

Teaching the Internet of Things: From STEM to STEAM

Kevin W. Lu
klu@ieee.org

Outline

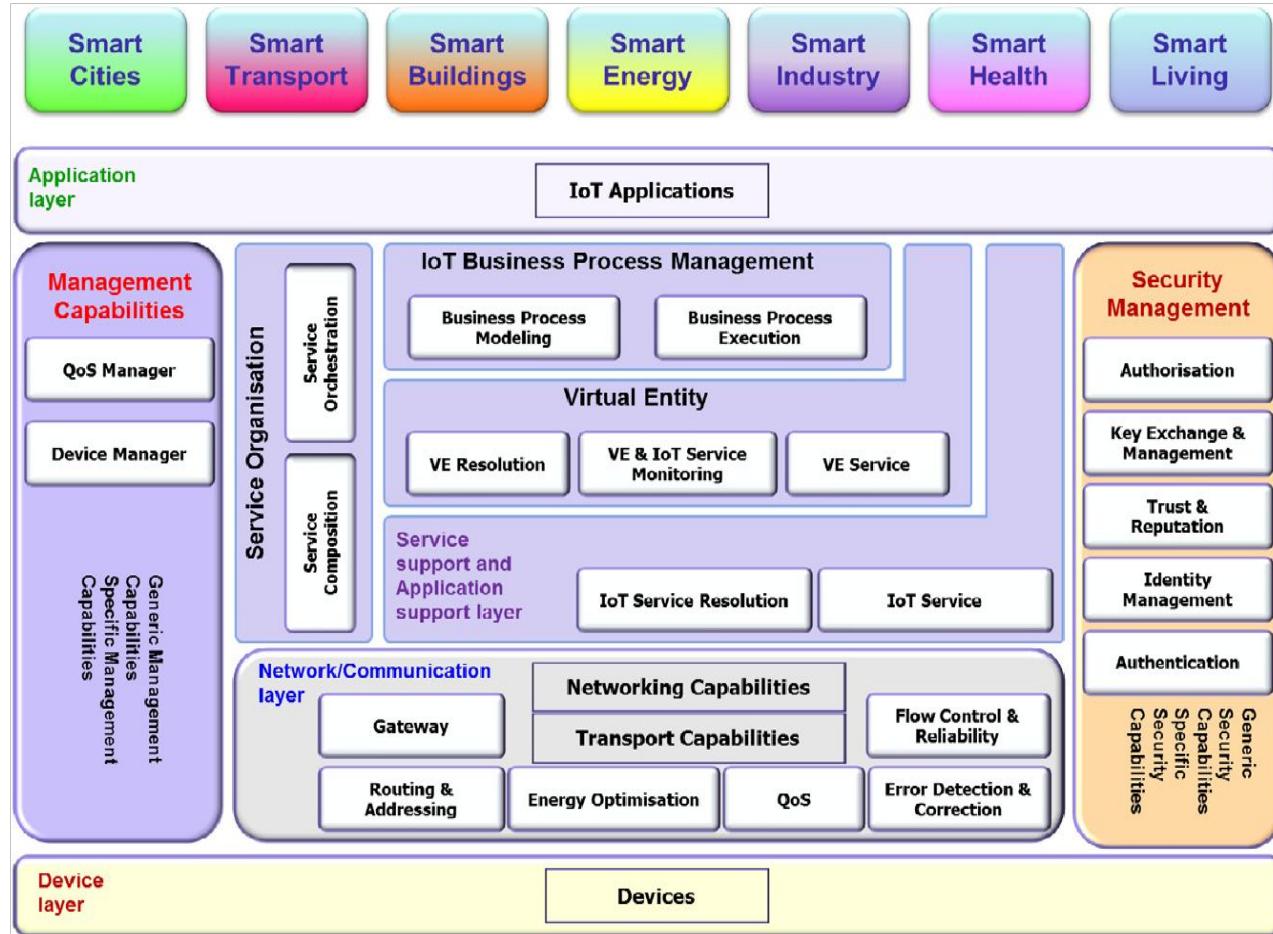
- The Internet of Things (IoT) definition, architecture, complexity levels, protocols, and application programming interfaces (APIs)
- IoT hype cycle, startups, landscape, alliances, standards, and value chain
- Development board examples: Arduino YÚN, BeagleBone Black Revision C, LinkIt Smart 7688 Duo, Particle Photon, Raspberry Pi 3B, and Tessel 2
- Cloud platform examples: gspread, ThingSpeak, etc.
- Communication models: request/response (*e.g.*, Django) and publish/subscribe (*e.g.*, Paho)
- Data analysis and visualization

IoT Definition by ITU-T

A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things”

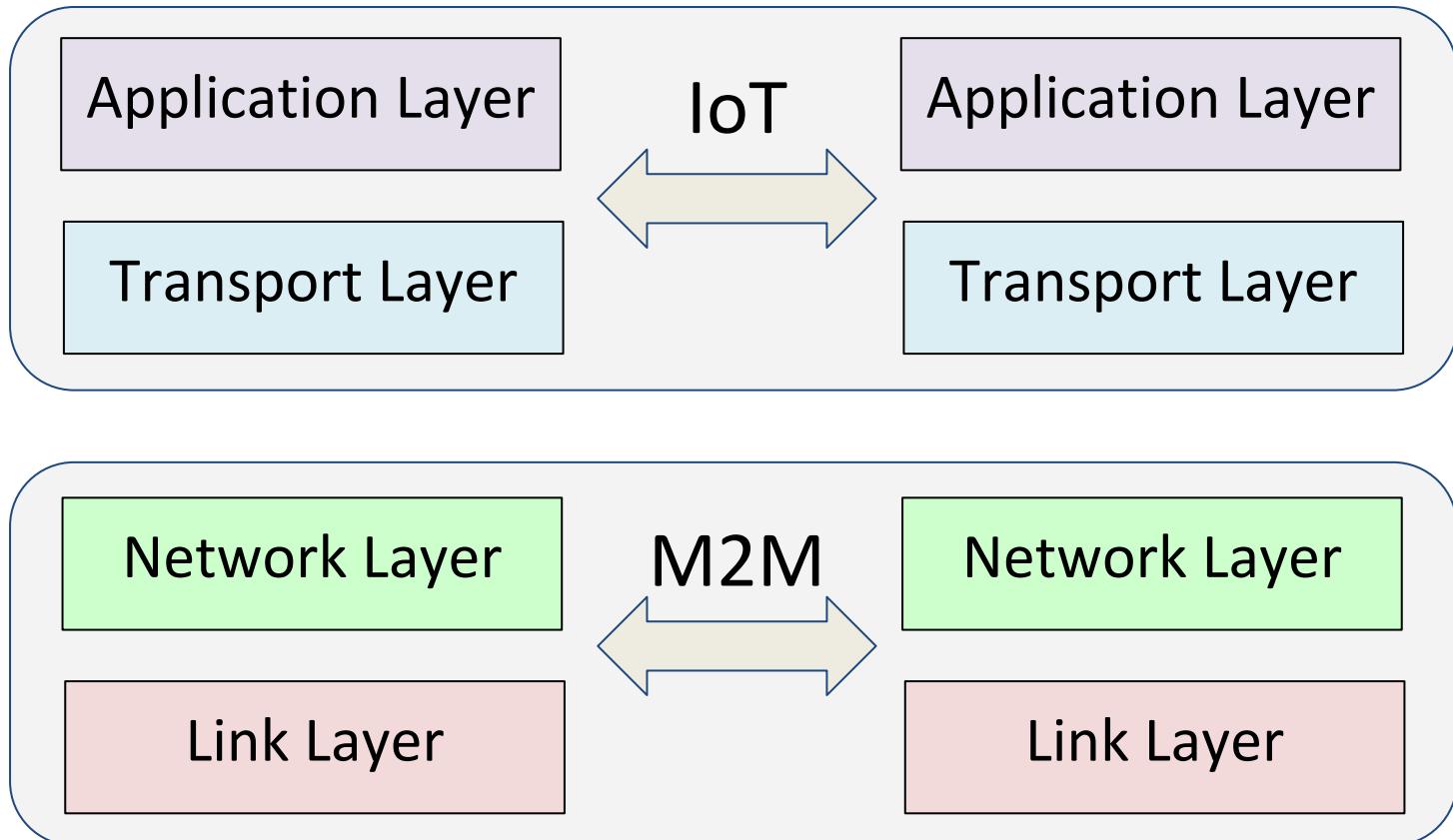
- have identities, physical attributes, and virtual personalities
- use intelligent interfaces
- are seamlessly integrated into the information network
- often communicate data associated with users and their environments

IoT Architecture by ITU-T



<http://www.internet-of-things-research.eu/documents.htm>

IoT vs. Machine-to-Machine (M2M)



<http://www.internet-of-things-book.com/>

Complexity Levels of IoT Systems

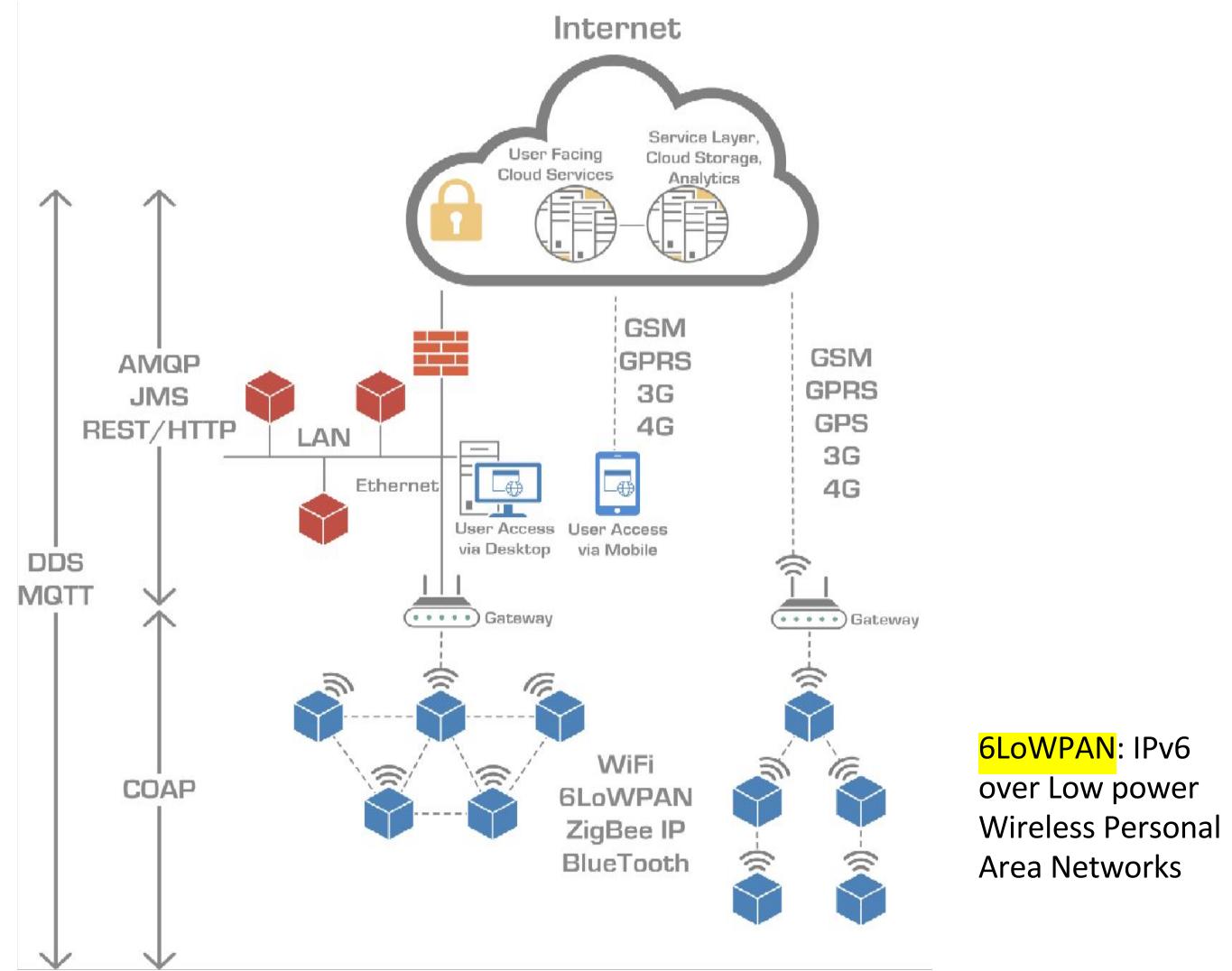
Level	Node	Analysis	Storage	Example
1	Single	Local	Local	Home Automation
2	Single	Local	Cloud	Smart Irrigation
3	Single	Cloud	Cloud	Vibration Monitoring
4	Multiple	Local	Cloud	Noise Monitoring
5	Multiple + Coordinator	Cloud	Cloud	Forest Fire detection
6	Multiple + Centralized Controller	Cloud	Cloud	Weather Monitoring

<http://www.internet-of-things-book.com/>

IoT Protocols

AMQP	Advanced Message Queuing Protocol
CoAP	Constrained Application Protocol
DDS	Data Distribution Service
HTTP	Hypertext Transfer Protocol
JMS	Java Message Service
MQTT	Message Queue Telemetry Transport
REST	Representational State Transfer
WAMP	Web Application Messaging Protocol
XMPP	Extensible Messaging and Presence Protocol

IoT/M2M Protocols



What is an API?

- API is a set of routines, protocols, and tools for building software applications
- It specifies how software components interact and are used when programming graphical user interface (GUI) components
- Example: **Django REST API** for smart lighting
 - /lighting
 - controller.py
 - db.sqlite3
 - /lighting
 - settings.py
 - urls.py
 - manage.py
 - /myapp
 - admin.py
 - models.py
 - serializers.py
 - /templates
 - /myapp
 - index.html
 - views.py

IoT Hype Cycle 2015



<http://www.gartner.com/newsroom/id/3114217>

IoT Startups on AngelList

The screenshot shows a web browser window for the AngelList platform. The title bar reads "Internet of Things Startups" and the URL is "https://angel.co/internet-of-things". The page header includes links for 3D, Dictionary, IEEE, IoT, Patents, Programming, Standards, Stevens, and Other Bookmarks, along with Syndicates, Startups, Funds, Startup Jobs, Recruiting, and More buttons. A search bar and "Join Log In" links are also present. The main content area displays the title "Internet of Things Startups" and "\$4.8M AVERAGE VALUATION". It features social sharing icons for Twitter and Facebook. Below this, statistics are shown: 2,072 COMPANIES, 1,365 INVESTORS, 7,627 FOLLOWERS, and 938 JOBS. A table lists companies under "All Markets" and "PARENTS". The table columns are Company, Joined, Followers, and Signal. Two companies are listed: IMRSV and SmartThings.

All Markets	Company	Joined	Followers	Signal
PARENTS	IMRSV Emotion Recognition using Web... New York City · Internet of Things	Jul '11	471	
All Markets	SmartThings Hello, Smart Home http://vimeo... Palo Alto · Home Automation	Nov '12	425	VIEW JOBS

IoT Landscape 2016

Internet of Things Landscape 2016

Platforms & Enablement (Horizontals)

Building Blocks

<http://mattturck.com/2016/03/28/2016-iot-landscape/>

Allseen Alliance

The screenshot shows a web browser window for the Allseen Alliance website at <https://allseenalliance.org>. The page features a large banner with the text "Connect. Contribute. Collaborate." and a background image of interconnected hexagonal icons representing various devices. The top navigation bar includes links for 3D, Dictionary, IEEE, IoT, Patents, Programming, Standards, Stevens, Other Bookmarks, Opportunities, Framework, Certification, Alliance, Announcements, News, Events, Blog, Members' Area, and a search function.

CONNECT. CONTRIBUTE. COLLABORATE.

The AllSeen Alliance is a cross-industry consortium dedicated to enabling the interoperability of billions of devices, services and apps that comprise the Internet of Things.

Open Interconnect Consortium

The screenshot shows a web browser window with the title bar "oic Open Interconnect Consort X". The address bar contains "openinterconnect.org". Below the address bar is a navigation menu with links: 3D, Dictionary, IEEE, IoT, Patents, Programming, Standards, Stevens, and Other Bookmarks. A yellow star icon is also present.

The main content area features the Open Interconnect Consortium logo, which consists of a network of green and blue circles connected by lines. To the right of the logo, the text "OPEN INTERCONNECT CONSORTIUM™" is displayed. Below this, a horizontal navigation bar includes links for HOME, ABOUT US, JOIN US, NEWS AND EVENTS, DEVELOPER RESOURCES, and CONTACT US.

The central part of the page has a brown background with the text "DELIVERING INDUSTRY STANDARDS AND OPEN SOURCE SOLUTIONS" in large, white, sans-serif capital letters. On either side of this text are white rectangular boxes containing a left-pointing arrow and a right-pointing arrow, respectively.

Below this section, a dark teal button contains the text "LEARN MORE" in white capital letters.

The bottom of the page has a light gray footer area.

The overall design is clean and professional, emphasizing connectivity and technology.

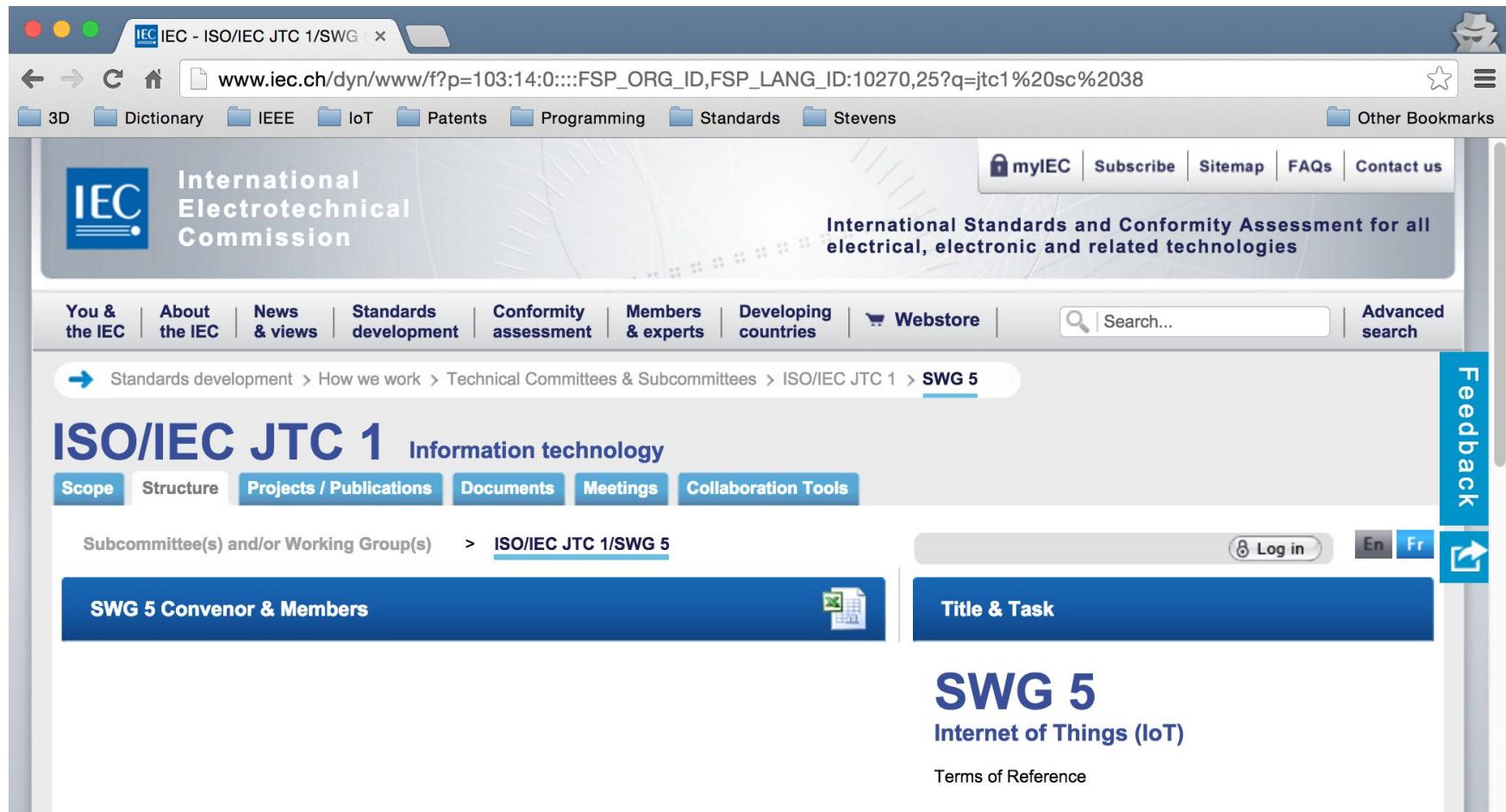
Long Range (LoRa) Networks

A screenshot of a web browser displaying the LoRa Alliance website at <https://www.lora-alliance.org>. The browser interface includes a back button, forward button, refresh button, a home icon, and a search bar. The address bar shows the URL with a green lock icon indicating a secure connection. Below the address bar are various bookmark icons for "3D", "Dictionary", "IEEE", "IoT", "Patents", "Programming", "Standards", and "Stevens". To the right of the address bar are a yellow star icon, a user profile icon, and a menu icon.

The website header features the LoRa Alliance logo with the tagline "Wide Area Networks for IoT". The main navigation menu includes links for "WHAT IS LORA?", "FOR DEVELOPERS", "THE ALLIANCE", "JOIN", and "NEWS & EVENTS". On the far right of the header, there are links for "IoT Challenge Area" and "Men".

The main content area features the LoRa Alliance logo and tagline again, set against a background of a grayscale city skyline, likely London, showing recognizable buildings like the Gherkin and the Shard.

ISO/IEC JTC 1/SWG 5



The screenshot shows a web browser displaying the ISO/IEC JTC 1/SWG 5 page. The URL in the address bar is www.iec.ch/dyn/www/f?p=103:14:0::::FSP_ORG_ID,FSP_LANG_ID:10270,25?q=jtc1%20sc%2038. The page header includes the IEC logo, navigation links for 3D, Dictionary, IEEE, IoT, Patents, Programming, Standards, Stevens, and Other Bookmarks, and links for myIEC, Subscribe, Sitemap, FAQs, and Contact us. The main content area features the IEC logo and the text "International Standards and Conformity Assessment for all electrical, electronic and related technologies". Below this are navigation links for You & the IEC, About the IEC, News & views, Standards development, Conformity assessment, Members & experts, Developing countries, Webstore, and search functions for Advanced search and a specific search bar. A breadcrumb navigation path is shown: Standards development > How we work > Technical Committees & Subcommittees > ISO/IEC JTC 1 > SWG 5. The main title is "ISO/IEC JTC 1 Information technology". Below it are tabs for Scope, Structure, Projects / Publications (which is selected), Documents, Meetings, and Collaboration Tools. A blue banner at the bottom left says "SWG 5 Convenor & Members" and has a document icon. Another blue banner at the bottom right says "Title & Task". On the far right, there is a vertical "Feedback" button and language selection buttons for En (English) and Fr (French). The central content area displays the title "SWG 5 Internet of Things (IoT)" and a link to "Terms of Reference".

IEEE P2413

The screenshot shows a web browser window displaying the IEEE Standards Association website. The URL in the address bar is <https://standards.ieee.org/develop/project/2413.html>. The page title is "IEEE SA - P2413 - Standard". The main content area features a large blue header with the text "IEEE PROJECT" and "P2413 - Standard for an Architectural Framework for the Internet of Things (IoT)". Below this, a paragraph describes the IoT market and the purpose of the standard. To the right, there is a "STATUS:" box indicating "Active Project". On the far right, a "Standards Help" box promotes IEEE-SA Standards Development Services. The top navigation bar includes links for "Find Standards", "Develop Standards" (which is highlighted), "Get Involved", "News & Events", "About Us", "Buy Standards", and "eTools". The IEEE logo is visible in the top right corner.

IEEE SA - P2413 - Standard

https://standards.ieee.org/develop/project/2413.html

IEEE.org | IEEE Xplore Digital Library | IEEE Standards | IEEE Spectrum | More Sites

IEEE

IEEE STANDARDS ASSOCIATION

Contact | FAQs | standards.ieee.org only | GO

Find Standards | Develop Standards | Get Involved | News & Events | About Us | Buy Standards | eTools

IEEE PROJECT

P2413 - Standard for an Architectural Framework for the Internet of Things (IoT)

The Internet of Things (IoT) is predicted to become one of the most significant drivers of growth in various technology markets. Most current standardization activities are confined to very specific verticals and represent islands of disjointed and often redundant development. The architectural framework defined in this standard will promote cross-domain

STATUS:
Active Project

RELATED MATERIALS
[Approved PAR](#)

Standards Help
IEEE-SA Standards Development Services are proven to expedite the process by 40%. Click here to [learn more!](#)

Feedback

oneM2M

The screenshot shows the homepage of the oneM2M website. At the top, there's a navigation bar with links for 3D, Dictionary, IEEE, IoT, Patents, Programming, Standards, and Stevens. On the right of the bar are icons for Member Login, Other Bookmarks, and a menu. Below the bar, the oneM2M logo is on the left, followed by the tagline "Standards for M2M and the Internet of Things". To the right of the tagline is a "Member Login" button. A red horizontal bar contains navigation links for HOME, ABOUT, MEMBERSHIP, INSIGHTS, TECHNICAL, and NEWS, along with a search bar. The main content area features a large image of interlocking gears, one red and one silver, symbolizing partnership. To the left of the gears, the text "Global Partnership" is displayed above a red square icon. Below the square, the text reads: "8 of the world's leading ICT standards bodies, 6 global ICT fora, over 200 companies from all industrial sectors".

oneM2M - Home

www.onem2m.org

3D Dictionary IEEE IoT Patents Programming Standards Stevens Other Bookmarks

Member Login

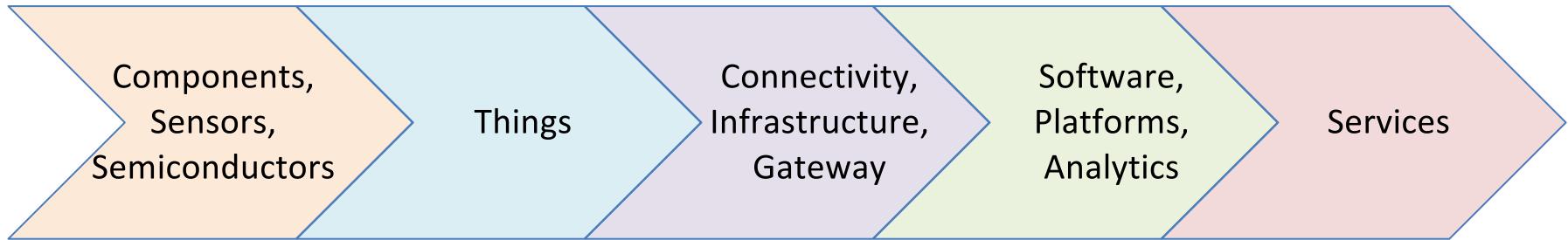
HOME ABOUT MEMBERSHIP INSIGHTS TECHNICAL NEWS Search...

Global Partnership

8 of the world's leading ICT standards bodies, 6 global ICT fora, over 200 companies from all industrial sectors

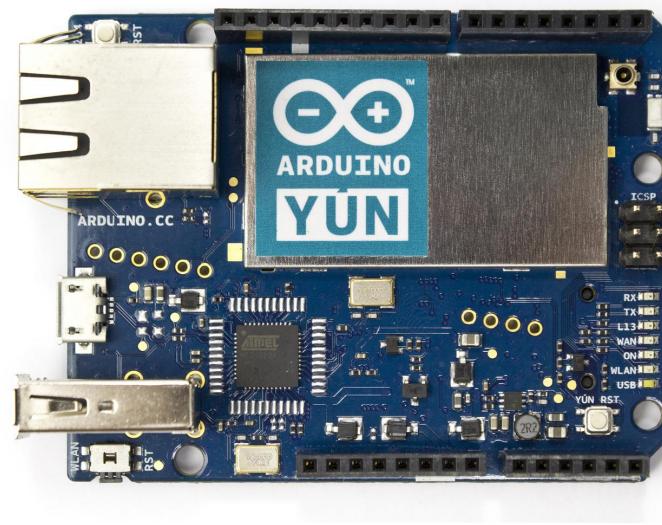


IoT Value Chain

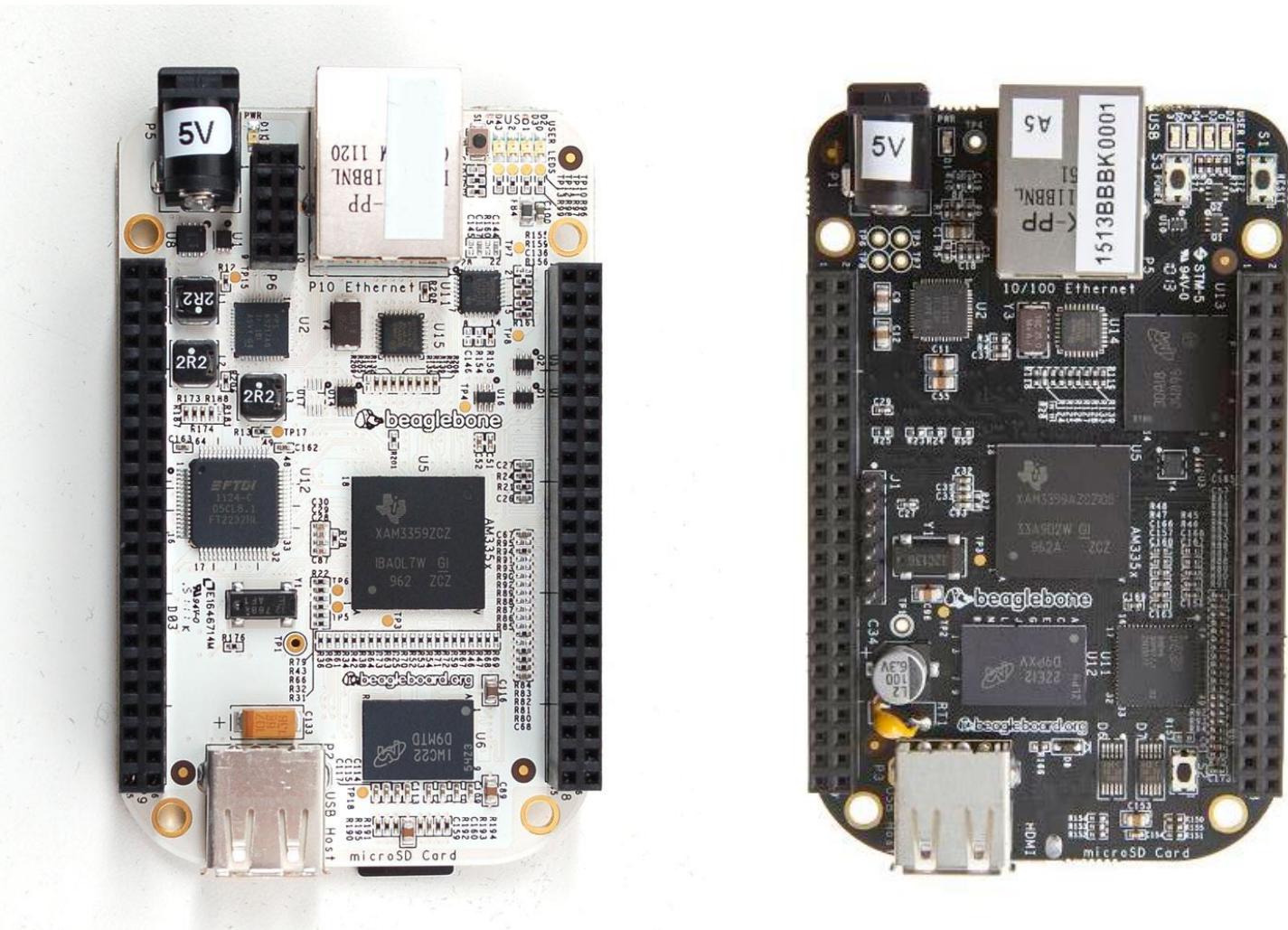


- The IoT can enable transformation of business and industry
- Enterprises can experiment with ***small-scale*** projects to gauge benefits while also monitoring what is happening in other industries, as a source of ideas
- A compelling business case and justifications must be developed, quantified, and articulated before ***large-scale*** deployment can happen

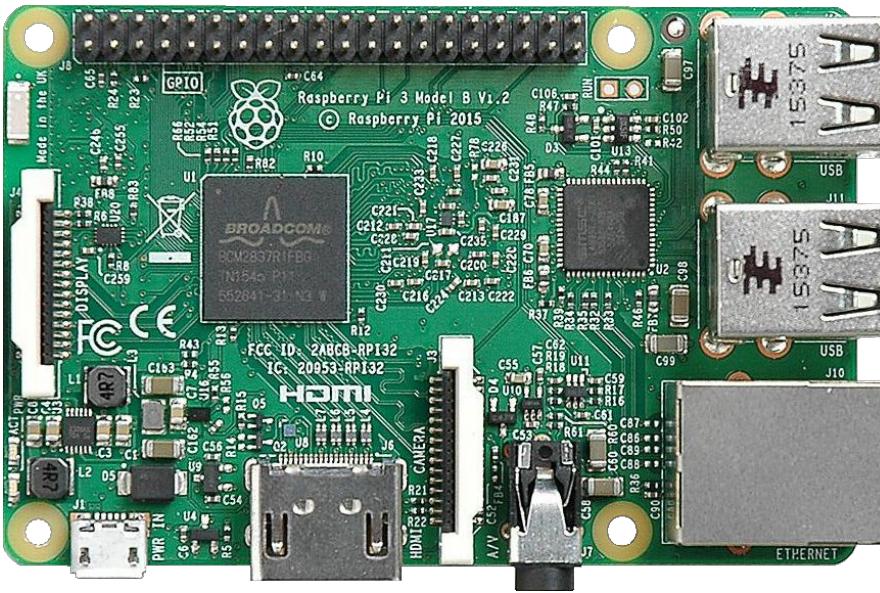
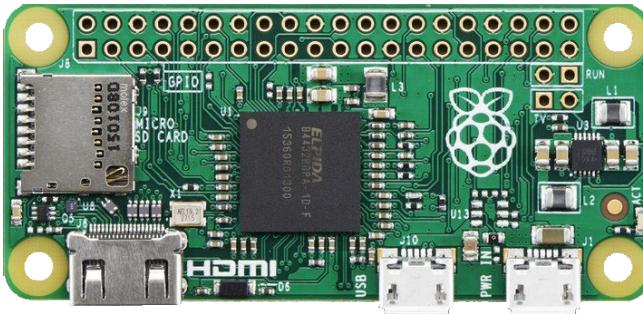
Arduino UNO and YÚN



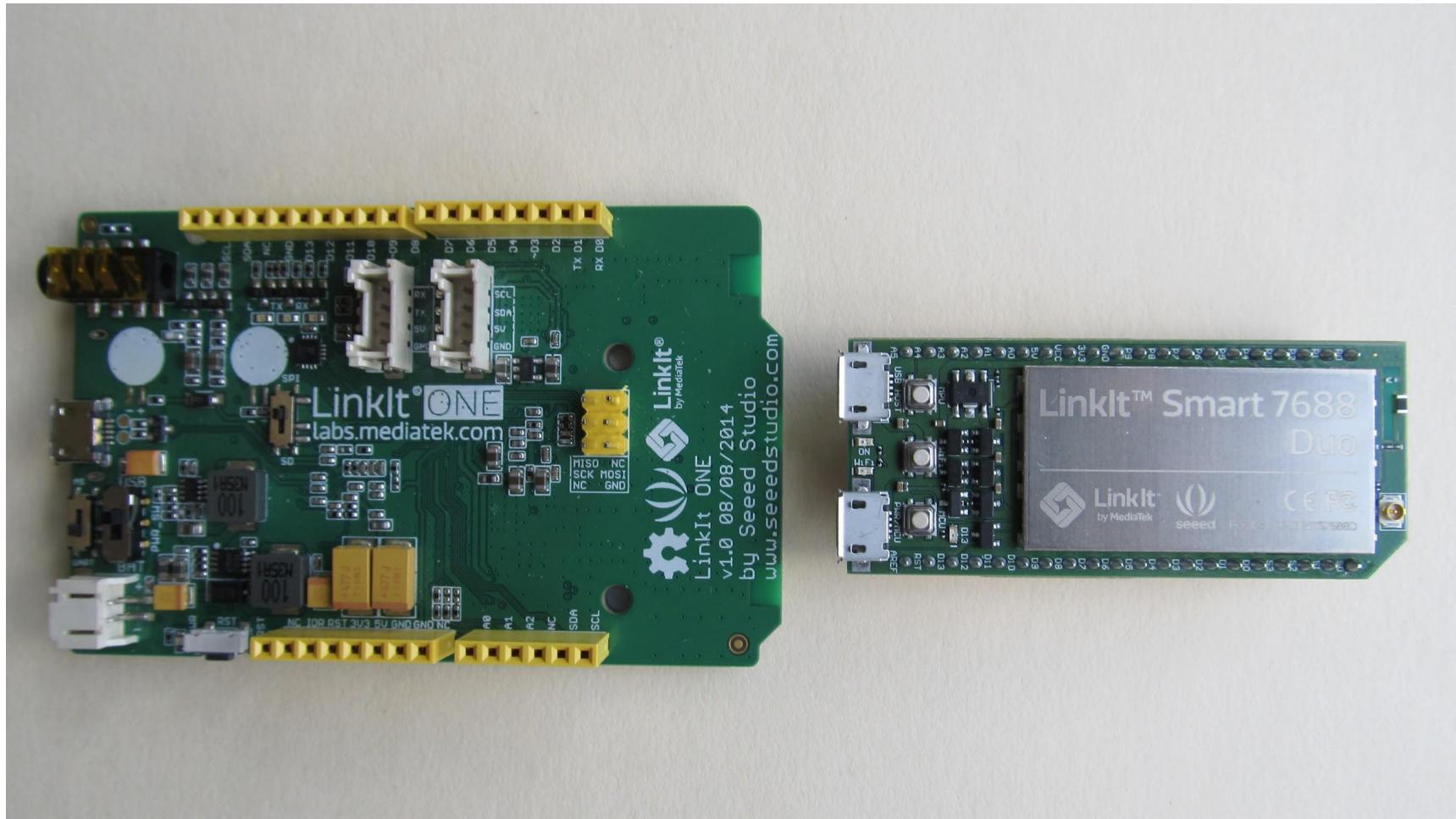
BeagleBone and BeagleBone Black



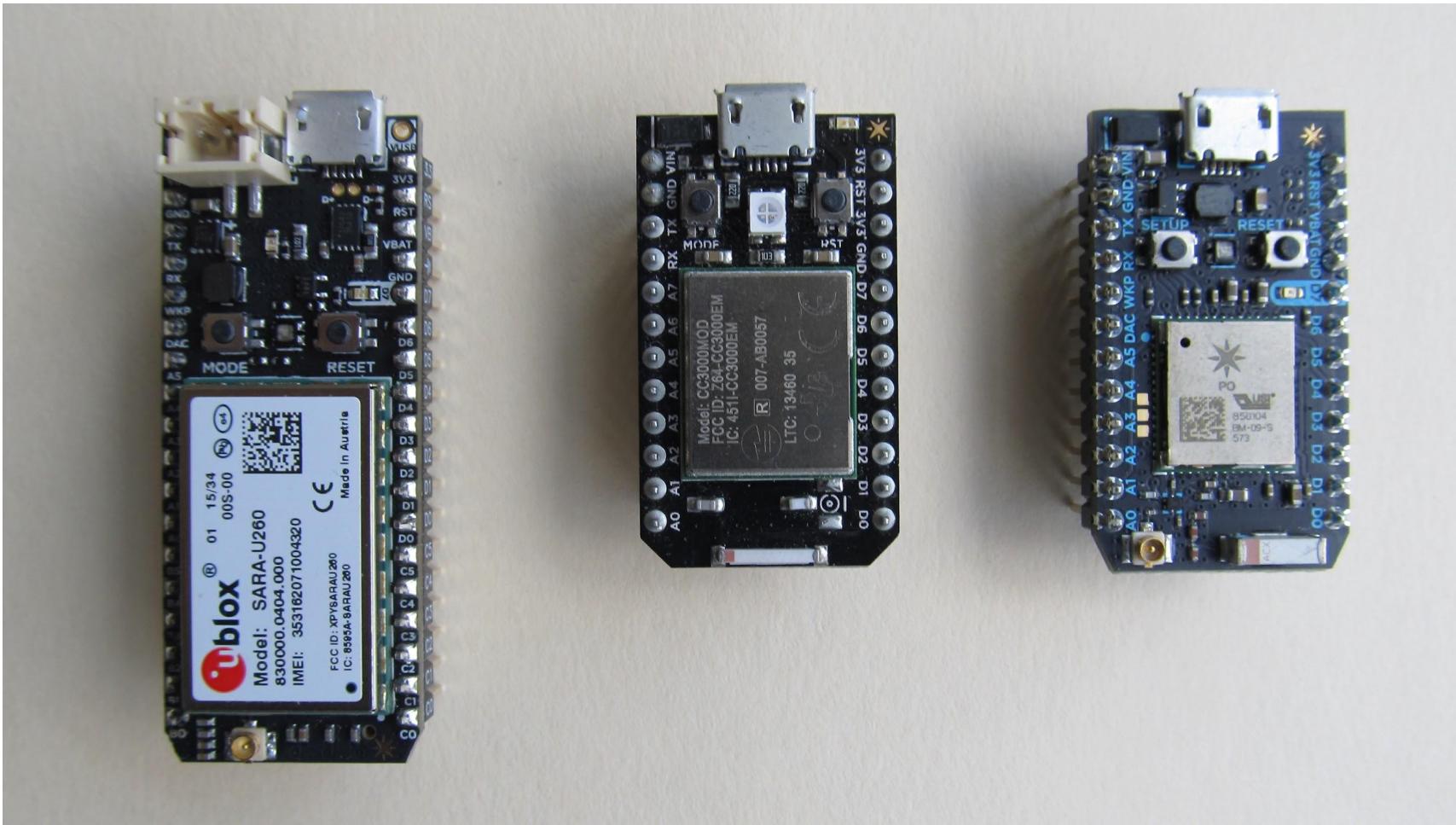
Raspberry Pi Zero and 3B



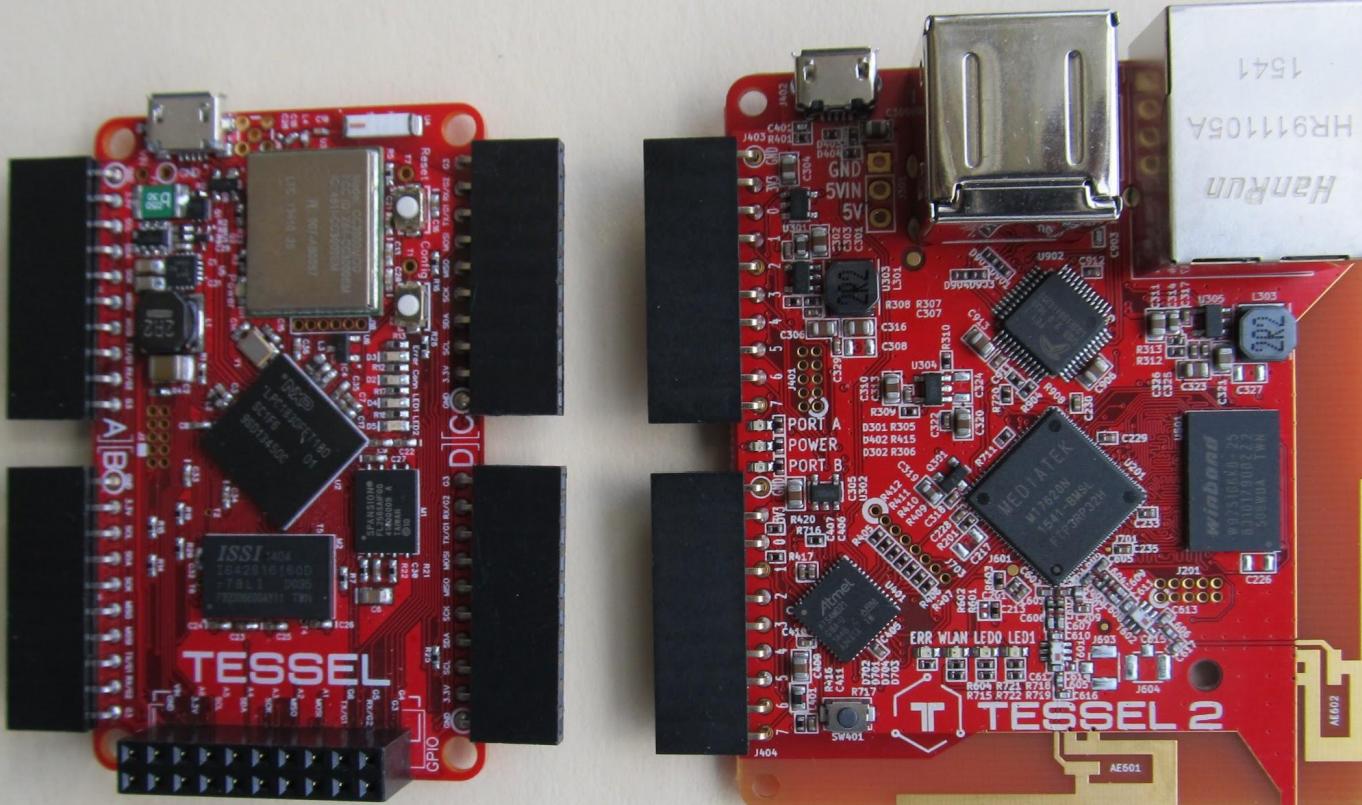
LinkIt ONE and Smart 7688 Duo



Particle Electron, Core, and Photon



Tessel and Tessel 2



Development Board Examples

	Arduino YÚN	BeagleBone Black Rev. C	Raspberry Pi 3B	LinkIt Smart 7688 Duo	Particle Photon	Tessel 2
Analog Input Pins	12	6		12	8	10
Digital I/O Pins	20	65	26	27	18	16
Micro SD Card	Yes	Yes	Yes			
Ethernet/Wi-Fi	Both	Ethernet	Both	Wi-Fi	Wi-Fi	Both
Programmable USB	Micro-B	Mini-B		Micro-B	Micro-B	Micro-B
Linux OS	Linino	Debian	Raspbian	OpenWrt		OpenWrt
HDMI video		Micro-HDMI	HDMI			
Desktop IDE	Arduino	Cloud9	IDLE	Arduino	Atom	
Web IDE	Temboo				Atom	
Node.js	Ideino	Default		Default	Default	Default
Price	\$74.95	\$48.00	\$35.00	\$15.90	\$19.00	\$44.45

Cloud Platform Examples

AWS IoT	https://console.aws.amazon.com/iot/	PrivateEyePi	http://www.privateeyepi.com/
Beebotte	https://beebotte.com/	Pushbullet	https://www.pushbullet.com/
Blynk	http://www.blynk.cc/	relayr	https://www.relayr.io/
Carriots	https://www.carriots.com/	SAMI	https://www.samsungsami.io/
Eclipse IoT	http://iot.eclipse.org/	Temboo	https://temboo.com/
EVRYTHNG	https://evrythng.com/	ThingSpeak	https://thingspeak.com/
Exosite	https://exosite.com/	ThingWorx	http://www.thingworx.com/
Fluxtream	https://fluxtream.org/	Watson IoT	http://www.ibm.com/internet-of-things/
Google Cloud	https://cloud.google.com/solutions/iot/	Weaved	https://www.weaved.com/
GroveStreams	https://grovestreams.com/	WebIOPi	http://webiopi.trouch.com/
Heroku	https://www.heroku.com/	wot.io	http://www.wot.io/
Instapush	https://instapush.im/	Xively	https://xively.com/
Ionic	http://ionic.io/	Yealink	http://www.yealink.net/

Arduino



- Arduino started in 2005 as a project for students at Interaction Design Institute Ivrea in Ivrea, Italy
- The name “Arduino” comes from a bar (now Movida) in Ivrea, where some of the founders of the project used to meet
- The bar was named after Arduino d’Ivrea, king of Italy from 1002 to 1014, popularly romanticized as a dedicated nationalist who sought to free his country from foreign domination

The Pythons in 1969



- Back: Graham Chapman, Eric Idle, Terry Gilliam
- Front: Terry Jones, John Cleese, Michael Palin
- The group's influence on comedy has been compared to The Beatles' influence on music



Raspberry Pi



- A nostalgia for naming computers after fruit
- Kids like blowing a raspberry
- Pi is short for Python
- Let users see the guts of devices that they usually don't see
- Feature Broadcom system on a chip (SOC)
BCM2835 in 2011, BCM2836 in 2014, and
BCM2837 in 2015
- Tech specs for all models: https://en.wikipedia.org/wiki/Raspberry_Pi
- Official history: <https://www.raspberrypi.org/about/>
- Teacher training initiative: <https://www.raspberrypi.org/picademy/>

Django Reinhardt 1910-1953



- Jean “Django” Reinhardt was a Belgian-born French jazz guitarist and composer of Romani ethnicity
- His nickname “Django” with the D silent is Romani for “I awake”
- He created a whole new fingering system built around his left index and middle fingers
- He could not read or write musical notation

Mosquitto Python → Eclipse Paho

The screenshot shows a web browser window with the following details:

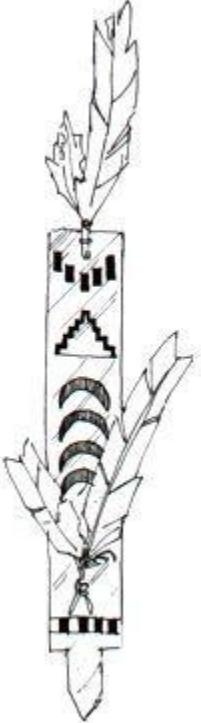
- Title Bar:** Python | Mosquitto
- Address Bar:** http://mosquitto.org/documentation/python/
- Page Content:**
 - Mosquitto Logo:** An icon of a mosquito.
 - Mosquitto Text:** Mosquitto
An Open Source MQTT v3.1/v3.1.1 Broker
 - eclipse Logo:** The Eclipse logo.
 - Section:** Python
 - The Mosquitto Python module has been donated to the [Eclipse Paho](#) project. It can be installed using "pip install paho-mqtt" and there is documentation available at <https://pypi.python.org/pypi/paho-mqtt>

Existing users of the Mosquitto Python module should find it very easy to port their code to the Paho version.

```
import mosquitto
client = mosquitto.Mosquitto()

becomes

import paho.mqtt.client as paho
client = paho.Client()
```
- Navigation Bar:** Home, Downloads, Documentation, Bugs / Support
- Search Bar:** A search input field with a magnifying glass icon.
- Pages Sidebar:**
 - Pages
 - Bugs / Support
 - Documentation
 - Python
 - Downloads
- Links Sidebar:**
 - Links
 - Mosquitto test server
 - MQTT community
 - mqtt2cosm
 - Paho
- Donate Button:** A small orange button labeled "Donate".

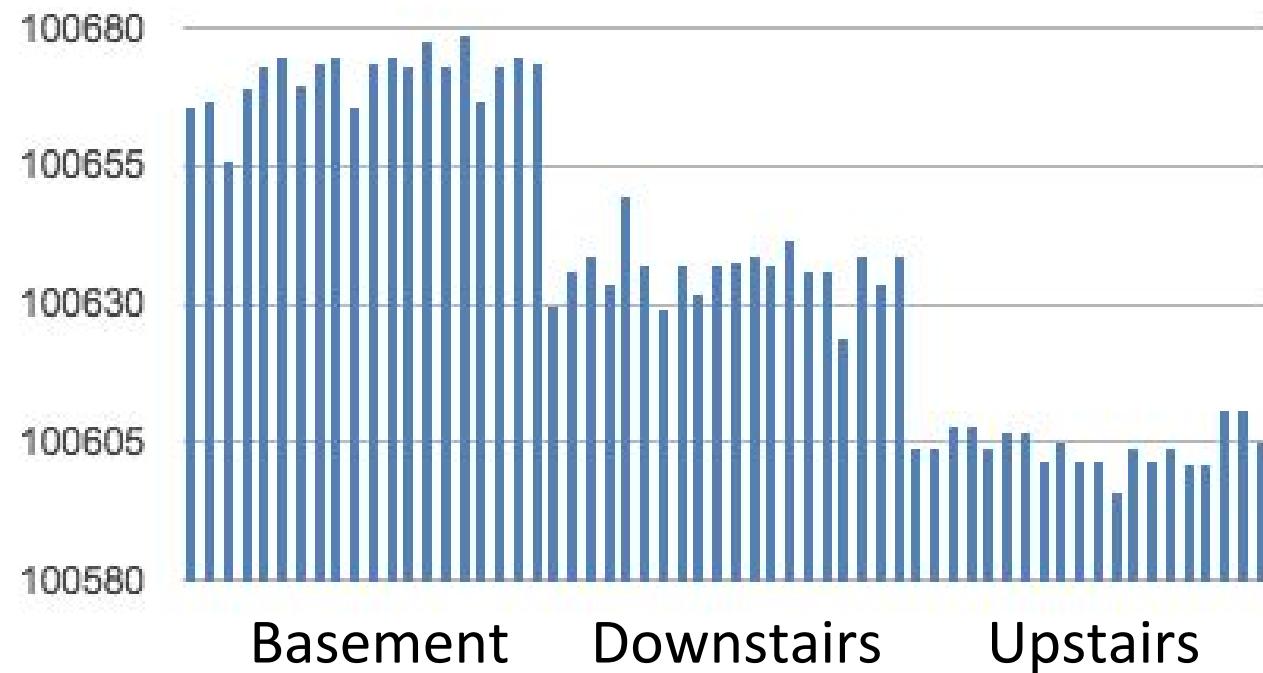


Paho

- A paho is a Hopi Indian plumed prayer stick
- The Hopi people are a group of indigenous Native American people from the Four Corners (the southwestern, northwestern, northeastern, and southeastern corners of Colorado, New Mexico, Arizona, and Utah, respectively)
- According to the 2000 US census, they have a population of approximately 7,000 members in the Hopi Reservation of northeastern Arizona
- They perform nine religious ceremonies inherited from ancient rituals

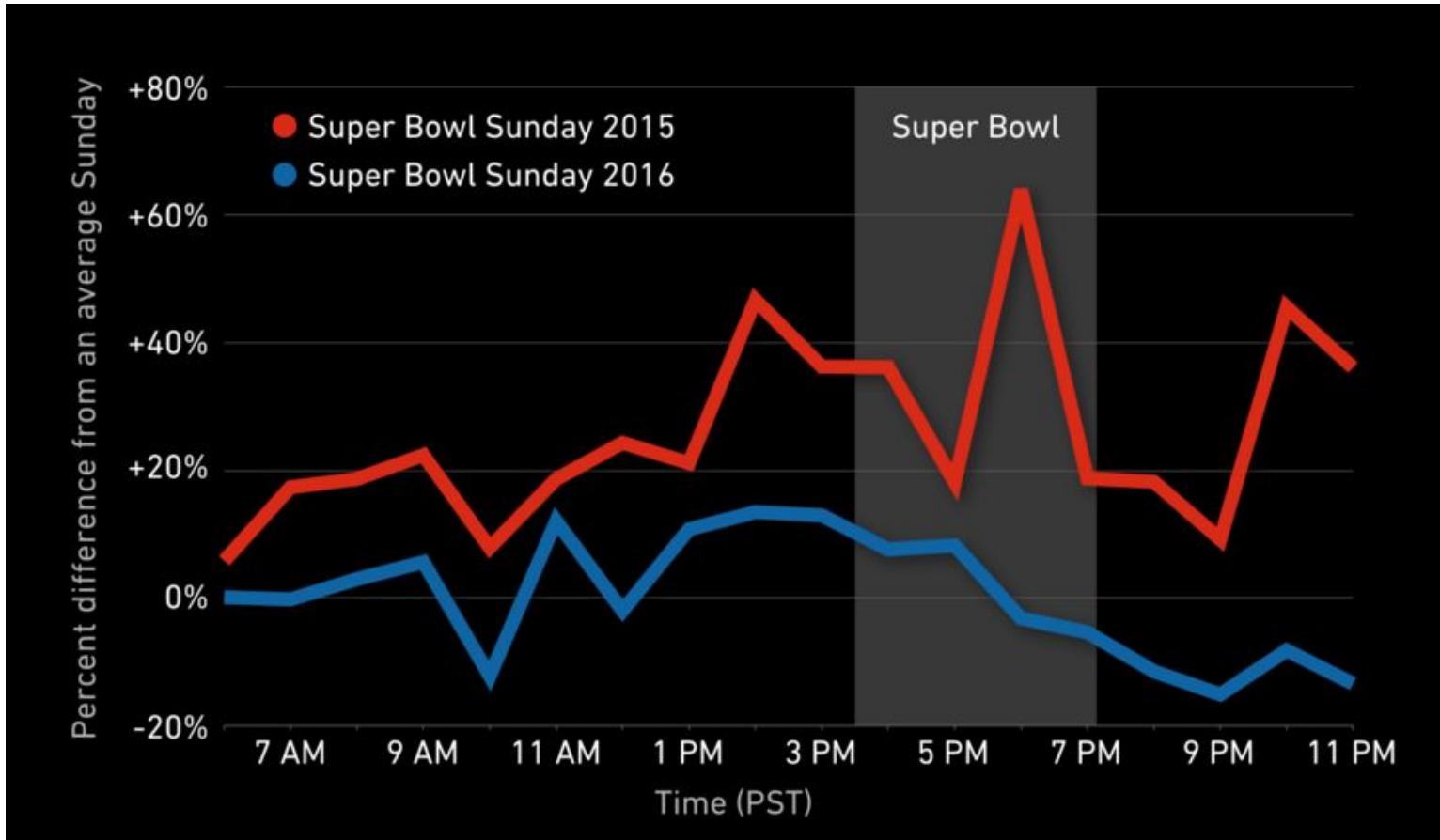
BMP180 Pressure Data

Pascal



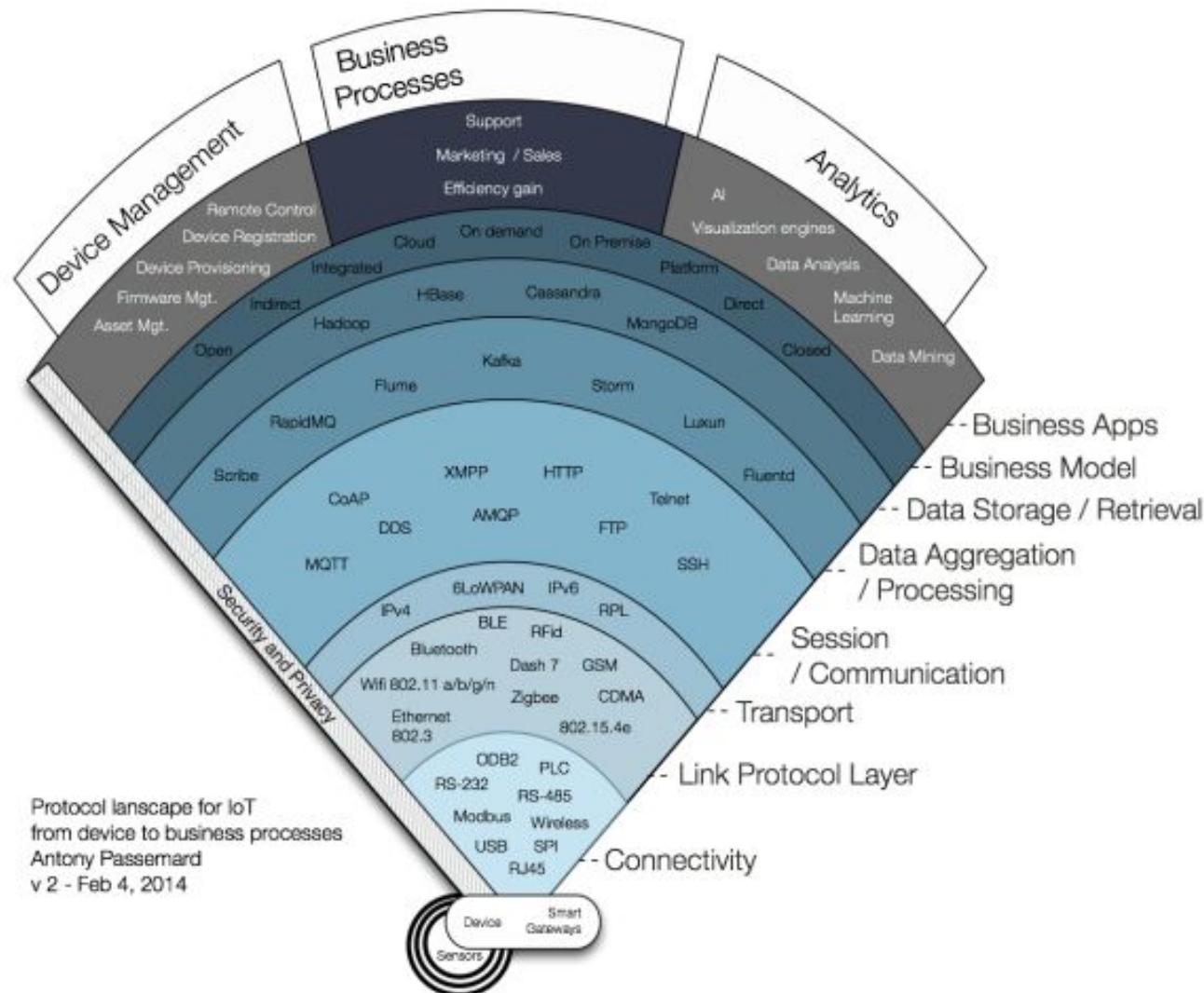
Data Visualization

Hard accelerations and breaks from a subset of Automatic drivers



<http://blog.automatic.com/super-bowl-50/>

From Sensors to Business Value



Summary

- IoT is not always active – it's mostly RESTful
- Not all data sent to the cloud
- IoT is not about adding connectivity to all things
- IoT is about how sensors, devices, things, and services can be integrated to create value
- Value is derived from making sense of data, turning it into knowledge and meaningful action
- Access to data ***shall*** have differential restrictions