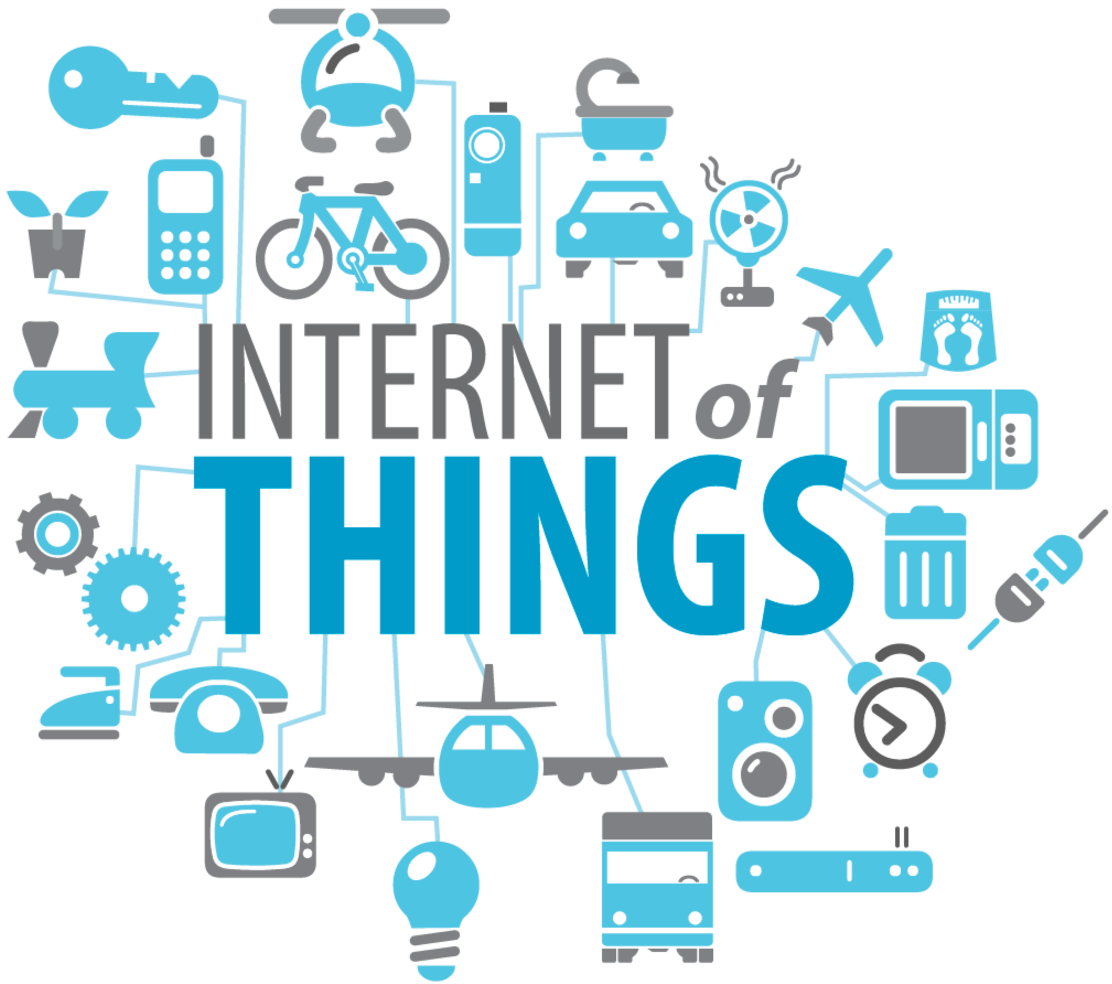


Prepared by

Çağdaş Döner
donercagdas@gmail.com

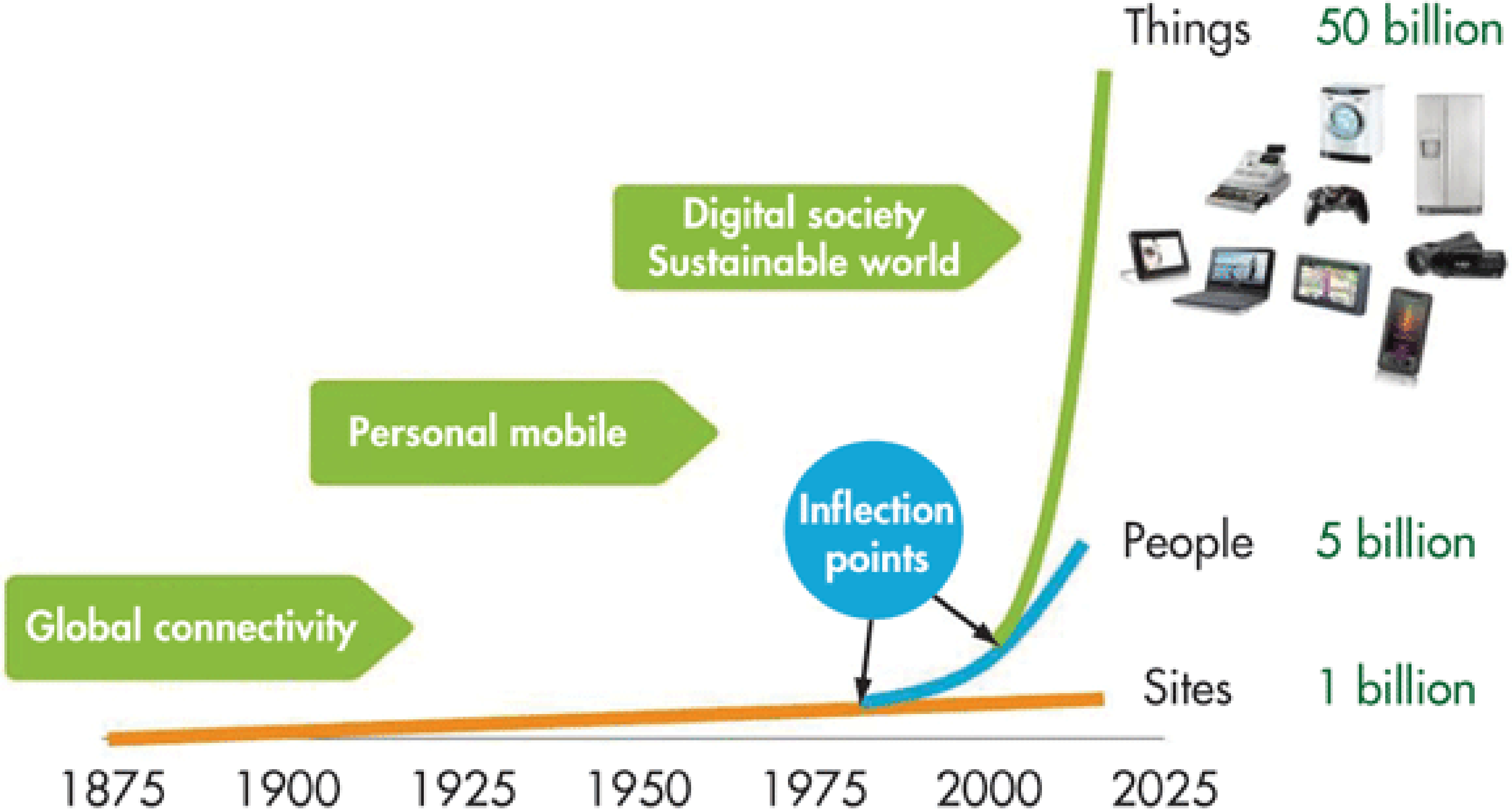
GUIDELINE

- Part 1 : IoT Fundamentals
- Part 2 : Networking
- Part 3 : Devices
- Part 4 : Applications
- Part 5 : Workshop

Part 1 : FUNDAMENTALS

- Evolution of Things
- Popular Guy IoT
- A Brief History
- Elements of the IoT
- Landscape of 2016
- Why Isn’t It Mainstream Yet ?

Evolution of Things



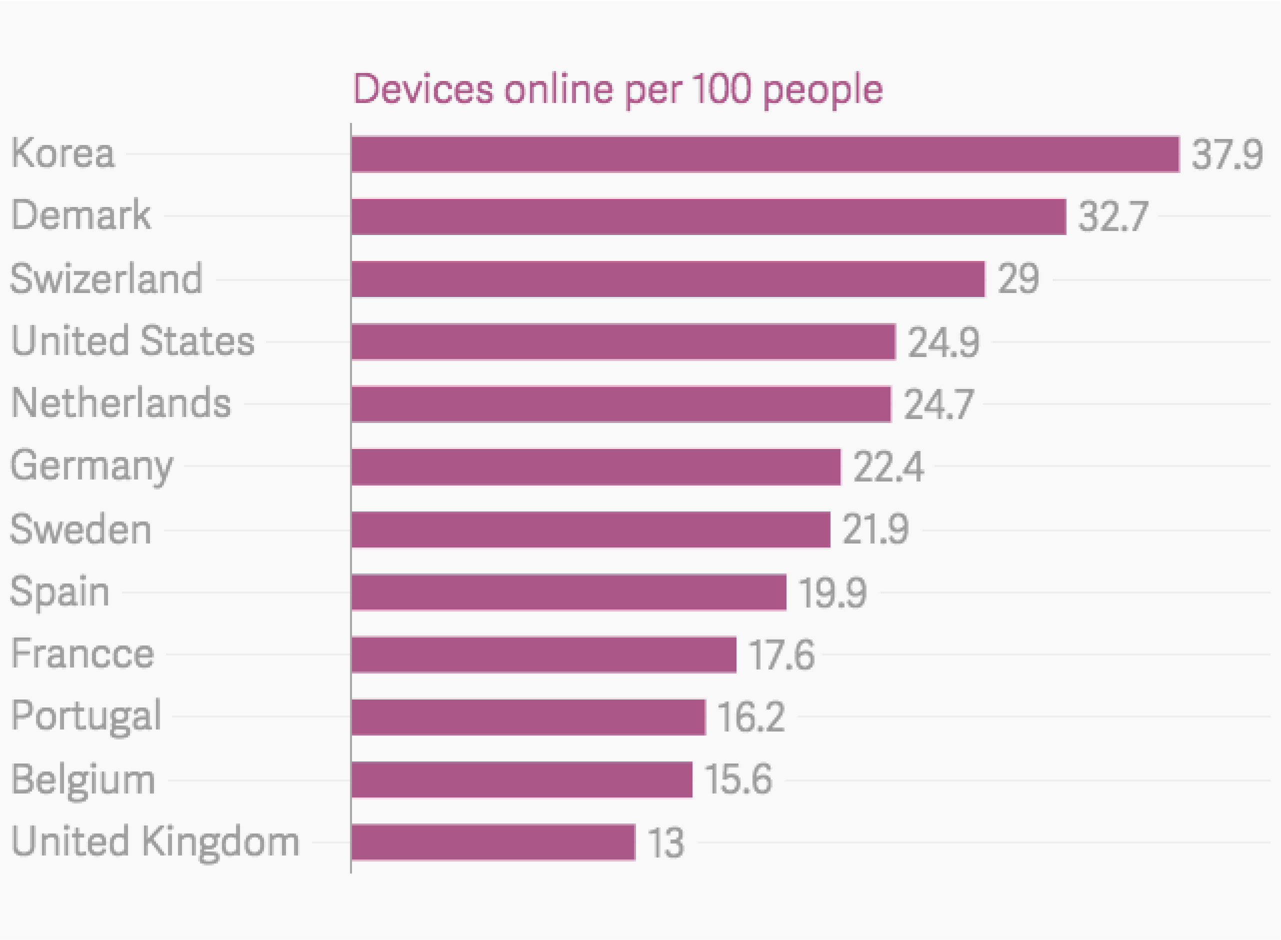
Evolution of Things

- Phase 1 : www
  - 1B PCs
  - $90B Market
- Phase 2 : Mobile
  - 5B Devices
  - $580B Market
- Phase 3: Internet of Things
  - 50B Objects
  - $4.5T Market

Popular Guy IoT

- Trending tech with billions of devices and thousands of developers
- Hardware component growth
  - Processing power
  - Cost downs
- Effortless Internet coverage
- Mobility & Cloud Computing

Popular Guy IoT



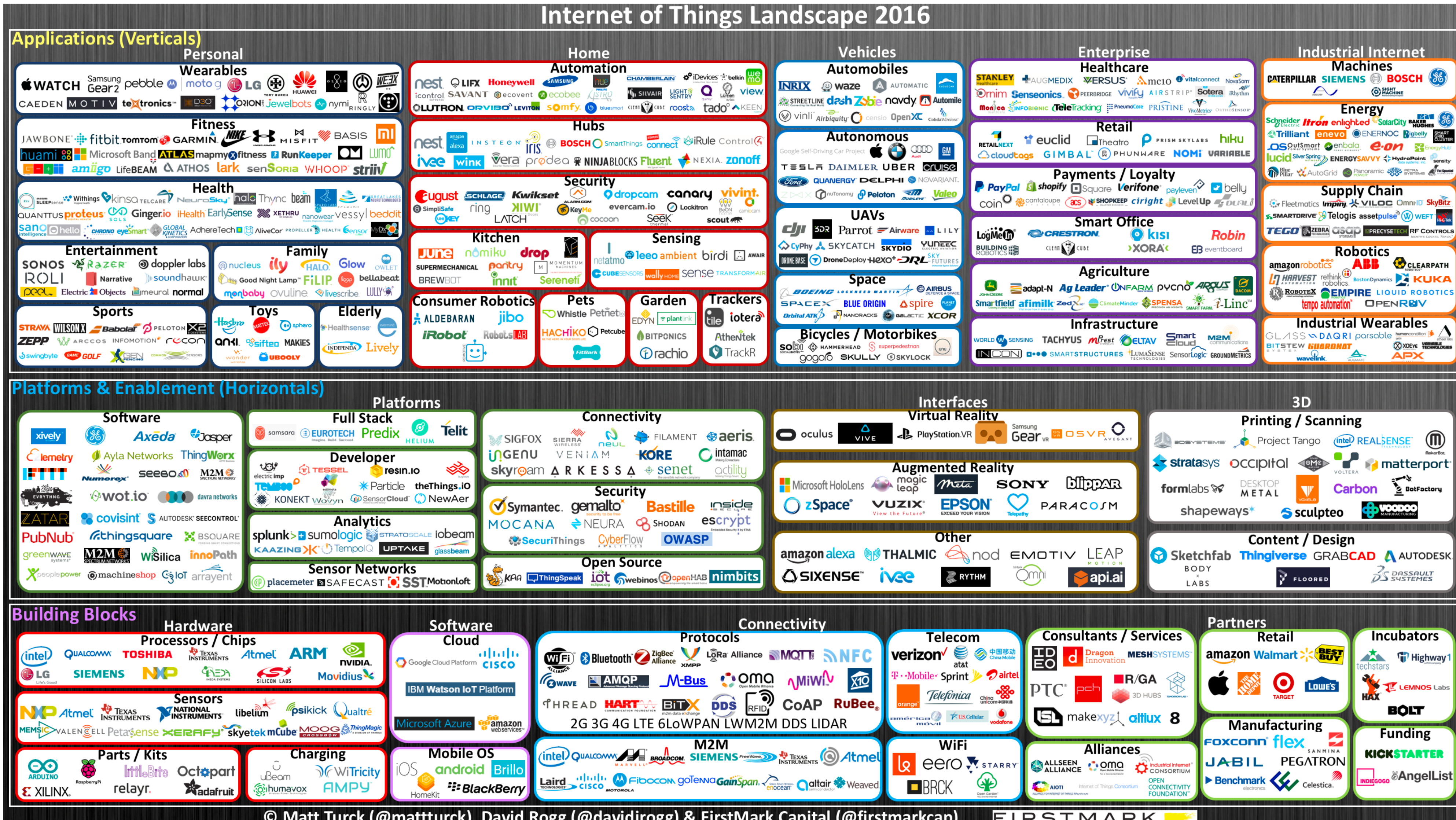
IoT Ecosystem

- Devices
  - Sensors & Actuators
  - Radios
- Cloud Platforms
  - Communication
  - Analytics
  - Big data
- Clients & Apps
  - Monitoring & Control
- Protocols

A Brief History

- 1982 : TCP/IP standardization, bla bla.
- 1990 : The thing. Connected Toaster.
- 1993 : Trojan Room Coffee Pot.
- 1999 : Naming the IoT & RFID.
- 1999 : An M2M Protocol, MQTT.
- 2000 : LG’s first connected refrigerator.
- 2005 : First IoT Conference.
- 2010 : BLE and IPv6 Introduced.

Landscape of 2016



Why Isn’t It Mainstream Yet ?

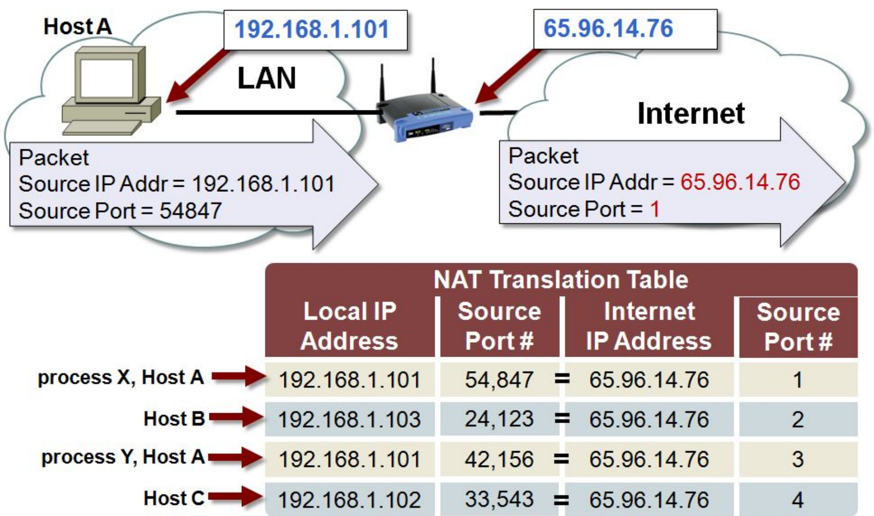
- Security issues
- Privacy concerns
- Change capacity of humanity
- Interoperability
- Power Consumption
- Hard to deploy
  - Deploy and Forget

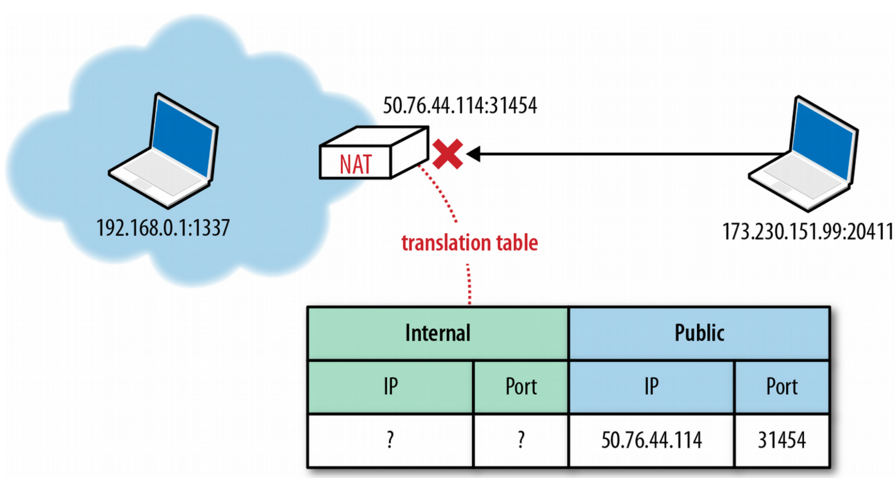
Part 2 : NETWORKING

- Traditional Stomachaches
- An IPv6 Break
- IoT Protocols
- Cloud Servers and Services
- IoT Frameworks and Tools
- A Fog Computing Break
- Security

Traditional Stomachaches

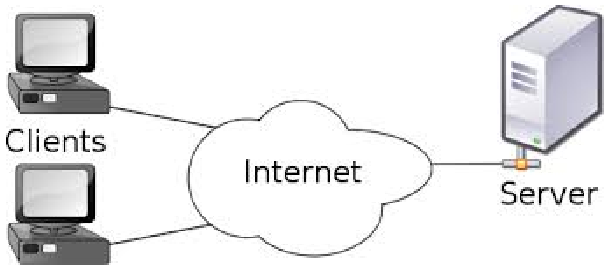
- NAT
  - For 32-bit IPv4
  - No end-to-end connectivity
  - Being behind the NAT
- Port forwarding
  - Insecure
- Static IP
  - Not free
- UPnP
- Dynamic DNS

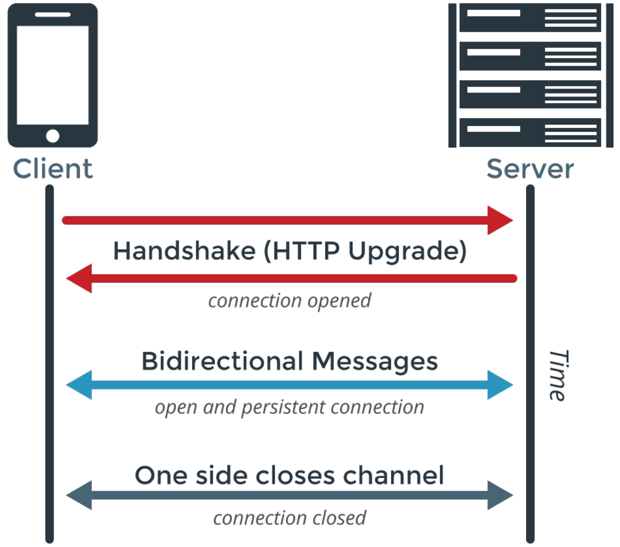




Traditional Stomachaches

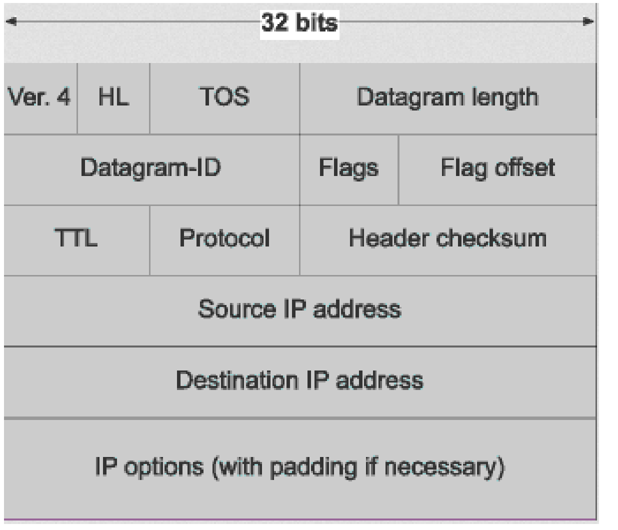
- Need a server on Internet
  - Handle client requests
  - Assign a DNS
  - Lots of cloud services available
- HTTP
  - Stateless
  - One way
  - Polling
- WebSockets
  - Bidirectional
  - Keeps connection alive





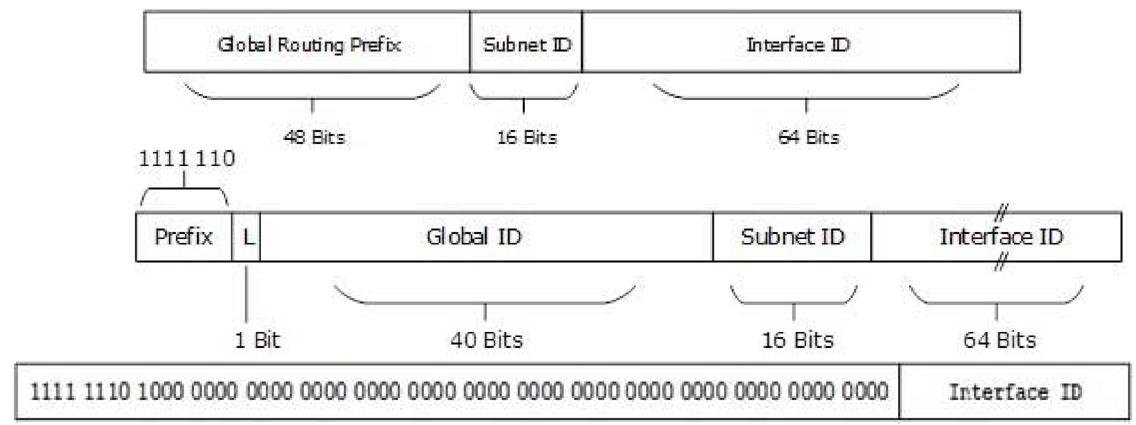
An IPv6 Break

- Larger address space
  - 128-bit IPv6 addresses
- Simplified Header
  - Faster routing
- End-to-end Connection
  - No NAT? Hooray!
- Auto Configuration
  - No DHCP needed
- IPSec

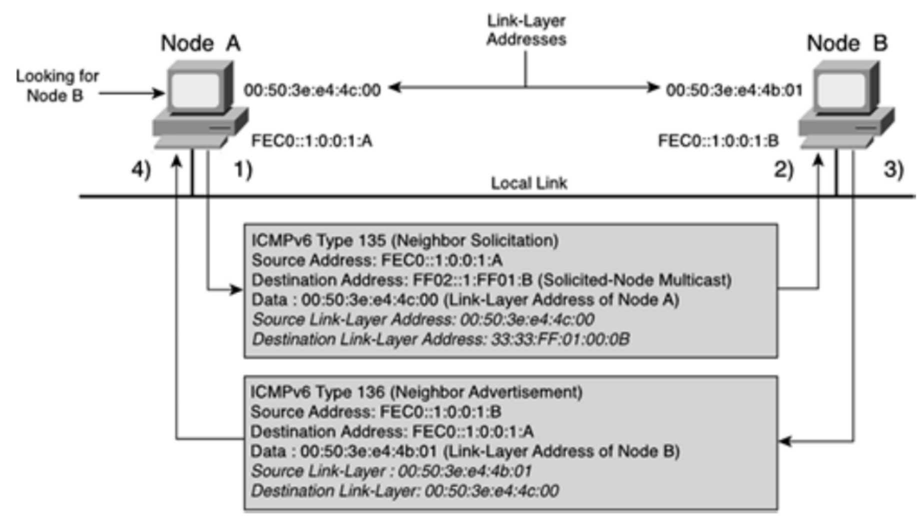


An IPv6 Break

- Address Types
  - Global-Unicast
  - Uniqe-Local
  - Link-Local



- No broadcasting on IPv6
- Neighbor Discovery Protocol
  - Neighbor Solicitation
  - Duplicate Address Detection
  - Neighbor Advertisement



IoT Protocols

- Data Link and Physical Layers
  - LP-WANs
  - LR-WPANs
- Network Layer
  - 6LowPAN
  - Thread
  - ZigBee-IP
- Session and App Layers
  - MQTT
  - CoAP
  - Websockets

IoT Protocols

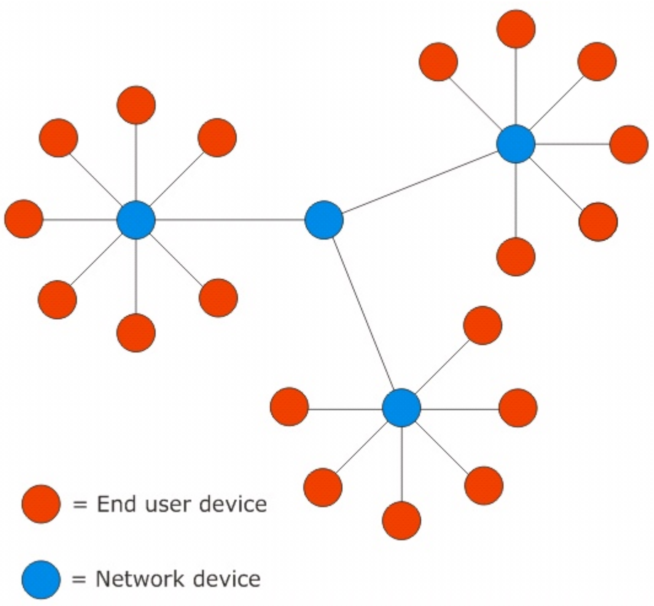
Session		**MQTT**, **SMQTT**, **CoRE**, **DDS**, **AMQP** , **XMPP**, **CoAP**, …
Network	Encapsulation	**6LowPAN**, **6TiSCH**, **6Lo**, Thread, …
	Routing	**RPL**, **CORPL**, **CARP**, …
Datalink		WiFi, **Bluetooth Low Energy**, **Z-Wave**, **ZigBee Smart**, **DECT/ULE**, 3G/LTE, NFC, **Weightless**, **HomePlug GP**, **802.11ah**, **802.15.4e**, **G.9959**, **WirelessHART**, **DASH7**, ANT+, **LTE-A**, **LoRaWAN**, …

Security
TCG, Oath 2.0, SMACK, SASL, ISASecure, ace, DTLS, Dice, …

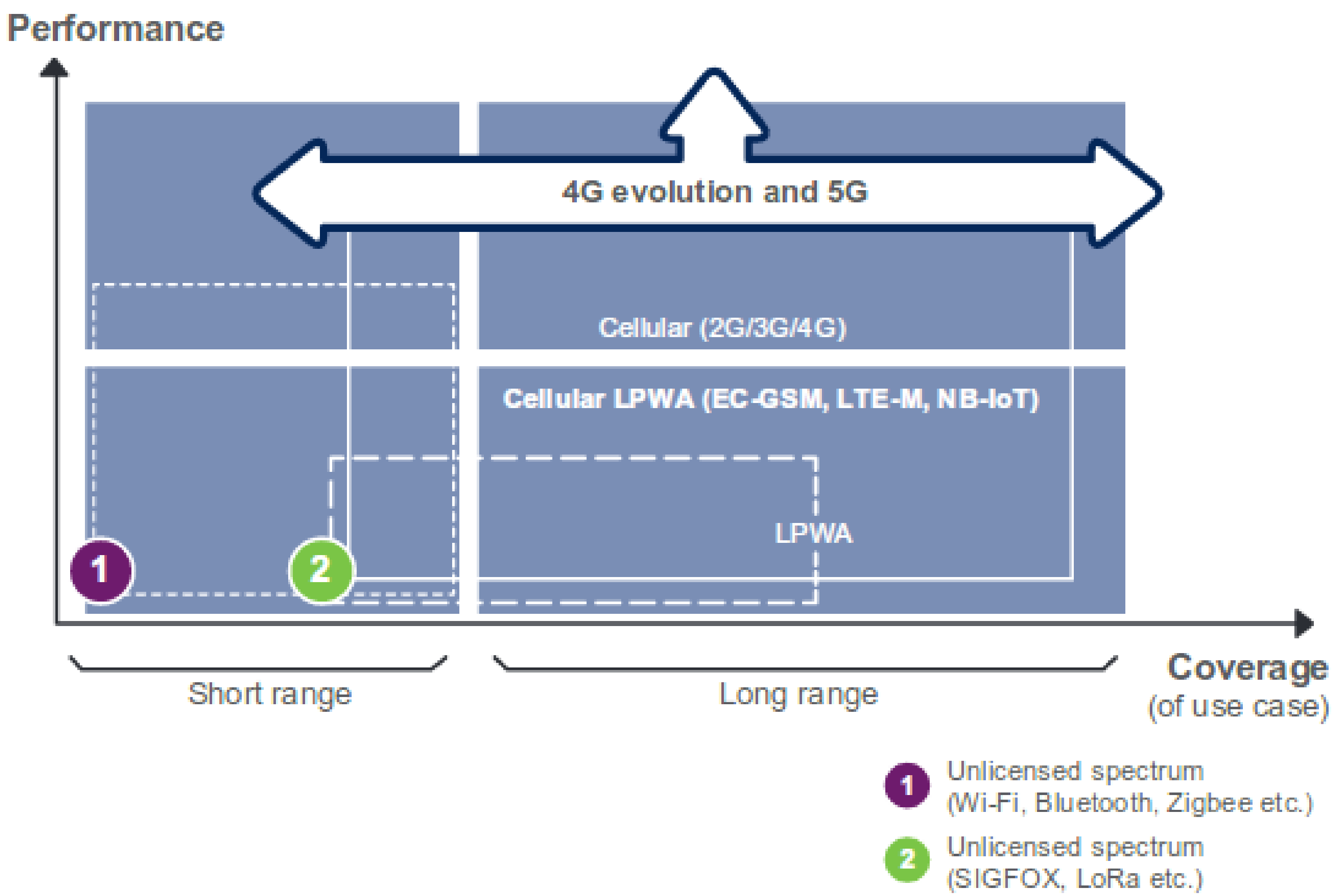
Management
IEEE 1905, **IEEE 1451**, …

LP-WANs

- Lower frequencies
  - Sub-1GHz
- Long range
  - Up to 15 kilometers
- Very low data rate
  - 300 bps - 50 Kbps
- Low power consumption
- Very high density
  - To 10 000 nodes per Access Point
- Infrastructure networks
  - Stars of star topology instead of mesh
  - Ease of routing
- Cheaper than cellular M2M



LP-WANs



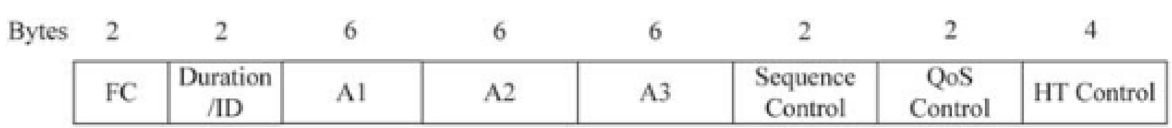
Performance
4G evolution and 5G
Cellular (2G/3G/4G)
Cellular LPWA (EC-GSM, LTE-M, NB-IoT)
LPWA
1
2
Short range
Long range
Coverage
(of use case)
1 Unlicensed spectrum
(Wi-Fi, Bluetooth, Zigbee etc.)
2 Unlicensed spectrum
(SIGFOX, LoRa etc.)

LP-WANs

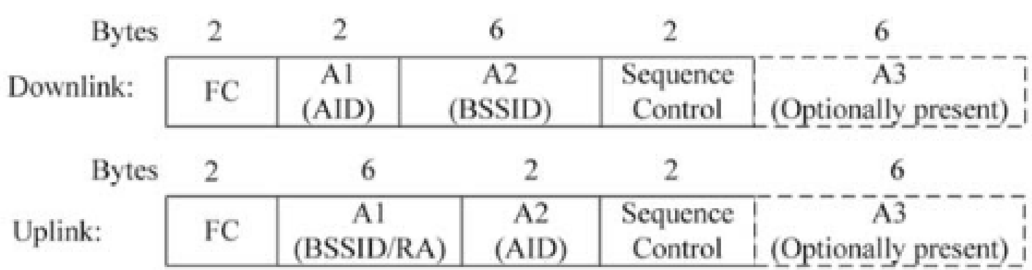
- WiFi HaLow
- LoraWAN
- SigFox
- Weightless
- NB-IoT
- LTE-M

Wi-Fi HaLow

- IEEE 802.11ah
- Sub – 1GHz
- 12 byte of MAC header
  - 802.11 has 30 bytes of MAC header
  - Easy to parse for low end devices
  - Some fields moved into PHY
  - Null Data Packet ACK
  - More data into payload
- Power Saving
  - Target Wake Time
- 802.11af
  - Cognitive radio



(a) Legacy 802.11 MAC header format.



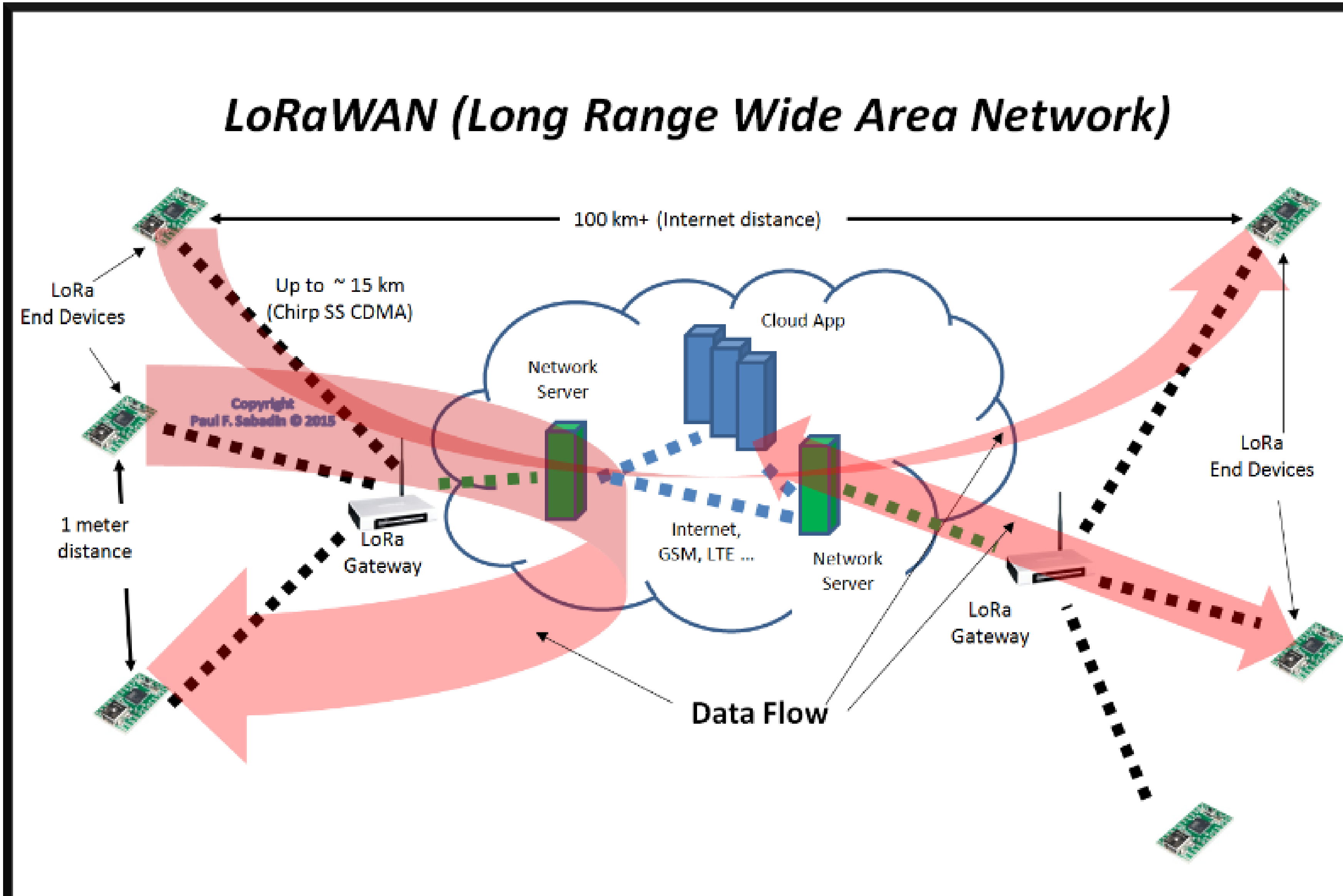
(b) 802.11ah short MAC header format.

LoRaWAN

- Developed by SemTech
- Built on Lora modulation
- Not an open standard
  - SemTech owns Lora-radio and Lora-IP
- Symmetric link
  - Better for control and monitoring
- Better data rate
  - Up to 50 Kbps
- One of the most supplied infrastructure

LoRa Alliance™
Wide Area Networks for IoT

LoRaWAN



LoRaWAN (Long Range Wide Area Network)
100 km+ (Internet distance)
LoRa
End Devices
Up to ~ 15 km
(Chirp SS CDMA)
Cloud App
Network
Server
Copyright
Paul F. Sabadin © 2015
1 meter
distance
LoRa
Gateway
Internet,
GSM, LTE ...
Network
Server
LoRa
End Devices
LoRa
Gateway
Data Flow

SigFox

- French born like LoRa
- Ultra narrow signal band
  - Lower interference
  - 12 bytes of data
  - Lowest energy ever
- SigFox Antennas
- Asymmetric link
  - 300bps
  - Better for small and infrequent data : Alarms, meters.
- Variety of SigFox radio vendors
  - Atmel, ST, Texas Instruments
- Problems on U.S. Market due to FCC
  - Microchip, early 2017

sigfox

Weightless

- W
  - TV spectrum, UHF band
  - Interference, regulations
    - Antenna size
  - QAM
- N
  - SigFox like
  - Ultra narrow band
    - Lower bit rate
    - Async link
- P
  - Higher performance
    - 12.5kHz
    - Up to 200 bps
    - Up to 100uW less power
  - Extended QoS
    - LTE-M rival

WEIGHTLESS™

NB-IoT

- Narrow Band IoT
  - Optimized cellular infrastructure
  - $5 modules
- MioT standard by 3GPP
- Better indoor coverage
  - +20 dB
- 50K connections per cell
- Guarantees 10 years of battery life
- Better for low end devices

LTE-M

- M2M LTE
- 1.4MHz narrow-band
- Up to 500Kbps data rate
- Uber QoS
- Software update on networks
- Cellular growth is faster than LPWA
  - 7B LPWA Vs. 30B cellular IOT devices by 2025
  - Machina Research, May 2015

LP-WAN Summary

COMPARISON – main LPWAN technologies

Vertical M2M

Feature	LORAWAN	SIGFOX	LTE Cat 1	LTE M	NB - LTE
Modulation	SS chip	UNB / GFSK / BPSK	OFDMA	OFDMA	OFDMA
Rx Bandwith	500 – 125 KHz	100 Hz	20 MHz	20 – 1.4 MHz	200 KHz
Data Rate	290bps – 50Kbps	100 bit / sec 12 / 8 bytes Max	10 Mbit /sec	200 kbps – 1 Mbps	Average 20K bit / sec
Max. # Msgs/day	Unlimited	UL: 140 msgs / day	Unlimited	Unlimited	Unlimited
Max Outpu Power	20 dBm	20 dBm	23 – 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Battery lifetime – 2000 mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very High	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes Oui	Yes	Yes
Mobility / localization	Yes	Limited mobility, No localization	Mobility	Mobility	Limited mobility, No localization

Source: LoRAWAN Alliance, 2015

www.vertical-m2m.com

LR-WPANs

- Low Rate Wireless Personal Area Networks
- 802.15.4
- Multi-hop & mesh networking
- Low range, low cost, fair speed
  - 20-meter communications range
  - Max 250 kbit/s transfer rate
  - 868/915/2480 MHz
  - O-QPSK modulation
- Frames of up to 127 bytes
- Usable with 6LoWPAN

LR-WPANs

- ZigBee
- Z-Wave
- WirelessHART
- MiWi
- ISA100

ZigBee

- Really doing well in low-end devices
  - 8-bit, 4 MHz, 8kB RAM
- PHY and MAC based on 802.15.4
  - Upper levels defined by ZigBee Alliance
- Up to 65K nodes within mesh
- 250 Kbps at 2.4 GHz
- Algorithm optimization for battery consumption
- ZigBee-IP on 3. Layer

ZigBee® Alliance

Z-Wave

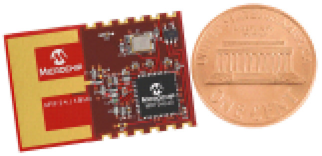
- Home-Automation protocol
  - 30 meter point-to-point communication
  - Low power
- Reliable
  - ACK messages
  - CSMA for collision detect
- Master/Slave architecture
- IPv6 addressed devices

WirelessHART

- Mesh architecture
  - Time synchronized
  - Self-organizing
  - Self-healing
- 25M deployed devices
- Security Manager to support per-hop security
- Network Manager to access Internet

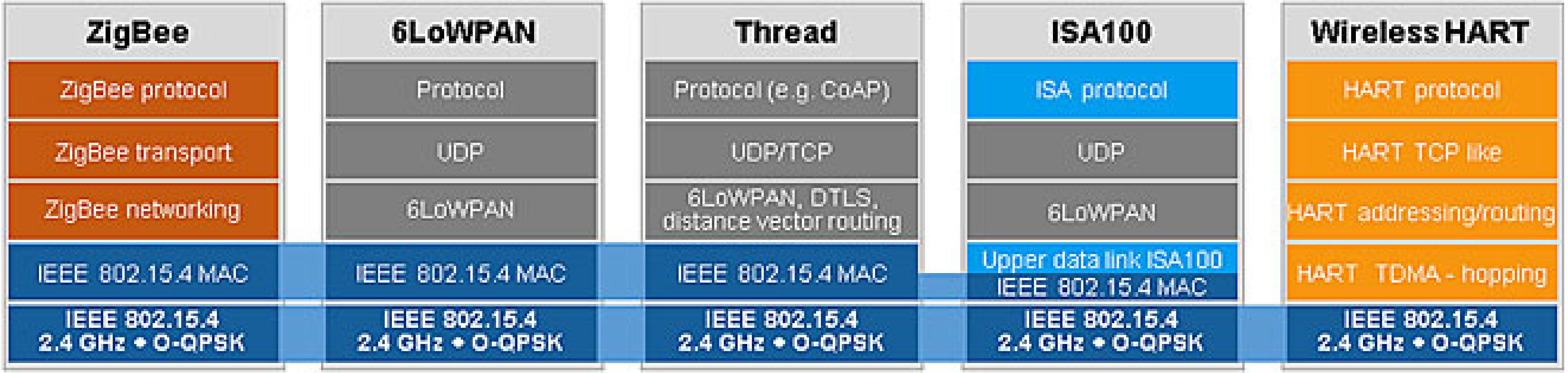
Mi-Wi & ISA100

- MiWi
  - Designed by Microchip
  - Low data, short distance
  - Supported on PIC
    - 3K protocol



- ISA100.11a
  - International Society of Automation
  - Wireless Systems for Industrial Automation
  - Addressing plant’s field applications
    - Periodic control and monitoring
    - Safety

LR-WPAN Summary

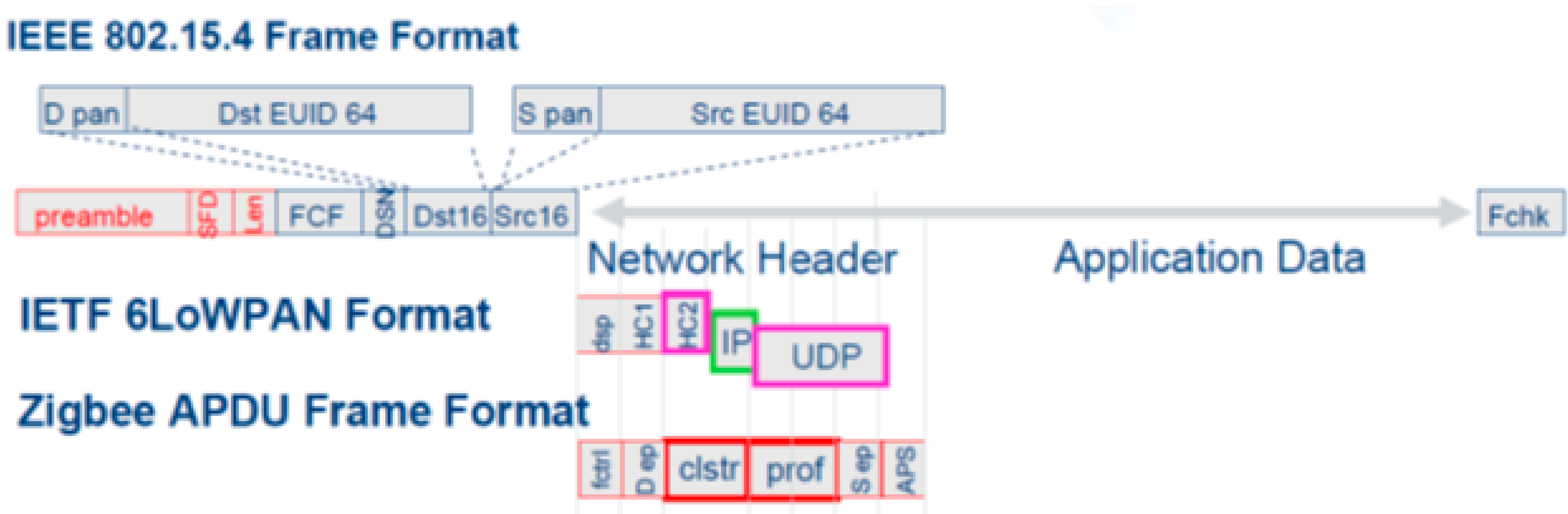


Various WPAN protocol stacks apply the physical layer of IEEE 802.15.4

6LoWPAN

- IPv6 over Low-Power WPAN
- Open IoT Networking Protocol
- Auto configuration with neighbor discovery
  - RPL
- Direct IP addressing of nodes
- Unlike ZigBee
  - PHY independent
  - Interoperability with other 802.15.4
  - No profile match
  - Thinner network header

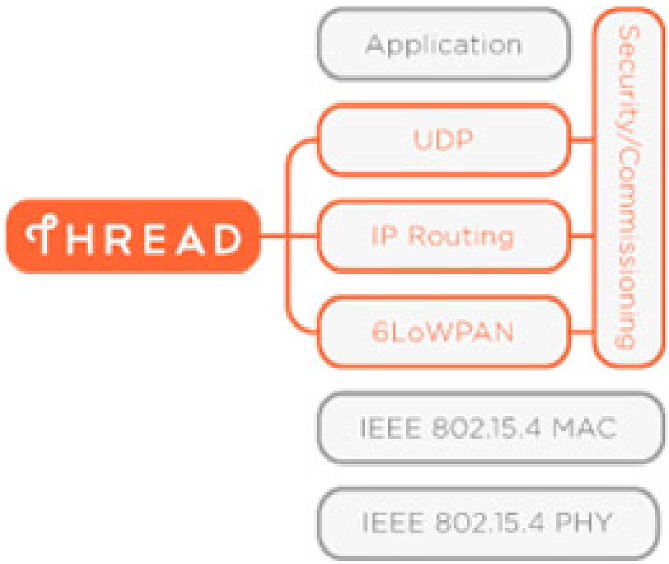
6LoWPAN



IEEE 802.15.4 Frame Format
D pan
Dst EUID 64
S pan
Src EUID 64
preamble
SFD
Len
FCF
DSN
Dst16
Src16
Fchk
Network Header
Application Data
IETF 6LoWPAN Format
dsp
HC1
HC2
IP
UDP
Zigbee APDU Frame Format
fctrl
D ep
clstr
prof
S ep
APS

Thread

- Wireless mesh protocol
  - IPv6-based
  - Close documentation
  - Nest devices
- Collaborators
  - Google, Samsung, Qualcomm, ARM, NXP
- Lower levels same with ZigBee
- AES encryption
- Up to 250 devices in a local mesh
- BSD licenced OpenThread



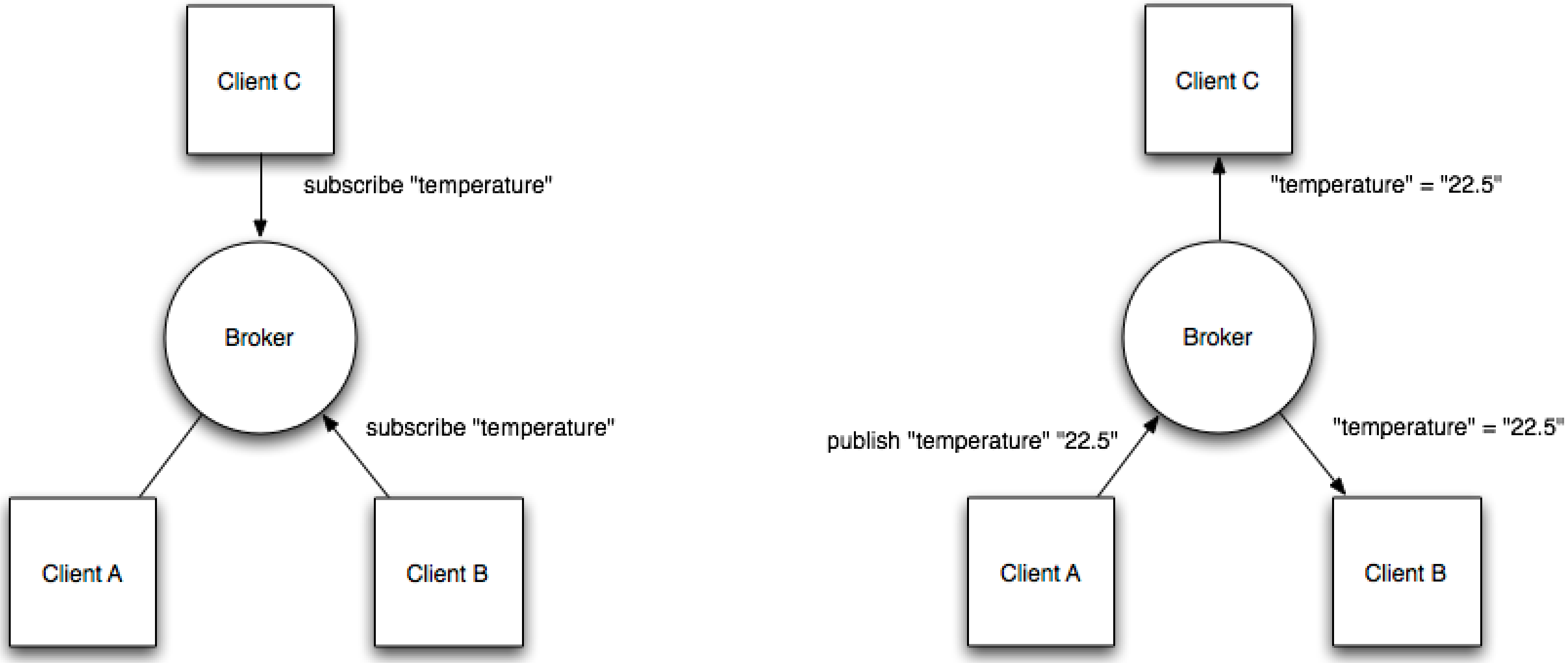
ZigBee-IP

- Standard IPv6 routing protocol
- 6LoWPAN header compression
- ZigBee +
  - Network Layer
  - Security Layer
  - Application Framework
- TLS v1.2 protocol for end-to-end security

MQTT

- Introduced by IBM in 1999 for M2M
- Asynchronous Communication
- Publish/Subscribe model
- TCP based
- Lightweight
  - Network Constrained
  - Low Power
- 3 QoS Levels
- Topic Matching
- TLS

MQTT

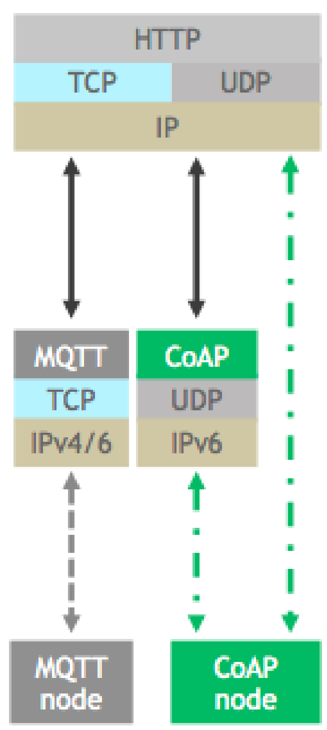


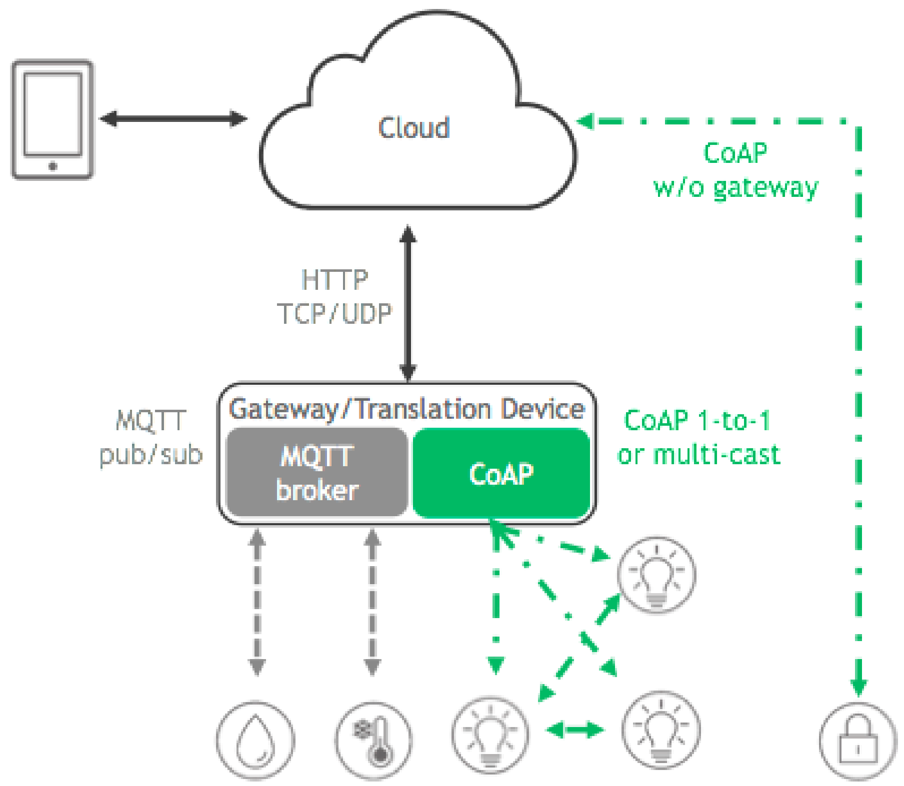
Client C
subscribe "temperature"
Broker
subscribe "temperature"
Client A
Client B
Client C
"temperature" = "22.5"
Broker
publish "temperature" "22.5"
"temperature" = "22.5"
Client A
Client B

CoAP

- Introduced by IETF at 2014
- Asynchronous Communication
- Client/Server model with Multicasting
- UDP based
- RESTFul
- 2 QoS Levels
- Resources
- DTLS

CoAP vs MQTT


HTTP
TCP
UDP
IP
MQTT
TCP
IPv4/6
CoAP
UDP
IPv6
MQTT node
CoAP node


Cloud
CoAP w/o gateway
HTTP TCP/UDP
MQTT pub/sub
Gateway/Translation Device
MQTT broker
CoAP
CoAP 1-to-1 or multi-cast

Cloud Servers and Services

- Amazon EC2 & IoT
- Other Giants
  - Azure IoT Hub
  - ARTIK
  - Watson
  - ...
- Firebase
- ThingSquare
- Xively
- IoTivity

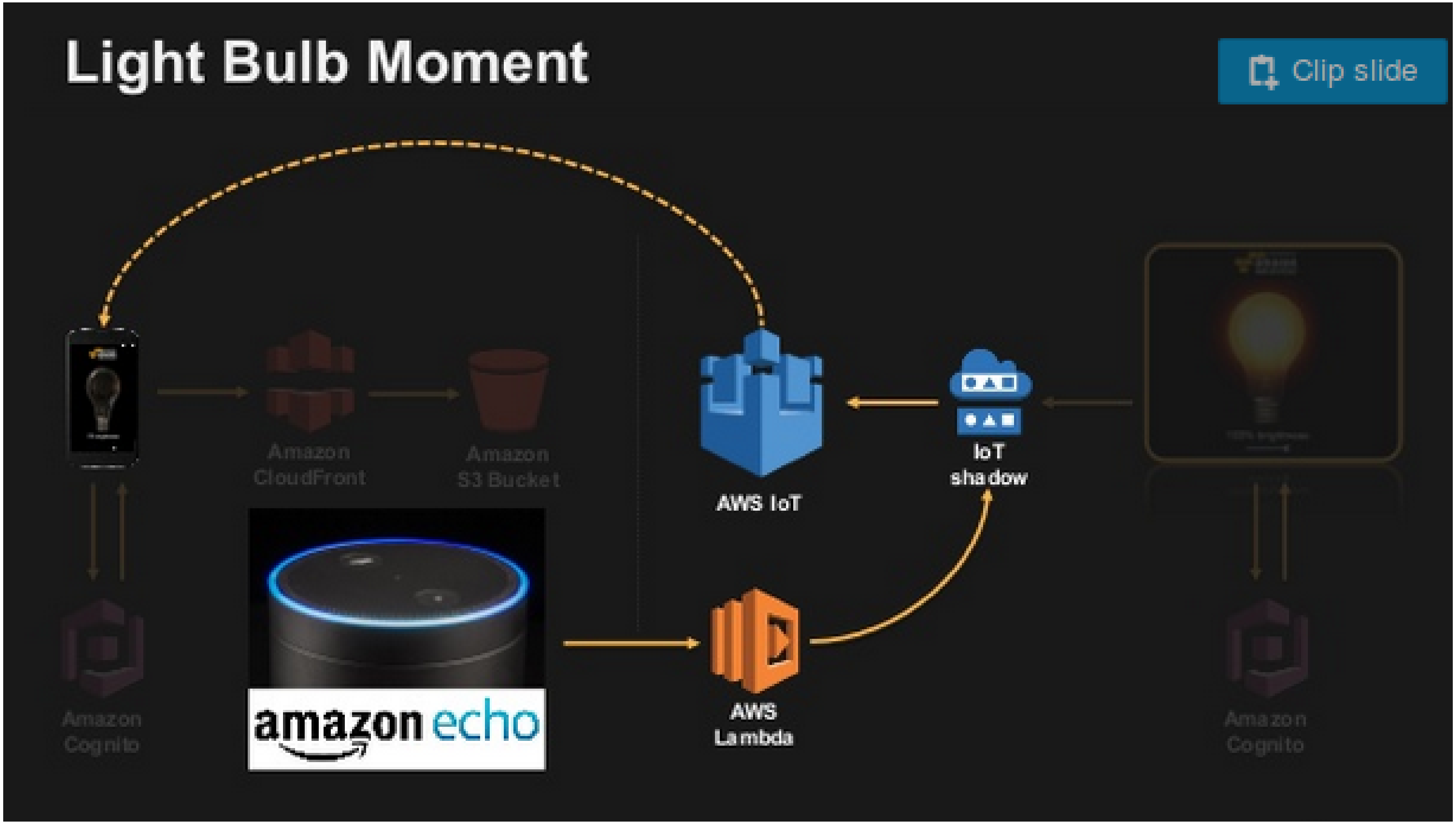
Amazon EC2

- Elastic Cloud Computing
- A machine on the cloud
  - Fixed IP
  - Resizable compute capacity
  - Linux instances
  - Easy to run services
- Easy to manage
  - Disks
  - Networks

Amazon IoT

- MQTT based communication
- Open-Source SDK
- Varying platform and language support
  - Embedded C
  - Arduino
- Easy to deploy
  - Register device
  - Install and run SDK on device
  - Configuration scripts to test
- DynamoDB for data storage
  - NoSQL

Amazon IoT


Light Bulb Moment
Clip slide
Amazon
CloudFront
Amazon
S3 Bucket
AWS IoT
IoT
shadow
Amazon
Cognito
amazon echo
AWS
Lambda
Amazon
Cognito

Other Giants

Microsoft Azure

IBM Watson

cisco Jasper

Samsung ARTIK™ Cloud

Google Cloud Platform

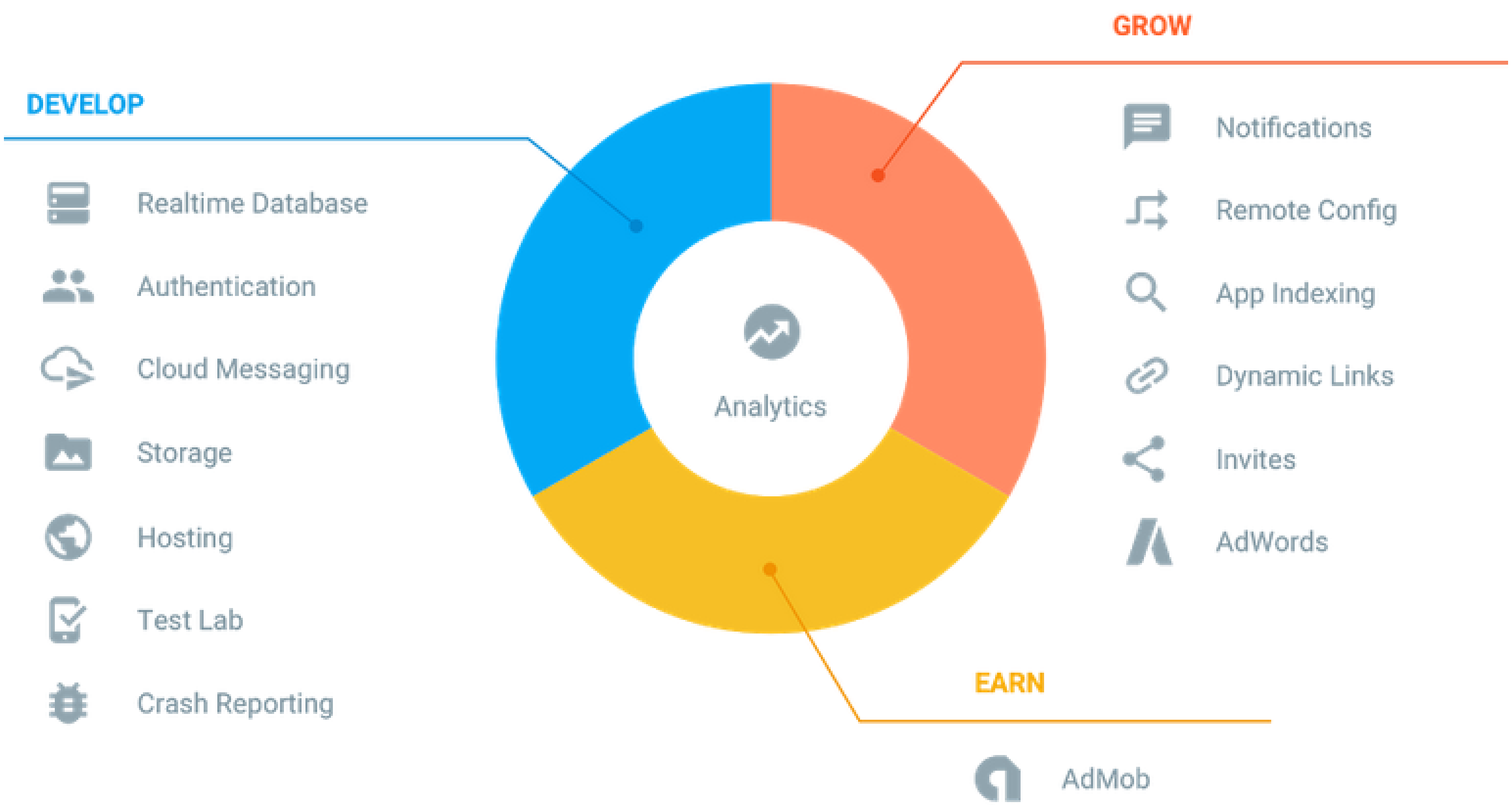
Ayla Networks

Firebase

- Storage & Infrastructure by Google
- Motto : Forget about infrastructure
- Quick development
  - Multiple PL support
  - Real time actions
  - Database integration
- Arduino support
- Semi-limited free tier

Firebase

Firebase



Firebase

ThingSquare

- Firmware and Backend solutions
  - REST API @ Backend
  - Mesh protocol in device firmware
- Requires gateway devices
- Over-the-air firmware update
- Starter-Kits
  - TI Sensortag hardware, pre-programmed
- Semi limited free-tier

Xively

- Ready to develop models
- IoT platform and framework
- Fukushima Disaster, 2011
  - Used by volunteers
  - Interlink Geiger counters
  - Monitoring critical sessions
- Based on MQTT
  - API available for REST & Websocket
- Not free

IoTivity

- A new standard spec for IoT
  - Hosted by Linux Foundation
  - Developing by Samsung & Intel
- Based on CoAP
- Multiple way communication
  - Device to Device
  - Device to Internet
  - Wired and wireless
- Runs on several platforms
  - Android, Tizen, Linux, Arduino
- 5K commit at GitHub repo

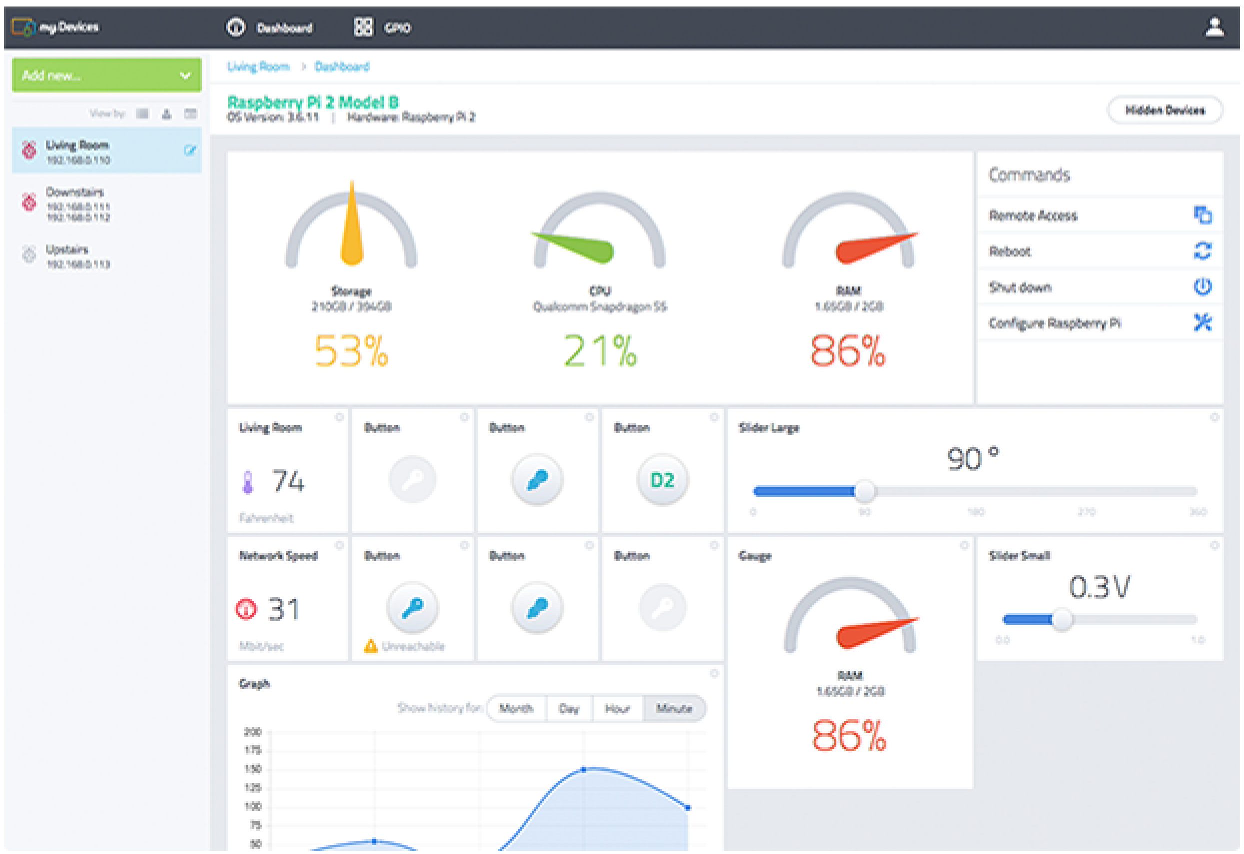
IoT Frameworks and Tools

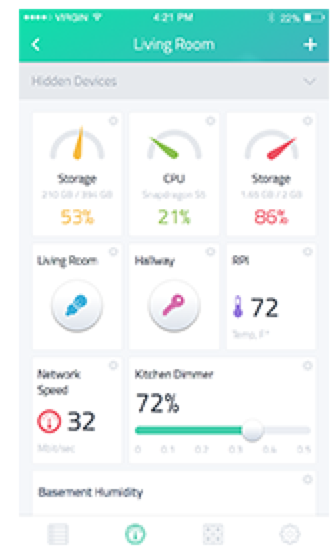
- Quick Quirks
  - Cayenne (*Demo)
  - Blynk
  - IoTPlayGround
- ThingSpeak
- CloudMQTT

Cayenne

- Control interface to the device
  - Free
  - Dashboards
  - Raspberry, Arduino, ESP8266
- Easy setup by API keys
  - Drag & Drop on UI
  - Mobile app generation
- LoRa support
- Not commercial, for prototyping

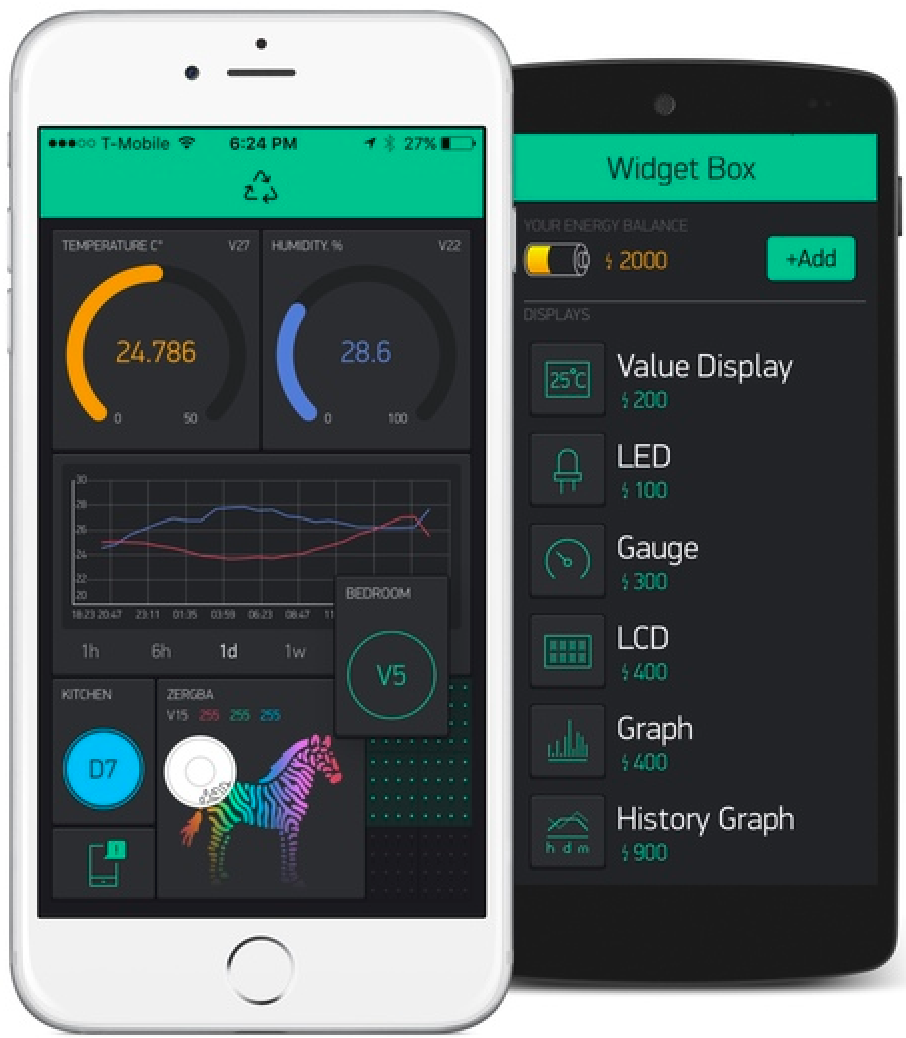
Cayenne





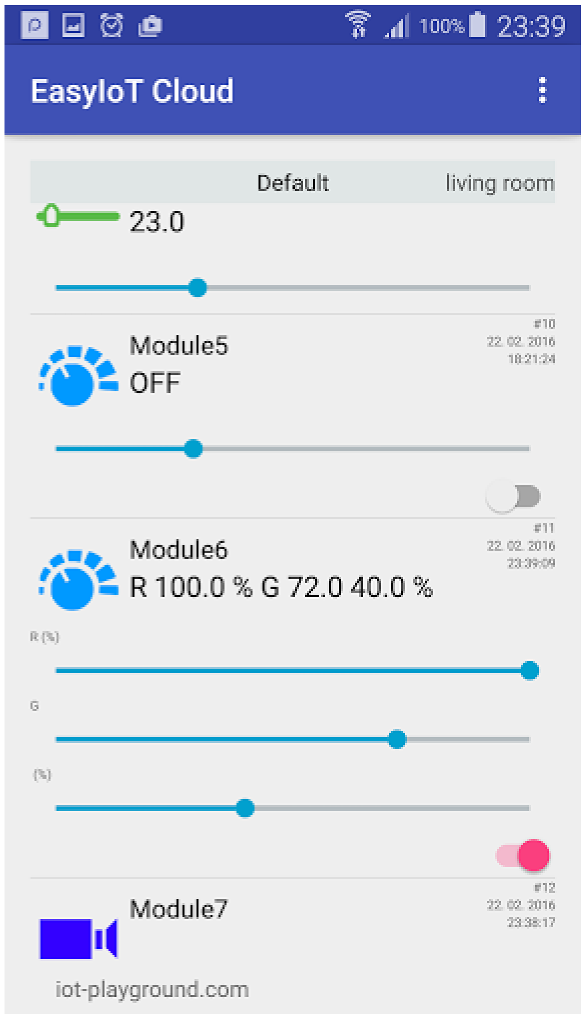
Cayenne

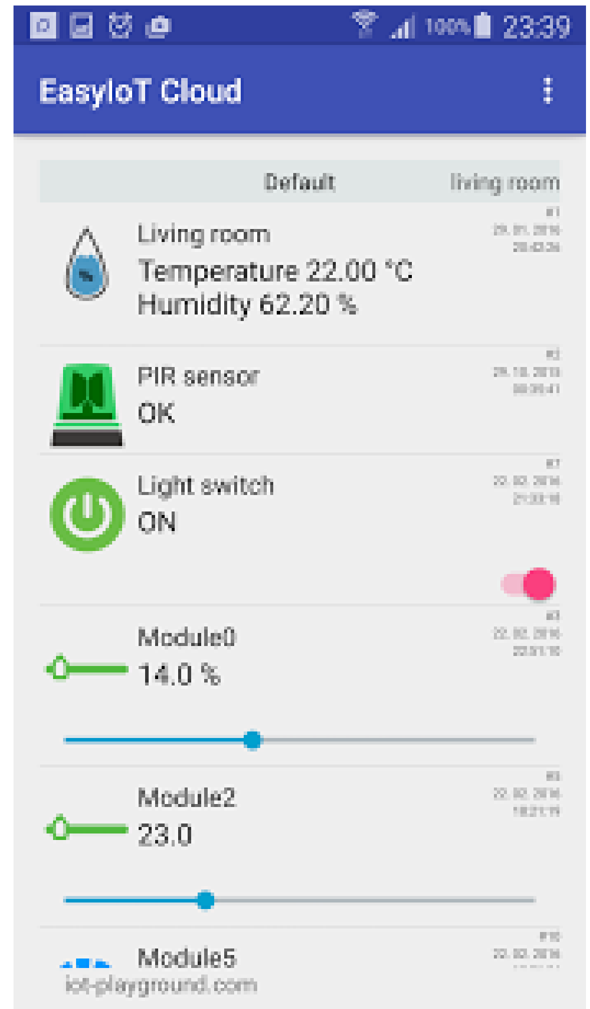
Blynk



T-Mobile
6:24 PM
27%
TEMPERATURE C°
V27
24.786
0
50
HUMIDITY %
V22
28.6
0
100
1h
6h
1d
1w
BEDROOM
V5
KITCHEN
D7
ZERGBA
V15
255
255
255
Widget Box
YOUR ENERGY BALANCE
2000
+Add
DISPLAYS
Value Display
200
LED
100
Gauge
300
LCD
400
Graph
400
History Graph
900

IoTPlayground



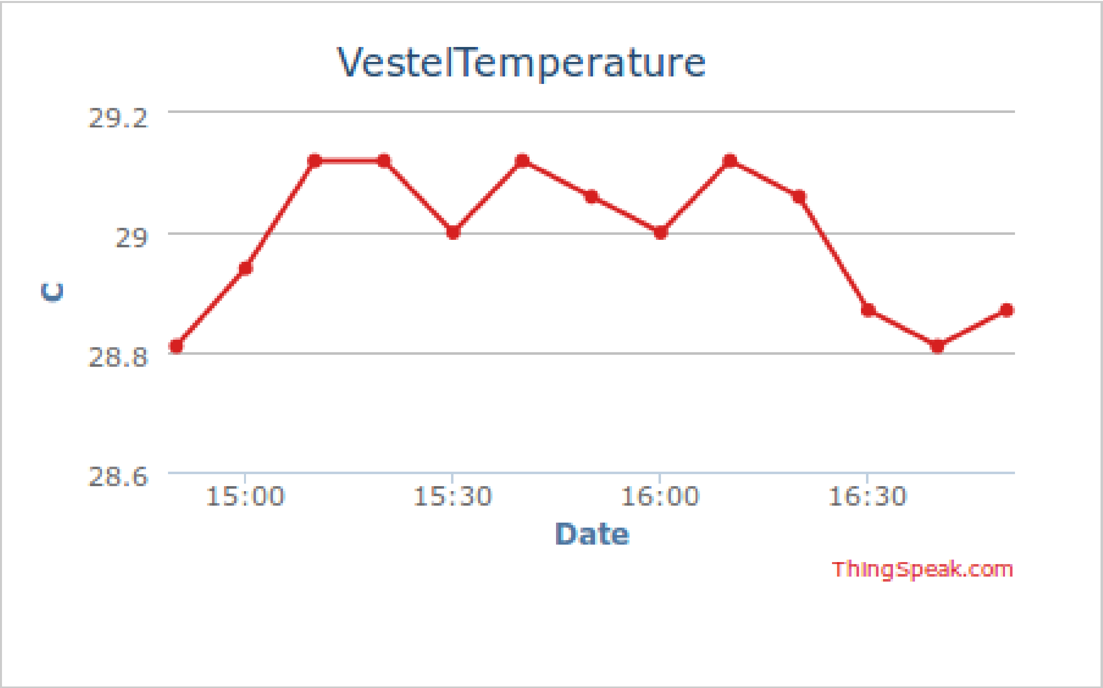


EasyIoT

ThingSpeak

- Visualization service
- Big data transaction
- Free tier
  - 3 message per minute
  - 622K message per year!
- REST API
- Channels for visualization

ThingSpeak



VestelTemperature
29.2
29
28.8
28.6
C
15:00
15:30
16:00
16:30
Date
ThingSpeak.com

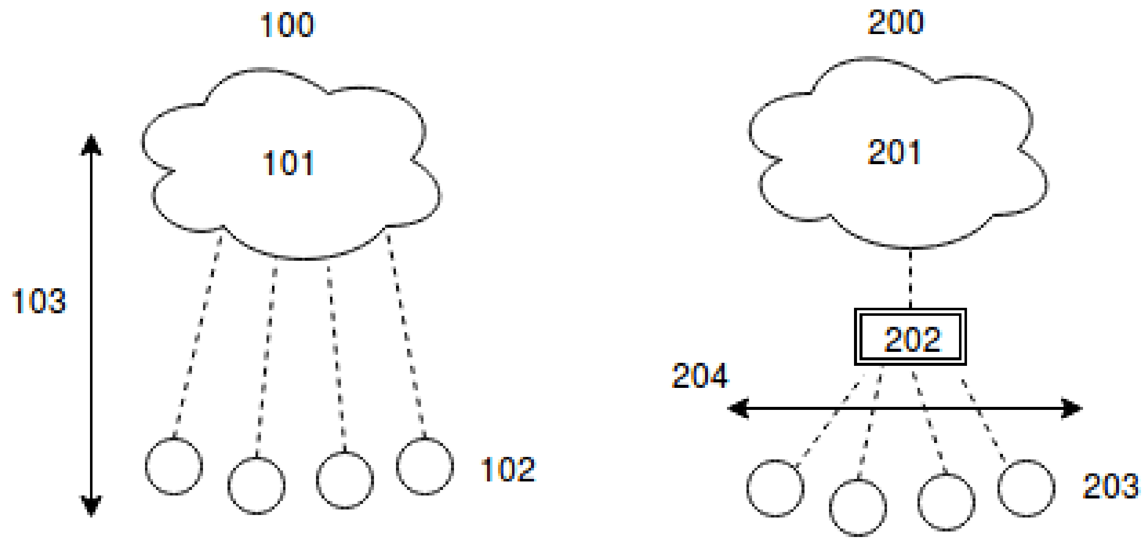
CloudMQTT

- Funded by Amazon
- Globally distributed MQTT Broker
- Offers a RESTFul API
- Free Tier
  - Up to 10 users
  - No message limit
- Running Mosquitto inside
  - Not a big deal ?

A Fog Computing Break

- A Node in Local Area Network
- Not direct access to Cloud Servers
  - Horizontal
- Reduced Latency
- Reduced Data Traffic on Internet
- Edge Computing
  - Efficient Data Processing

A Fog Computing Break



Security

- Device oriented
  - Sniffing
  - Secure Boot
  - AES, SSL, TLS, DTLS
- Server oriented
  - Spoofing
  - Authorization of resources
  - Deep Packet Inspection
- Configuration and Debugging Interfaces
  - HTTP, SSH
  - CAN
  - Jeep Cherokee hack, WiFi access
- Denial of Service
  - October 2016 attacks
  - Embedded Botnet army (Mirai)
  - 1.2Tbps attack rate

Part 3 : DEVICES

- Requirements and Costs
- Operating Systems
- Embedded Devices of the Connected World
- External Radios
- Power Consumption

Requirements and Costs

- Low-End devices
  - Lower processing power
  - Less memory
  - Reduced costs
- Ability to implement protocol layers
  - TCP/IP stack
  - Bluetooth, ZigBee
- Data processing
- Power Consumption
  - Radios
- OS Support

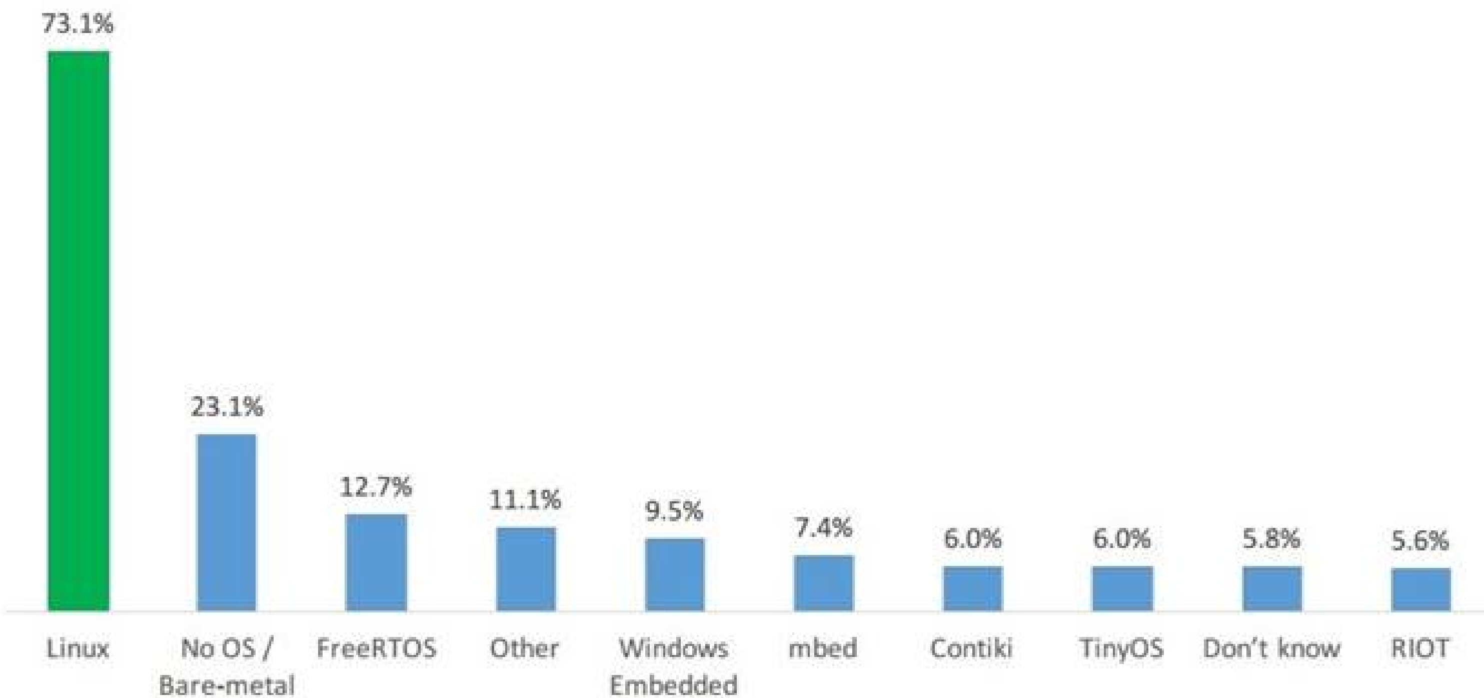
Operating Systems

- Small memory footprint
- Real-time capabilities
- Energy efficiency
- Network and protocol support
- Security
- Variety of hardware support

Operating Systems

- Linux
  - Brillo
  - Yocto
    - Ostro OS
  - OpenWRT
    - Linino OS
  - Raspbian
  - ucLinux
- RTOS
  - FreeRTOS
  - Contiki
  - ARM mbed OS
  - RIOT
  - TinyOS
  - WindowsCE
  - Zephyr

Operating Systems



Survey results for Operating Systems used for IoT
(Source: IoT Developer Survey 2016)

Brillo (Android Things)

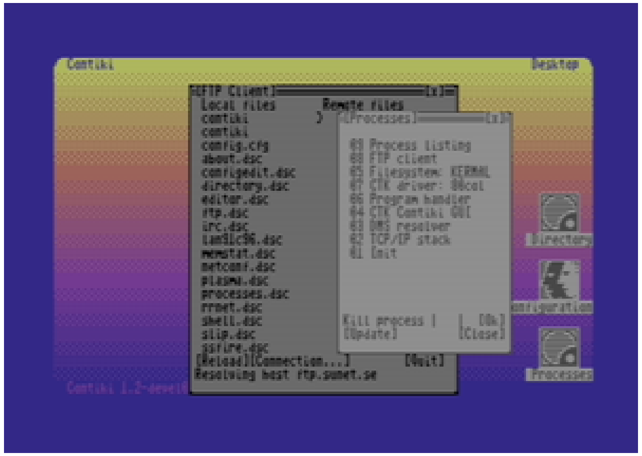
- Android Things
- Android based embedded OS
  - Bionic
  - Binders
- 35MB Memory Footprint (minimum)
- Weave
  - Comm standard for IoT
  - Schema driven over XMPP
  - BT + WiFi + 802.15.4
  - Cloud + Mobile support

FreeRTOS

- Popular Embedded RT Kernel
- Variety of vendors
  - Atmel
  - Espressif
  - MicroChip for PIC
- Implementation consists 5 C files
  - timers.c - queue.c
  - task.c - croutine.c
  - list.c
- FreeRTOS+TCP stack
- Tickless mode for power saving
- FreeRTOS+Nabto IoT
  - 10Kb of code and just a few Kb of RAM

Contiki

- OS for connected and embedded devices
- Open source
- 10KB Memory Footprint (minimum)
  - Even able run in Commodore64
- uIP TCP/IP stack
  - 8-16 bit MCUs
  - A few KBs of RAM
  - UIPv6
- Battery-constrained devices
  - ContikiMAC
- Protothreads
- GUI



Contiki
The Open Source OS for the Internet of Things

ARM mbed OS

- Open source
  - 9.5K commits at GitHub
- Developed for IoT
  - Especially for battery powered guys
- Based on an ARM Cortex-M
  - About to run with 8KB of RAM
- Single threaded architecture
- Variety of protocol support
  - LoraWAN
  - 6LoWPAN & Thread
  - Cellular
  - RFID & NFC

RIoT & TinyOS

- RIoT
  - Another open IoT OS
    - 15K commits @ GitHub
    - Inherited from FireKernel of WSNs
  - Support for over 50 devices
    - 8-bit Atmega
    - 16-bit MSP430
  - CoAP and 6LoWPAN support
  - Partial POSIX support
- TinyOS
  - OS for Wireless Sensor Networks
  - Programming with nesC
  - Component based architecture
  - Non-preemptive
    - First in, first out order

Operating Systems Summary

	Contiki	RIOT	FreeRTOS	TinyOS	uClinux	Mbed
Architecture	monolithic	microkernel RTOS	microkernel RTOS	monolithic	monolithic	monolithic
Scheduler	cooperative	preemptive, tickless	preemptive, optional tickless	cooperative	preemptive	preemptive
Programming model	event-driven, protothreads	multi-threading	multi-threading	event-driven	multi-threading	Event driven, single-thread[2]
Targeted device class[1]	Class 0, 1	Class 1,2	Class 1,2	Class 0	>Class 2	Class 1,2
Supported MCU families or vendors	AVR®, MSP430 ™, ARM® Cortex-M®, PIC32, 6502	AVR®, MSP430 ™, ARM® Cortex-M®, x86	AVR®, MSP430™, ARM®, x86, 8052, Renesas	AVR®, MSP430 ™, px27ax	ARM7 ™, ARM® Cortex-M®	ARM® Cortex-M®
Programming languages	C	C, C++	C	nesC	C	C, C++
License	BSD	LGPLv2	modified GPL	BSD	GPLv2	Apache License 2.0

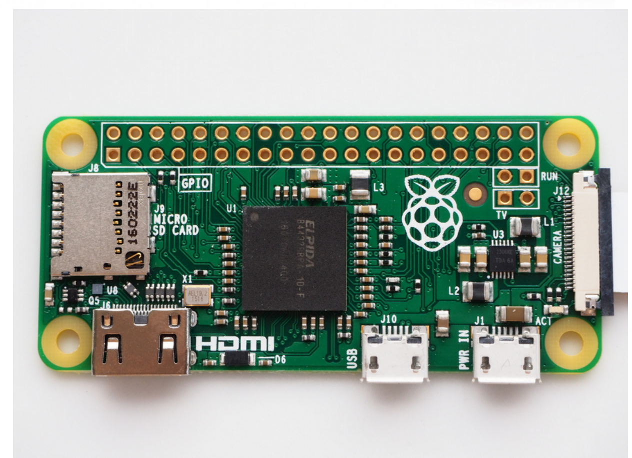
Class 0 << 10kB data size (ex: RAM) and << 100kB code size (ex: Flash),
Class 1 ~10kB data size (ex: RAM) and ~100kB code size (ex: Flash), and
Class 2 ~50kB data size (ex: RAM) and ~250kB code size (ex: Flash)

Embedded Devices of The Connected World

- Best Friends
  - Raspberry
  - Arduino
  - Orange & BeagleBone
- Piece of cake
  - Espressif ESP8266
  - ESP32
  - NodeMCU
  - Realtek RTL8710
  - MXCHIP EMW3165
- Industrial Things
  - MTK LinkIt
  - TI SimpleLink
  - Broadcom WICED
  - Particle
  - ARTIK 5/7/10
  - Intel Edison

Raspberry

- A naked computer
- Peripherals
  - LCD, Camera, HDMI, USB
- Raspbian inside
- Pi 3
  - 64-bit quad ARMv8 @ 1.2GHz
  - BCM43438 WiFi + BLE
  - 1GB RAM
- Pi Zero
  - 1Ghz ARM Single-core CPU
  - 512MB RAM
  - $5 ?



Arduino

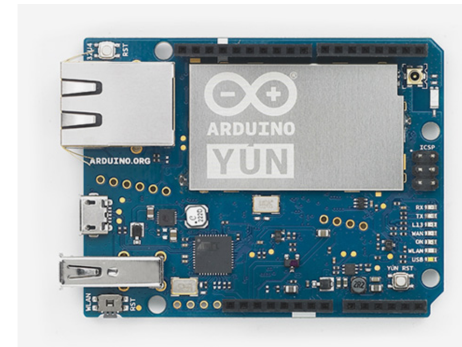
- Open HW and SW
- Single-board computer
- Arduino IDE
  - Sketch
  - C/C++
  - Library Manager
  - Board Manager
- Shields
- 15 official boards since 2005
- Analog I/Os

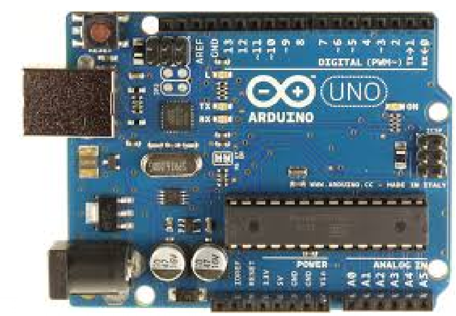
Arduino

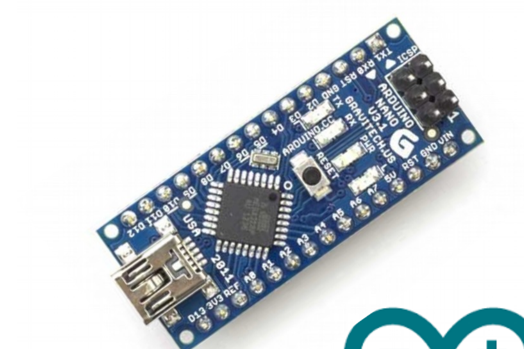
```
#define LED_PIN 13                    // Pin number attached to LED.

void setup() {
    pinMode(LED_PIN, OUTPUT);         // Configure pin 13 to be a digital output.
}

void loop() {
    digitalWrite(LED_PIN, HIGH);      // Turn on the LED.
    delay(1000);                      // Wait 1 second (1000 milliseconds).
    digitalWrite(LED_PIN, LOW);       // Turn off the LED.
    delay(1000);                      // Wait 1 second.
}
```

Arduino

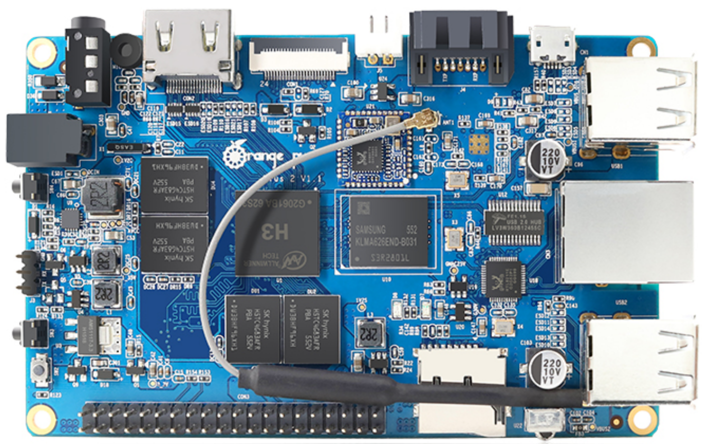
- Yún
  - LininoOS
  - 8-bit 16MHz AVR ATmega32u4
  - 32-bit 400MHz Atheros AR9331 WiFi SoC
  - 20 Digital, 12 Analog I/O, 7 PWM
- Uno
  - 8-bit 20MHz ATmega328P
  - 14 Digital, 6 Analog IO
- Nano
  - 8-bit 20MHz ATmega168
  - 14 Digital, 8 Analog I/O
  - 16KB Flash

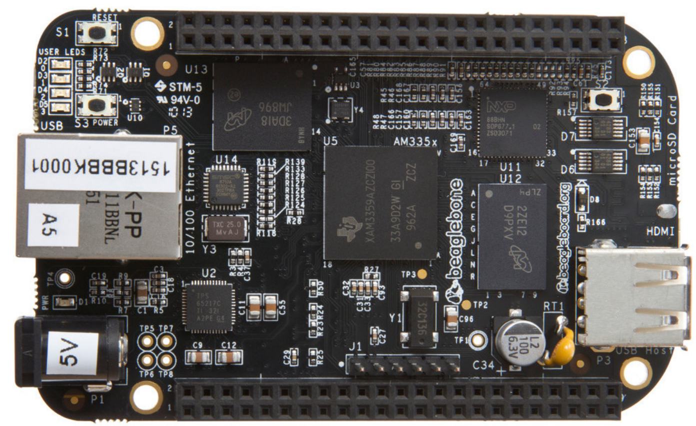






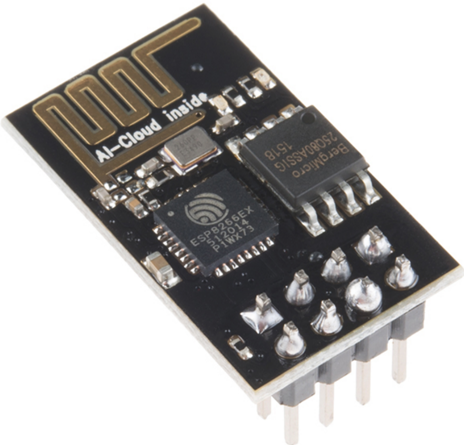
Orange Pi and BeagleBone

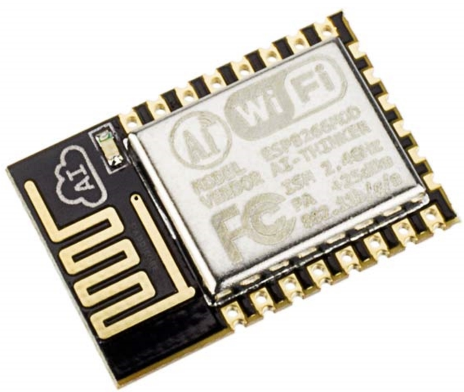




Espressif ESP8266

- Low cost WiFi Chip
  - Internet access for $1.5
- Full TCP/IP stack
- Launched at December 2013
- 32-bit RISC CPU
  - Tensilica Xtensa LX106 running at 80 MHz
- 64 KiB of RAM
- 512 KiB QSPI Flash
- 16 GPIO pins
- RTOS support





Espressif ESP32

- Ultra low power
- WiFi + Bluetooth combo
  - 802.11b/g/n/e/i
  - BT v4.2 and BLE
- 32-bit LX6 microprocessor
  - Tensilica Xtensa Dual-Core 240 MHz
- 520 KiB SRAM
- 16 MByte flash
- 36 GPIO pins

NodeMCU

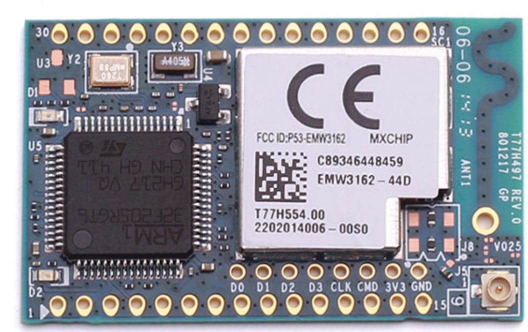
- Open source IoT platform
- ESP8266 based SDKs
  - AT commands
  - Open SDK in C
  - FreeRTOS derivative
  - Arduino
  - LUA
  - MicroPython
- USB-Serial convertor
- Not battery friendly

Realtek RTL8710

- Alternative to ESP8266
  - Cheap as well
- 32-bit ARM Cortex-M3
  - 166 MHz
- 1MiB Flash
- 48 KiB RAM
- 21 GPIOs
- RTOS support
- Pine64 PADI
  - Kickstarted

MXCHIP EMW3165

- Another Chinese low cost dude
- Marvell WiFi Chip
- 32-bit ARM Cortex M4
  - STM32F4 @ 100MHz
- 128 KiB RAM
- 2MiB SPI Flash
- 22 GPIOs
- ….



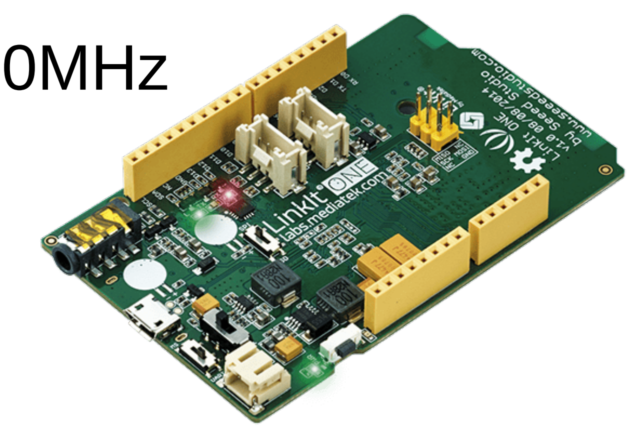
RTL8710 Vs. ESP8266

	Realtek RTL8710	Espresif ESP8266
Package	QFN-48 (6×6 mm)	QFN-32 (5×5 mm)
CPU	ARM Cortex M3 @ 166 MHz	Tensilica LX106 @ 80 / 160 MHz
RAM	48KB available to user	36KB available to user
Flash	1MB Built-in	1, 2, 4, 8 or 16 MB
WiFi	802.11n up to 150 Mbps, 802.11g up to 54 Mbps	802.11n up to 65 Mbps, 802.11g up to 54 Mbps
GPIO	Up to 21	Up to 17
I2C	Up to 3	Up to 1
PCM	Up to 2	None
PWM	Up to 4	
UART	2x high-speed UART, 1x low-speed UART	Up to 2x UART
Power	Voltage: 3.0 to 3.6V; Current: 80 mA	
Temperature range	-40 to 125 °C	
Standard certifications	FCC/CE/TELEC/SRRC/ WiFi Alliance	FCC/CE/TELEC/SRRC

MTK LinkIt

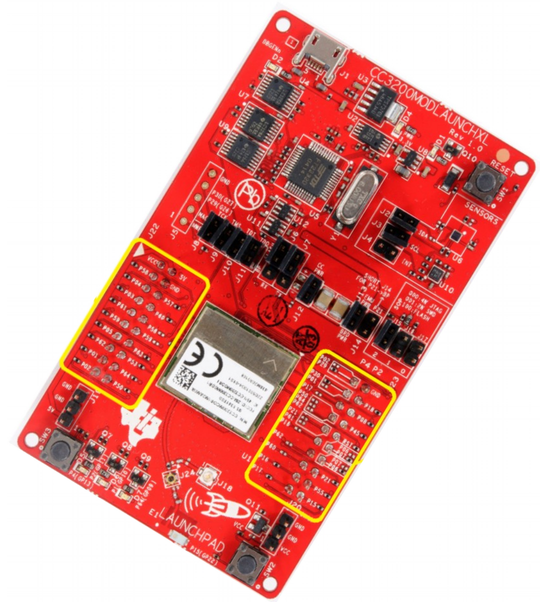
- Smart 7688
  - MT7688AN MIPS WiFi SoC @580MHz
  - C, Node.js and Python support
  - PWM, I2C, SPI …
  - 128MB DDR2, 32MB Flash

- ONE
  - MT2502A MIPS SoC + ARM7EJ-S™ @ 260MHz
  - WiFi + BT + GSM (2G) + GPS
  - Official AWS IoT device
  - 4MB RAM, 16MB Flash
  - Arduino support



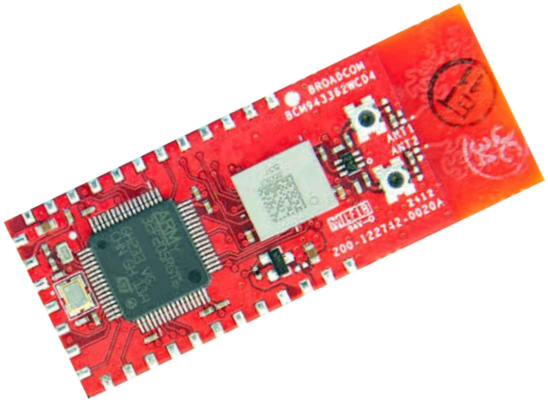
TI SimpleLink

- WiFi
  - TI CC3200 WiFi Network Processor
    - 32-bit ARM Cortex-M4 @ 80MHz
    - 256KB RAM
    - 25 GPIOs
  - Power-Management Subsystem
    - 2.1V Operating voltage
    - TX Traffic (MCU Active): 229 mA
- Multistandard
  - TI CC2650 RF microcontroller
    - 32-bit ARM Cortex M3 @ 48MHz
    - ZigBee, 6LoWPAN, BLE, RF4C
    - 128KB Flash, 20KB SRAM
    - Active-Mode TX at +5 dBm: 9.1 mA



Broadcom WICED

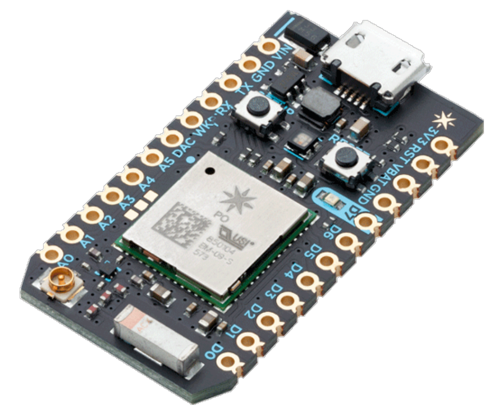
- Broadcom’s IoT acquired by Cypress
  - Summer, 2016
  - $180M revenue previous year
  - Intel hit $2.4B
- Sense
  - 32-bit BCM20737L ARM, BLE
  - Humidity, Temp, Accelerometer
- BCM943362WCD4
  - 32-bit STM32F205 ARM @ 120MHz
  - 128KB RAM, 1MB Flash
  - Amazon DASH

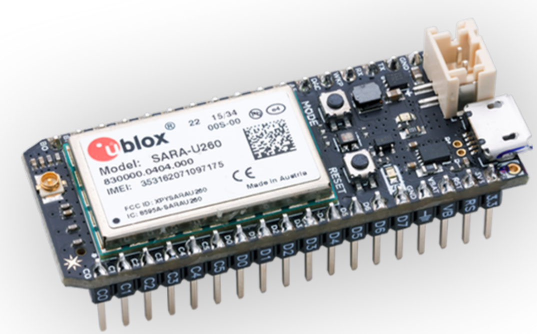


WICED by CYPRESS

Particle

- Photon
  - BCM943362WCD4
  - FreeRTOS support
  - 18 GPIOs
  - Particle Cloud
- Electron
  - 2G + 3G Cellular module
  - STM32 ARM @ 120MHz
  - 30GPIOs
  - 800mA peaks on network scan

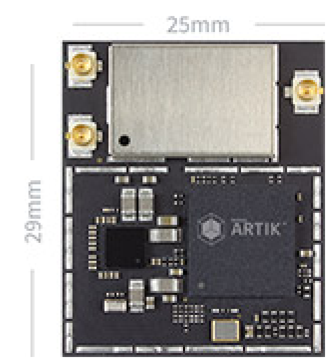




Samsung ARTIK

- 020
  - Thin Bluetooth 4.2 module
  - 32-bit ARM Cortex M4 @ 40 MHz
  - 8.2mA TX current
  - 32KB RAM, 256KB Flash

- 520
  - WiFi, BT, ZigBee, Thread
  - Dual core ARM Cortex-A7 @ 1.0 GHz
  - 512MB LPDDR3, 4GB eMMC
  - Fedora Linux derivative

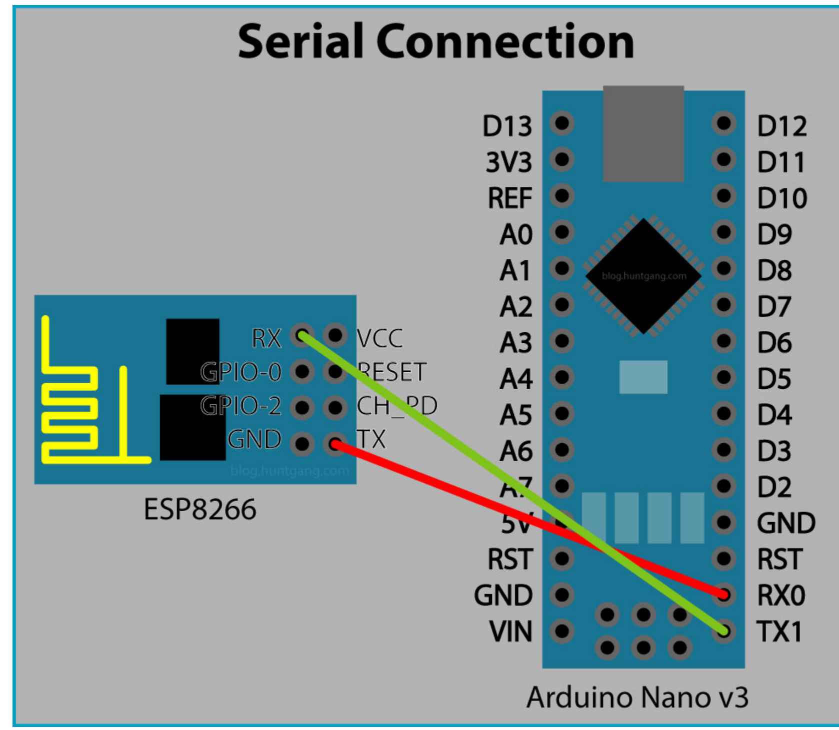


Intel Edison

- Dual-core Intel Atom @ 500 MHz
- Broadcom 43340 WiFi Chip
- Bluetooth 4.0
- 1GB DDR3, 4GB eMMC
- 40 multiplexed GPIO interfaces
- Yocto based Linux, Brillo, Arduino
- C/C++, Python, Node.js

External Radios

- Hayes Command Set
  - AT commands
  - Serial interface
  - Dedicated firmware
  - Bidirectional
  - Timing issues
- HCI
  - Bluetooth interface
  - Opcodes
  - UART USB & SPI

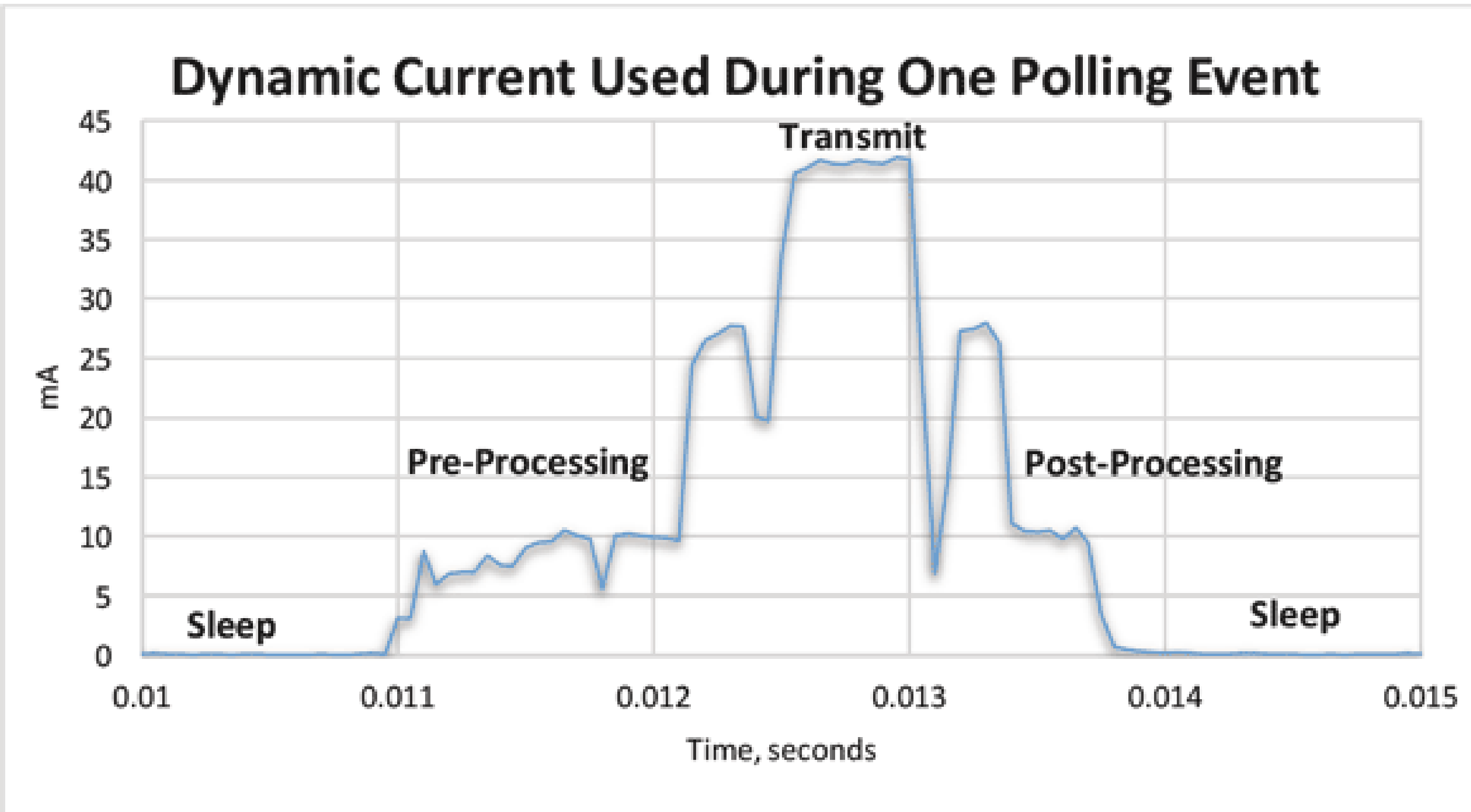



```
AT+CWJAP="MBLAZE-AC3633-1C5","als54321"
OK
```

Power Consumption

- Transmitting drains battery
- 802.11 not appropriate to be battery powered
  - LPWAs
  - LR-WPANs
- Algorithm design
  - Deep sleep switches
  - Buffering data
  - Critical sessions
- Choosing correct device
  - Powerful CPUs
  - Unnecessary peripherals

Power Consumption



Power Consumption

- Arduino Yun

Power consumption in mA			
Configuration	**min**	**typical**	**max**
WiFi on, no wired connection, no sd	170	240	300
WiFi on, wired connection, no sd		277	
WiFi on, wired connection, no sd, max. load		315	

- Raspberry

	Model B+	**Model A+**	**Zero**	**Pi 2**	**Pi 3**
Idle (Amps)	0.25	0.11	0.1	0.26	0.31
Loaded (Amps)	0.31	0.17	0.25	0.42	0.58

Power Consumption

- ESP8266

Parameter	Typical	Unit
Tx 802.11b, CCK 11Mbps, P_{OUT}=+17dBm	170	mA
Tx 802.11g, OFDM 54Mbps, P_{OUT} =+15dBm	140	mA
Tx 802.11n, MCS7, P_{OUT} =+13dBm	120	mA
Rx 802.11b, 1024 bytes packet length , -80dBm	50	mA
Rx 802.11g, 1024 bytes packet length, -70dBm	56	mA
Rx 802.11n, 1024 bytes packet length, -65dBm	56	mA
Modem-Sleep	15	mA
Light-Sleep	0.5	mA
Power save mode DTIM 1	1.2	mA
Power save mode DTIM 3	0.9	mA
Deep-Sleep	10	uA
Power OFF	0.5	uA

Power Consumption

- Realtek RTL8710

Model	Min	Tye	Max	unit
Transmit 802.11b, CCK 11Mbps, P_{OUT}=+17dBm		87		mA
Transmit 802.11g, OFDM 54Mbps, P_{OUT}=+15dBm		180		mA
Transmit 802.11n(HT20), MCS7, P_{OUT} =+14dBm		168		mA
Transmit 802.11n(HT40), MCS7, P_{OUT} =+14dBm		148		mA
Deep-Sleep③		10		uA

- TI SimpleLink CC3200

TEST CONDITIONS (1) (2)			MIN	TYP	MAX	UNIT
TX	1 DSSS	TX power level = 0		278		mA
		TX power level = 4		194		
	6 OFDM	TX power level = 0		254		
		TX power level = 4		185		
	54 OFDM	TX power level = 0		229		
		TX power level = 4		166		
RX	1 DSSS			59		
	54 OFDM			59		

Power Consumption

- SemTech SX1272 (LoRa)

Symbol	Description	Conditions	Min	Typ	Max	Unit
IDDSL	Supply current in Sleep mode		-	0.1	1	uA
IDDIDLE	Supply current in Idle mode	RC oscillator enabled	-	1.5	-	uA
IDDST	Supply current in Standby mode	Crystal oscillator enabled	-	1.4	1.6	mA
IDDFS	Supply current in Synthesizer mode	FSRx	-	4.5	-	mA
IDDR	Supply current in Receive mode	*LnaBoost* Off *LnaBoost* On	- -	10.5 11.2	- -	mA
IDDT	Supply current in Transmit mode with impedance matching	RFOP = +20 dBm on PA_BOOST RFOP = +17 dBm on PA_BOOST RFOP = +13 dBm on RFO pin RFOP = + 7 dBm on RFO pin	- - - -	125 90 28 18	- - - -	mA mA mA mA

- Microchip RN2903 (LoRa)

TX Power Setting	Output Power (dBm)	Typical Supply Current at 3V (mA)
2	3.0	42.6
3	4.0	44.8
4	5.0	47.3
16	16.3	95.8
17	17.0	103.6
20	18.5	124.4

Mode	Typical Current at 3V (mA)
Idle	2.7
RX	13.5
Deep Sleep	0.002

Power Consumption

- TI CC2650 (ZigBee + 6LowPAN + BLE)

TEST CONDITIONS	MIN	TYP	MAX	UNIT
Reset. RESET_N pin asserted or VDDS below Power-on-Reset threshold		100		nA
Shutdown. No clocks running, no retention		150		
Standby. With RTC, CPU, RAM and (partial) register retention. RCOSC_LF		1		µA
Standby. With RTC, CPU, RAM and (partial) register retention. XOSC_LF		1.2		
Standby. With Cache, RTC, CPU, RAM and (partial) register retention. RCOSC_LF		2.5		
Standby. With Cache, RTC, CPU, RAM and (partial) register retention. XOSC_LF		2.7		
Idle. Supply Systems and RAM powered.		550		
Active. Core running CoreMark		1.45 mA + 31 µA/MHz		
Radio RX [1]		5.9		mA
Radio RX [2]		6.1		
Radio TX, 0-dBm output power [1]		6.1		
Radio TX, 5-dBm output power [2]		9.1		

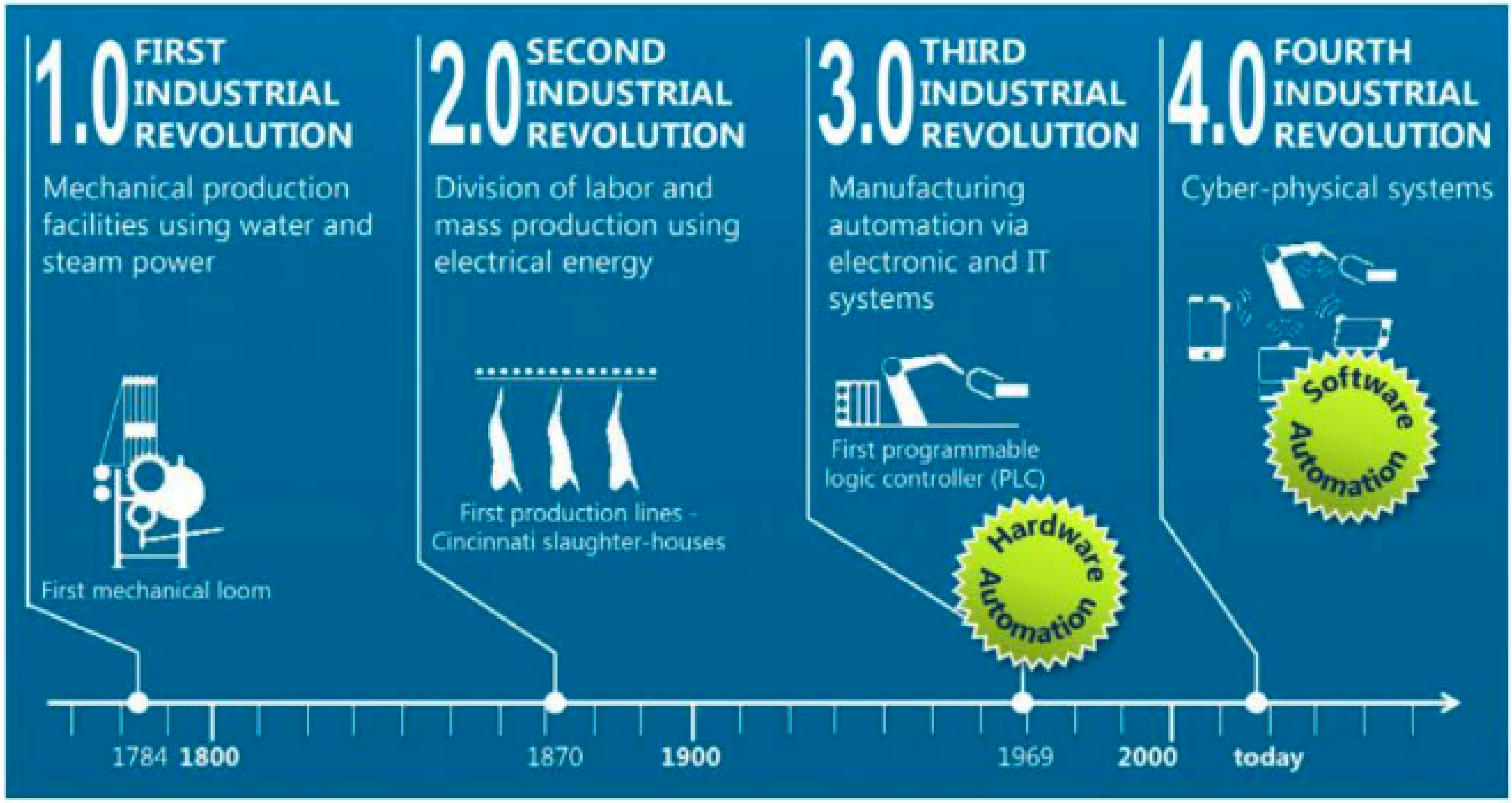
Part 4 : APPLICATIONS

- Industry 4.0
- Automation
  - Smart Buttons
  - Smart Home
- Smart Agriculture
- Smart Health
- ...

An Industry 4.0 Break

- 2011, by German Government
- Competition with human power
- New Age Factories
  - Connected
  - Dark
- Strong customization of products
- Supply Chain Management

An Industry 4.0 Break



Part 5 : WORKSHOP

- A basic MQTT publish/subscribe operation :
  - A sensor mote will publish some sensor data to the given topic
  - As an actuator, you will need to listen incoming sensor data from the broker
    - Need to subscribe to the related topic
- Send all retrieved sensor data to the Thingspeak to store them all.
- Additional : Publish relay on/off command to control the switch on specified conditions. Achieve CoAP or WebSocket example.
- Arduino based ESP8266 application :
  - https://github.com/cagdasdoner/IoTPractices
- For device related source, go to :
  - src/device/esp8266_arduino/actuator
- Assuming that, you've completed prerequisites that defined in the training page, stepping forward ...

Updating Credentials

- Credentials.h

```
#ifndef ARDUINO_CREDENTIALS_H
#define ARDUINO_CREDENTIALS_H

/* WiFi Credentials*/
#define STA_SSID "Venus_V3_5580"
#define STA_PASS "c12345678"

/* WebSocket Credentials */
#define WSOCK_HOST "WS_HOST"
#define WSOCK_PORT 80

/* MQTT Credentials */
#define MQTT_BROKER       "vestelmqtt.xyz"
#define MQTT_BROKER_PORT  1883
#define MQTT_USERNAME     "iotPractise"
#define MQTT_KEY          "hacknbreak"

/* ThingSpeak Credentials */
#define TSPEAK_HOST       "http://api.thingspeak.com"
#define TSPEAK_PORT       80
#define TSPEAK_API_KEY    "YOUR_API_KEY"
#endif /* ARDUINO_CREDENTIALS_H */
```

Using MQTT API

- MQTTConnector.h

```
#ifndef ARDUINO_MQTTCONNECTOR_H
#define ARDUINO_MQTTCONNECTOR_H

#include <Arduino.h>

#define MQTT_TOPIC_SENSOR  "/iot/text/sensor"
#define MQTT_TOPIC_RELAY   "/iot/text/relay"

void    MQTTBegin();
void    MQTTLoop();
boolean MQTTDeliver(const char* topic, const char* payload);
boolean MQTTSubscribe(const char* topicToSubscribe);
boolean MQTTConnected();

#endif /* ARDUINO_MQTTCONNECTOR_H */
```

URLs

- http://www.rfidjournal.com/articles/view?4986
- http://www.livinginternet.com/i/ia_myths_toast.htm
- http://www.cl.cam.ac.uk/coffee/qsf/coffee.html
- http://mattturck.com/2016/03/28/2016-iot-landscape/
- http://cloudtweaks.com/2016/04/growing-popularity-iot/
- http://public.dhe.ibm.com/software/dw/webservices/ws-mqtt/mqtt-v3r1.html
- https://eclipse.org/community/eclipse_newsletter/2014/february/article2.php
- http://www.cse.wustl.edu/~jain/cse570-15/ftp/iot_prot.pdf
- https://tools.ietf.org/html/rfc7252
- http://public.dhe.ibm.com/software/dw/webservices/ws-mqtt/MQTT_V3.1_Protocol_Specific.pdf
- http://www.postscapes.com/internet-of-things-protocols/
- https://en.wikipedia.org/wiki/IEEE_802.15.4
- https://en.wikipedia.org/wiki/6LoWPAN
- https://github.com/openthread/openthread
- http://www.ti.com/lit/wp/swry013/swry013.pdf
- https://pdfs.semanticscholar.org/dbe4/3f9e28e125203439c8b554f19f0b6ce79443.pdf

URLs

- https://www.lora-alliance.org/For-Developers/LoRaWANDevelopers
- https://www.link-labs.com/sigfox-vs-lora/
- http://www.slideshare.net/AmazonWebServices/developing-connected-applications-with-aws-iot-technical-301
- https://en.wikipedia.org/wiki/Comparison_of_single-board_computers
- http://www.silabs.com/products/wireless/Pages/battery-life-in-connected-wireless-iot-devices.aspx
- https://www.pidramble.com/wiki/benchmarks/power-consumption
- http://playground.arduino.cc/Hardware/Yun#power_consumption
- http://aitendo3.sakura.ne.jp/aitendo_data/product_img/wireless/2.4G/RTL-00/RTL8710%20wifi%20module%20specification.pdf
- http://bbs.espressif.com/viewtopic.php?t=133
- http://noumanqaiser.blogspot.com.tr/2014/03/rtos-in-pic-microcontrollers-devil.html
- http://www.freertos.org/FreeRTOS-Plus/Nabto/How_Nabto_Does_It.shtml
- https://www.arrow.com/en/research-and-events/articles/iot-operating-systems
- https://www.linux.com/news/open-source-operating-systems-iot
- https://www.theatlas.com/search/IoT
- https://www.link-labs.com/what-is-weightless/
- https://www.tutorialspoint.com/ipv6/ipv6_address_types.htm