IoT Devices and Network Connectivity

CHRISTIAN LEGARE | JULY 17 2017

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IPSO Alliance

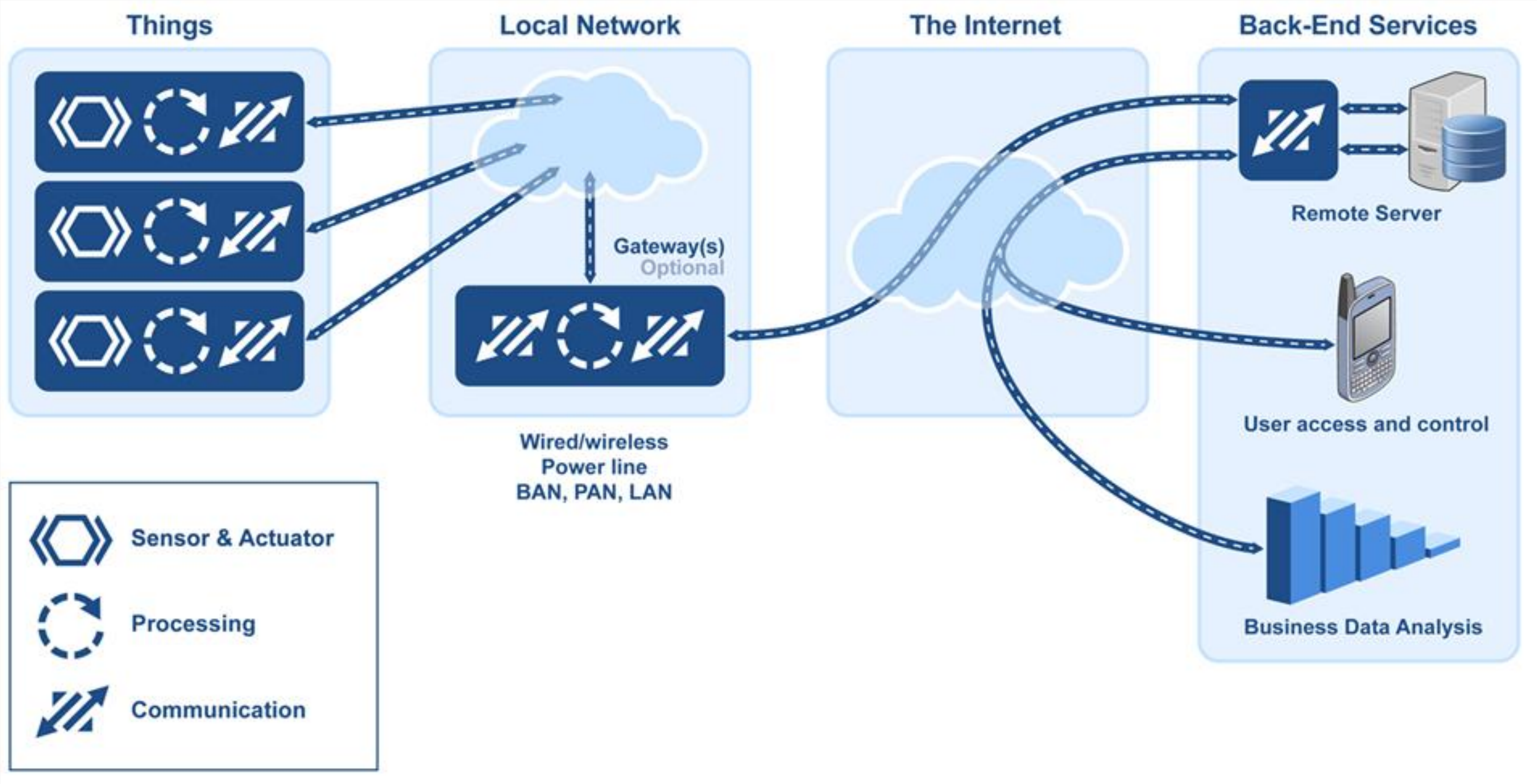
IPSO Alliance

Enabling the IoT at the Device Level

A collaborative group of organizations committed to enabling the IoT at the device level by outlining the semantic, protocol, identity, services, physical, autonomous and resource models to define a smart object and ensure smart object interoperability

www.ipso-alliance.org

Connected Device System versus IoT



IoT Building Blocks

	Layer							
Application Protocol		DDS	CoAP	AMQP	MQTT	MQTT-SN	XMPP	HTTP REST
Service Discovery		mDNS				DNS-SD		
Infrastructure Protocols	Routing Protocol	RPL						
	Network Layer	6loWPAN					IPv4 / IPv6	
	Link Layer	IEEE 802.15.4						
	Physical / Device Layer	LTE-A		EPCglobal		IEEE 802.15.4	Z-Wave	
Influential Protocols		IEEE 1888.3, IPSec				IEEE 1905.1		

Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications

Ala Al-Fuqaha, Senior Member, IEEE
Mohsen Guizani, Fellow, IEEE
Mehdi Mohammadi, Student Member, IEEE
Mohammed Aledhari, Student Member, IEEE
Moussa Ayyash, Senior Member, IEEE

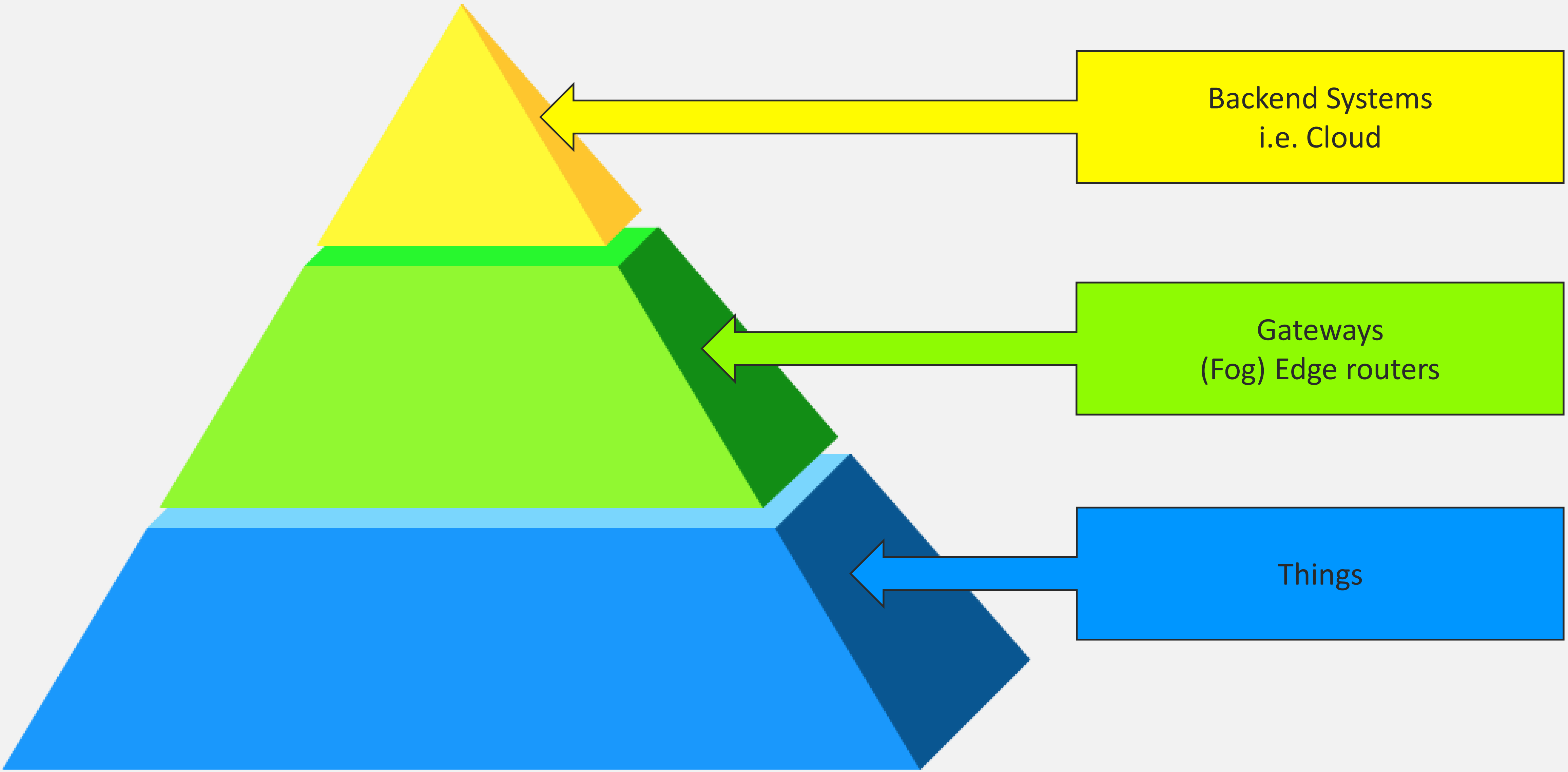
IoT Systems – Consumer vs Industrial

Even though this industry is very young, we are starting to see the emergence of two types of IoT systems

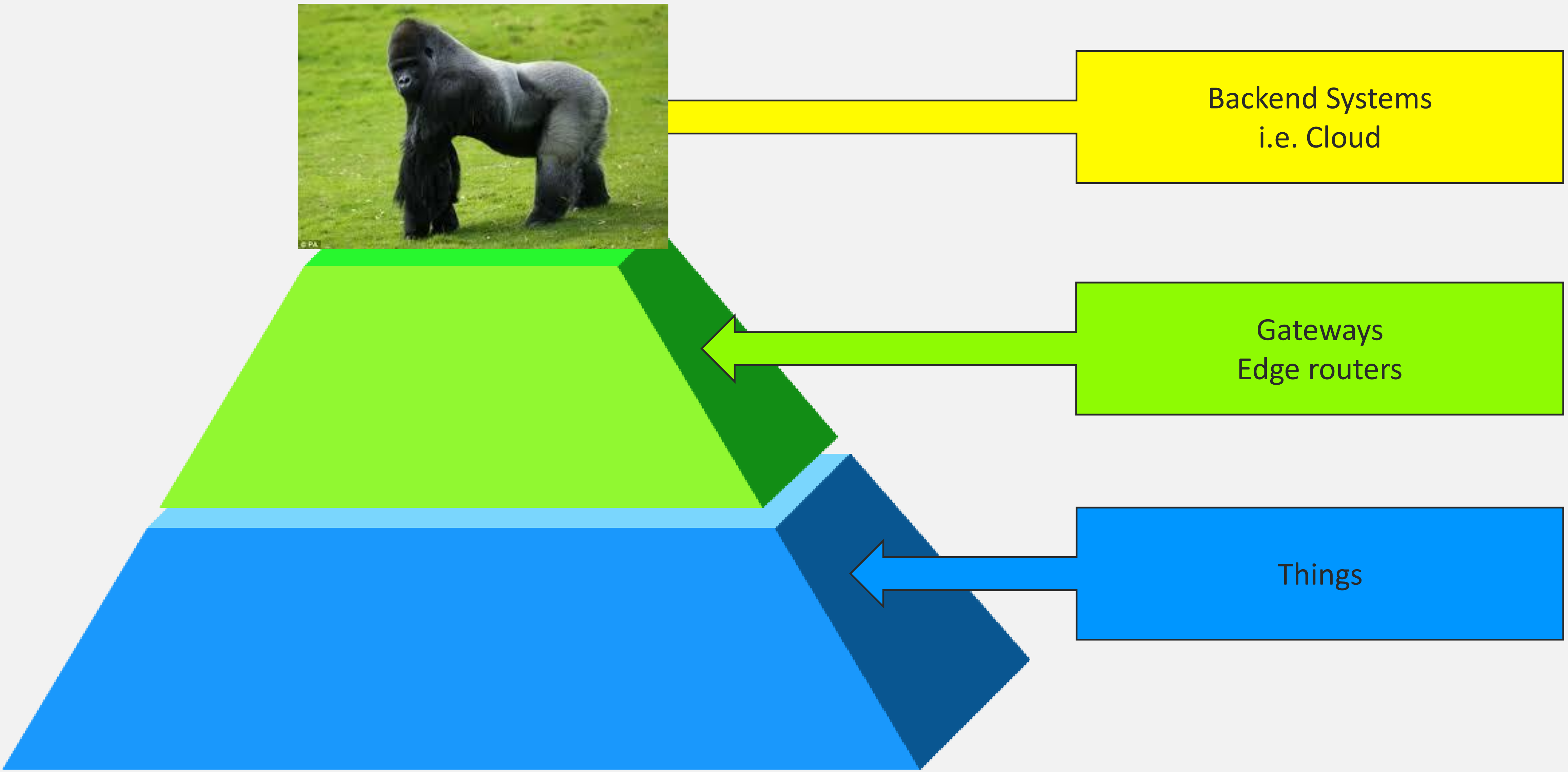
Attribute	Industrial IoT	Human IoT
Market Opportunity	Brownfield (known environment)	Greenfield (unchartered domain)
Product Lifecycle	Until dead or obsolete	Whims of style and/or budget
Solution Integration	Heterogeneous APIs	Vertically integrated
Security	Access	Identity & privacy
Interaction	Autonomous	Reactive
Availability	0.9999 to 0.99999 (4–5 ‘9’s)	0.99 to 0.999 (2–3 ‘9’s)
Access to Internet	Intermittent to independent	Persistent to interrupted
Response to Failure	Resilient, fail-in-place	Retry, replace
Network Topology	Federations of peer-to-peer	Constellations of peripherals
Physical Connectivity	Legacy & purpose-built	Evolving broadband & wireless

Source: Patrick Morehead, Forbes, “Who Wins In The Industrial Internet Of Things (IIoT)?”, October 29 2013

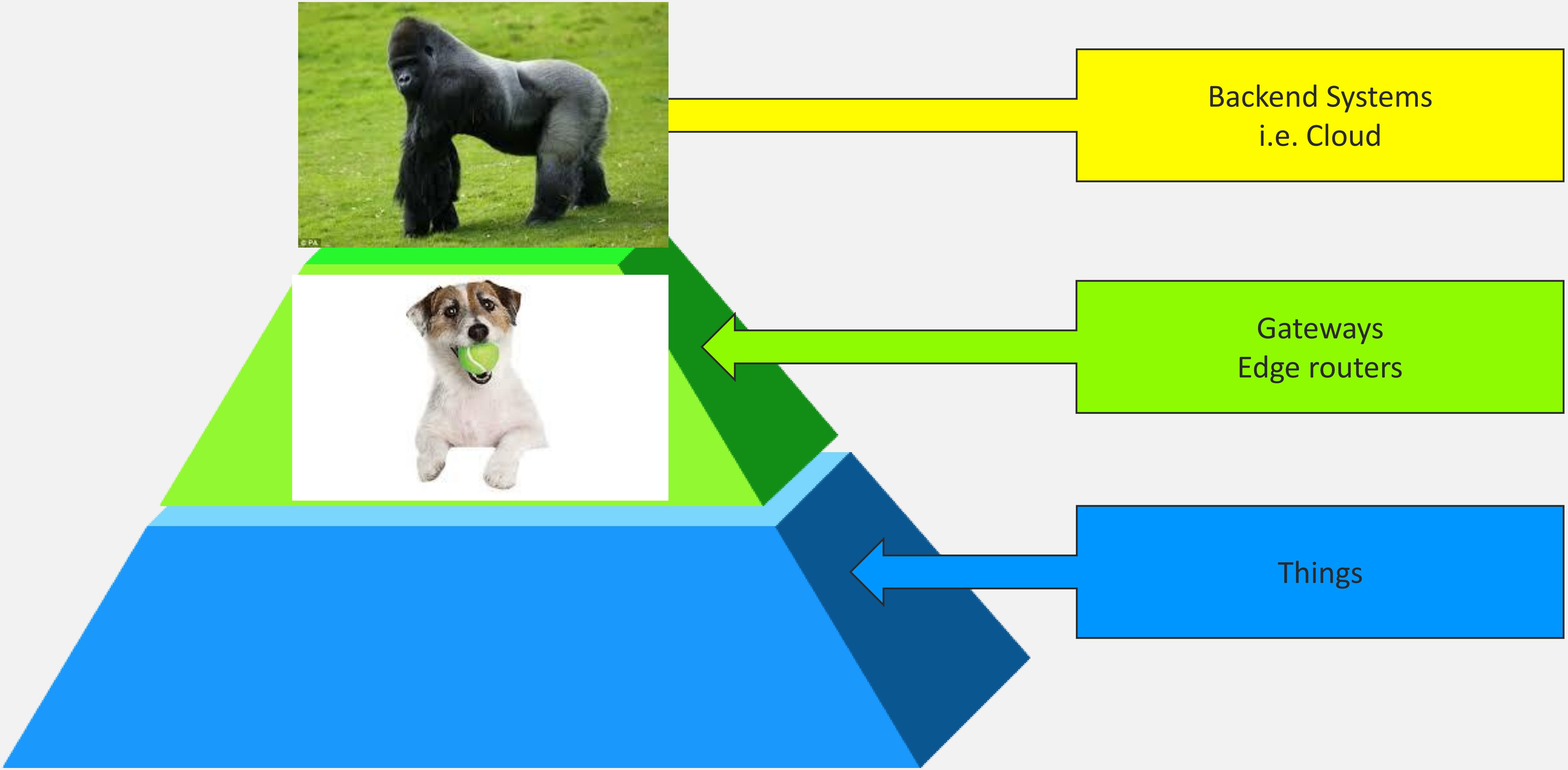
Relative size of IoT components in number of units



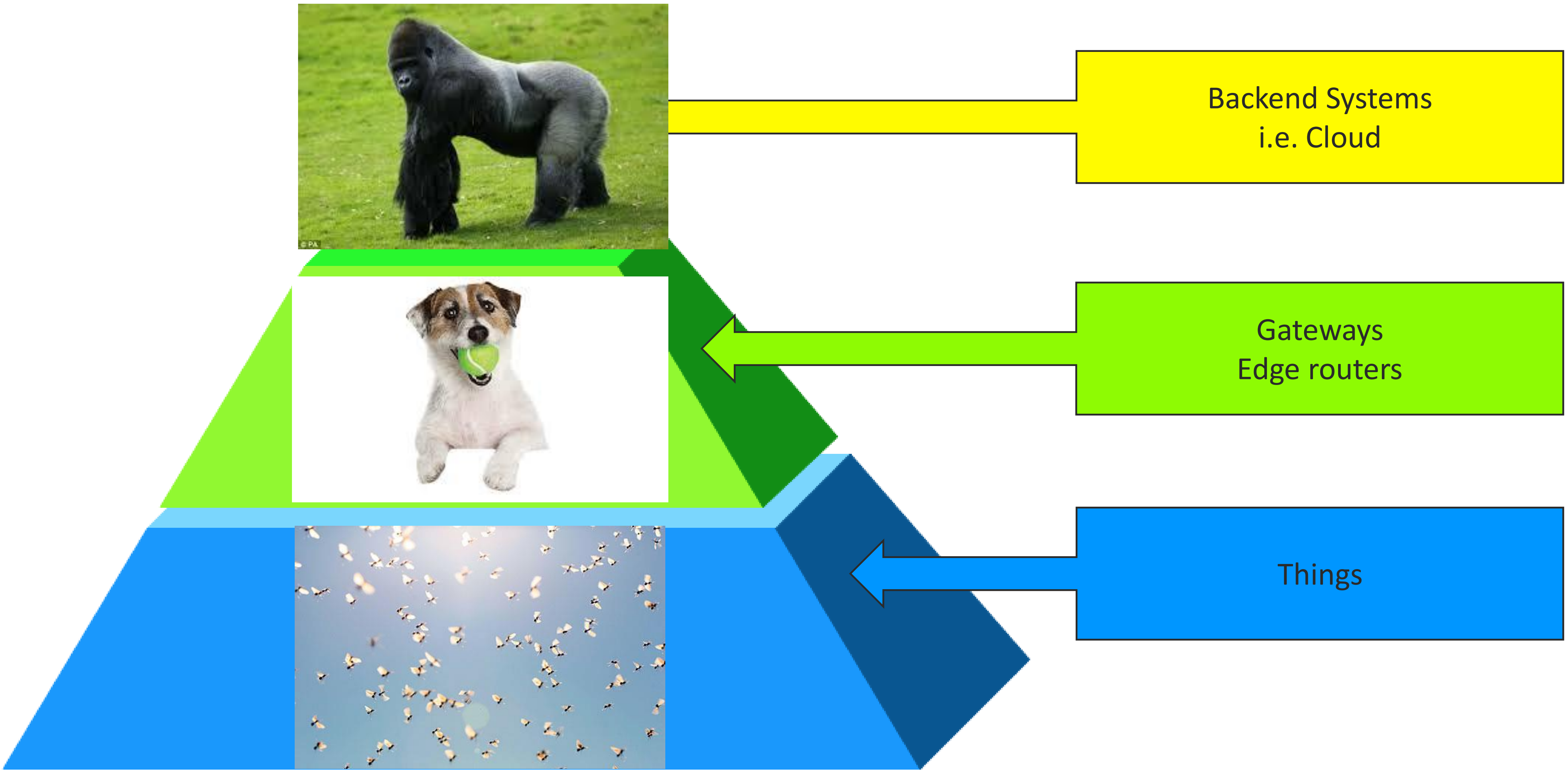
Relative size of IoT components in number of units



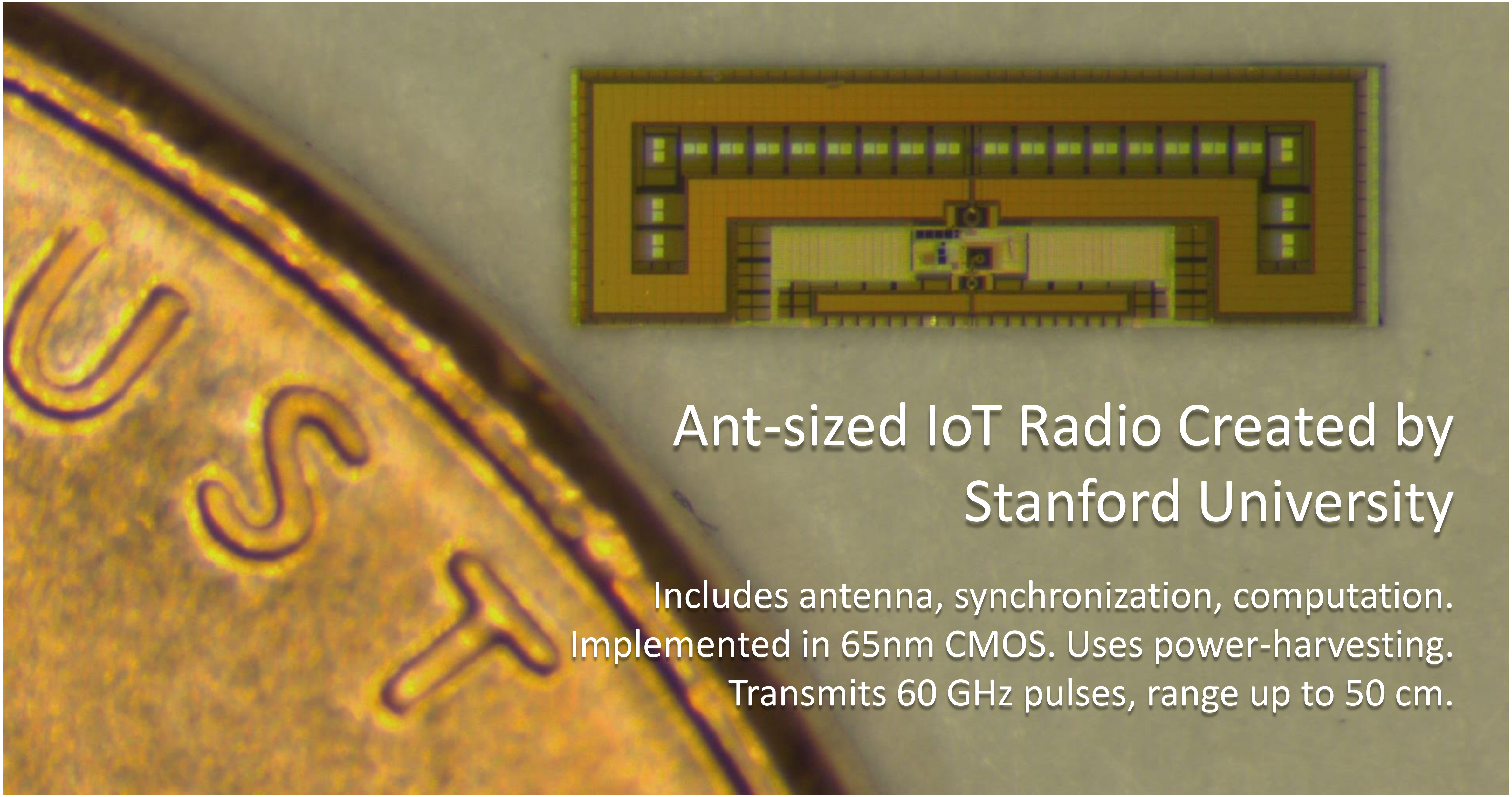
Relative size of IoT components in number of units



Relative size of IoT components in number of units



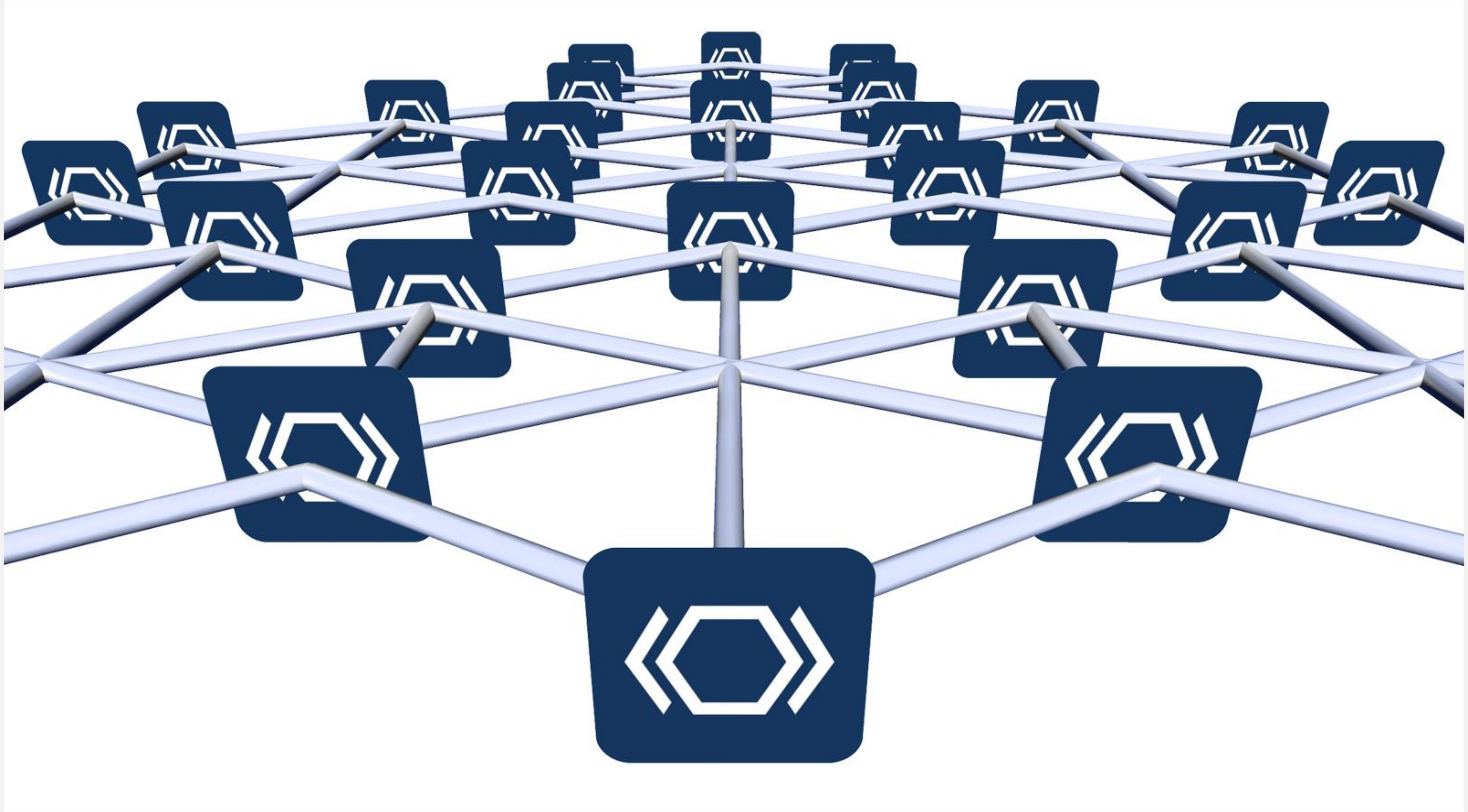

“We sometimes underestimate the influence of little things…”
Charles W. Chesnutt
The Springtail is smaller than the head of a pin. There are 200,000
per square meter of soil.



Ant-sized IoT Radio Created by Stanford University

Includes antenna, synchronization, computation.
Implemented in 65nm CMOS. Uses power-harvesting.
Transmits 60 GHz pulses, range up to 50 cm.

Local Networking Technologies



Local Networking Technologies

In a Wireless Sensor Network (WSN) node, the networking technology is usually a short-range wireless access link. There are other IoT end devices that do not use WSN but other types of networking technology.

Wired

- Ethernet, EtherCAT, EtherIP
- Modbus, Profinet
- DASH7
- HART
- HomePlug, GreenPhy, G.hnn (HomeGrid)
- And more…

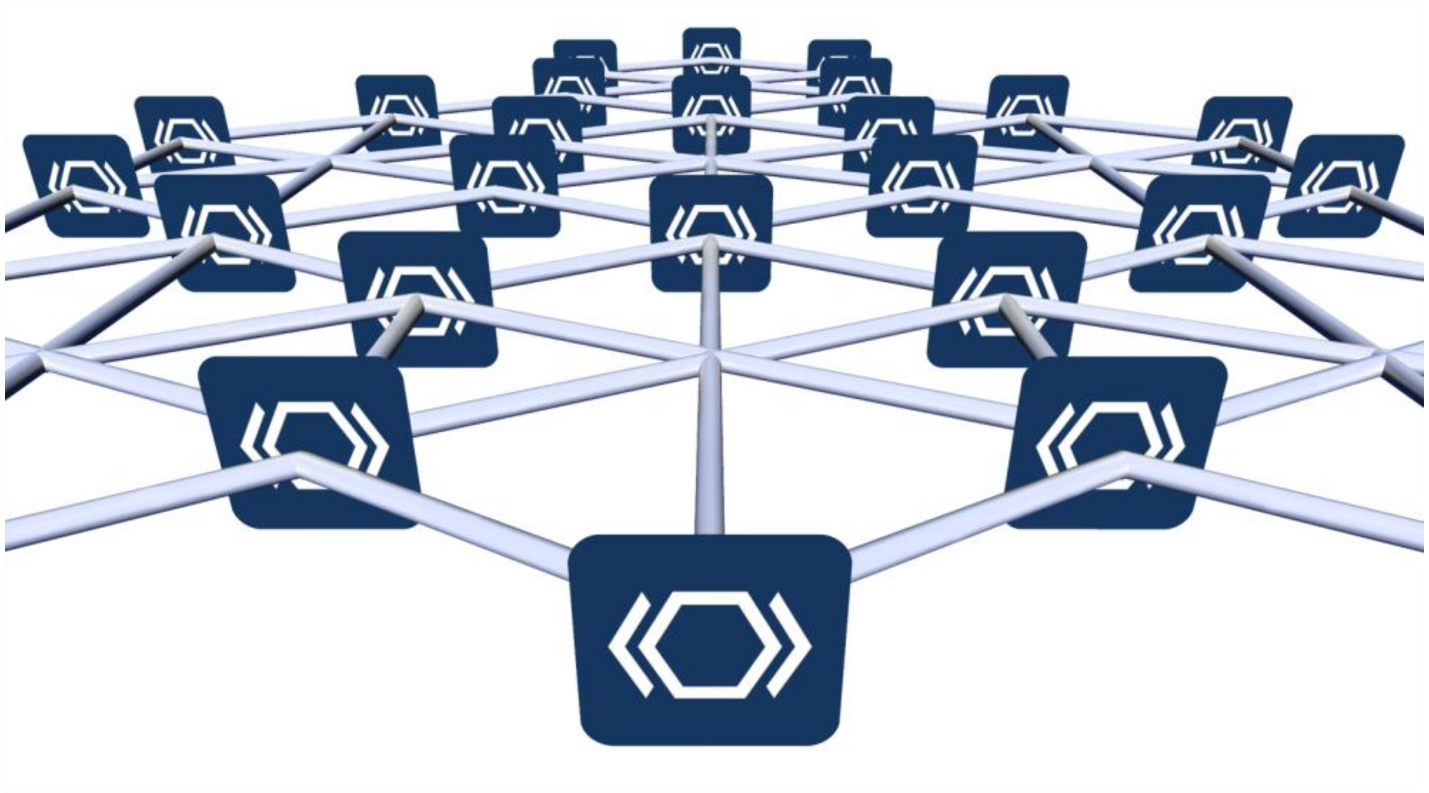
Wireless

- Bluetooth
- Wi-Fi
- Zigbee, Zigbee IP and other 802.15.4 capable protocols such as 6LoWPAN
- ANT, Z-Wave
- DASH7
- ISA100: Wireless Systems for Industrial Automation, Process Control and Related Applications
- Wireless HART
- EnOcean
- Wireless M-Bus
- And more…

Wireless LAN

- **WLAN Selection Criteria**

- **Protocol Efficiency**
- **Power Efficiency**
  - How long will my battery last?
- **Peak Power Consumption**
- **Performance**
- **Range**
- **Robustness**
- **Throughput**
- **Latency**
- **Coexistence**



Memory Requirements
A Few Short Range Wireless Examples

Coordinator/Router - 116 kB flash 7 kB RAM
End Device - 99 kB flash 3.8 kB RAM

6LoWPAN stacks range in code sizes of 50-100 kB typically. RAM size depends on the buffer approach used, but it is typically a few kB of RAM.

TCP/IP

ROM

Options	IPv4 Only	IPv6 Only	IPv4 & IPv6
TCP Enabled	66.5 kB	75.4 kB	93.8 kB
TCP Disabled	44.4 kB	53.2 kB	70.0 kB

RAM

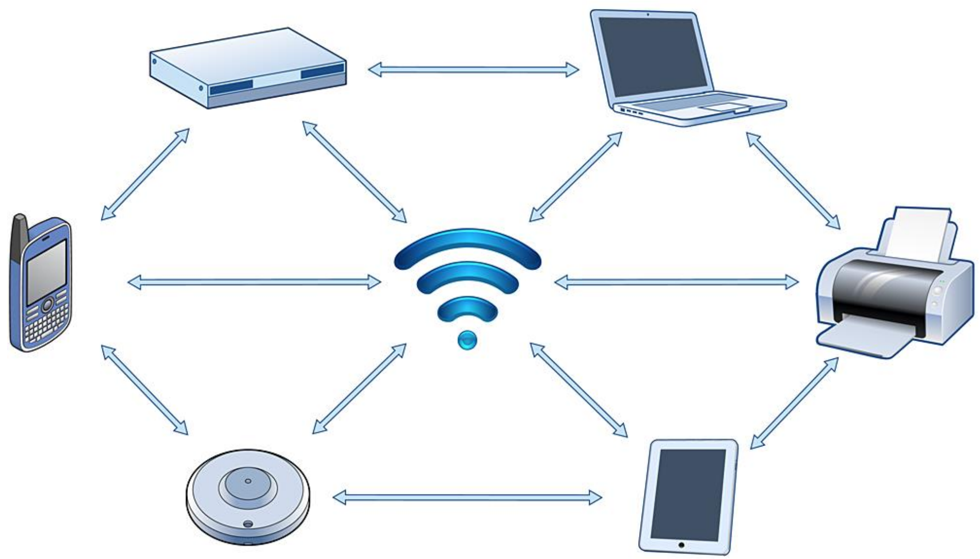
Configuration	IPv4 Only	IPv6 Only	IPv4 & IPv6
Minimum	16.7 kB	17.8 kB	18.5 kB
Typical	42.0 kB	44.2 kB	45.5 kB

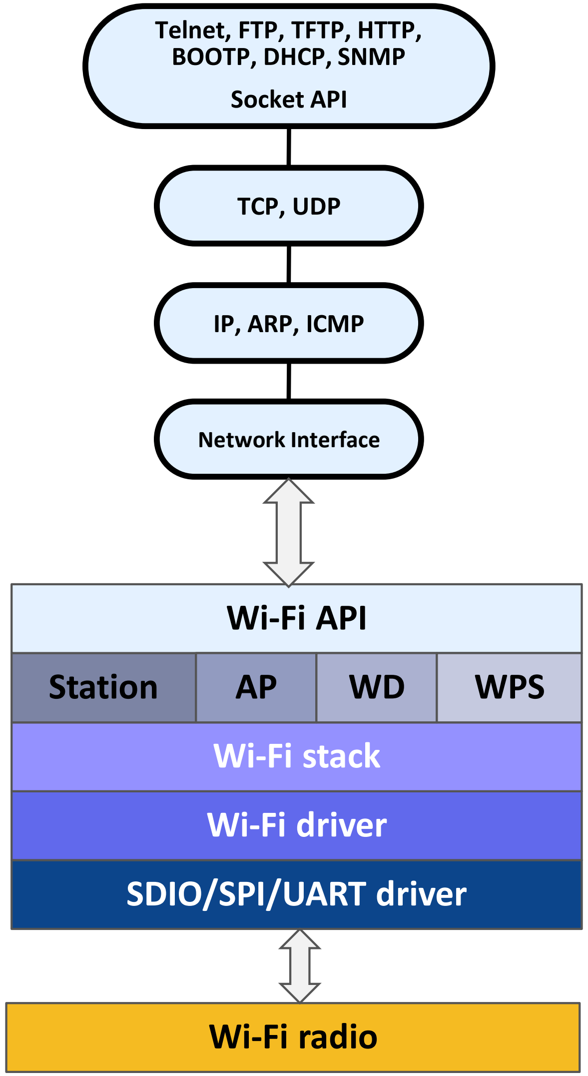
Fully RFC compliant
Interrupt driven

Wi-Fi

There are multiple ways to use Wi-Fi:

- Wi-Fi station
- Wi-Fi Access Point (AP, needs a DHCP server)
- Wi-Fi Direct (WD, needs a DHCP server)
- Wi-Fi Protected Setup (WPS)
- Wi-Fi stack typical footprint is about 200 KB for AP, STA and WD





802.15.4, Wi-Fi, Bluetooth and others

Running the wireless network on-board or off-board?

- On-board requires the manufacturer to FCC certify the product
- Using an off-board radio module is more expensive but is certified
- A similar approach is applicable to many wired or wireless interfaces

WiFi example

Solution 1 – Low volume

- Run the TCP/IP stack and Wi-Fi stack off board

Solution 2 – Med volume

- Run the TCP/IP stack on the host target and the Wi-Fi supplicant on the Wi-Fi module

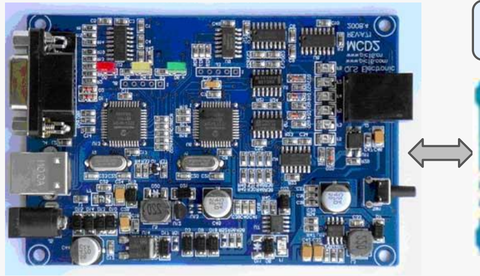
Solution 3 – High volume

- Run the TCP/IP stack and Wi-Fi stack on the target board

On-Board

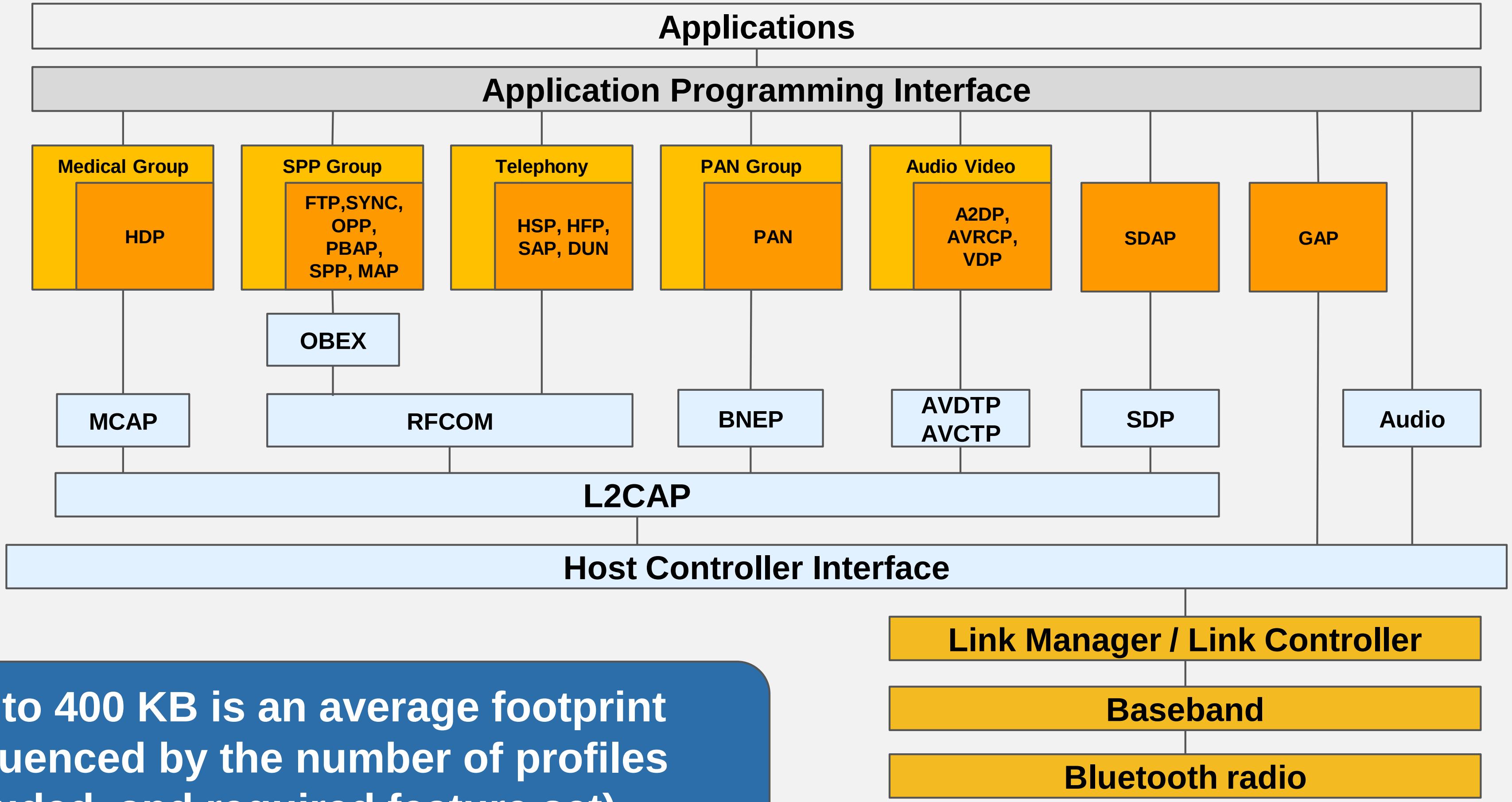
or

Off-Board



Wireless Module

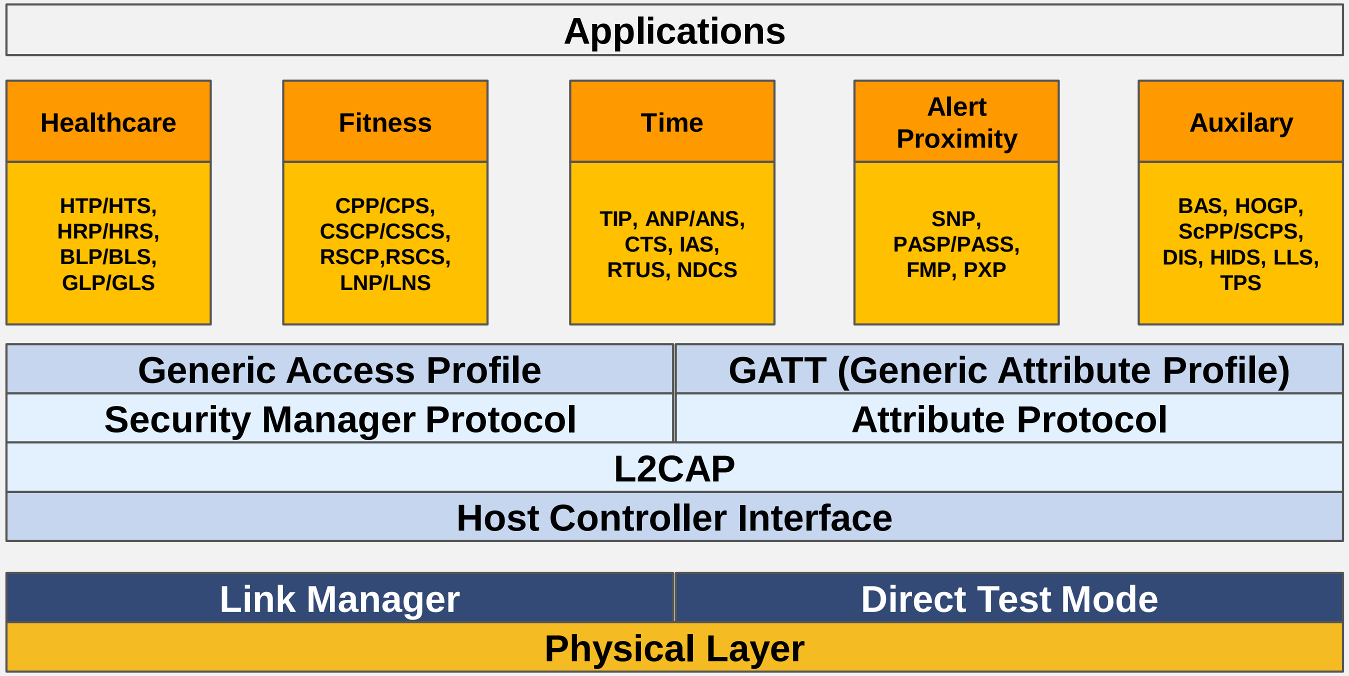
Bluetooth Classic



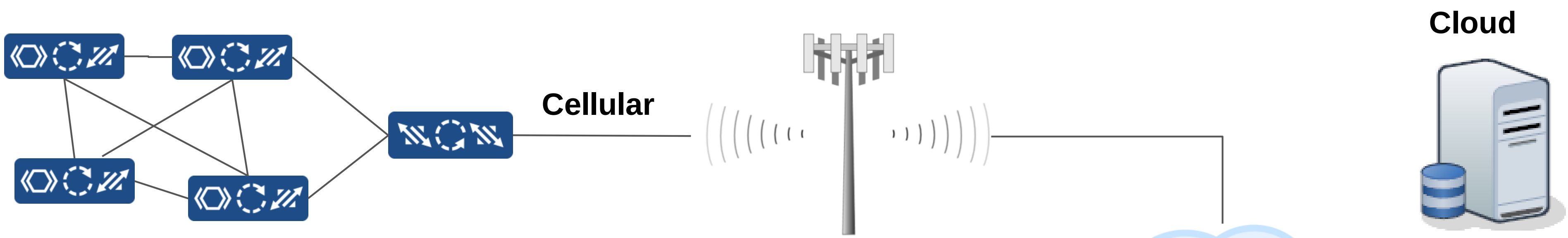
300 to 400 KB is an average footprint (influenced by the number of profiles included, and required feature set)

Bluetooth Smart (BTLE)

Bluetooth Smart
Around 200 KB is an average footprint
Dependent on feature set



Cellular WAN



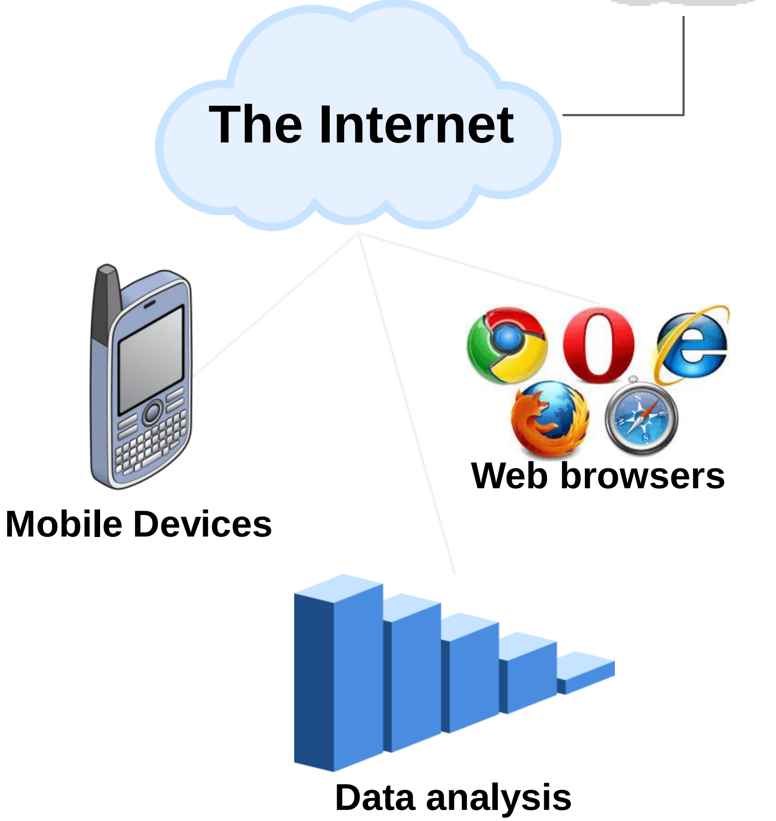
Cellular modem for the WAN

TCP/IP stack requires PPP to connect to the cellular modem (small code and RAM add-on)

Modem needs to be approved by the cellular carrier

Some possible modems:

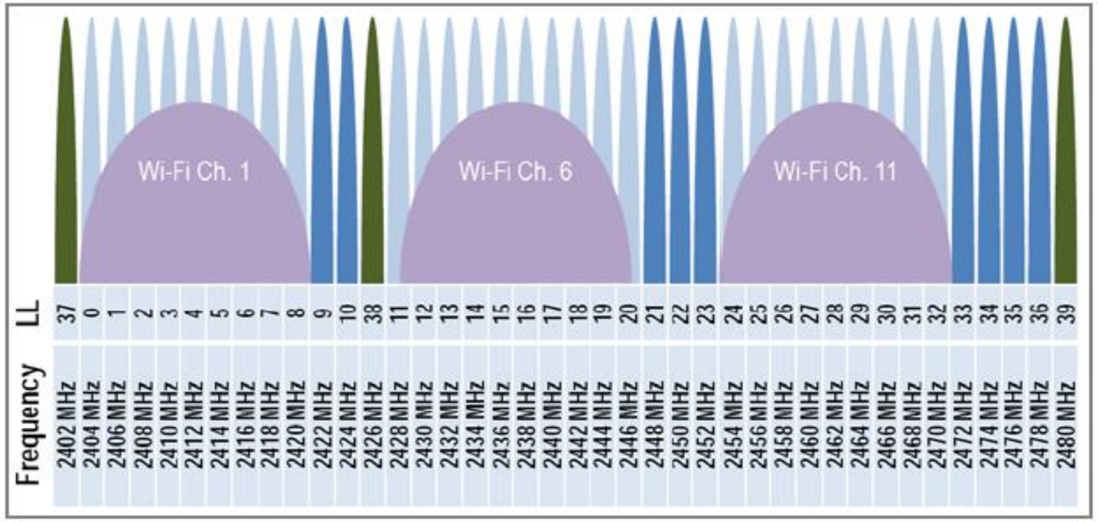
- Telit
- Gemalto
- Sirerra Wireless
- …



Wireless LAN Coexistence

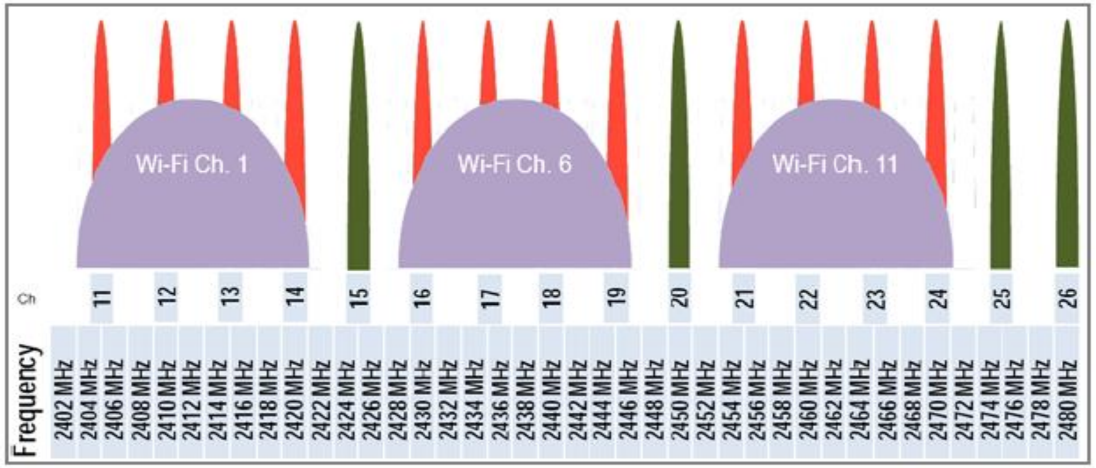
Bluetooth LE and Wi-Fi spectrum usage

Each channel is 2MHz wide with no wasted spectrum



Zigbee and Wi-Fi spectrum usage

Each channel is 2MHz wide with a wasteful 5MHz spacing. In the presence of Wi-Fi, only 4 channels are likely to be available.



Source : CSR application note CS-213199-AN

Wireless LAN
Low Power Wireless Technology Target Markets

The long term forecast puts Bluetooth LE and WiFi as the predominant WLAN technologies

Expect 6LoWPAN (Thread) to run on Bluetooth radios.

	LE	A	A+	RF	Zi	Wi	Ni	Ir	NF
Remote Control	✓	×	×	✓	×	✓	×	✓	×
Security	✓	×	×	×	✓	✓	×	×	✓
Health and Fitness	✓	✓	✓	×	×	×	✓	×	×
Smart Meters	✓	×	×	×	✓	✓	×	×	×
Cell Phones	✓	×	✓	×	×	✓	×	✓	✓
Automotive	✓	×	×	×	×	✓	×	×	✓
Heart Rate	✓	×	✓	×	×	×	×	×	×
Blood Glucose	✓	×	✓	×	×	×	×	×	×
Positioning	✓	×	×	×	✓	✓	×	×	×
Tracking	✓	×	×	×	✓	×	×	×	✓
Payment	×	×	×	×	×	×	×	×	✓
Gaming	✓	×	×	×	×	×	×	✓	×
Key Fobs	✓	×	×	✓	×	×	×	✓	✓
3D TV	✓	×	×	×	×	×	×	✓	×
Smart Applications	✓	×	×	×	✓	×	×	×	×
Intelligent Transport Systems	✓	✓	✓	×	✓	×	×	×	✓
PCs	✓	×	×	×	×	✓	×	✓	✓
TVs	✓	×	×	✓	×	✓	×	✓	×
Animal Tagging	✓	×	×	×	✓	×	×	×	✓
Assisted Living	✓	✓	✓	×	×	×	×	×	✓

Source : CSR application note CS-213199-AN

Legend
LE (Bluetooth low energy), **A** (ANT),
A+ (ANT+), **RF** (RF4CE), **Zi** (ZigBee),
Wi (Wi-Fi), **Ni** (Nike+), **Ir** (IrDA), **NF** (NFC).

Java Usage in IoT

- **There are around 450,000 embedded software engineers using C/C++**
- **There are 9 million Java developers in the world**
- **ARM, Oracle and Freescale believe Java is the solution to the creation of an IoT ecosystem**

Java ME Memory footprint (approximate)

From: 350KB ROM, 130 KB RAM (for a minimal, customized configuration)

To: 2000 KB ROM, 700 KB RAM (for the full, standard configuration)

- **It is too large for the typical IoT device processor**
- **Java virtual machines for smaller processor exist, but not from Oracle**

The Thing

The Thing

To plan for the software and hardware requirements, the Thing design must take into consideration the environment:

- The variables to measure or control (analog interface)
- The frequency at which these variables processing needs to be done (processor performance)
- The transport technology of these variables value and variable control (wired or wireless)
- Sensing, processing and networking software memory requirement
- The availability for a secure device firmware upgrade (SDFU)
  - Secure bootloader RAM and Flash requirement
  - SDFU can be remote [over the air] (networking capabilities required, Firmware Over the Air : FOTA)
- The availability for device management (Commissioning [ID and Auth], Provisioning, Fault and Service management)

Processor Selection

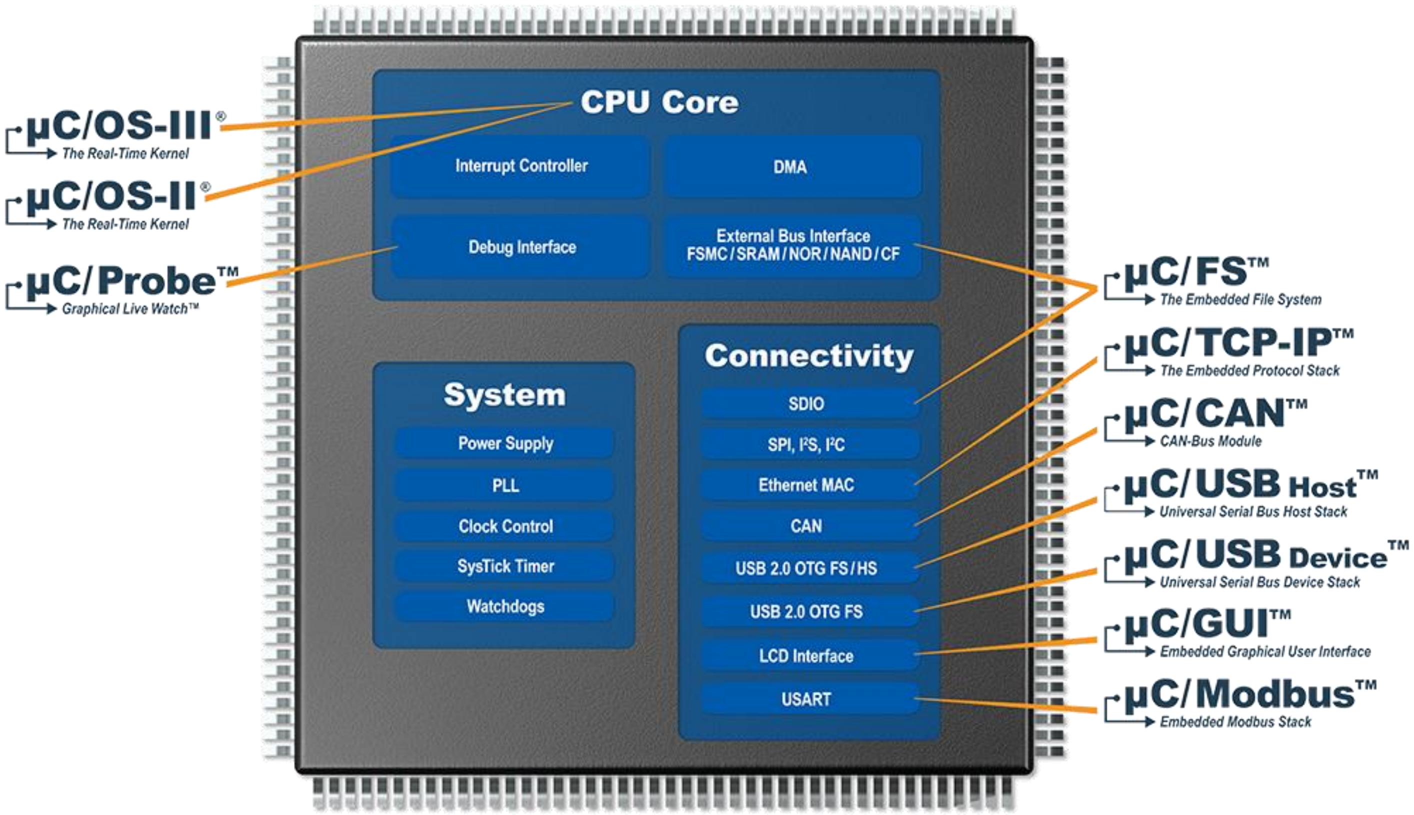
Power vs Performance

- 8/16-bit processors are still very popular for sensor devices because of their low power consumption
- 32 bit devices are required to **integrate** IP networking capabilities
- MCUs with integrated radio are becoming mainstream
- ARM is designing a compatible Cortex-M0 with close to threshold voltage of CMOS transistors, and at clock frequencies of the order of tens of kilohertz.

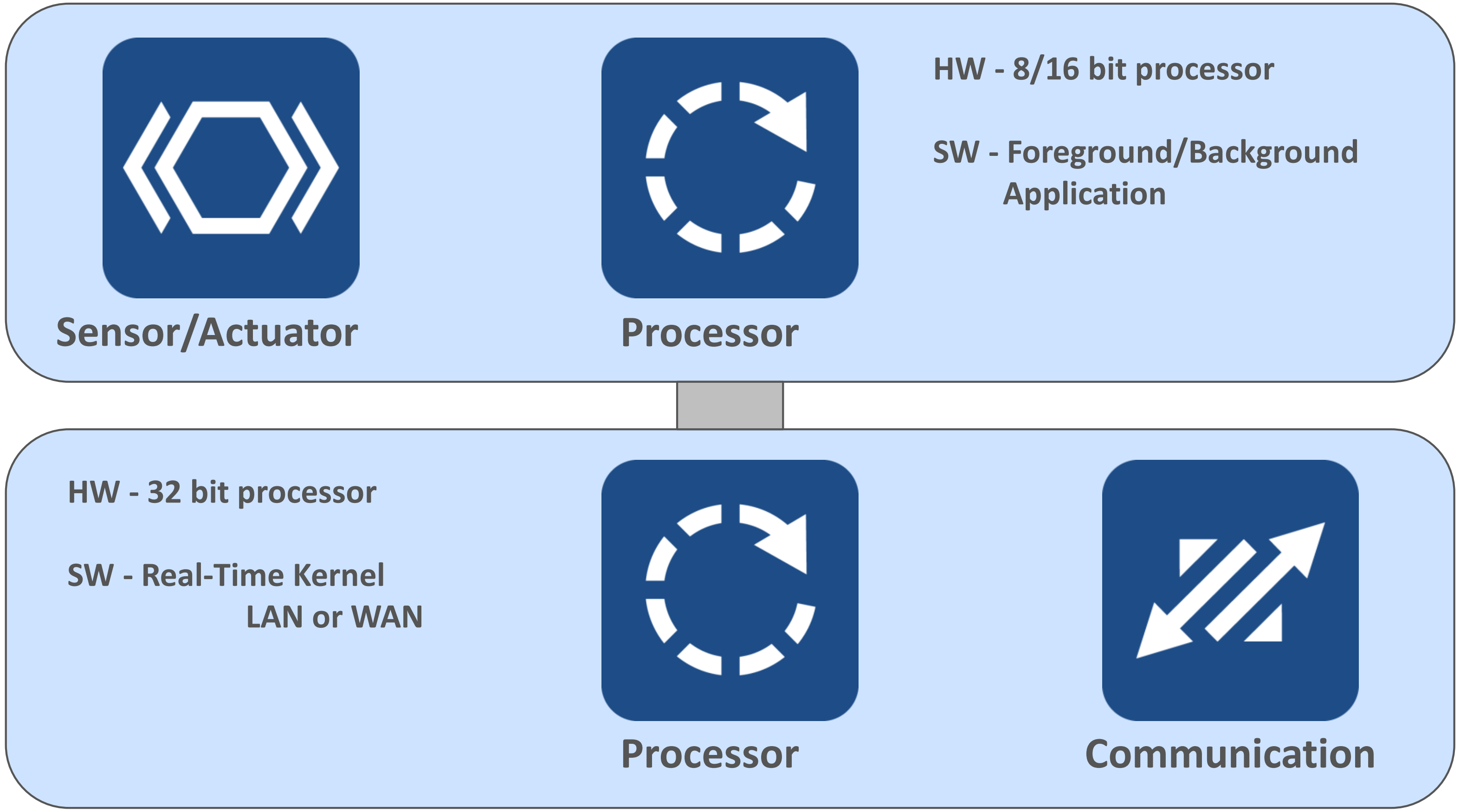
Typical Thing Processor

The Average MCU

- 50 to 200 Mhz CPU Clock
- 64KB to 2MB Flash (code space)
- 4KB to 512KB RAM



IoT Device / WSN Node
Two-Processor Solution



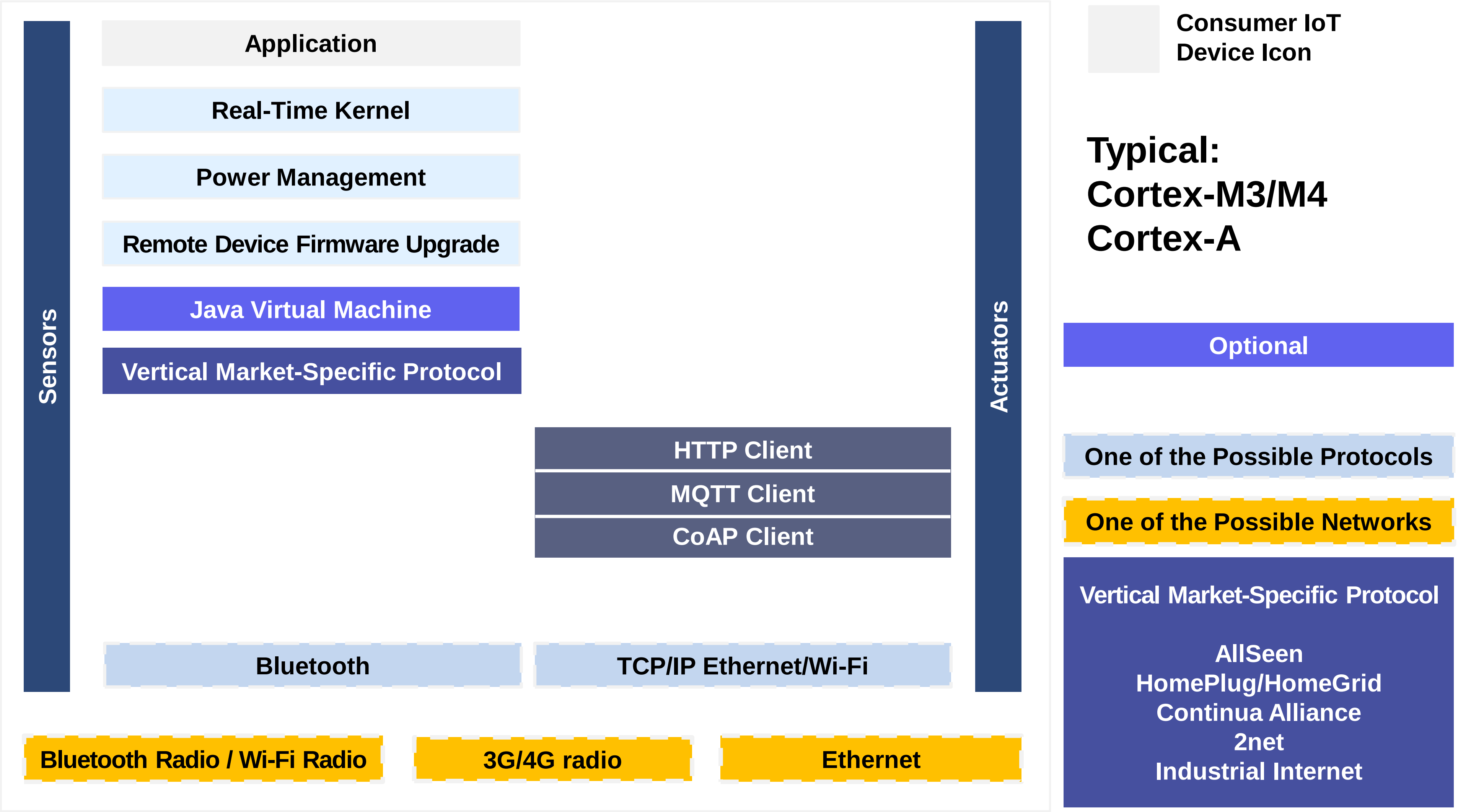
IoT Device / Sensor Node
One-Processor Solution

Sensor/Actuator | **Processor** | **Communication**

Hardware:
32 bit processor

Software:
Real-Time Kernel
Application
LAN or WAN

Consumer IoT Device



Wireless Sensor Node
Software architecture

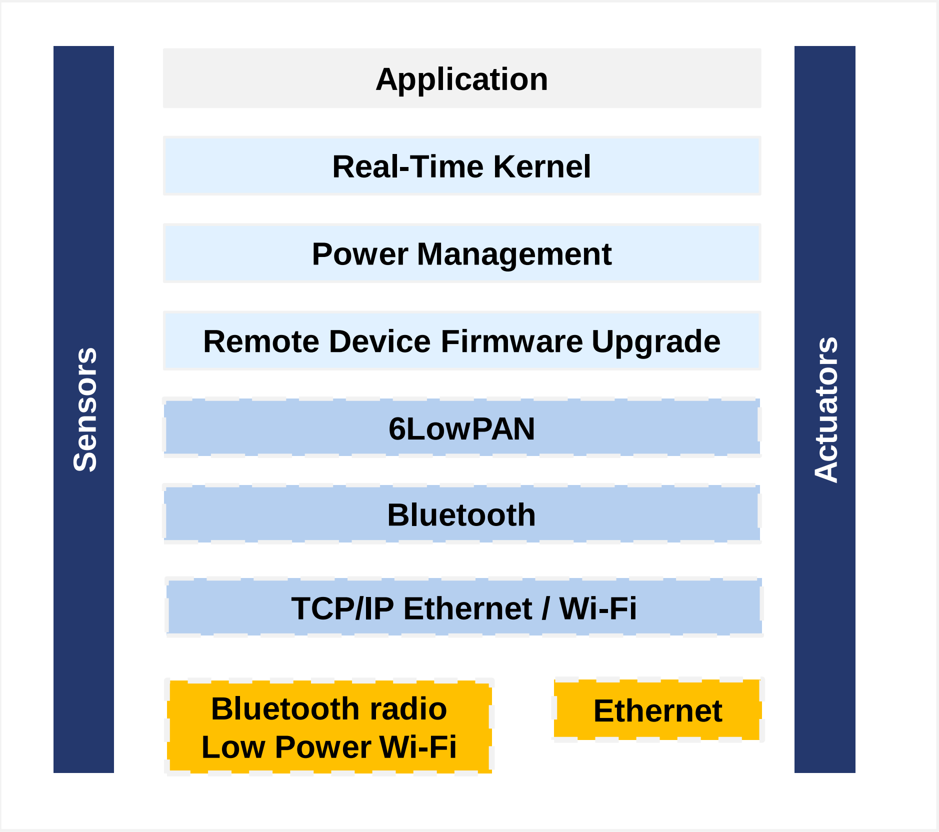
- **A sensor node can be written as a foreground/background (single thread / super loop) system**

- **When networking is involve, the use of a real-time kernel is highly recommended**
  - Best usage of the processor time
  - Better software architecture
  - Simplified development
  - Simplified maintenance

- **Code mainly written in C**

- **Java is also an option, but not from Oracle**
  - The Oracle JVM is too large for the average IOT device (thing)

Low Power (or not) IoT Device / WSN Node
Single Processor Solution



Low Power IoT Device/ WSN Node Icon

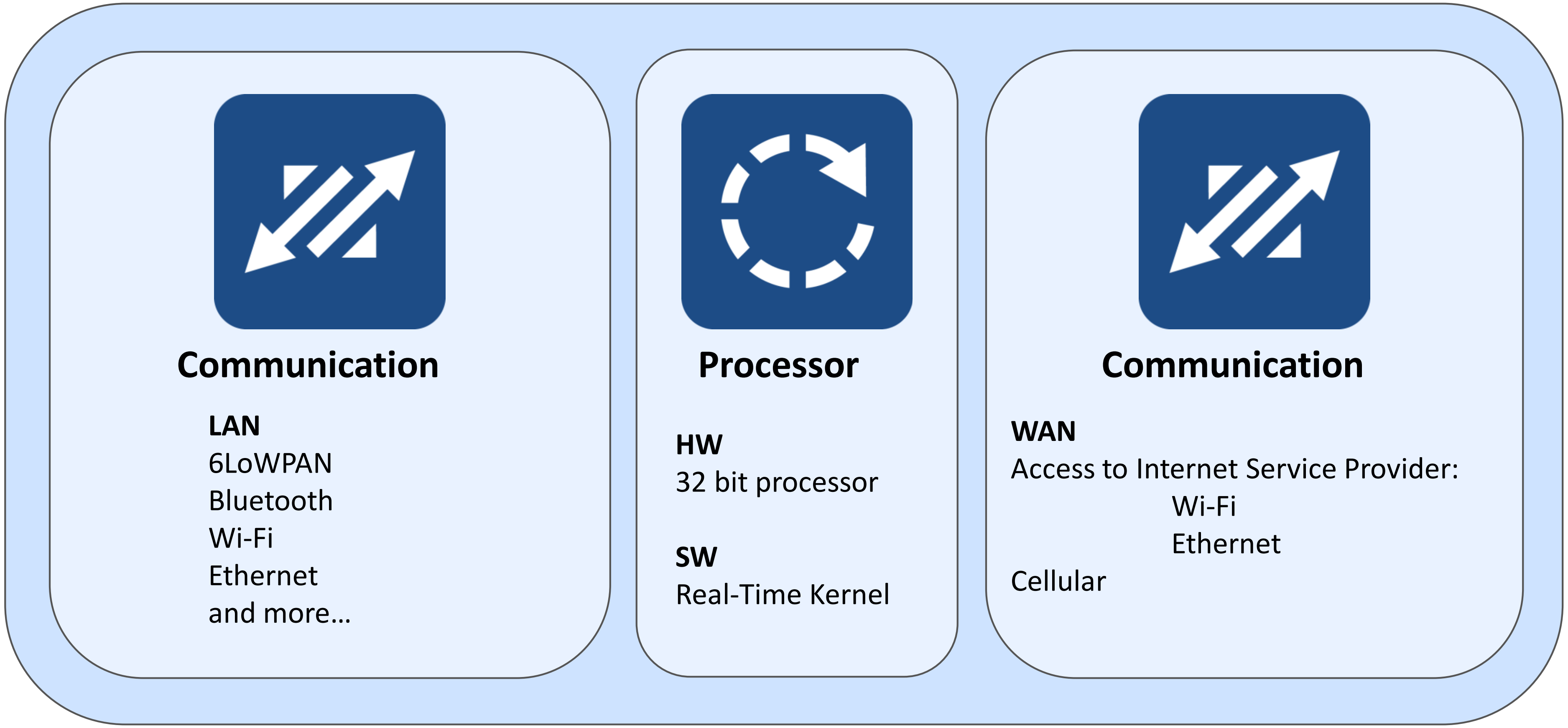
Typical:
Cortex M0/M0+
Cortex M3/M4

LAN protocol

LAN **One or Multiple LAN**

Assumption: 6LoWPAN runs on the BTLE radio

WSN Edge Node or Gateway



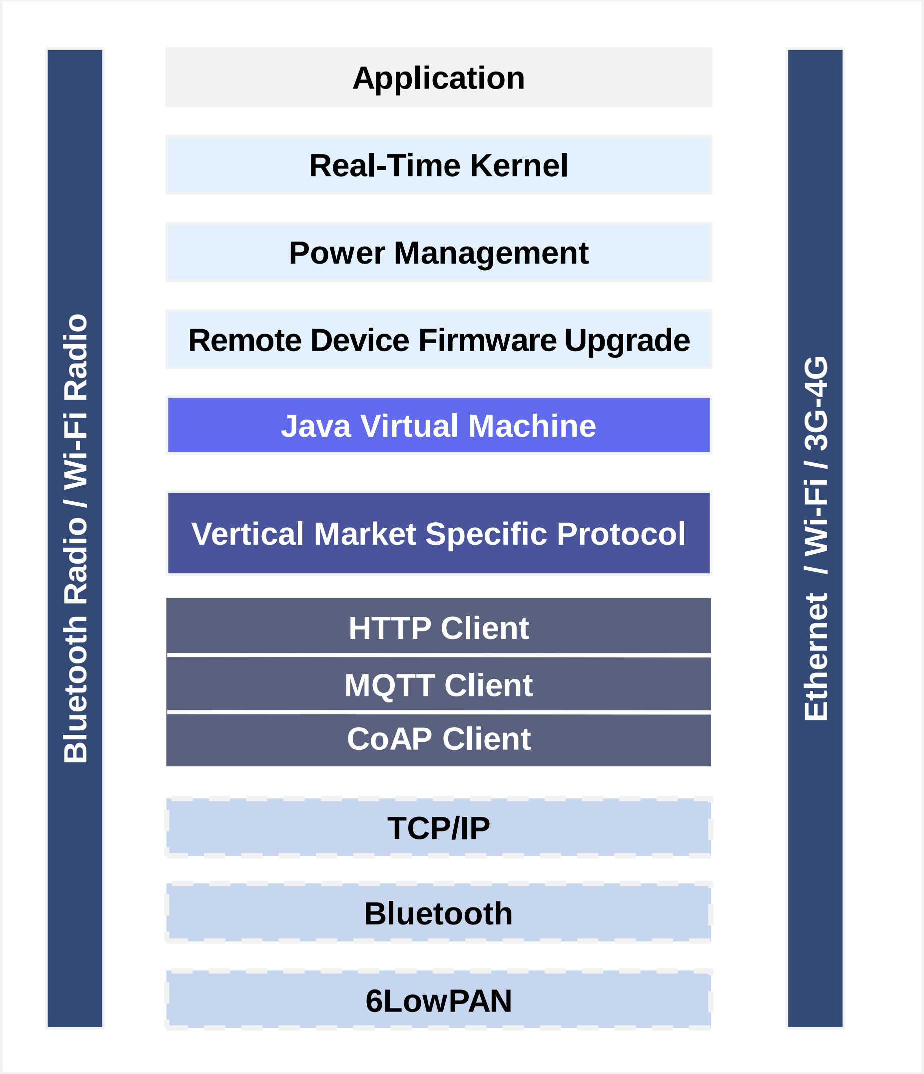
Edge Node/Gateway
Software architecture

- **With LAN and WAN present in an edge node/gateway, it is mandatory to use of a real-time kernel or other form of OS**
  - Best usage of the processor time
  - Better software architecture
  - Simplified development
  - Simplified maintenance

- **Code mainly written in C**

- **Java is also an option**
  - With a Cortex-A class processor, Oracle JVM is possible
  - With a Cortex-M class processor, the Oracle JVM is too large. Another solution is required and exist.

Gateway / WSN Edge Node



Gateway / WSN Edge Node

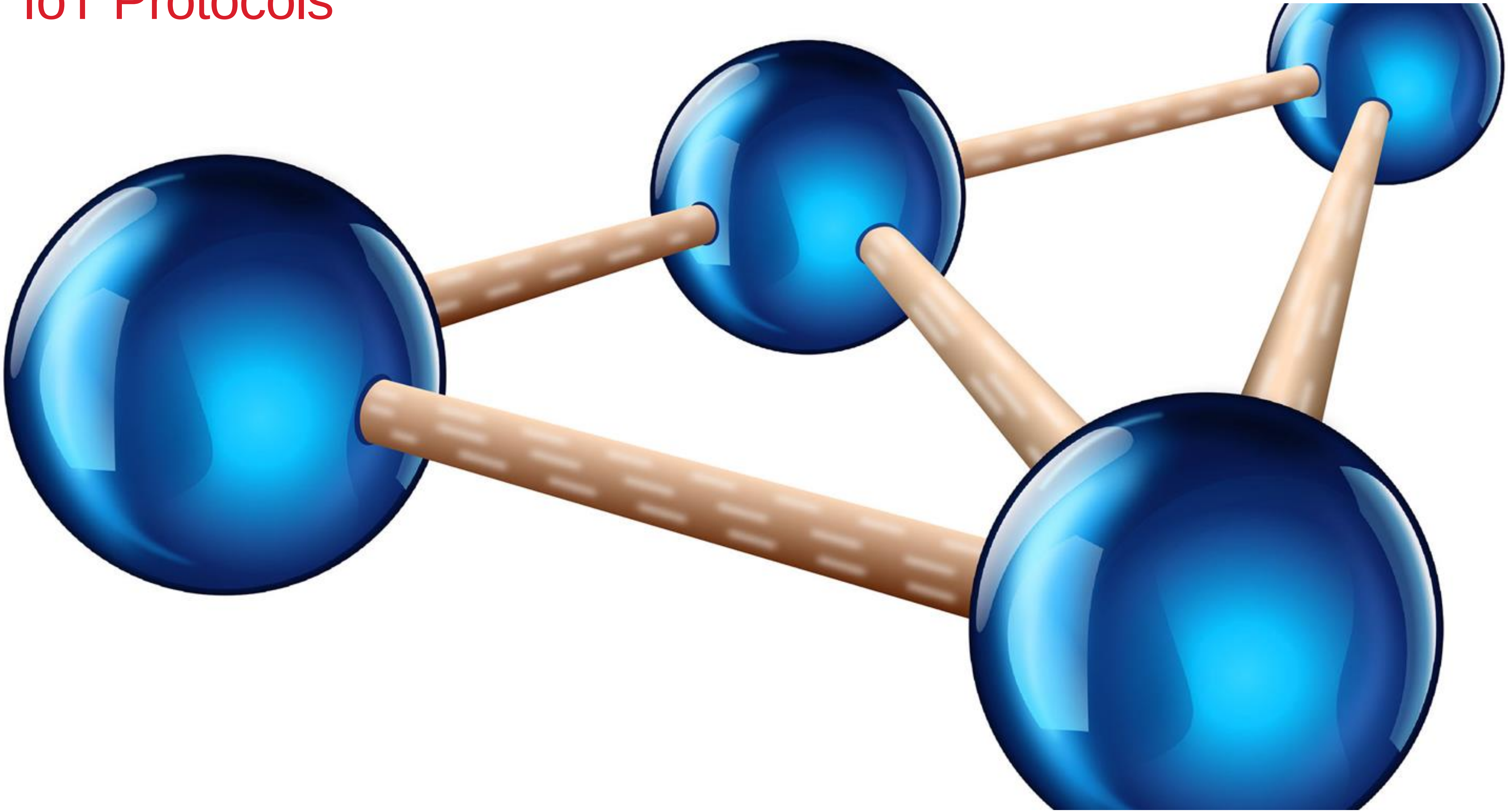
Typical:
Cortex-M3/M4
Cortex-A

One of the possible protocols

Vertical Market-Specific Protocol

- **AllSeen**
- **HomePlug/HomeGrid**
- **Continua Alliance**
- **2net**
- **Industrial Internet**

IoT Protocols



IP Usage

Web Services

IP family of protocols can be used to provide services to device

- Examples: SMS text, e-mail, file sharing, streaming audio, speech to text, social media …

IP Usage

IoT Services

The availability of back-end services based on IP protocols are what is differentiating “IoT devices” from “connected devices”:

Storage, multiple devices/applications data usage, system analytics and potential for efficiency gain…

Internet Protocol Types

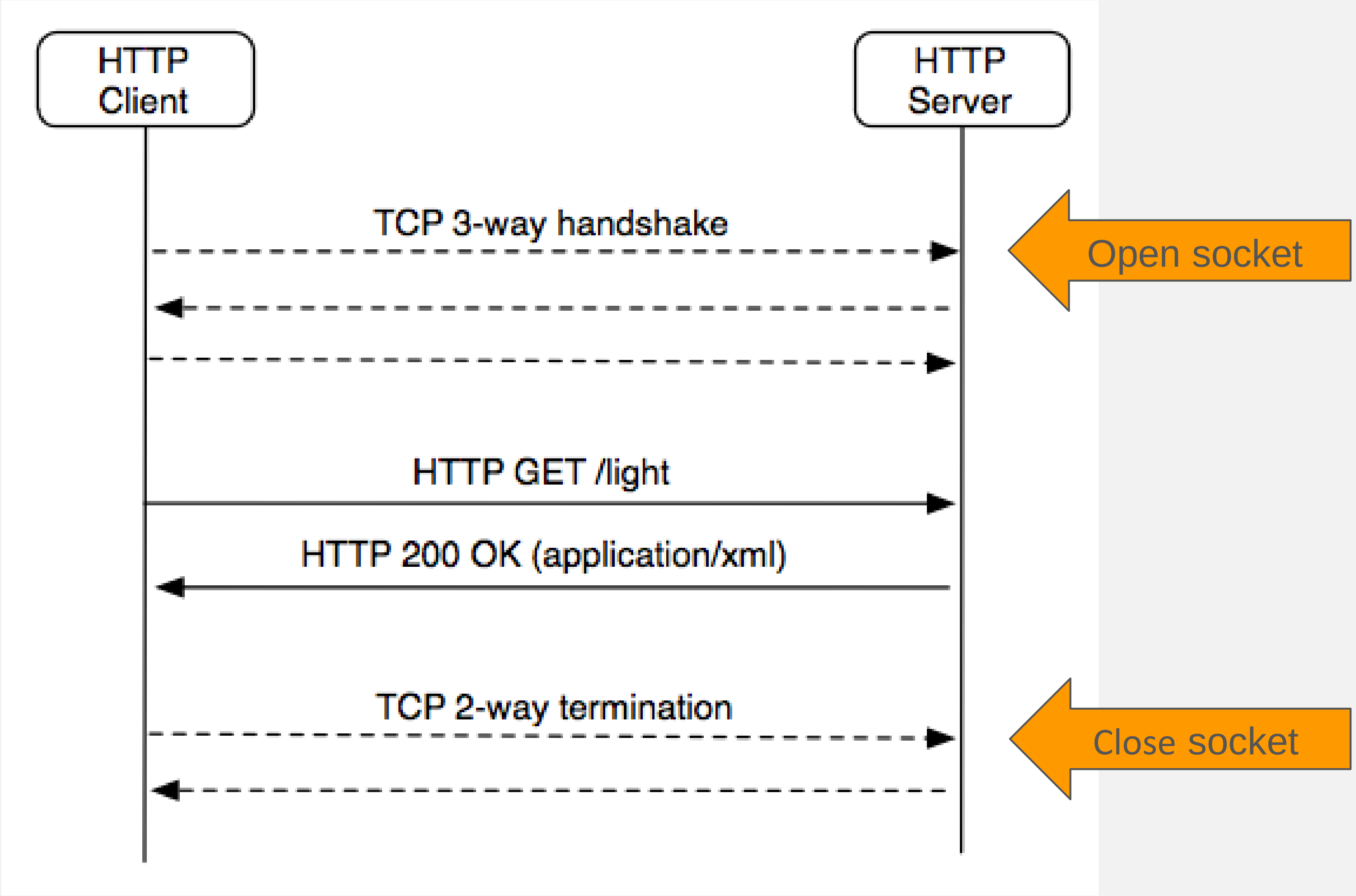
Request/Response		**Publish/Subscribe**	
HTTP	Web Services	MQTT	IoT Services
WebSocket	Web Services	CoAP	IoT Services
CoAP	IoT Services	XMPP	

Can do Request/Response with polling

Request/Response

HTTP

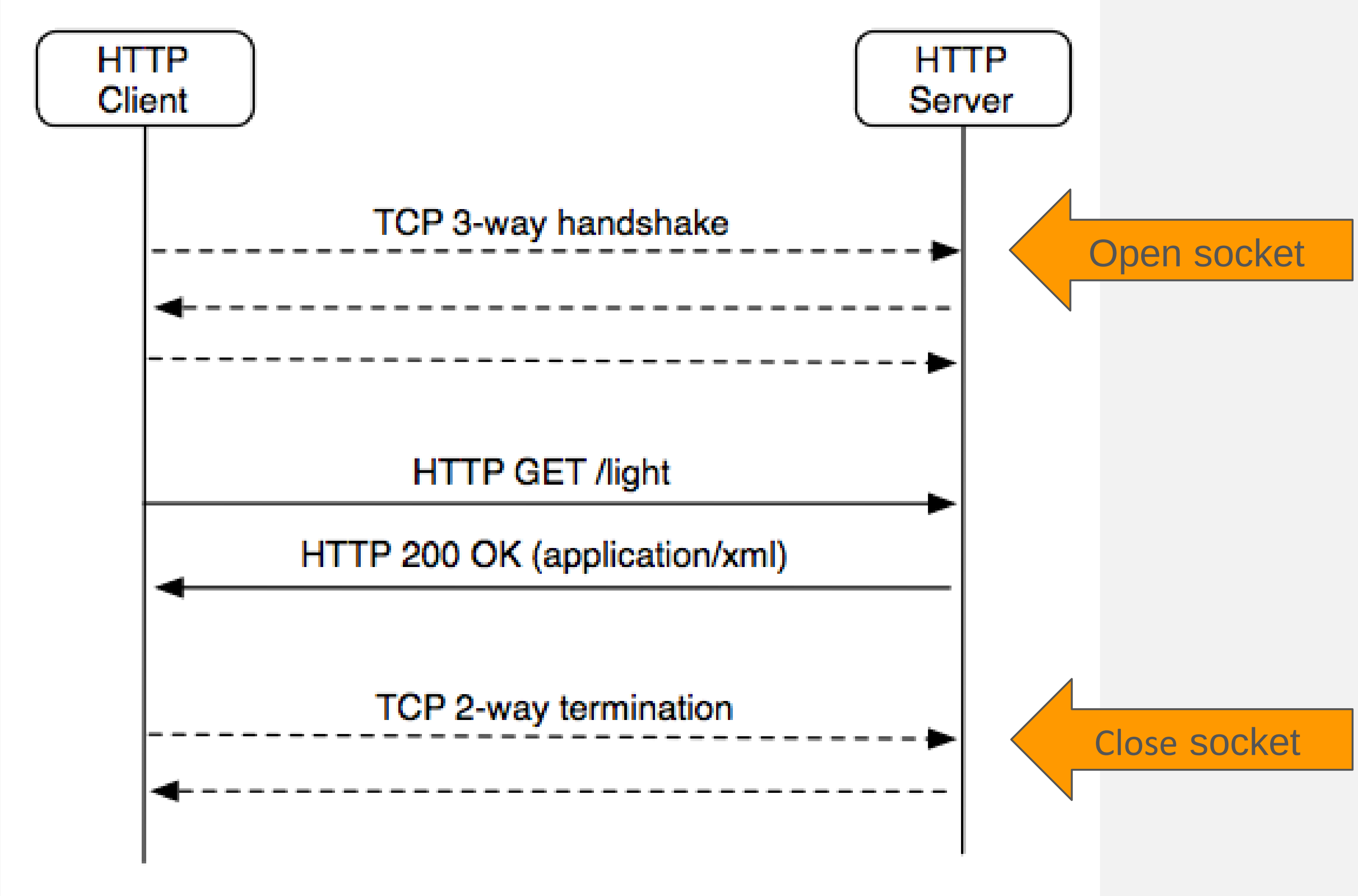
HTTP Request – The Notion of REST



HTTP client opens a connection (socket) and sends a request message to an HTTP server.

The server then returns a response message, usually containing the resource that was requested.

HTTP Request – The Notion of REST

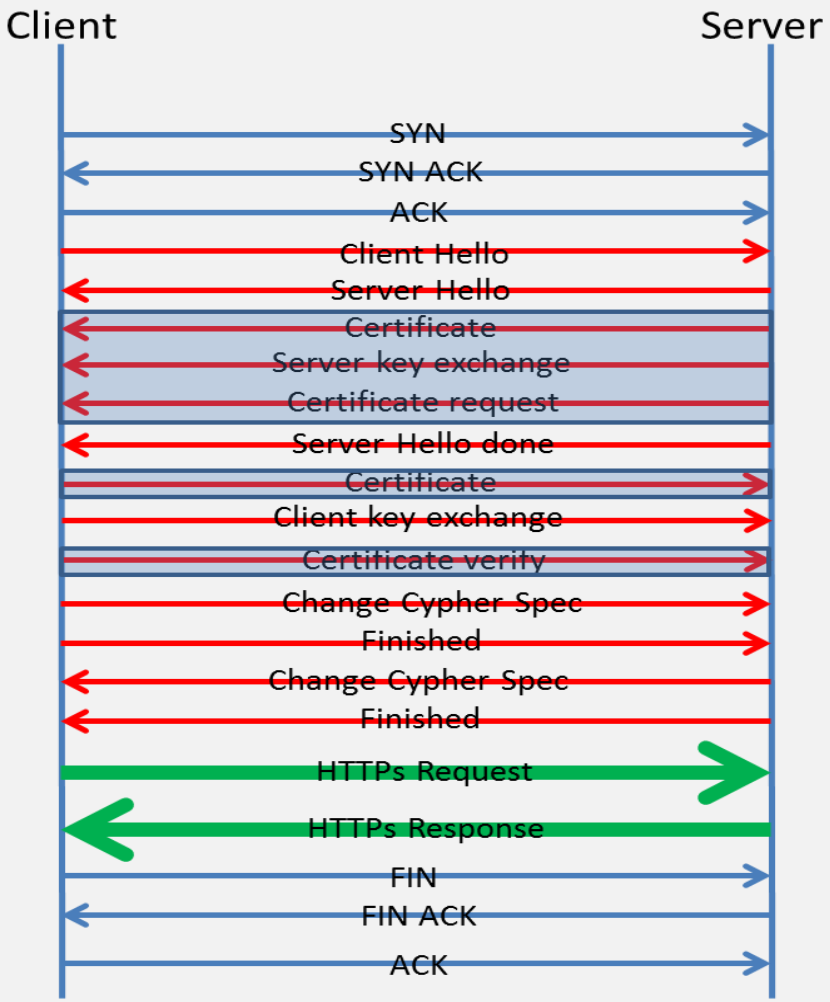


After delivering the response, the client closes the connection (making HTTP a stateless protocol, that is, not maintaining any connection information between transactions).

This is where the notion of REST (REpresentational State Transfer) comes from.

HTTP and HTTPS

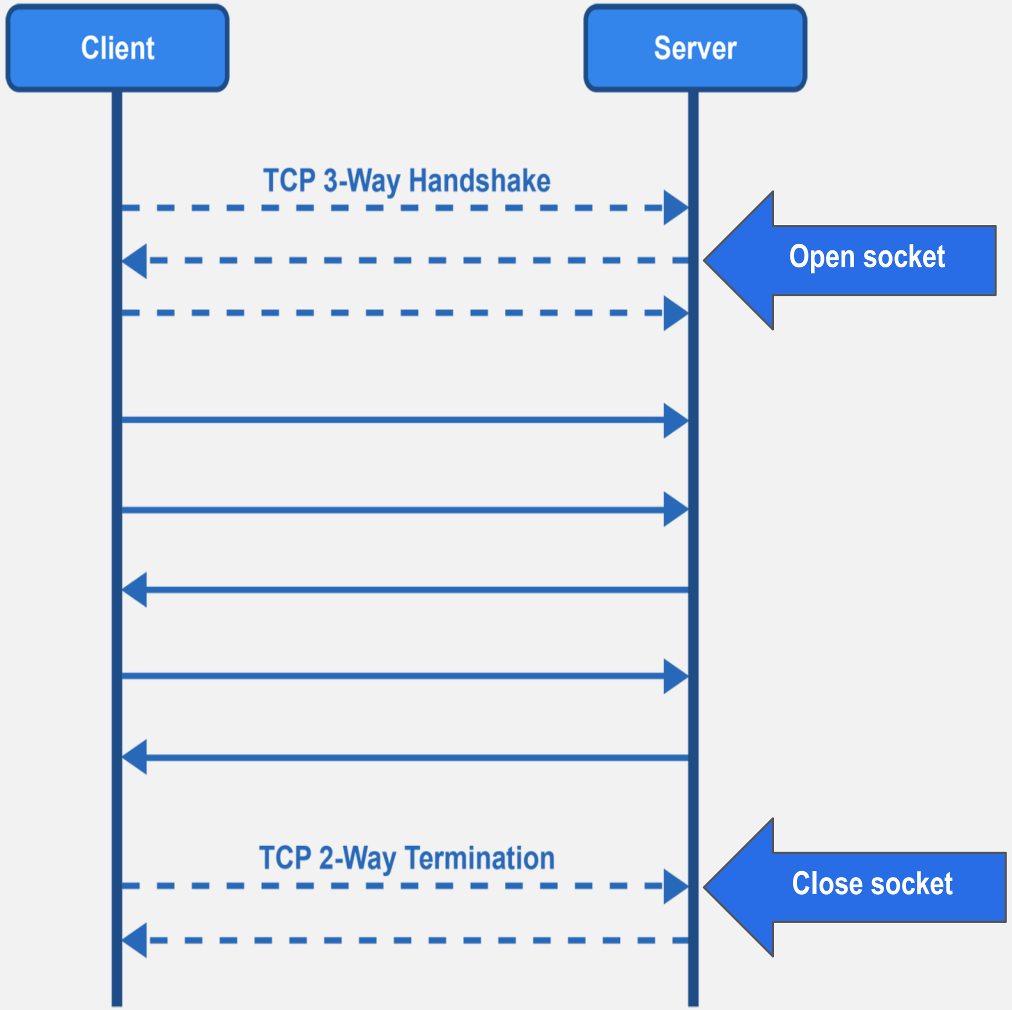
- Typical HTTPS (showing the messages, not the number of packets)
- Areas in blue are optional (bidirectional SSL/TLS)
- Connection is initiated by a client
- Client always has to poll the server, server cannot initiate connection: not efficient for an embedded device
- High overhead: Open/Send/Close for every application message



Request/Response

Websocket

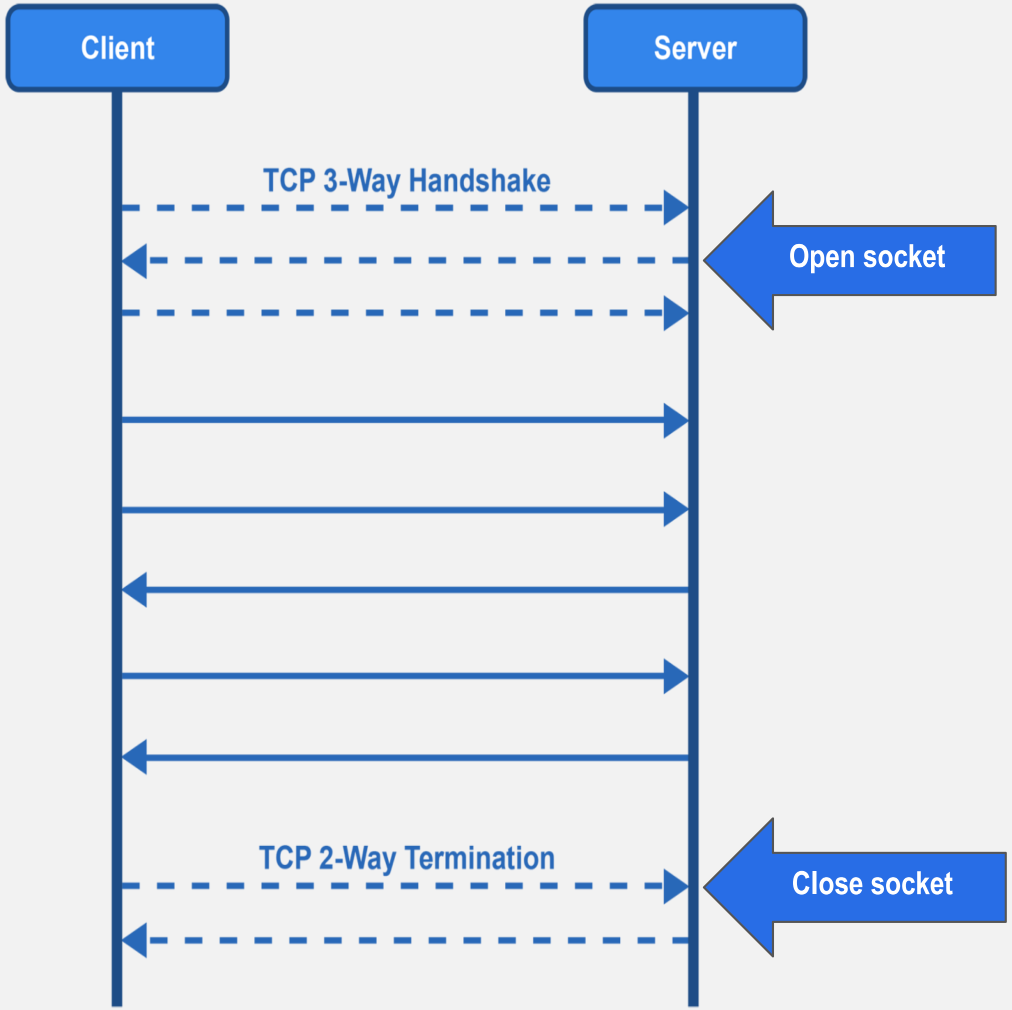
A Websocket Connection



WebSockets are a bi-directional, full-duplex, persistent connections from a client to a server.

Once a WebSocket connection is established the connection stays open until the client or server decides to close this connection.

A Websocket Connection



With this open connection, the client or server can send a message at any given time to the other.

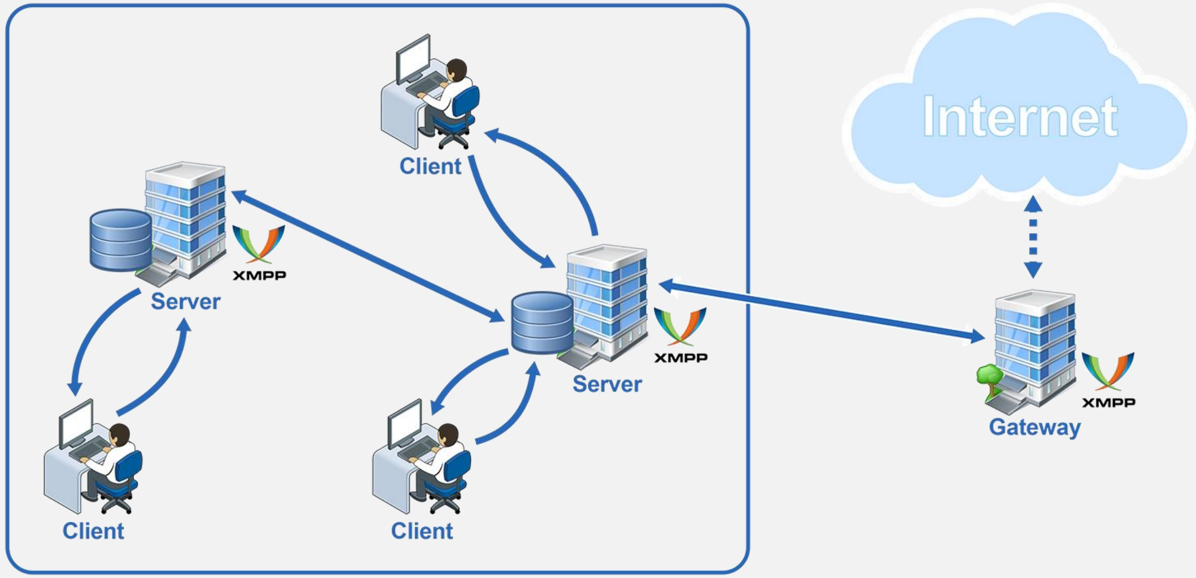
This makes web programming entirely event driven, not (just) user initiated.

It is stateful.

Publish/Subscribe

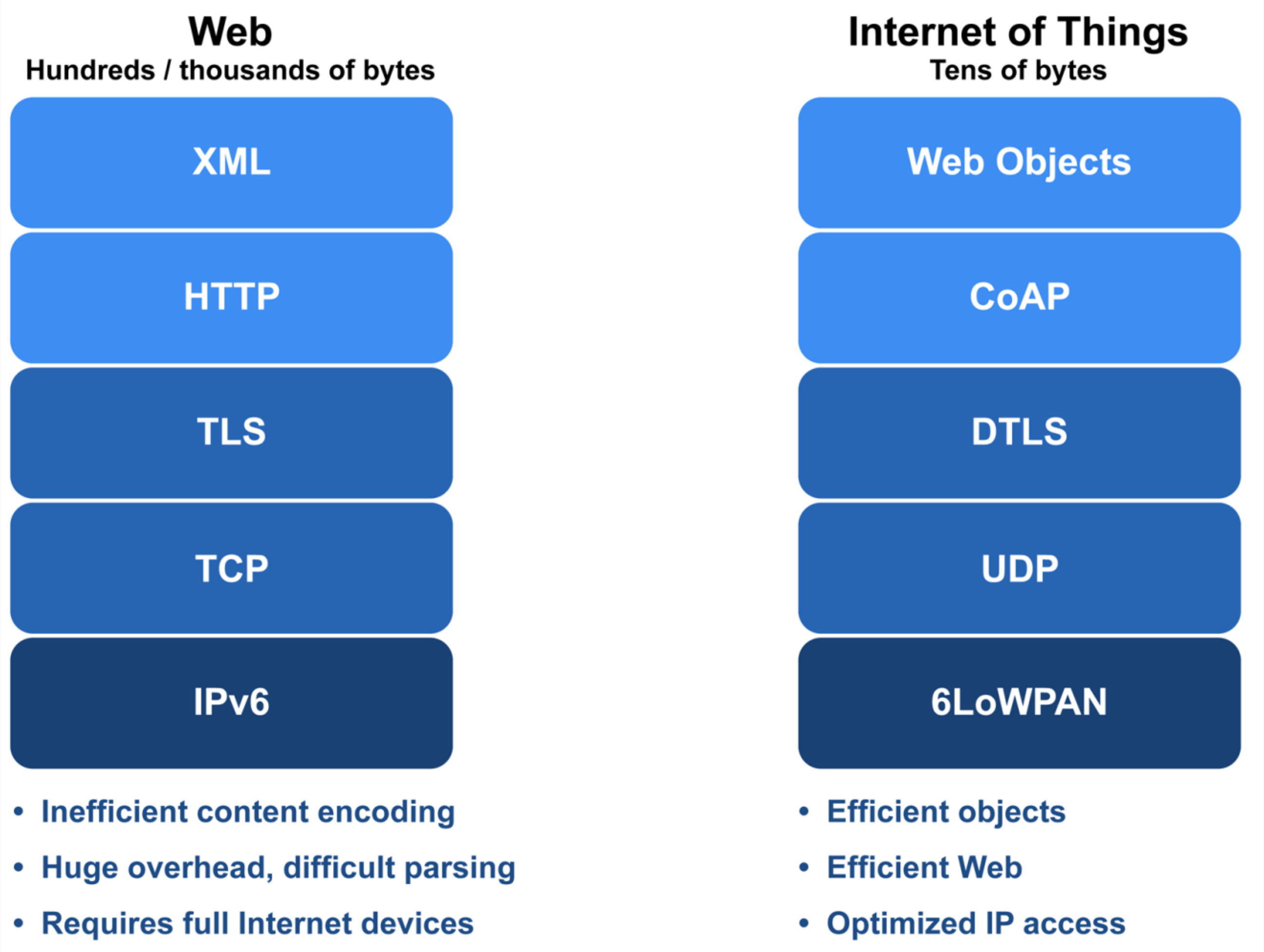
XMPP

XMPP



- Extensible Messaging and Presence Protocol
- Runs over TCP, and sometimes over HTTP over TCP
- Key strength is the use of the *name@domain.com* addressing scheme that leverages the global DNS infrastructure making it easy to find devices on the Internet
- XMPP mainly use polling
- Servers can push using BOSH (Bidirectional streams over Synchronous HTTP)

Web Versus Dedicated IoT



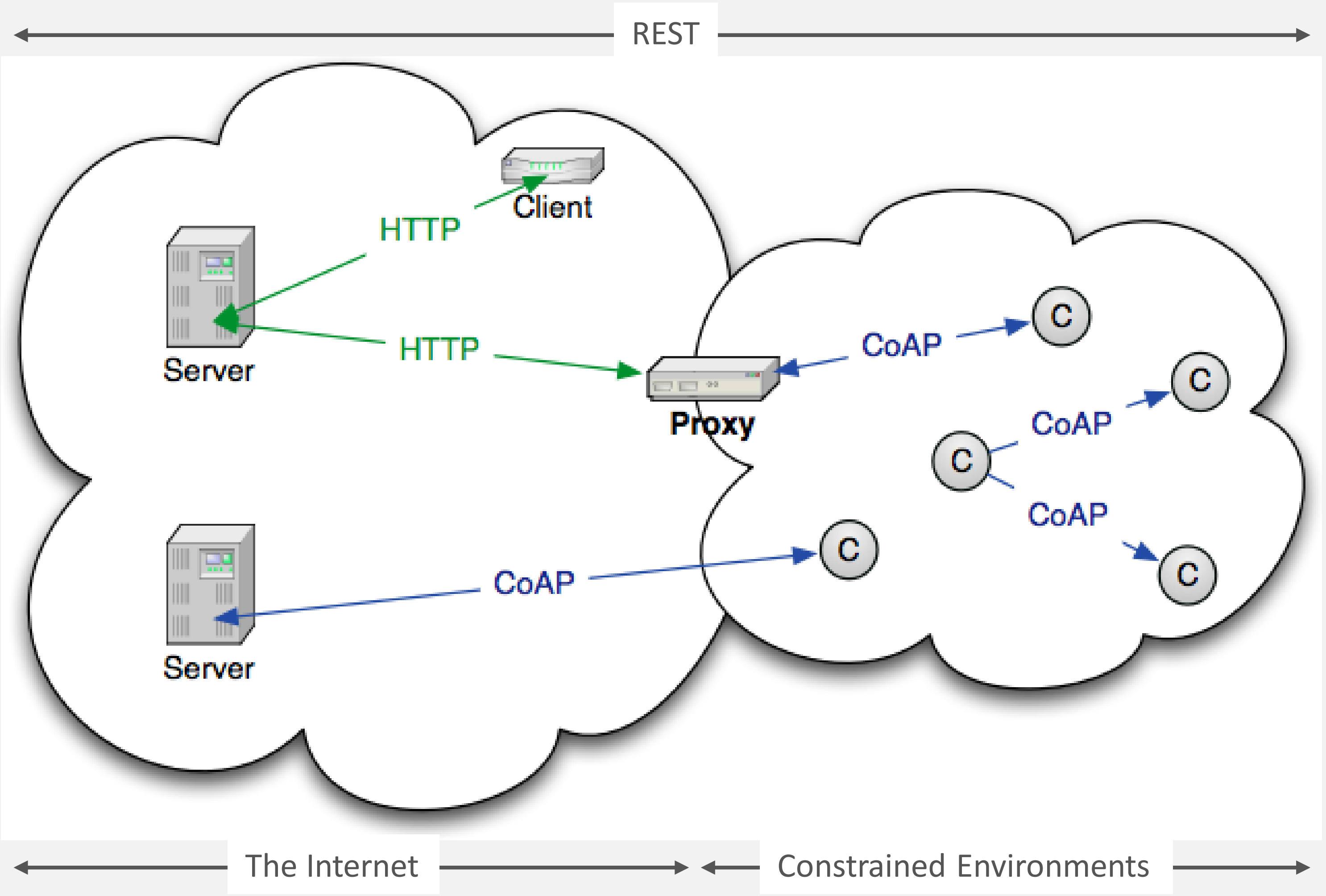
Publish/Subscribe

CoAP

CoAP – Design Goals

- Constrained devices
  Processor - Flash/RAM
- Constrained Networks
  i.e., Wireless Sensor Networks
- Low power devices (sleep modes)
- Caching/Mapping to HTTP
- Resource processing
- Subscribe/Notify architecture
- Resource discovery
- Multicast
- UDP Transport
- Reliable
- Low Latency
- Use of MIME types
- Manageability

CoAP Architecture



RFC 7252

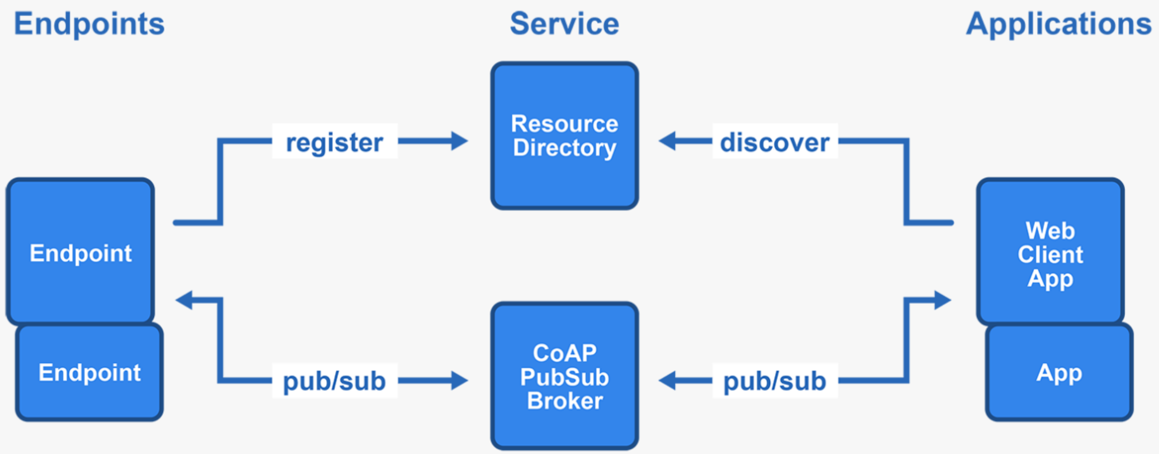
Proxy/Gateway

Constrained device

Publish/Subscribe with CoAP

As of July 2016, the IETF draft defining publish/subscribe and message queuing functionality for CoAP that extends the capabilities for supporting nodes with long breaks in connectivity and/or up-time is in its 5th iteration.

https://datatracker.ietf.org/doc/draft-koster-core-coap-pubsub/



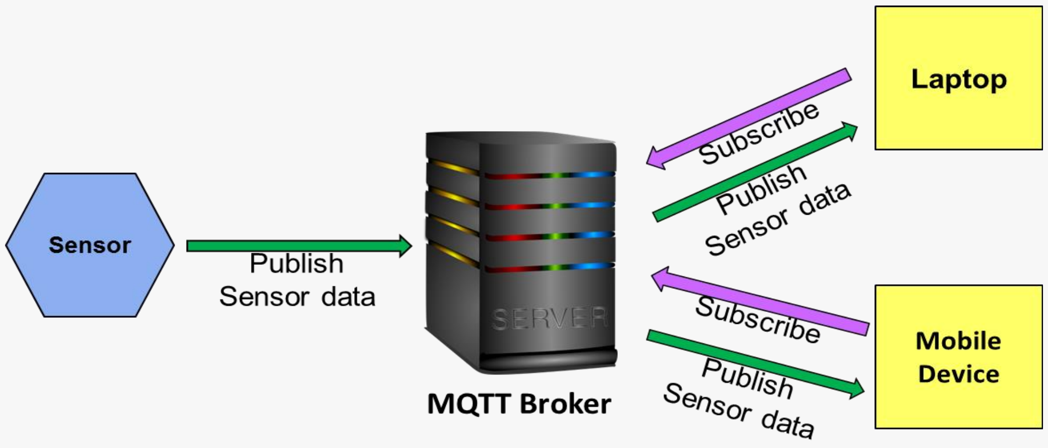
CoAP Publish/Subscribe Architecture

Publish/Subscribe

MQTT

MQTT

- MQTT has a client/server model, where every device is a client and connects to a server, known as a broker, over TCP.
- MQTT is message oriented. Every message is a discrete chunk of data, opaque to the broker.
- Every message is published to an address, known as a topic. Clients may subscribe to multiple topics.
- Every client subscribed to a topic receives every message published to the topic.



A simple network with three clients and a central broker

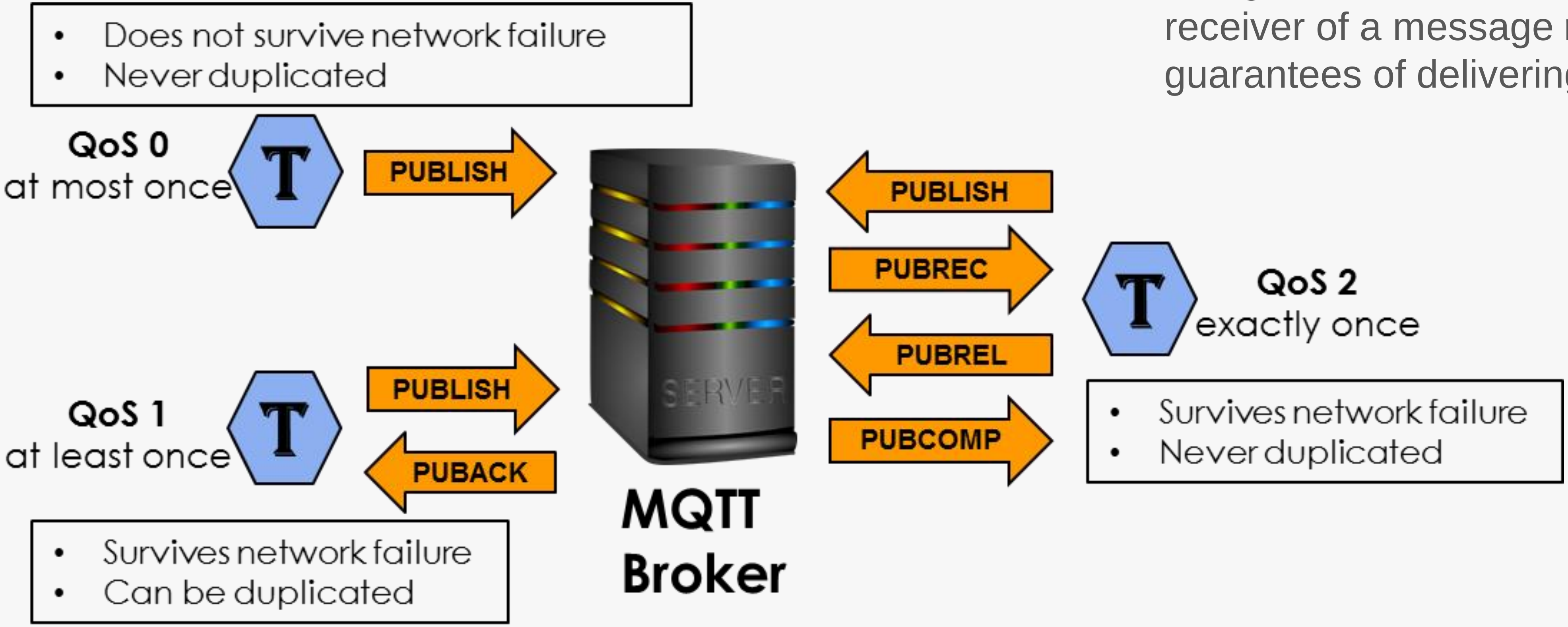
MQTT

MQTT Version 3.1.1 was last revised or approved by the membership of OASIS on 29 October 2014.

- "OASIS" (Organization for the Advancement of Structured Information Standards) is a non-profit consortium that drives the development, convergence and adoption of open standards for the global information society
- IBM and Microsoft are amongst the initial foundational founders. The list of members can be found at this link: https://www.oasis-open.org/member-roster
- Excellent training source: http://www.hivemq.com/

MQTT Quality of Service (QoS)

There are 3 QoS levels in MQTT:



The Quality of Service (QoS) level is an agreement between sender and receiver of a message regarding the guarantees of delivering a message.

MQTT-SN

MQTT is lightweight but has two drawbacks for very constrained devices:

- Every MQTT client must support TCP and will typically hold a connection open to the broker at all times. For some environments where packet loss is high or computing resources are scarce, this is a problem
- MQTT topic names are often long strings which make them impractical for 802.15.4

Both of these shortcomings are addressed by the MQTT-SN protocol, which defines a MQTT UDP mapping and adds broker support for indexing topic names

DDS

DDS is Decentralized

DDS

- Is an Object Management Group (OMG) standard
- Was introduced in 2004
- Uses a Publish/Subscribe architecture
- Uses network resources efficiently
- Commercial and Open Source versions available

Can be deployed without servers/brokers

Fast

- 100,000's update/sec

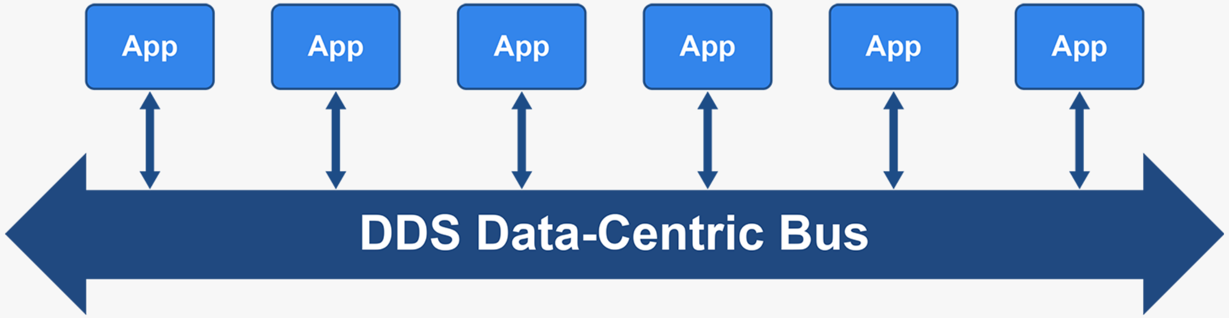
Scalable

- Load independent # apps

Managed with QoS

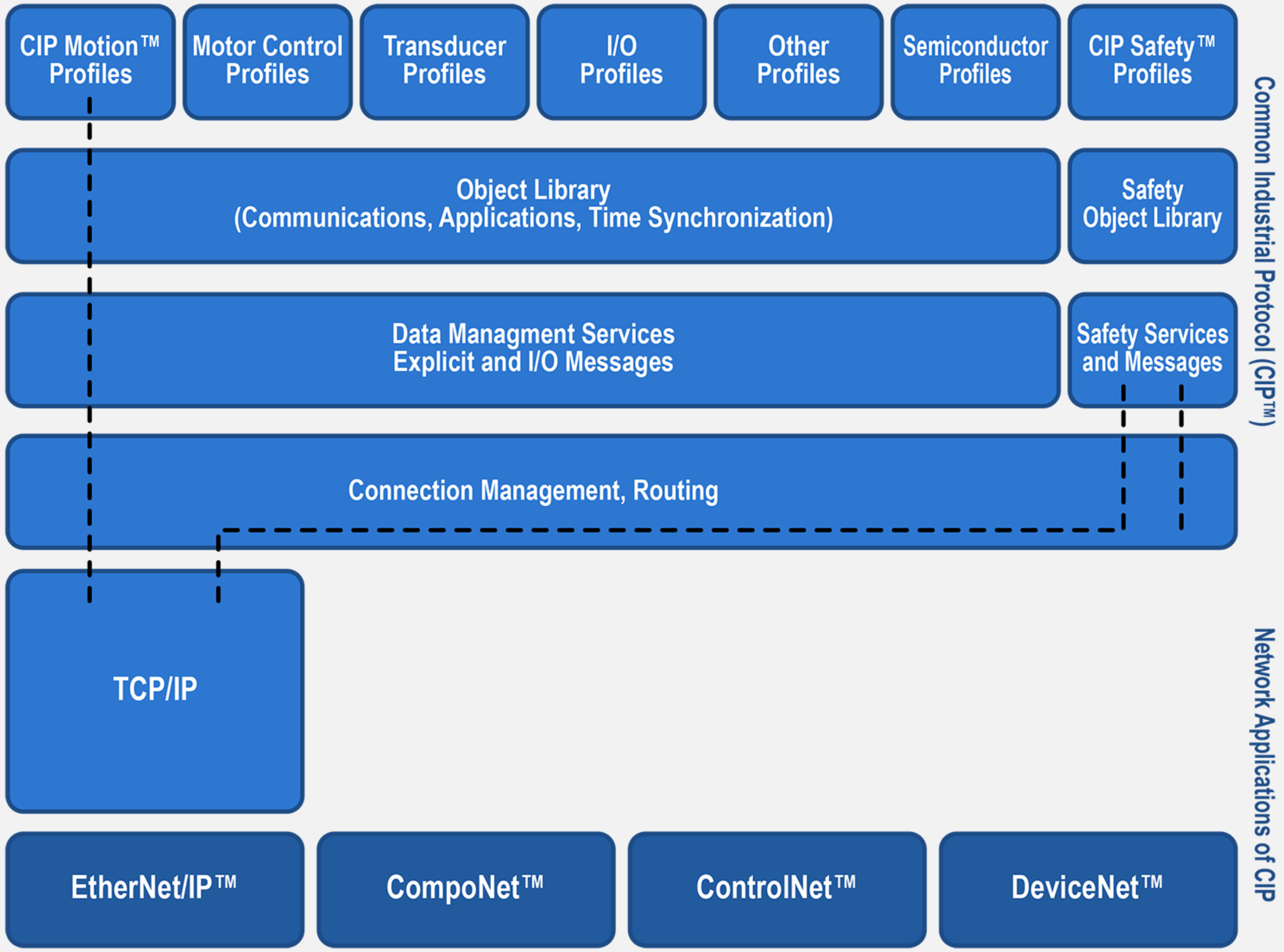
Reliable

- No single point of failure



CIP

Common Industrial Protocol (CIP)



One More Level

Device Management

Device Management

One of the most important requirement for an IoT system

- Very much Cloud based

Device Management

- Configure the device (provisioning)
- Update the firmware securely (and maybe the application)
- Monitor and gather connectivity statistics

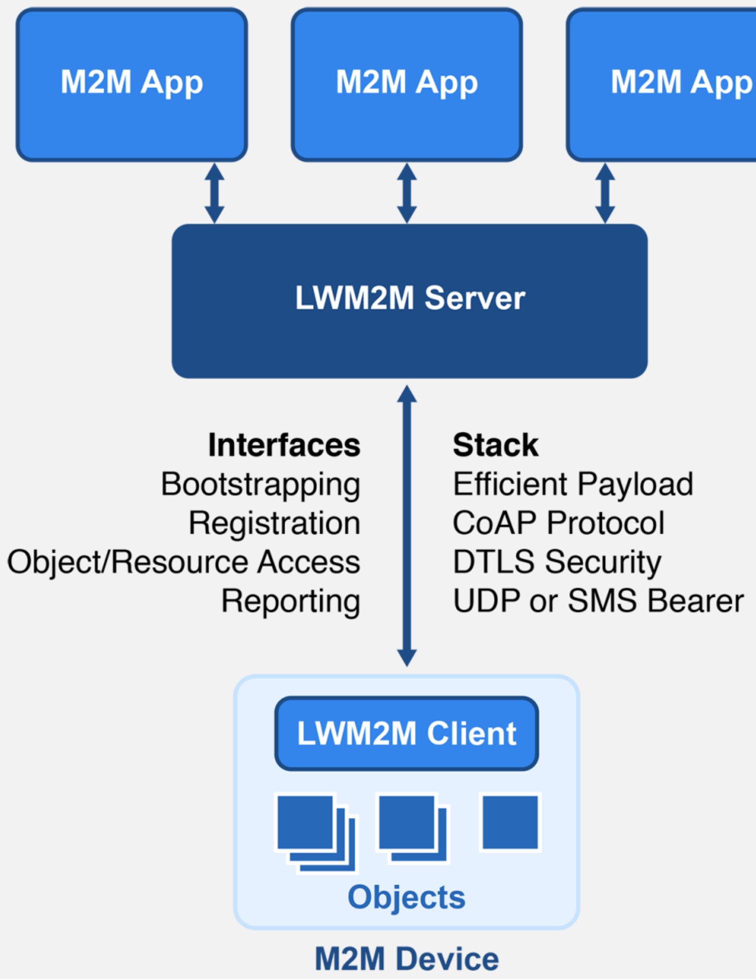
Out of the multiple device management functions, security and provisioning are the most complex ones

Device Management

Existing Systems/Protocols

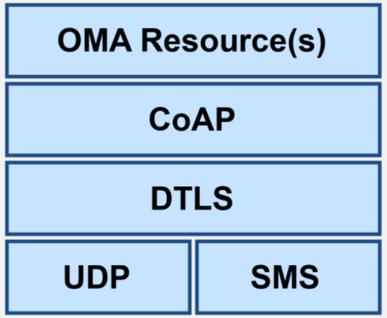
- **TR-069** (well know for broadband modem management, SOAP based)
- **OMA-DM** (An Open Mobile Alliance [OMA] standard for Device Management, mainly used by mobile network operators)
- **Lightweight M2M** (new OMA standard)

LWM2M Architecture



Built on top of CoAP
MQTT also used now (Eclipse projects)

Much lighter than OMA-DM and TRS-069



Benefits of OMA Lightweight M2M

- Simple, efficient protocol, interfaces and payload formats
- Transport security based on DTLS
  - With Pre-shared and Public Key modes, Provisioning and Bootstrapping
- Powerful Object and Resource model
  - Global registry and public lookup of all Objects
  - Provides application semantics that are easy to use and re-use
  - Standard device management Objects already defined by OMA

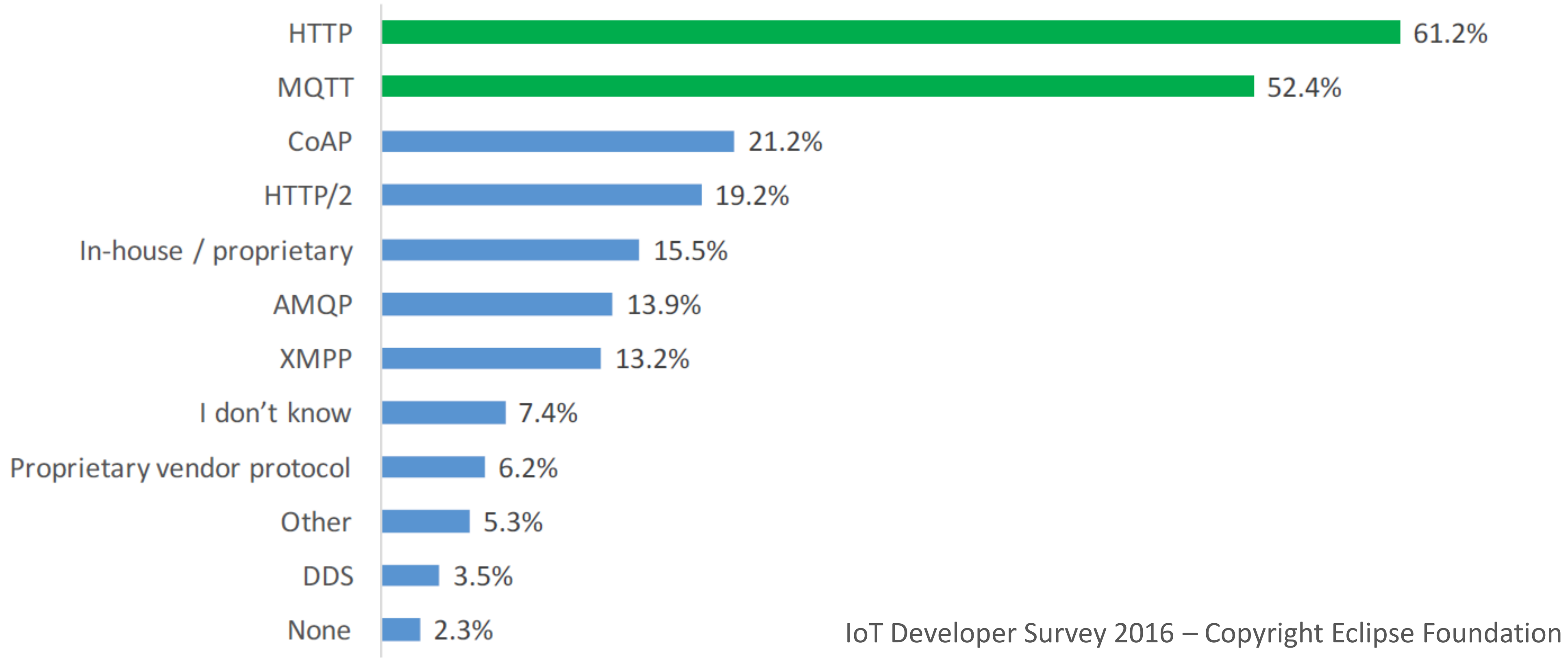
Benefits of OMA Lightweight M2M

- Applicable to Cellular, 6LoWPAN, Wi-Fi and ZigBee IP or any other IP based constrained devices or networks
- Ideal time-to-market for the standard
  - LWM2M is commercially deployed since 2013
  - Can be combined with existing Device Management offerings
  - Will be supported in OneM2M and can be integrated with ETSI M2M

http://www.slideshare.net/IanSkerrett/iot-developer-survey-2016

Messaging Standards

What messaging protocols do you use for your IoT solution?



Questions?

Thank you!