
  - < 1 - 2 km, max up to 15km (ideal propagation conditions)
- Features: proprietary solution, early development, very low energy consumption, long range

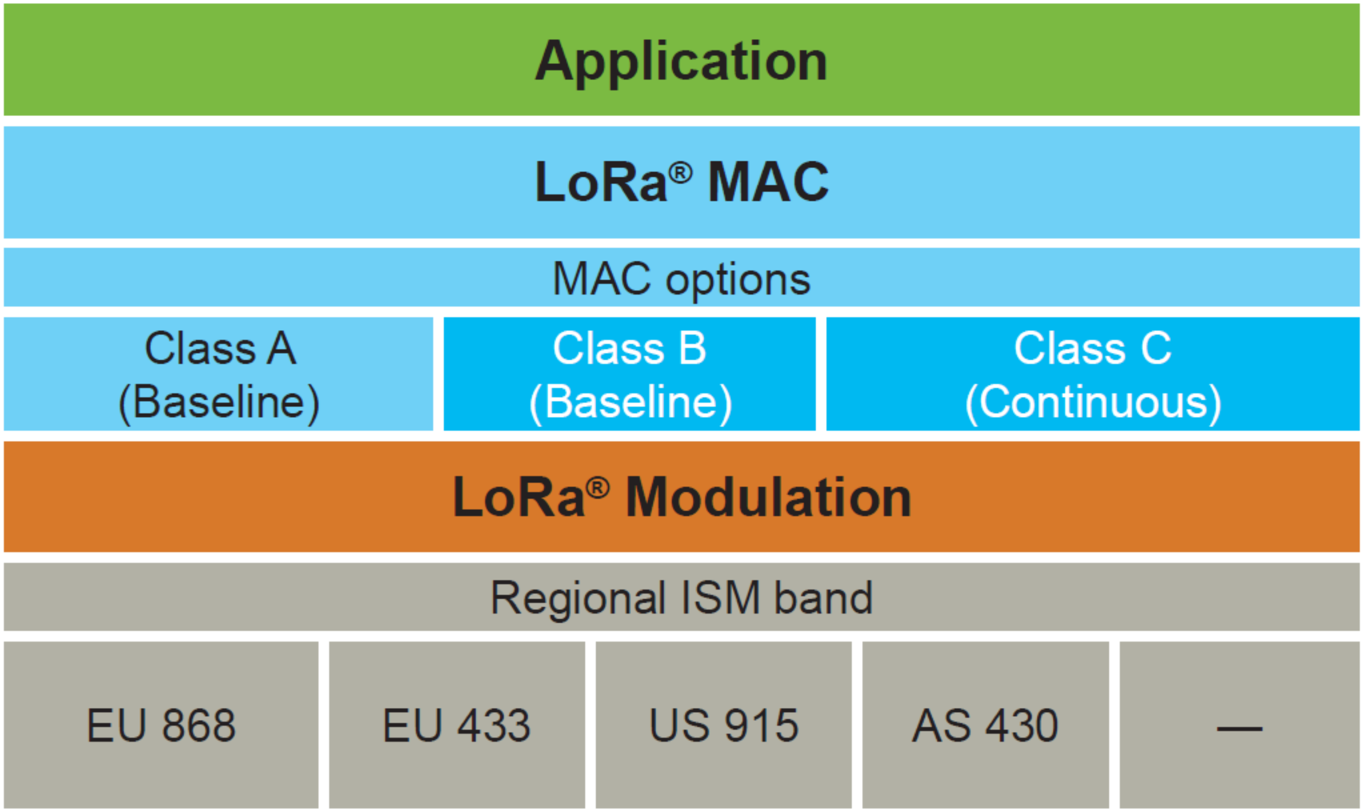
LoRa (2)

- Scenario



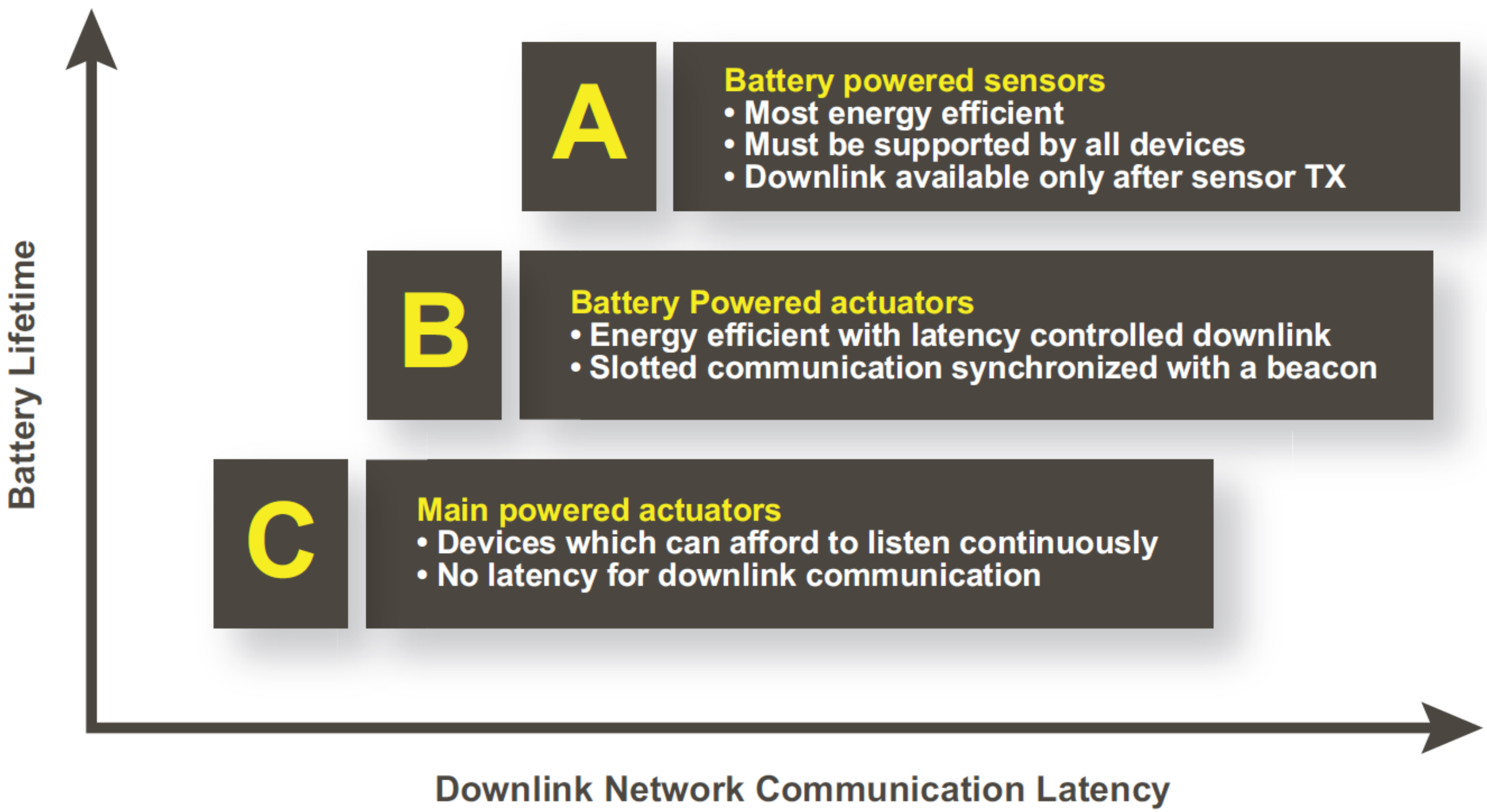
LoRa (3)

- Architecture



LoRa (4)

- 3 modes



Other communication standards for IoT

	eMTC (LTE Cat M1)	NB-IOT		EC-GSM-IoT
Deployment	In-band LTE	In-band & Guard-band LTE, standalone		In-band GSM
Coverage*	155.7 dB	164 dB for standalone, FFS others		164 dB, with 33dBm power class 154 dB, with 23dBm power class
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx	OFDMA, 15 KHz tone spacing, 1 Rx		TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx
Uplink	SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM	Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code		TDMA/FDMA, GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 KHz		200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]
Peak rate (DL/UL)	1 Mbps for DL and UL	DL: ~50 kbps UL: ~50 for multi-tone, ~20 kbps for single tone		For DL and UL (using 4 timeslots): ~70 kbps (GMSK), ~240kbps (8PSK)
Duplexing	FD & HD (type B), FDD & TDD	HD (type B), FDD		HD, FDD
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX		PSM, ext. I-DRX
Power class	23 dBm, 20 dBm	23 dBm, others TBD		33 dBm, 23 dBm

6LoWPAN

- IPv6 over Low-Power Wireless Personal Area Networks
- Method to adapt IPv6 into WPAN environment:
  - Compress IPV6 header: form 48 B - > 7 B
  - Fragment and reassembly packets
  - IP Ruting
- Specifications about
  - Zigbee
  - BLE

MQTT

- Message Queue Telemetry Transport (MQTT) is:
  - publish/subscribe messaging transport protocol
  - light weight, open, simple
  - standardised: ISO/IEC 20922:2016 (2016)
  - Many implemetations & widely used
    - Facebook messenger
    - *Amazon IoT*
    - Microsoft Azure IoT Hub

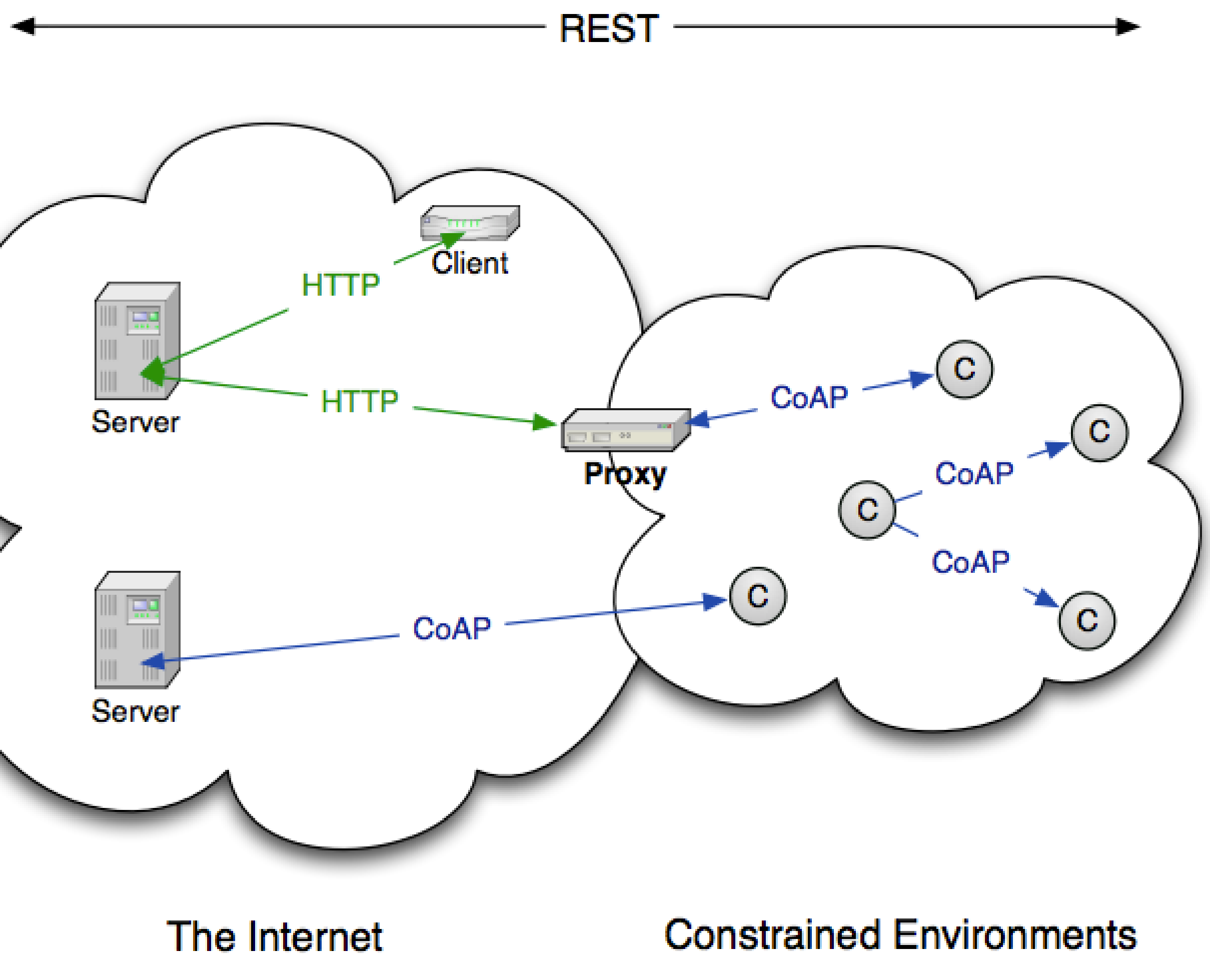
CoAP Protocol (1)

- CoAP - Constrained Application Protocol (RFC 7252) is one of key IoT standards enabling **Web of Things**

- Like HTTP, CoAP is based REST based (Representational State Transfer) protocol:
  - Servers make resources available under an URL
  - Clients access these resources using methods such as GET, PUT, POST and DELETE.

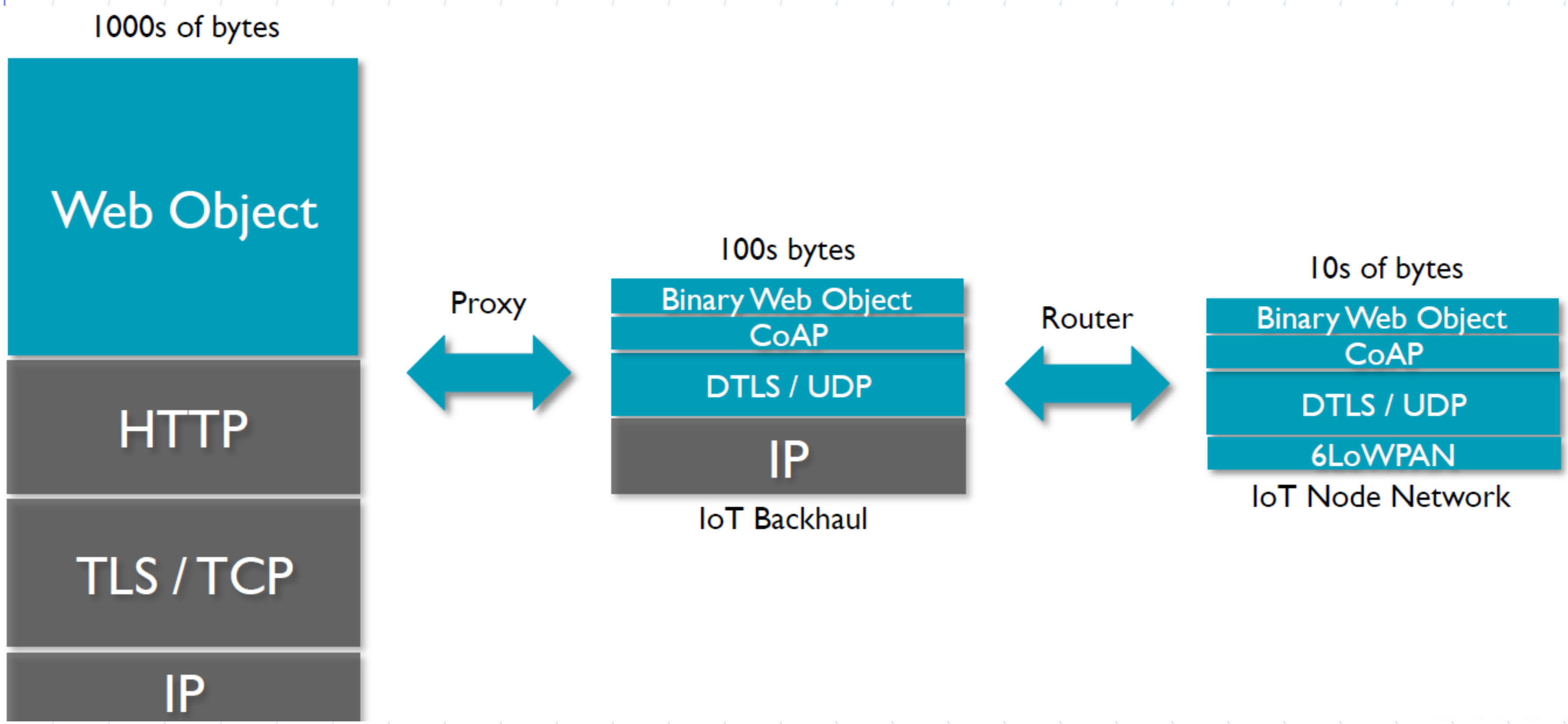
CoAP Protocol (2)

- Scenario



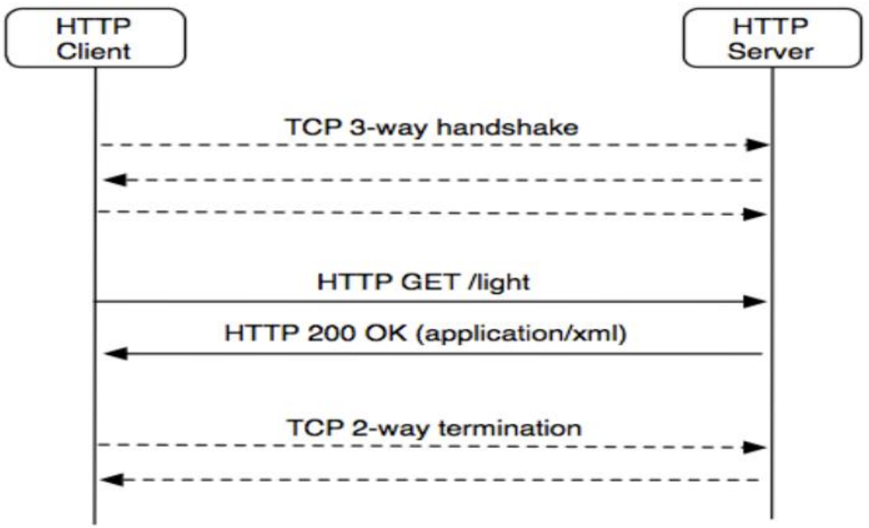
CoAP Protocol (3)

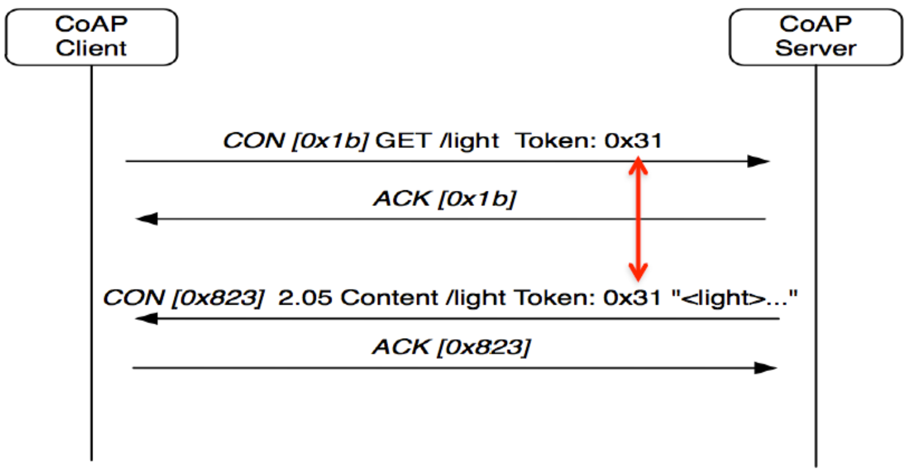
- Low header overhead (4B) and parsing complexity
- UDP binding (may use IPsec or DTLS)
- Web transfer protocol (coap://)
- Reliable unicast and best-effort multicast support



CoAP Protocol (4)

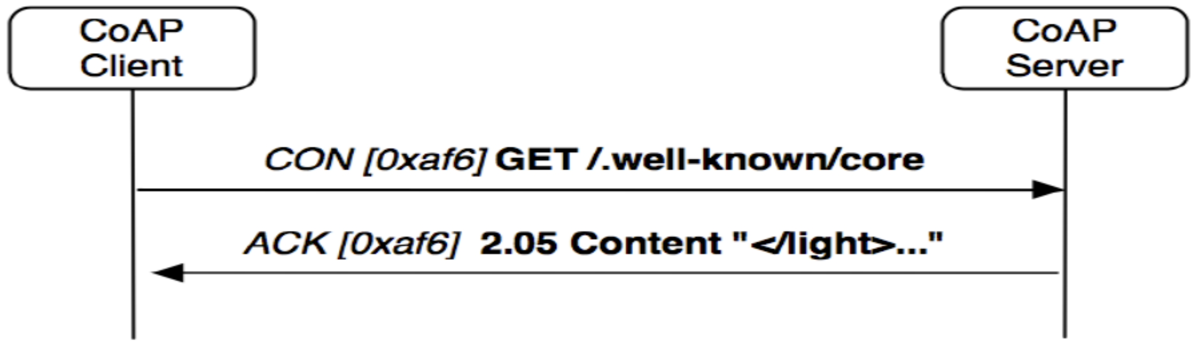
- HTTP vs. CoAP





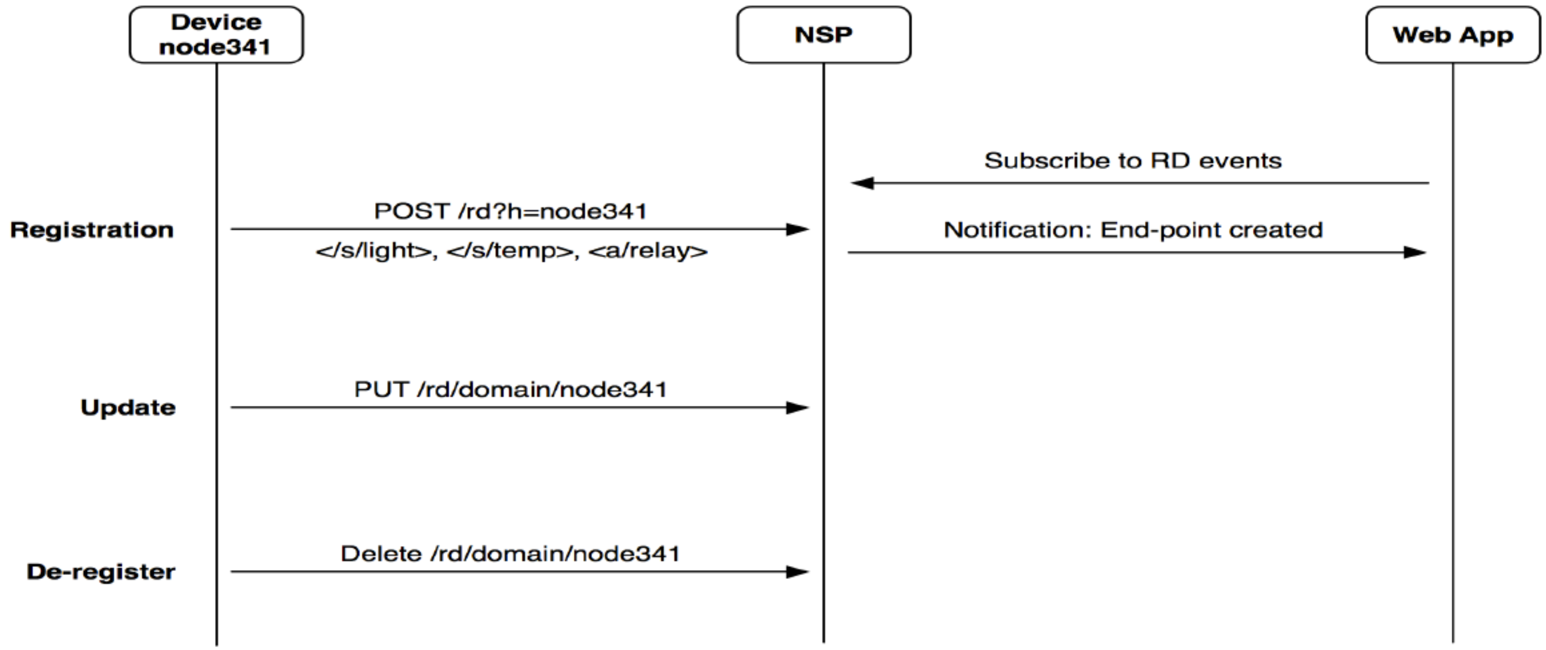
Resource discovery

- Defined RFC 6690



Resource directory

- Pub/subscribe model

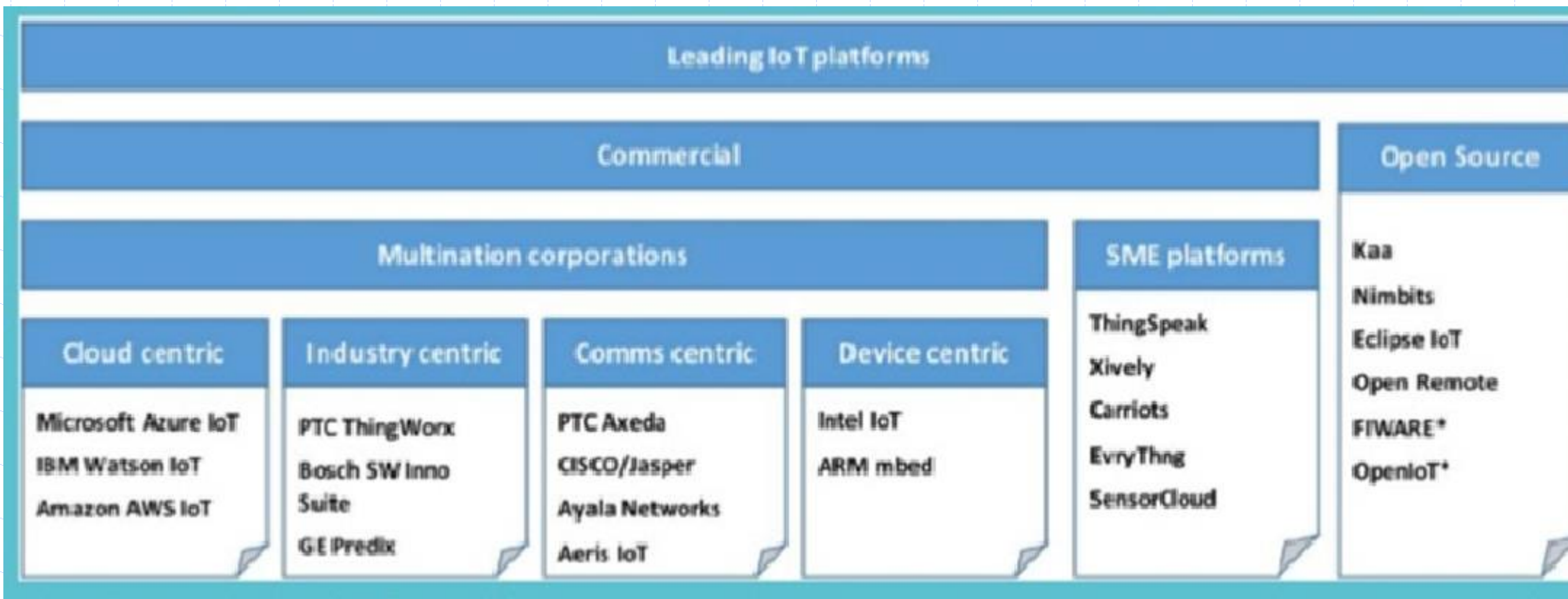


Open issues and challenges

- Naming, addressing
- Semantics
- Service discovery & composition
- Data processing (cloud/fog offloading)
- Interoperability

IoT Platforms

- IoT platform is a support software bringing together IoT ecosystem of edge hardware, access points, data networks, clouds enabling application development



FIWARE

- Mission:
  - build an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors
- Offers:
  - a rather **simple yet powerful set of APIs** (Application Programming Interfaces) that ease the development of Smart Applications in multiple vertical sectors.

Fed4FIRE+ (1)

FED4FIRE
FEDERATION FOR FIRE PLUS

- European federation of testbeds for experimentally driven research on Future Internet
- IoT testbeds are: SmartSantnder, w-iLAB.t, PL-LAB, Perfomr LTE

WIRED TESTBEDS:

- Virtual Wall (iMinds)
- PlanetLab Europe (UPMC)
- Ultra Access (UC3M, Stanford)
- 10G Trace Tester (UAM)*
- PL-LAB (PSNC)*

WIRELESS:

- Norbit (NICTA)
- w-iLab.t (iMinds)
- NITOS (UTH)
- Netmode (NTUA)
- SmartSantander (UC)
- FuSeCo (FOKUS)
- PerformLTE (UMA)
- C-Lab (UPC)
- IRIS (TCD)*
- LOG-a-TEC (JSI)*

OPENFLOW:

- UBristol OFELIA island
- i2CAT OFELIA island
- Koren (NIA)
- NITOS (UTH)

CLOUD COMPUTING:

- BonFIRE cloud sites (EPCC , Inria)
- Virtual Wall (iMinds)

OTHER:

- FIONA (Adele Robots)*

* Currently being federated

EU Projects on IoT

- The lead project responsible for delivering the Activity Chain is OPENIOT. The projects Involved in the Activity Chain are:
  - OpenIoT
    - Open Source Solution for the Internet of Things into the Cloud
  - IOT-A
    - Internet of Things Architecture
  - EBBITS
    - Enabling the Business-Based Internet of Things and Services
  - IoT@Work
    - Internet of Things at Work
  - SPRINT
    - Software Platform For Integration Of Engineering And Things
  - CASAGRAS2
    - Coordination and Support Action for Global RFIDrelated Activities and Standardisation – 2