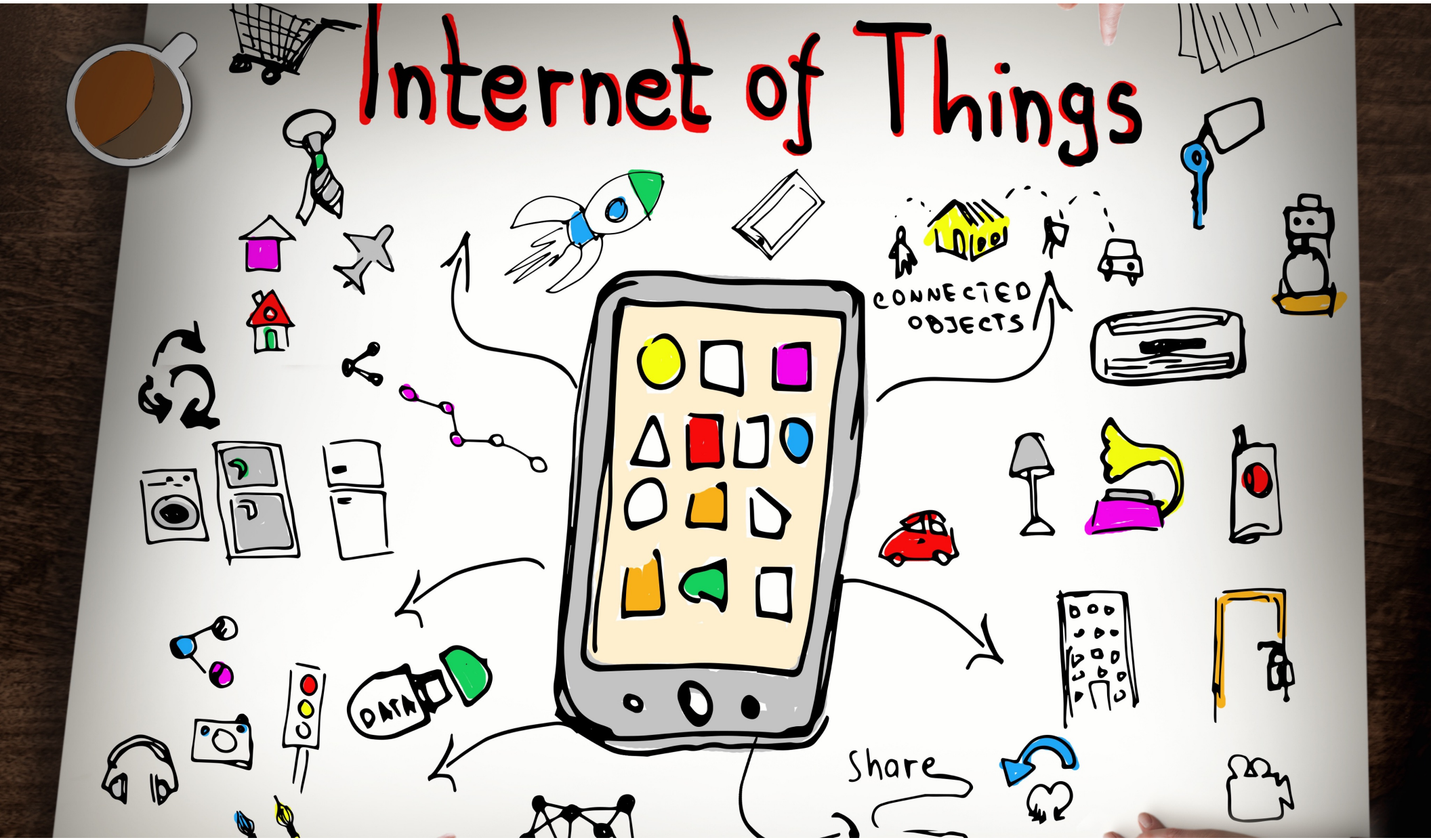

IoT Protocols & Applications

18-738 Sports Technology

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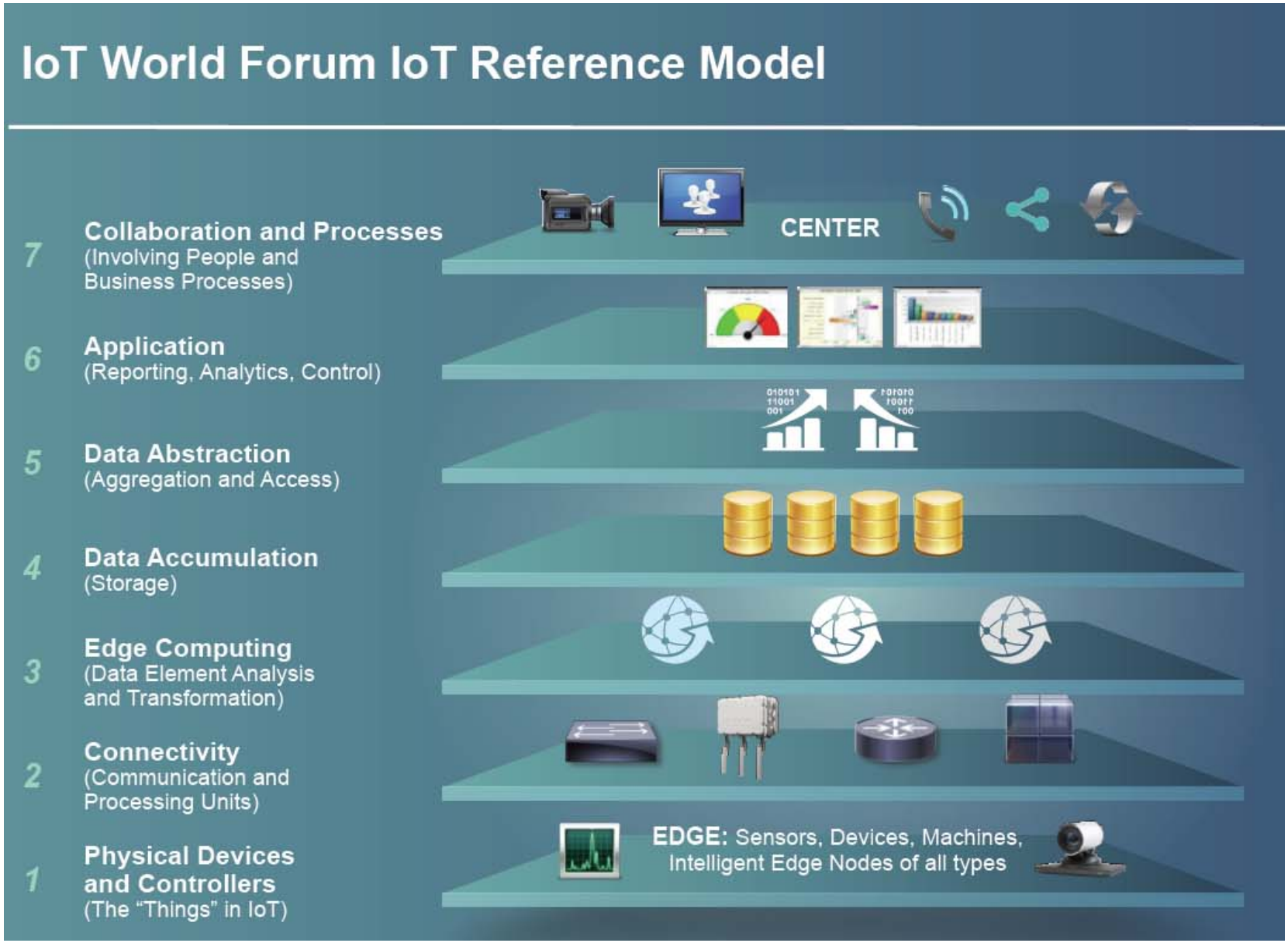
Overview


IoT World Forum IoT Reference Model
7
Collaboration and Processes
(Involving People and
Business Processes)
6
Application
(Reporting, Analytics, Control)
5
Data Abstraction
(Aggregation and Access)
4
Data Accumulation
(Storage)
3
Edge Computing
(Data Element Analysis
and Transformation)
2
Connectivity
(Communication and
Processing Units)
1
Physical Devices
and Controllers
(The "Things" in IoT)
CENTER
EDGE: Sensors, Devices, Machines,
Intelligent Edge Nodes of all types

How many things?

1.1 Billion smart phones

244 Million smart meters
487 Million e-readers and tablets
2.37 Billion networked office devices
86 Million medical devices
45 Million connected automobiles
547 Million connected appliances
105 Million connected military devices
431 Million information technology devices
45 Million supervisory control and data acquisition (SCADA)

5+ Billion other (non-phone/tablet/e-reader) electronic devices

.

The Industry Viewpoint

- Cisco:
  - “Connecting physical objects to provide better safety, comfort, efficiency”
- IBM:
  - “A new World-Wide Web, comprised of messages that digitally empowered devices would send to each other”
- General Electric:
  - “Convergence of machine and intelligent data to create brilliant machines”

Standardization bodies

- IoT will connect way more devices that mobile networks do (or will)
- These smart devices are everywhere
  - Home, car, work, healthcare
- IoT protocols standardized by
  - World Wide Web Consortium (W3C)
  - Internet Engineering Task Force (IETF)
  - EPCGlobal
  - Institute of Electrical and Electronics Engineers (IEEE)
  - European Telecommunications Standards Institute (ETSI)

What protocols, and why?

- Infrastructure, e.g., 6LowPAN, IPv4/IPv6, RPL (**TODAY**)
- Identification, e.g., EPC, uCode, IPv6, URIs
- Communications/Transport, e.g., Wi-Fi, Bluetooth, LPWAN
- Discovery, e.g., Physical Web, mDNS, DNS-SD
- Data Protocols, e.g., MQTT, CoAP, AMQP (**TODAY**)
- Device Management, e.g., TR-069, OMA-DM
- Semantic, e.g., JSON-LD, Web Thing Model
- Multi-layer Frameworks, e.g., Alljoyn, IoTivity, Weave, Homekit)

Recap: Communications/Transport Layer

Technology	Frequency	Data Rate	Range	Power Usage	Cost
2G/3G	Cellular Bands	10 Mbps	Several Miles	High	High
Bluetooth/BLE	2.4Ghz	1, 2, 3 Mbps	~300 feet	Low	Low
802.15.4	subGhz, 2.4GHz	40, 250 kbps	> 100 square miles	Low	Low
LoRa	subGhz	< 50 kbps	1-3 miles	Low	Medium
LTE Cat 0/1	Cellular Bands	1-10 Mbps	Several Miles	Medium	High
NB-IoT	Cellular Bands	0.1-1 Mbps	Several Miles	Medium	High
SigFox	subGhz	< 1 kbps	Several Miles	Low	Medium
Weightless	subGhz	0.1-24 Mbps	Several Miles	Low	Low
Wi-Fi	subGhz, 2.4Ghz, 5Ghz	0.1-54 Mbps	< 300 feet	Medium	Low
WirelessHART	2.4Ghz	250 kbps	~300 feet	Medium	Medium
ZigBee	2.4Ghz	250 kbps	~300 feet	Low	Medium
Z-Wave	subGhz	40 kbps	~100 feet	Low	Medium

Image Credit: Helium

Choices, choices (for wireless IoT protocols alone)

IEEE802.11

Bluetooth/BluetoothSmart

ZigBee/ZigBeeSmartEnergy2.0

IEEE802.15.6-2012:BodyAreaNetworking

WirelessHART (HighwayAddressableRemoteTransducer Protocol)

International Society of Automation (ISA)100.11a

Z-Wave

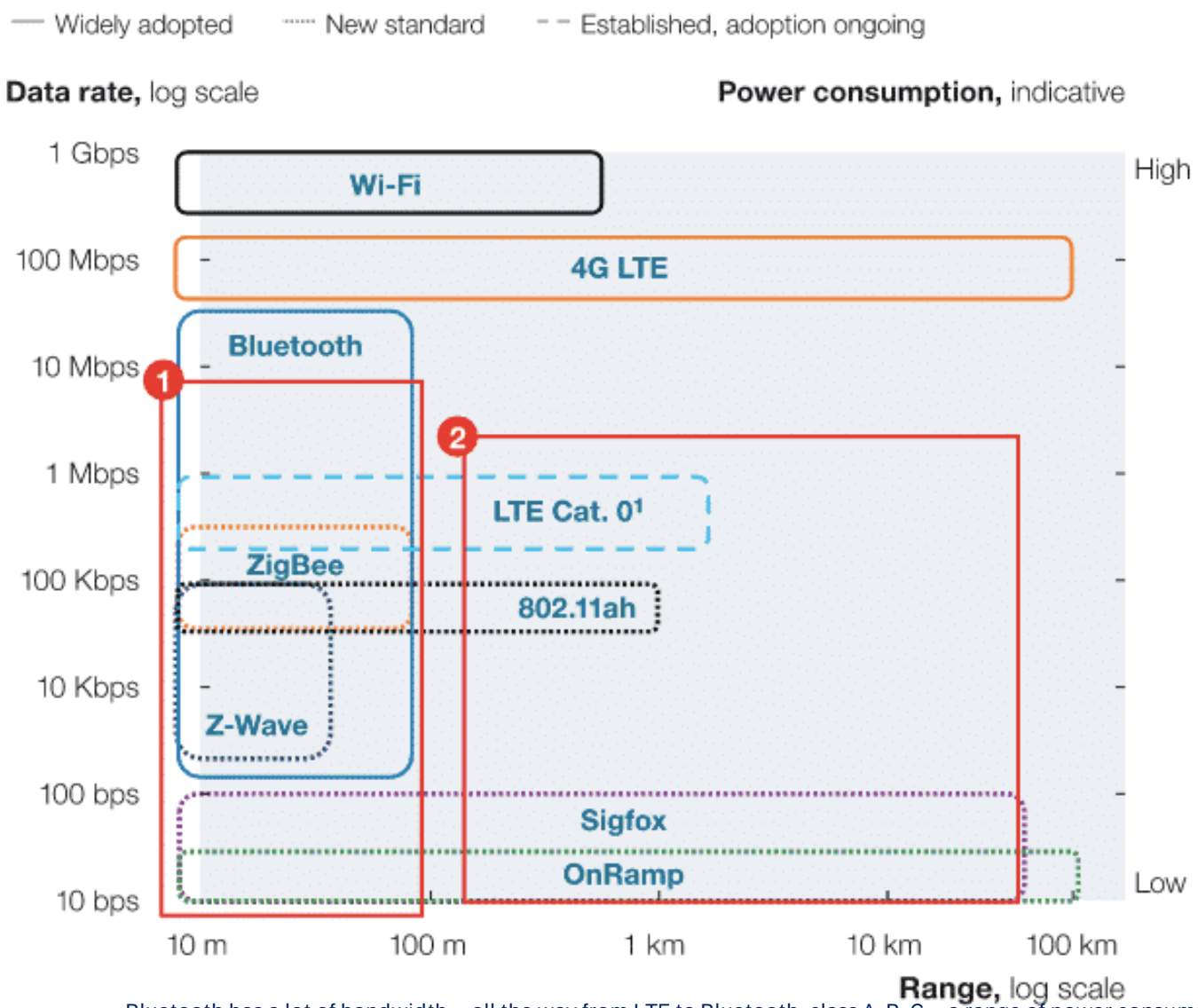
MiWi(MicrochipTechnologyWireless)

ANT+

WirelessMBUS

.

Recap: Wireless Communications/Transport Layer

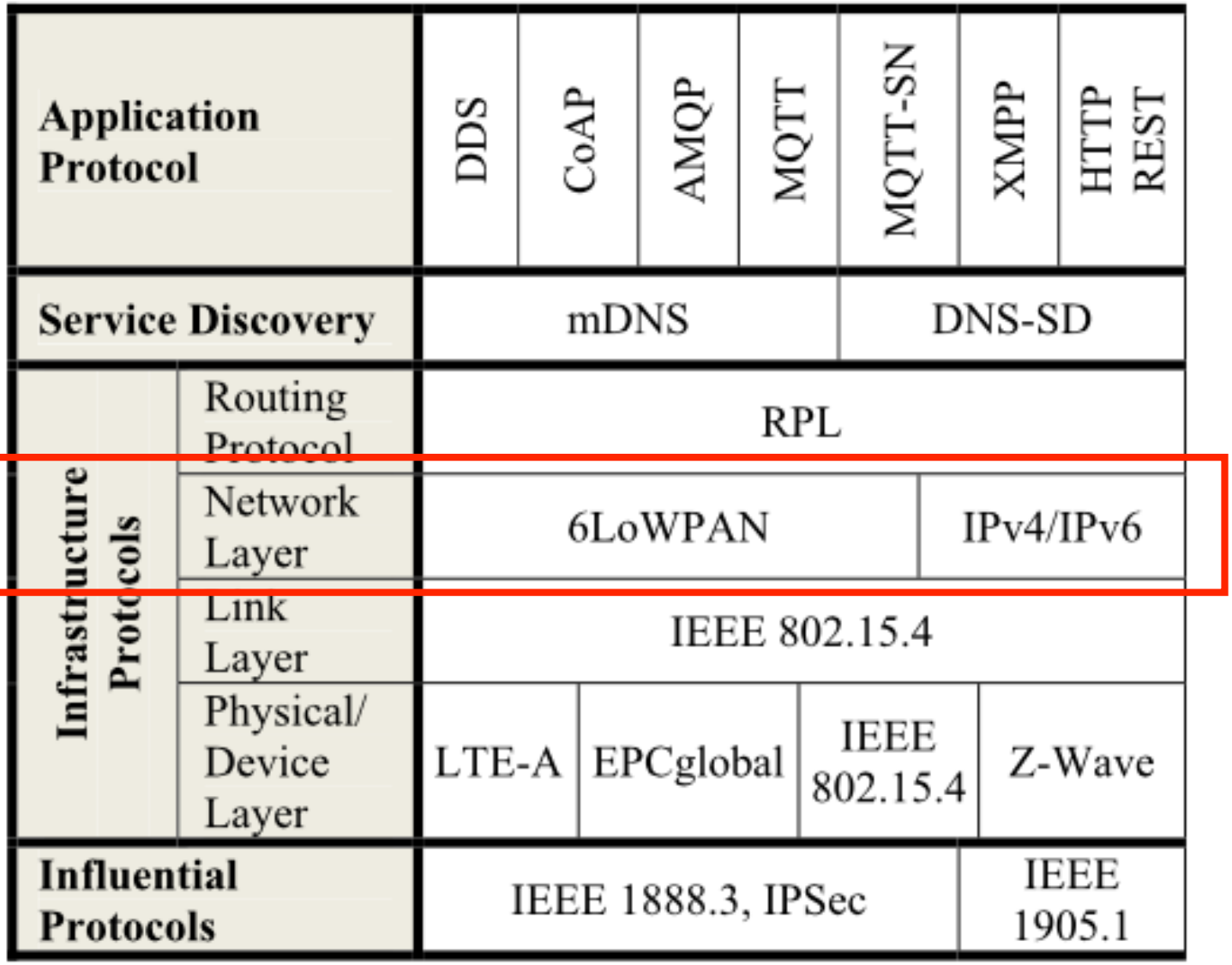


1 Many competing standards for low-range, medium-low data rate hinder growth for many IoT applications
- Interoperability missing
- Consortia wars might be emerging
- Additional incompatibilities in higher communication layers, eg, 6LoWPAN vs ZigBee

2 Standard white space for low-data-rate, low-power, high-range applications such as smart grid
- Wi-Fi and LTE have high power consumption
- Alternatives with low power and wide range (eg, LTE Cat. 0, 802.11ah, Sigfox, and OnRamp) are in very early stages and compete against each other

Bluetooth has a lot of bandwidth -- all the way from LTE to Bluetooth, class A, B, C -- a range of power consumption
4G and LTE has long range.

How the Protocols Relate to Each Other



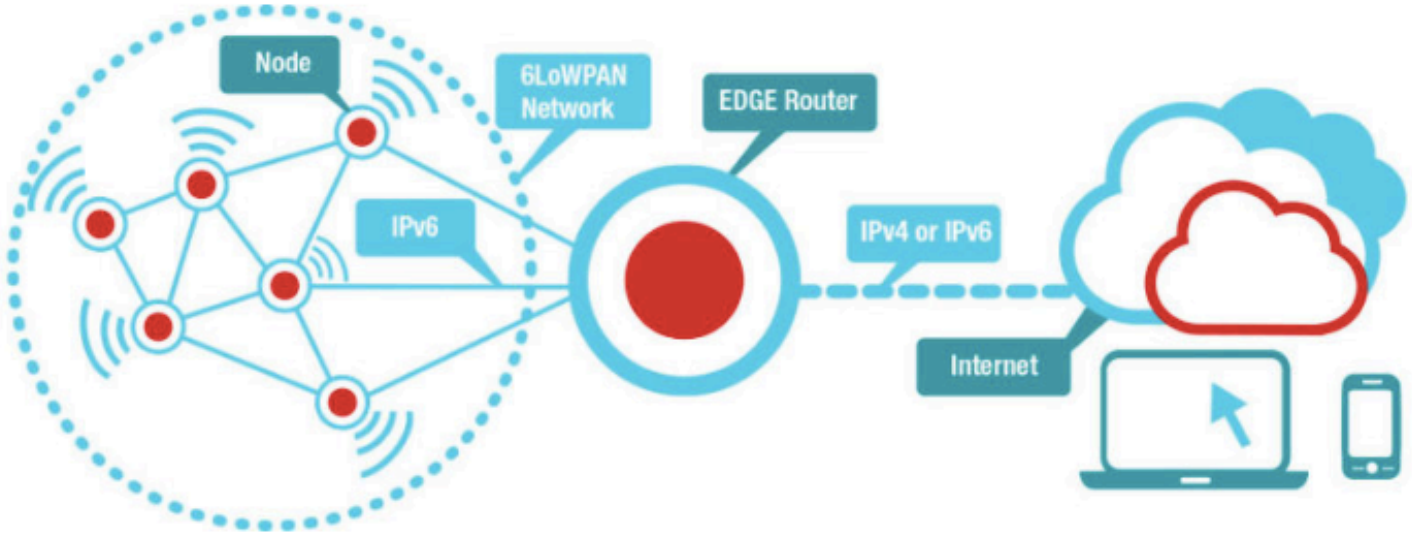
Example: 6LowPAN

- IPv6 over Low-Power Wireless Personal Area Networks
- Every device has its own IPv6 address

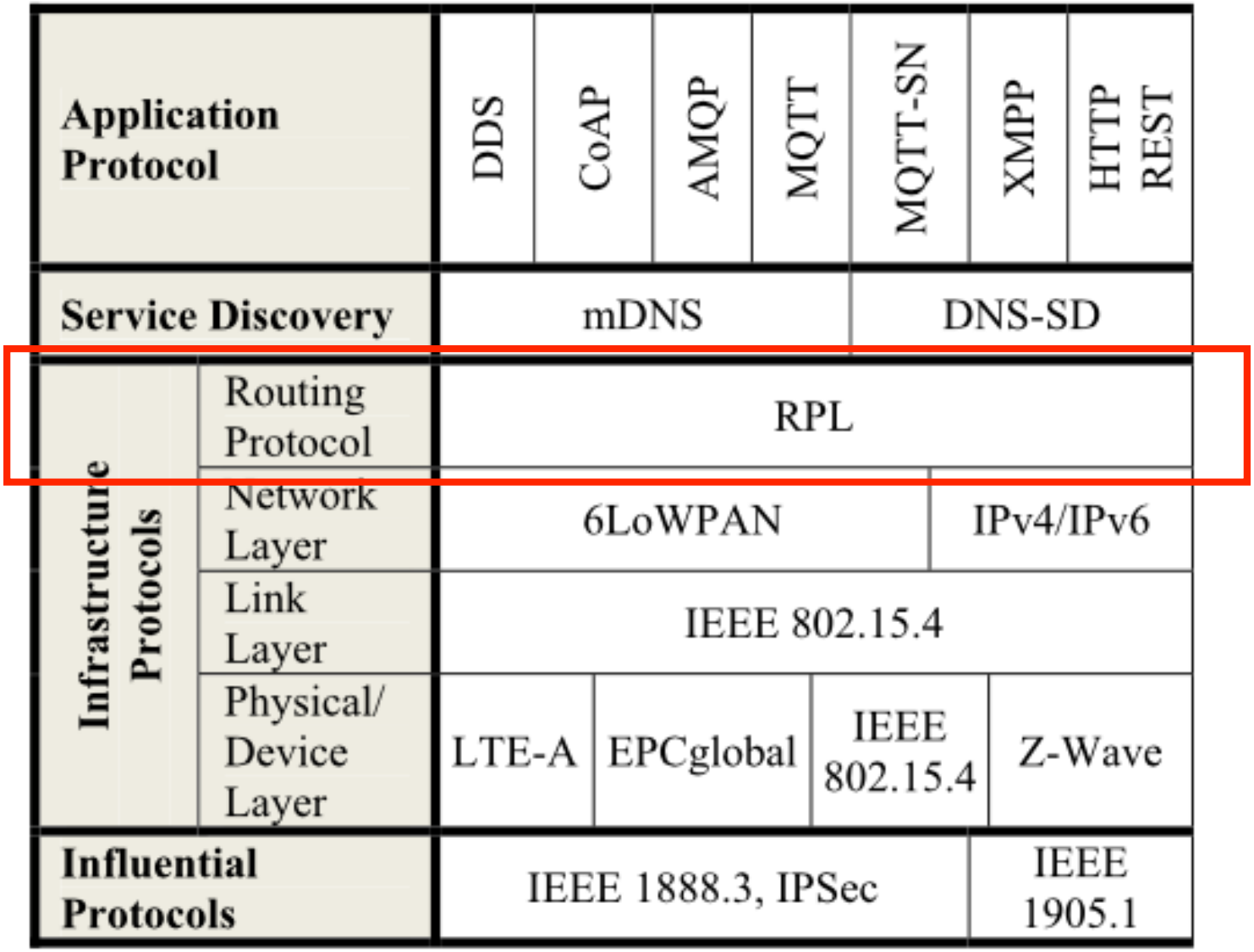
Create a mesh network of nodes.
The edge router can speak 6LowPAN, bascially IPV6 over low power network.

- Built on the principle that the Internet Protocol (IP) should apply to any “thing”
- End-to-end IP-addressable nodes
- Ability to create a mesh network of nodes, connected by an edge router

6LowPAN is another protocal that help with edge computing.



How the Protocols Relate to Each Other



Example: RPL

Routing Protocal in Low Power: routing protocal tries to get one packet to another node. The routing has some topology of the network.

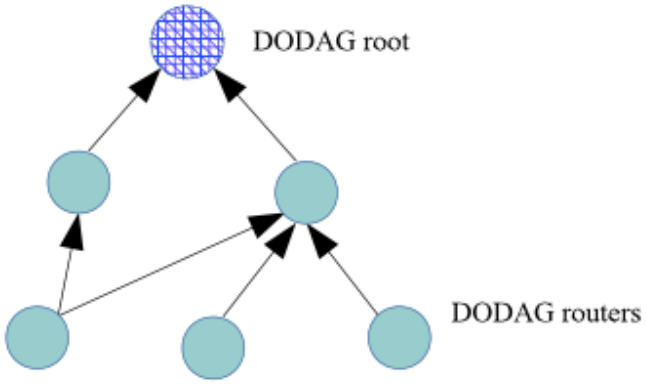
- Routing Protocol for Low Power and Lossy Networks (RPL)
- An IETF working group standardized this for resource-constrained devices

Routing makes sure you can transfer packet to other parts of network.

- Focus was on: Minimal routing, lossy links, topology
- Different traffic models: multipoint-to-point, point-to-multipoint, point-to-point
- Routing via a DODAG (Destination Oriented Directed Acyclic Graph)
- DODAG shows a routing diagram of nodes
- Each node is aware of parents, but not children
- HTTP get, post, put, and delete methods as verbs
- At least one path maintained for each node to the root
- And a path maintained for each node via preferred parent for performance

RPL (2)

- Four types of control messages 'Ranked Levels of Nodes.'
- DIO (DODAG Information Object) message—most important type
  - Keeps current rank (level) of the node
  - Determines the distance of each node to the root based on metrics
  - Determines the choice of the preferred path



- DODAG built in waves and iteratively
  - Root sends DIO messages to all levels
  - Each level registers parent path and propagates DIO messages
  - Preferred parent path is designated based on metrics
  - Downward routes and upward routes can be flagged

How the Protocols Relate to Each Other

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	

The Players in the Ecosystem

- Device (D)
- Server (S)
- Device-to-device (D2D)
- Device-to-server (D2S) Device to server may not only be single straright up link, it can be device- edge server- fog server - cloud server.
- Server-to-server (S2S)

- Devices must be able to communicate with each other (D2D)
- Device data is likely dispatched to a server (D2S)
- Servers may communicated with each other to provide functionality (S2S)
- Result may be provided to people, to devices, to other servers, etc.

Example Protocols

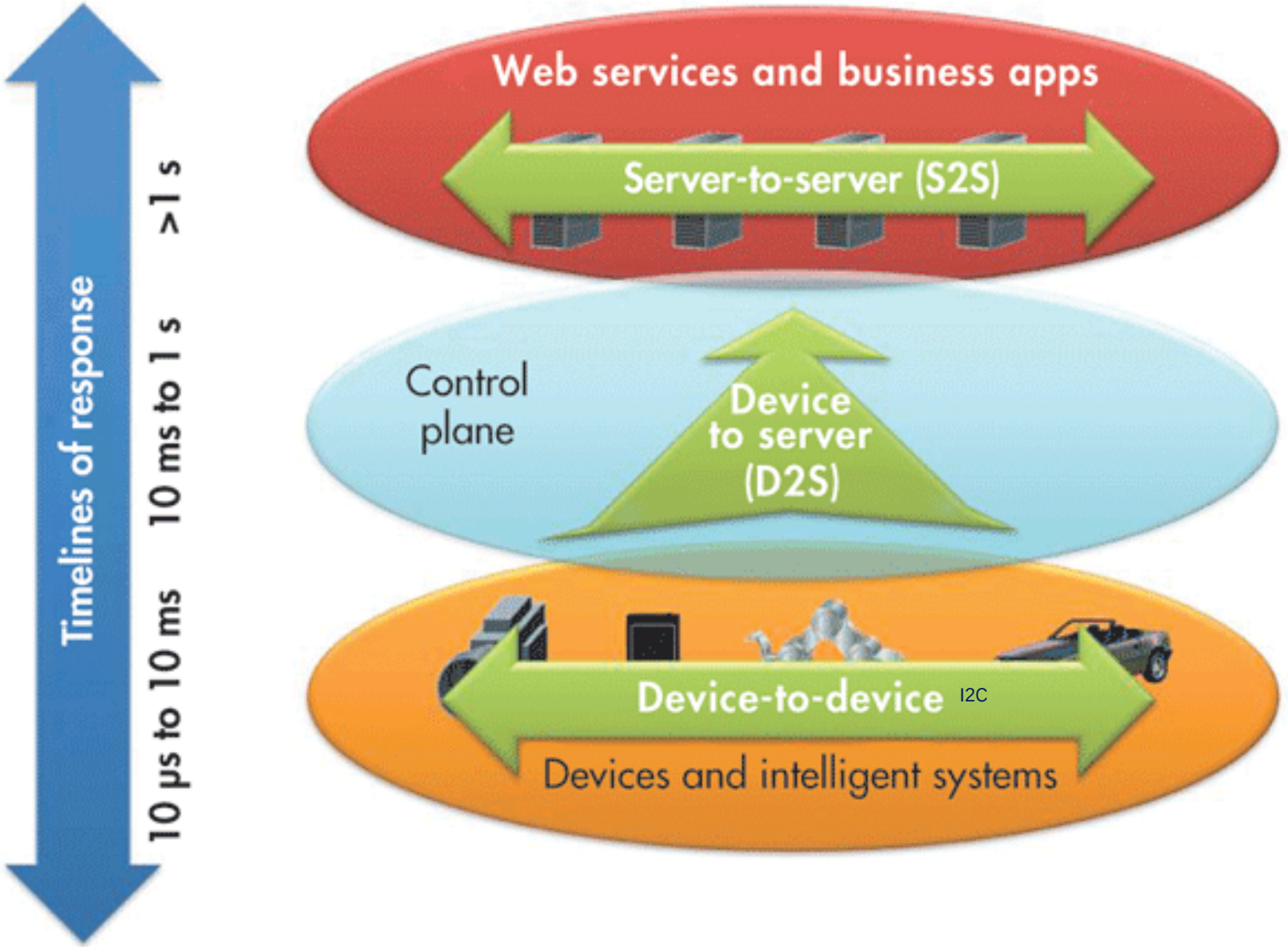
All of these are application layer protocal, they have emphasis in different level.

- MQTT: Protocol for collective device data and sending it to servers (D2S)
- XMPP: Protocol for collective device data and sending it to people (D2S)

XMPP not necessarily server, can be device to people.

  - Special case of D2S because people act as (or are connected to) servers
- DDS: Fast machine-to-machine bus for disseminating information (D2D)
- AMQP: Queueing system designed to connect servers to each other (S2S)
- Each protocol widely adopted; at least 10 implementations of each
- All claim to be
  - Real-time publish-subscribe IoT protocols
  - Able to connect 1000s of devices
  - Depends on your definition of “real-time”

A Real-Time (Responsiveness) Perspective



MQTT

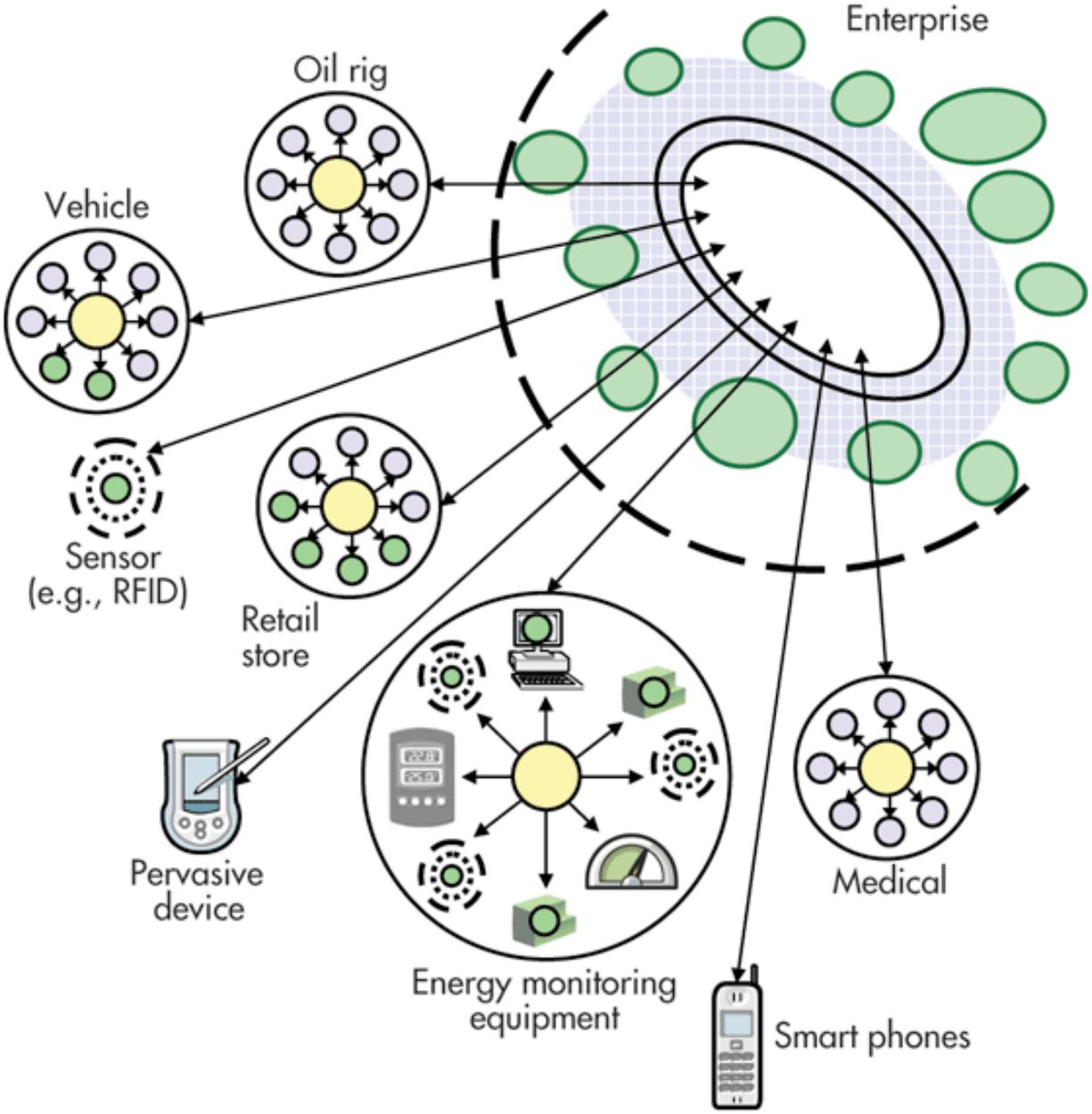
- Message Queue Telemetry Transport
- Main purpose started off with telemetry (remote monitoring of objects)
  - Focus is to collect a lot of data from a lot of devices and send it to servers
  - Targets large collections of devices that need to be connected to the cloud
  - Simple, not particularly fast (responsiveness in seconds)
- Makes little attempt at
  - Device-to-device (D2D) data transfer, publishing data to many recipients
- Hub-and-spoke architecture
  - Devices connect to a “data-concentrator” server, TCP/IP for reliable delivery
- Examples
  - Vast oil-pipeline monitoring for leaks/vandalism, smart lighting/power

data-concentrator basically the notion of edge computing , instead of millions of device directly connected to cloud server.

MQTT

Large amount of data need to upload large amount of data.

Yellow dots are edge server
The Cloud is the enterprise.



CoAP

Limited Resource MQTT. Tiny device need to update tiny data.

- Constrained Application Protocol
- Targets low-footprint resource-constrained devices
- From an architectural standpoint
  - Smaller packets than TCP/IP flows
  - Bitfields and mappings from strings to integers to save space

    some tricks
  - Runs over UDP, broadcast and multicast discovery for addressing

    UDP is basically an unsafe TCP. Fire-and-forget best effort protocal.
  - Confirmable messages require acknowledgment
  - Non-confirmable messages are the fire-and-forget type
  - Primarily a one-to-one protocol (unlike MQTT's many-to-many)

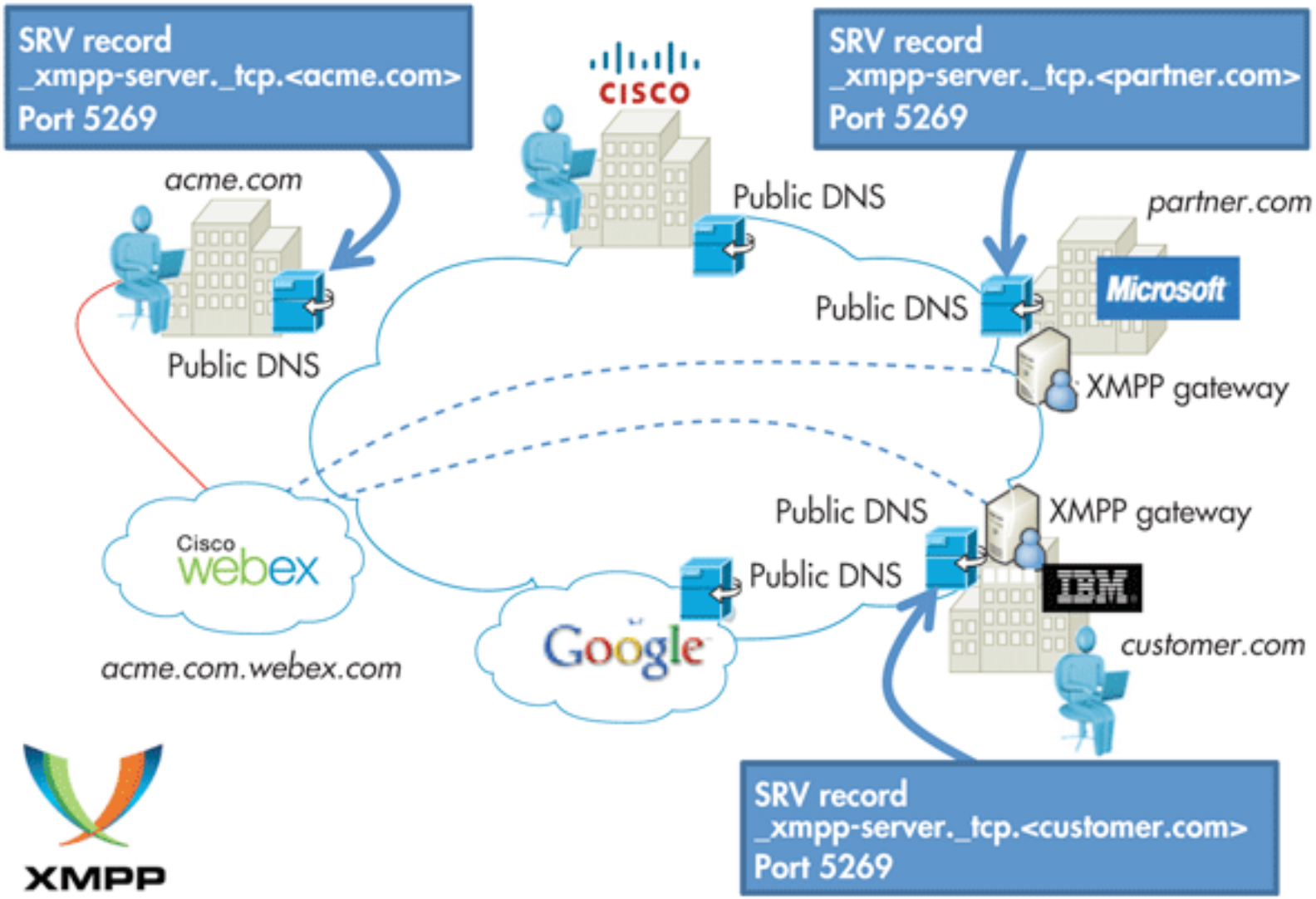
XMPP

This updates sensor on some sort of data.

- Extensible Messaging and Presence Protocol (originally called “Jabber”)
- Originated with instant messaging (IM) to connect people via text messages
- From an architectural standpoint
  - Uses XML text format as the native type for messages
  - Uses TCP, and often HTTP over TCP xml requires parsing, that takes time, you should not expect real-time.
    HTTPS vs TCP, it is easy way of addressing device at an ip address 192.168.0.xxx. You can address even the edge routers.
  - Key strength: Easy way to address a device as name@domain.com
  - Primarily polling-based, for servers to check devices for updates
  - Servers can push via BOSH (Bidirectional streams over Synchronous HTTP)
  - Real-time on human time-scales, in several seconds.
- Examples
  - Connecting your home thermostat to a Web Server to access from phone

XMPP

Examples, you can access devices remotely at very long distances.



DDS

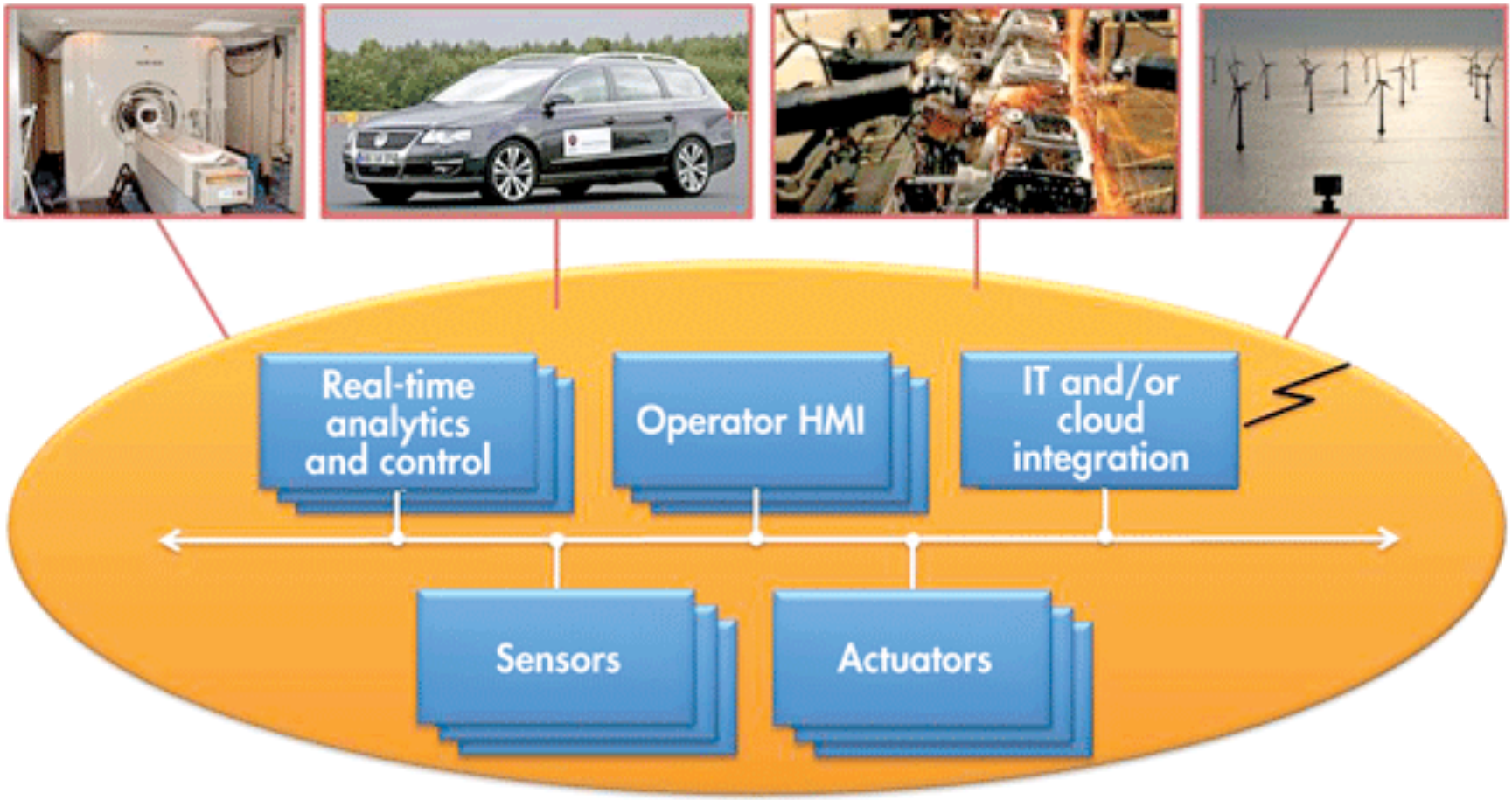
Almost a device to device bus where all devices can listen to.
Like in an airplane, all the sensors listen to...

- Data Distribution Service
- Targets devices that directly use device data (without going to a server)
- Has its roots in high-performance industrial and military embedded applications
- From an architectural standpoint
  - Can deliver millions of messages simultaneously to 1000s of receivers
  - TCP's point-to-point protocol too restrictive
  - Instead, uses fan-out multicast protocol with configurable QoS control
  - Publishing to a device-to-device "bus" that 1000s of devices listen on
  - Real-time on device time-scales, which means microseconds
  - Respects device constraints, so lightweight DDS implementations exist
- Examples: Military, wind farms, hospitals, asset-tracking systems

DHL tracking where their packages are. There's no luxury of using edge server using TCP. This is the case where you need massive bus devices can talk directly. There's no luxury of going to cloud and going back.

DDS

Device-device server



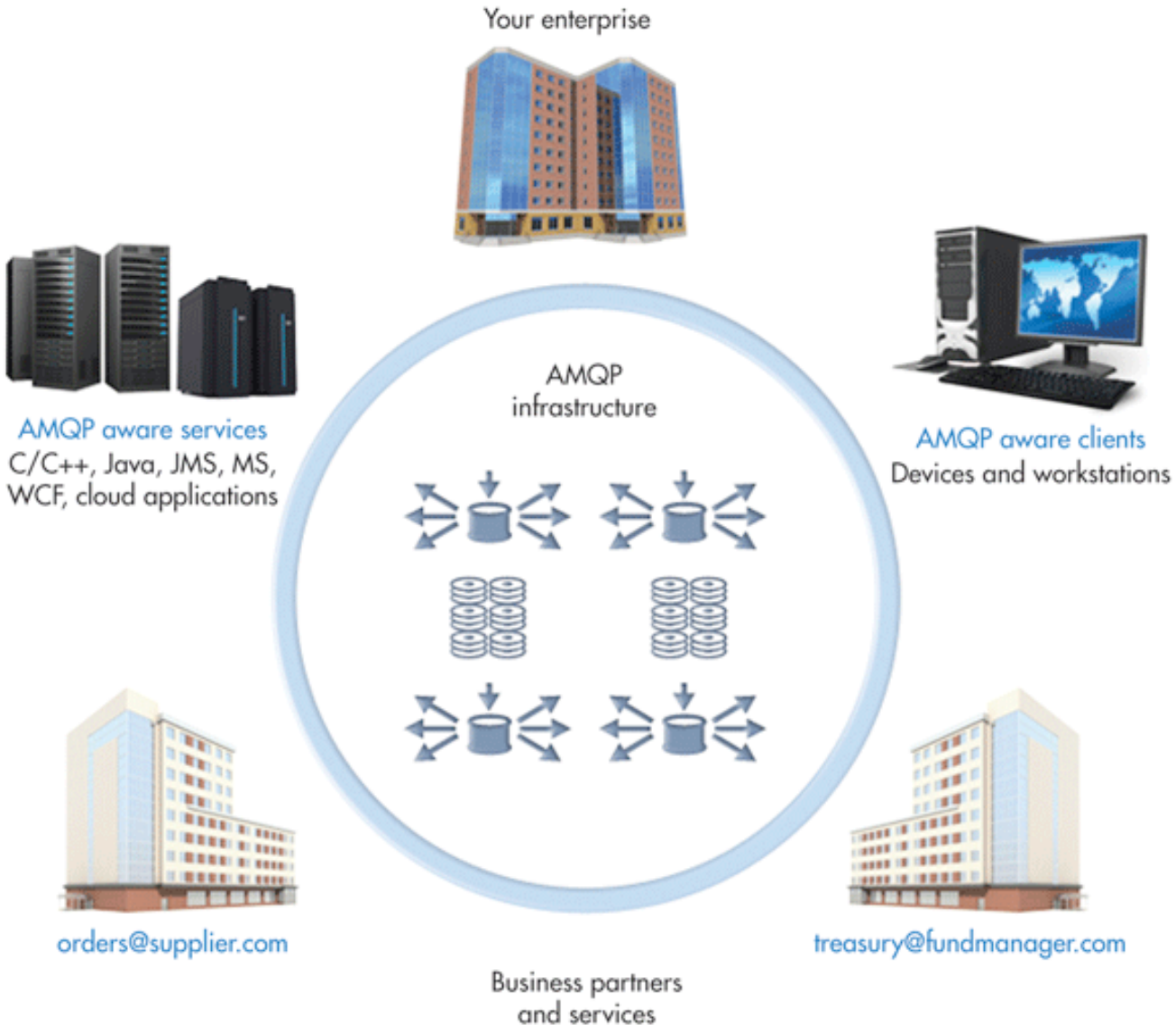
AMQP

Server-Sever Protol

It can handle scale.

- Advanced Message Queuing Protocol
- Originated in the banking industry; sometimes considered an IoT protocol
- Sends transactional messages between end-points (servers)
- From an architectural standpoint
  - Focus on processing 1000s of reliable, queued transactions
  - Focus on reliability; uses TCP and requires message acknowledgments
  - More reliability; tracking messages, ensuring fault-tolerant delivery
  - Formal, multi-phase commit sequence
  - Device here means mobile phones connecting to back-office data centers
- Examples: Business messaging, high-volume transactions

AMQP


Your enterprise
AMQP aware services
C/C++, Java, JMS, MS,
WCF, cloud applications
AMQP
infrastructure
AMQP aware clients
Devices and workstations
orders@supplier.com
treasury@fundmanager.com
Business partners
and services

Reliability = TCP
Timing = Multi-line UDP.

Which Protocol Where?

- Quality-of-Service (QoS) perspective

  timing, reliable.
  If you want reliability - you want TCP.

  - TCP provides simple, reliable, point-to-point, ordered delivery
  - Lacks timing control, TCP's (single-lane) traffic backs up with slow consumer
  - Multicast may work better to decouple senders and receivers loosely
- Addressing perspective ("finding the data needle in the IoT haystack")
  - XMPP provides simple, intuitive addressing of devices

    Turning on light switch from phone.
  - Does not work as well with large collections of devices to a single server
- Use-case perspective
  - Turning on your light switch (XMPP), generating that power (DDS)
  - Monitoring the transmission lines (MQTT)
  - Analyzing power usage at the data center (AMQP)

How the Protocols Relate to Each Other

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	

Application Protocol	**RESTful**	**Transport**	**Publish/ Subscribe**	**Request/ Response**	**Security**	**QoS**	**Header Size (Byte)**
COAP	✓	UDP	✓	✓	DTLS	✓	4
MQTT	×	TCP	✓	×	SSL	✓	2
MQTT-SN	×	TCP	✓	×	SSL	✓	2
XMPP	×	TCP	✓	✓	SSL	×	-
AMQP	×	TCP	✓	×	SSL	✓	8
DDS	×	TCP UDP	✓	×	SSL DTLS	✓	-
HTTP	✓	TCP	×	✓	SSL	×	-

The Smart Grid

Goal is to identify surges, outages, and failure points

In addition, contain damage and re-route power around failures

Balance load dynamically

Be resilient in the face of accidental or malicious faults

Accommodate new energy sources that are off the grid

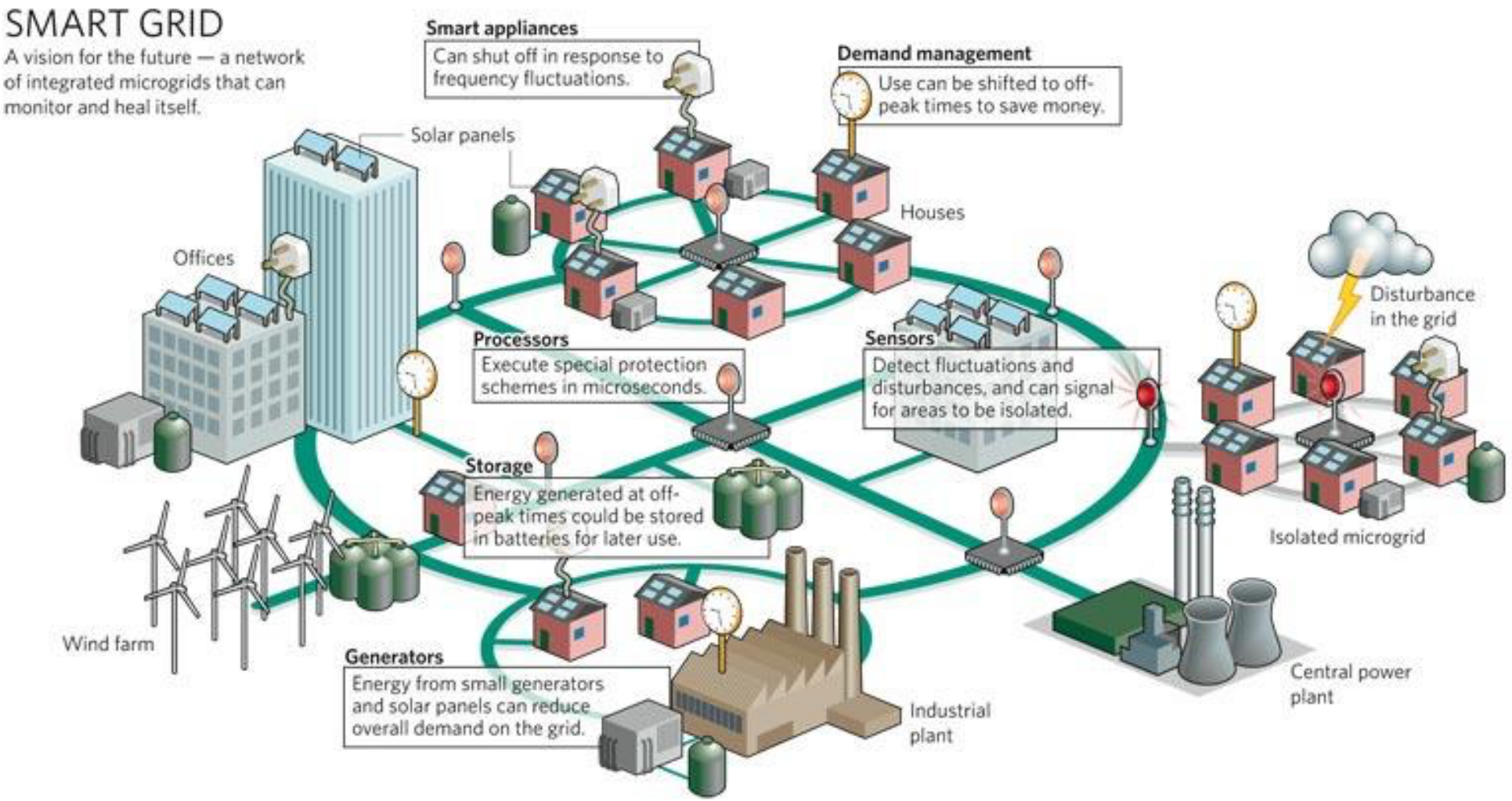
How?

Through meters at “the edge”

+ Publish/subscribe protocols for gathering data from the edges

+ Cryptographic protocols between substations and control centers

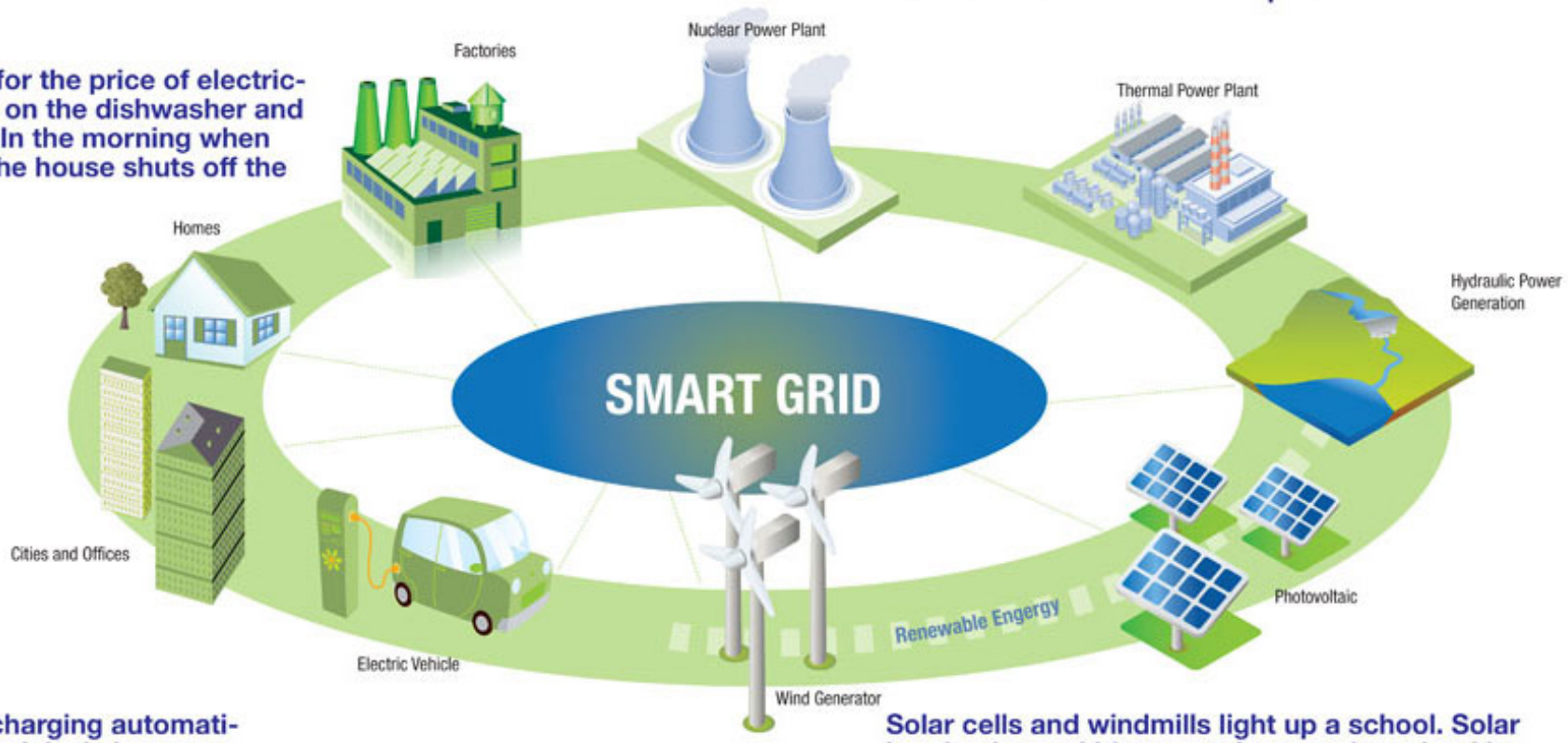
What is the Smart Grid?



How can the Smart Grid impact us everyday?

Lightning shuts down a substation. The smart grid takes it out of the loop. A dozen smart microgrids immediately access stored electricity in homes and cars, and all power from solar panels and windmills, distributing it where it's needed most. No services are interrupted.

The smart house waits for the price of electricity to drop, then it turns on the dishwasher and starts charging the car. In the morning when electricity costs peak, the house shuts off the refrigerator.



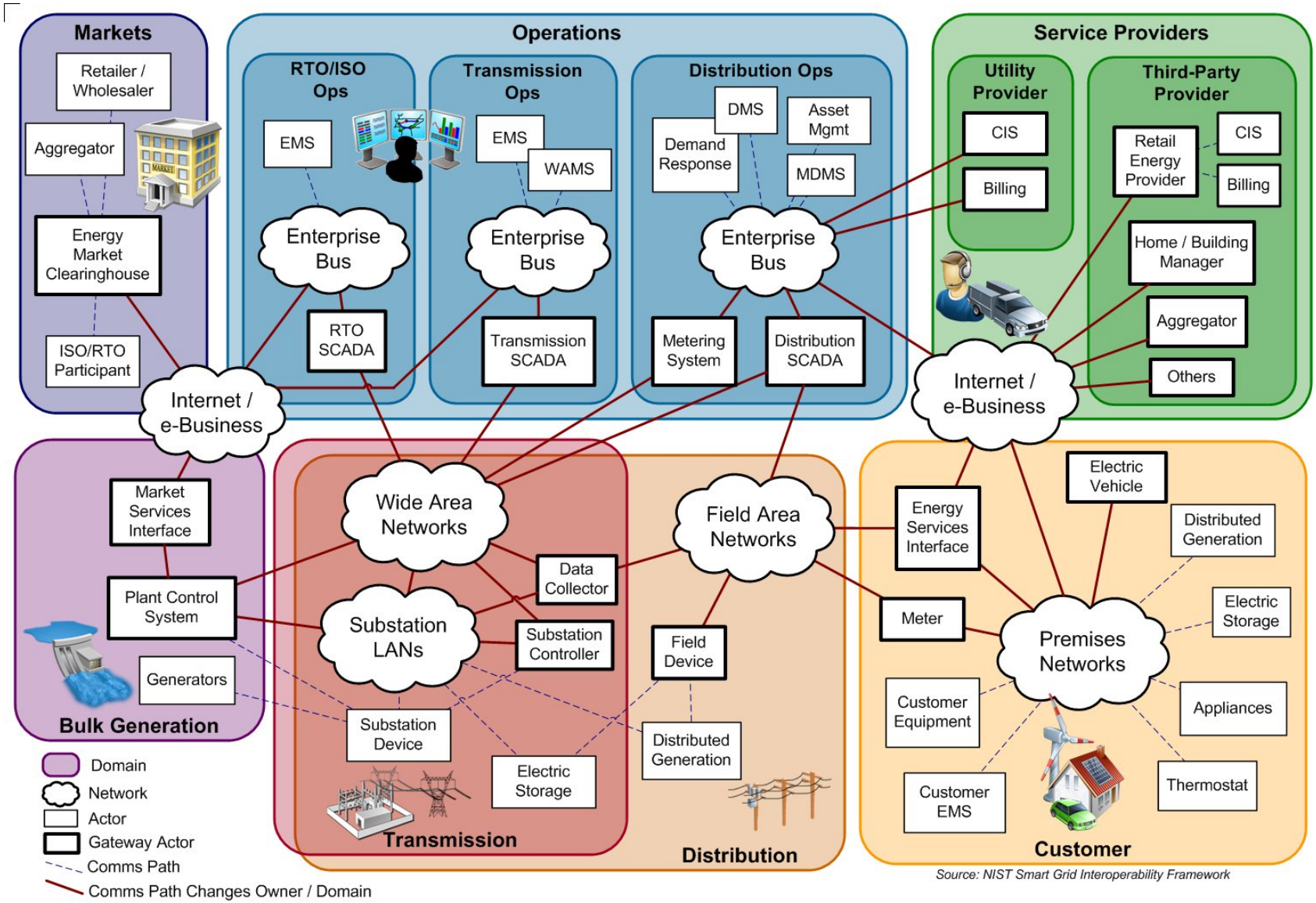
The electric car starts charging automatically at night when electricity is least expensive. At 7 a.m. the house tells the car to stop charging and use its battery to power the coffee maker in the kitchen.

Solar cells and windmills light up a school. Solar heating keeps kids warm. At noon the school has more power stored than it needs, so the smart grid distributes it to homes and offices. The school gets a power credit.

NIST: national institue of smart technology

This is a very standardized architecture, where each part use different protocals.

Connecting the Grid elements



Source: NIST Smart Grid Interoperability Framework

Legacy Protocols

BACnet

LonWorks

ModBus

KNX

ZigBee

Z-Wave

M-Bus

ANSI CI-12

Device Language Message Specification (DLMS) / Company Specification for Energy Metering (COSEM)

New Protocols for the Smart Grid

MQ Telemetry Transport (MQTT)

Powerline Communications (PLC)

IPv6 over Low Power Wireless Personal Area Network (6LowPAN)

Routing Protocol for Low Power and Lossy Networks (RPL)

ZigBee Smart Energy 2.0

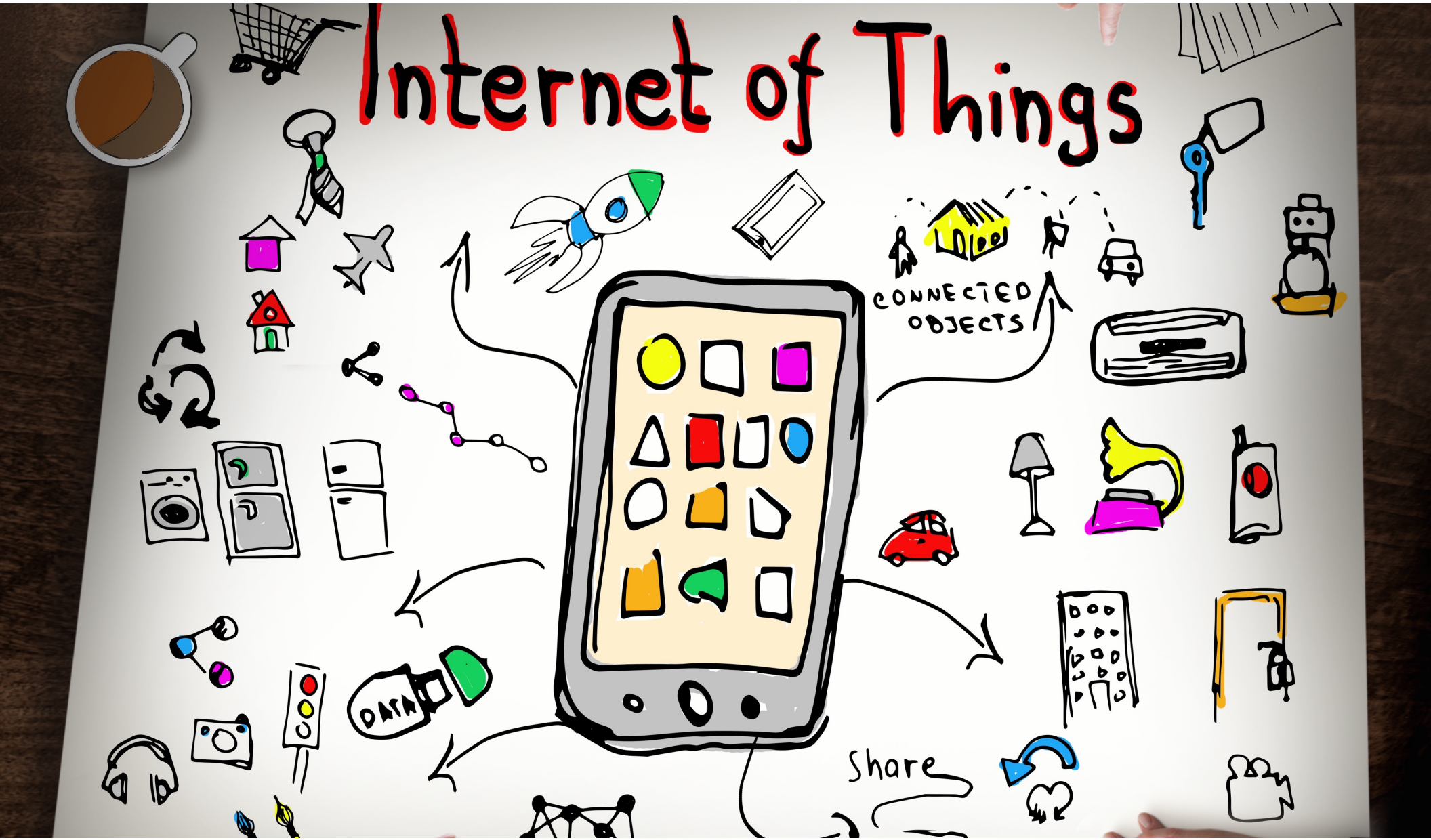
ETSI M2M Architecture

Example: PLC (Power Line Communications)

Wall socket you plug into, you can use it to carry data, not only the power.

The powerline can be used as a source of data.

- IoT protocol that uses electrical wiring to transmit data and AC power
- Power-line carrier/networking, power-line digital subscriber line (PDSL)
- Can be used for automation
- Can be used for Internet access (called broadband over power line—BPL)
- Interference between radio/wireless and PLC is common



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