# Survey of IoT Platforms

The Web of Things is intended to be an abstraction layer for the IoT so we need to ensure that it is an effective fit to a broad range of commercial IoT platforms

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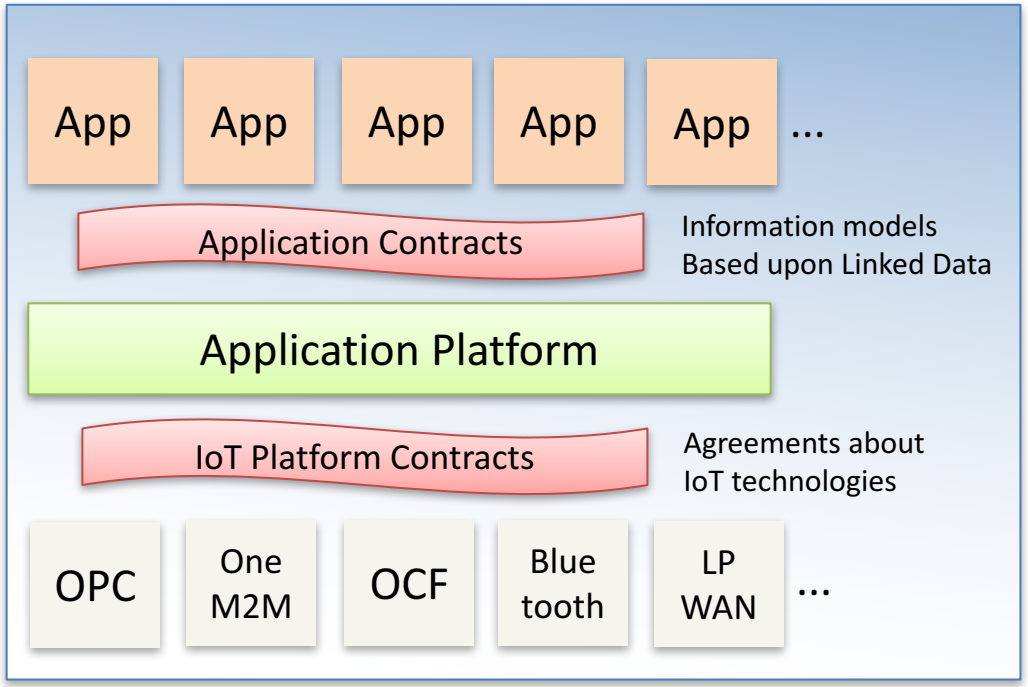
*W3C champion for the Web of Things*

# Web of Things

- By analogy to the Internet as an abstraction layer that enables services over different networks and technologies
- Web of Things seeks to enable application platforms and open markets of services based upon an abstraction layer for the IoT
- Based upon Linked Data as a lingua franca for data and data models



# Linked Data

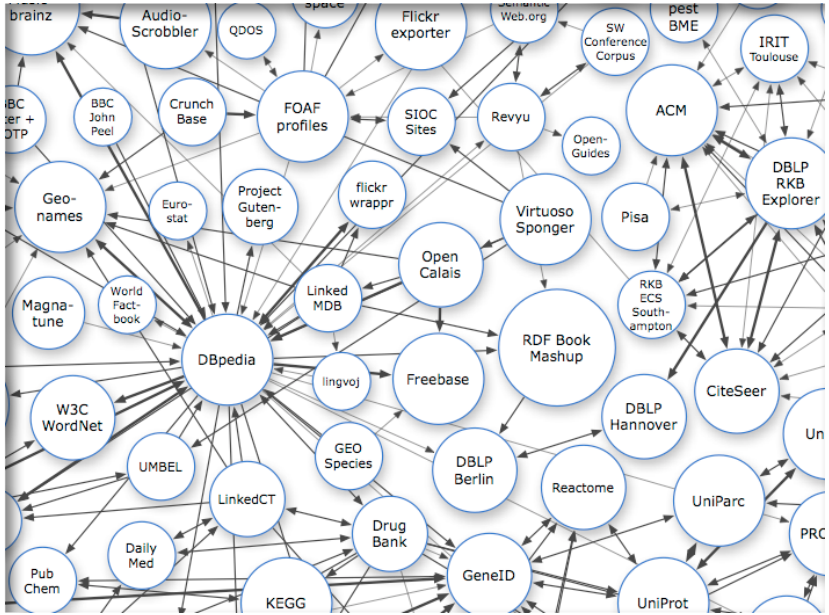
- A *lingua franca* for data and metadata
  - Basis for relating data and metadata in different formats and data models
- Concepts and relationships are given globally unique identifiers using Web addresses
- These addresses can be used to obtain further information enabling a Web of Linked Data
- W3C has a mature suite of standards
  - e.g. OWL ontology language, SPARQL query language (analogous to SQL)

Linked Data makes it easy to combine distributed sources of information

UK Companies House Linked Data Service

# Linked Data* for Integration

- Expose existing information sources via Linked Data front end that hides the different internal data formats
- Provide Linked Data models for each source
- SPARQL endpoints for remote queries
- RDF-S and OWL for ontologies
- Shape rules for validation and transformation of RDF graphs
- Big data with Linked Data streams
- Combine with access control and terms and conditions of use




* See [W3C's Linked Data page]

# Survey of IoT Platforms


- Work funded by the European Commission through the Create-IoT Coordination and Support Action
  - Project ID: 732929, part of IoT-02-2016 - IoT Horizontal activities
- Based upon publicly available information for a broad range of IoT platforms
  - Not restricted to IoT sensors and actuators
  - Web of things encompasses abstract entities
    - e.g. Virtual devices, Web services, etc.
- Status – ongoing
- Will be published as a Create-IoT report

# Coverage

- So far I have studied
  - OCF OIC 1.1 specifications
  - oneM2M
  - BACnet
  - ECHONET
  - Smart Device Template (HGI)
  - Basic REST over HTTP and CoAP
- Looking for information on other platforms
  - OPC-UA
  - Hypermedia controls
  - Web services
- This survey focuses on the information model
- A further survey is planned for security

# Methodology

- Read the IoT platform specifications and look for common patterns
- Examine requirements for the objects exposed to applications
  - Where these objects are decoupled from the underlying IoT platforms, communication patterns, protocols and data formats
- Attempt to reverse engineer Linked Data models for the capabilities defined by each IoT platform
- Express the models in JSON and Linked Data
  - Plain JSON* using a context free grammar
  - Turtle format for Linked Data
- Show case with an HTML based model browser

* Easier to understand than JSON-LD + JSON Schema

# OCF

- OIC 1.1 specifications
  - RESTful interface over CoAP and HTTP
  - Specification uses Restful API Markup Language (RAML)
    - Text based, but not markup in the sense of XML
    - Supplemented with tables for property definition and CRUDN behaviour
- OCF define devices in terms of a composition of resources
  - See Smart Home Device specification and Resource Type specification
- Each resource is defined in RAML
  - Identified by a resource type, e.g.
    - oic.r.sensor.acceleration
  - Can import shared definitions for resource types
  - RAML is not used at run-time
  - RAML is verbose with a high degree of predictability
    - I was able to regenerate the RAML from concise thing descriptions using simple heuristics
- OCF specifications available from
  - https://openconnectivity.org/resources/specifications

# OCF OIC 1.1 release

- 63 Resources
  - Acceleration sensor
  - Activity Count
  - Altimeter
  - Atmospheric Pressure
  - Air Flow
  - Audio Controls
  - Auto Focus
  - Auto Document Feeder
  - Auto White Balance
  - Battery
  - Binary Switch
  - Brightness
  - …
  - Water Sensor
  - Weight

- 15 Devices
  - Air Conditioner
  - Air Purifier
  - Window Blind
  - Camera
  - Dishwasher
  - Door
  - Dryer
  - Fan
  - Garage Door
  - Light
  - Oven
  - Printer
  - Multifunction Printer
  - Receiver
  - Refrigerator

See: http://www.w3.org/WoT/demos/td2ttl/oic.html

# oneM2M

- RESTful interfaces over CoAP, HTTP and MQTT
- Defines devices in terms of a composition of modules
- Modules are formalized in XML
- Home Appliances and Information Models
  - Defines a large set of devices and modules
  - Broadly speaking similar in coverage to OCF
  - But not compatible …
  - Guidelines on interworking with LwM2M, AllJoyn and OIC
- See also the base ontology and the SAREF ontology
- oneM2M specifications available from
  - http://www.onem2m.org/technical/published-documents

# oneM2M

- 40 Modules
  - Alarm Speaker
  - Audio Video Input
  - Audio Volume
  - Battery
  - Binary Switch
  - Bio Electrical Impedance Analysis
  - Boiler
  - Brightness
  - Clock
  - Colour
  - Colour Saturation
  - …
  - Wind
- 13 Devices
  - Air Conditioner
  - Clothes Washer
  - Electric Vehicle Charger
  - Light
  - Micro Generation
  - Oven
  - Refrigerator
  - Robot Cleaner
  - Smart Electric Meter
  - Storage Battery
  - Television
  - Thermostat
  - Hot Water

See: http://www.w3.org/WoT/demos/td2ttl/m2m.html

# BACnet

- Building automation
  - Lighting, Heating, ventilation and air conditioning, elevators, emergency lighting & alarms
- Core specs define information model, metadata and protocols
  - Standardised as ISO 164845 and ISO 16484-6
  - BACnet objects are a collection of attributes called “properties”
  - BACnet objects correspond to Web of Things properties
    - 54 object types in BACnet 2012 specification
  - BACnet properties correspond to Web of Things metadata
    - e.g. object  names and IDs, high and low limits for values
- Vendors can extend this to suit their devices
  - Need to look at vendor documentation for device definitions
- Essentially properties, actions, events and a lot of metadata
  - Information on whether device is in or out of service, and its reliability
  - 16 level priority mechanism for resolving conflicting property updates
- See Michael Newman’s book
  - “BACnet: the global standard for building automation and control networks”
    - The eBook is much cheaper than the ISO standard!

# ECHONET

- Home automation and personal health
  - Devices with properties, events and metadata
  - No actions that I've found so far, but …
  - Includes a vocabulary for describing homes
    - Living room, dining room, kitchen, bathroom, lavatory, wash room, passageway, room, stairway, front door, store room, garden, veranda/balcony
- ECHONET specifications available from
  - https://echonet.jp/spec_en/

# ECHONET Shared Properties (22)

- Operation Status
- Installation Location
- Standard Version
- Fault Status
- Fault Description
- Manufacturer Code
- Business Facility
- Product Code
- Production Number
- Production Date
- Property Map
- Identification Number
- Manufacturer’s Fault Code
- Current Limit Setting
- Power-Saving Operation Setting
- Remote Control Setting
- Cumulative Operating Time
- Current Time
- Current Date
- Measured Instantaneous Power
- Measured Cumulative Power
- Power Limit Setting

# ECHONET Sensors (44)

- Gas Leak
- Crime Prevention
- Emergency Button
- First-Aid
- Earthquake
- Electric Leak
- Human Detection
- Visitor
- Call
- Condensation
- Air Pollution
- Oxygen
- Illuminance
- Sound
- Mailing
- Weight
- Temperature
- Humidity
- Rain
- Water Level
- Bath Water Level
- Bath Heating Status
- Water Leak
- Water  Overflow
- Fire
- Cigarette Smoke
- Carbon Dioxide
- Gas
- VOC
- Differential Pressure Loss
- Air Speed
- Odor
- Flame
- Electric Energy
- Current Value
- Water Flow
- Micro-Motion
- Passage
- Bed Presence
- Open/Dose
- Activity Amount
- Human Body Location
- Snow
- Air Pressure

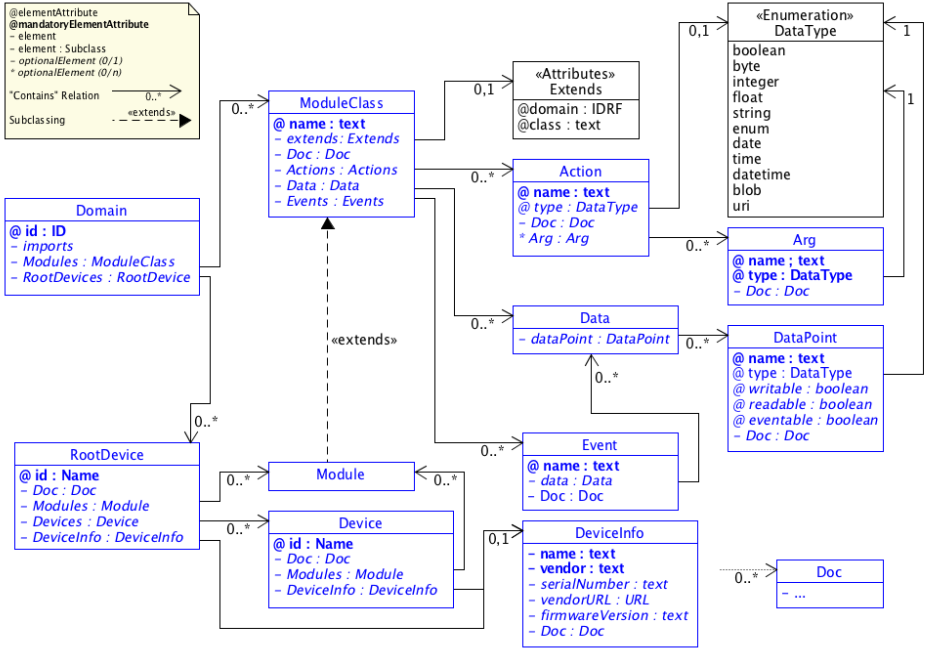
# ECHONET Device Groups

- Air Conditioners (10)
  - Home/commercial, ventilation fan, air conditioner fan, air cleaner, humidifier, electric heater, fan, indoor/outdoor, electric storage heater
- Housing/Facilities related (31)
  - Blind/shade, shutter, rain sliding door, …, buzzer, electric vehicle charger
- Cooking/Household related (10)
  - Electric thermos, refrigerator, microwave, cooker, rice cooker, …, washer/dryer, outdoor unit
- Health related (5)
  - Weighing machine, thermometer, blood pressure, blood sugar, body fat
- Management Operation related (3)
  - Switch, JEM-A/HA controller, DR event controller
- Audio Visual related (4)
  - Display, television, audio, network camera

Frequent use of enumerations with binary codes, e.g. clean rinsing = 0x29

# Smart Device Template

- Defined by the Home Gateway Initiative
  - XML Schema for smart home devices, see
    - https://github.com/Homegateway/RWD050-public
- Devices defined as a set of modules
- Modules define data, actions and events
- Data is HGI's name for property
- Device info metadata



# REST over CoAP and HTTP

- Roy Fielding's representational state transfer design pattern for stateless protocols
- Resources identified by URLs
- Core methods for operations
  - Create, Read, Update, Delete and Notify
  - Internet media types for content
- Plus means to embed metadata in protocol headers
  - Link relations as basis for discovery
- Used as building blocks for IoT platforms like OCF
- Related to formats for describing RESTful APIs, e.g.
  - RAML
  - Open API Specification (previously Swagger)
  - Hydra: Hypermedia-driven Web APIs
  - WADL
  - Slate

# Results

# Emergent Requirements

- Strong support for objects with properties, actions and events
- Object model for things
  - Common data types
    - Boolean, string, integer, number
  - Less common data types
    - Enumerations, unions, vectors, ordered/unordered collections
    - Application types in terms of predefined types
    - Things as first class types
    - Compound (nested) properties
    - Compound arguments for actions and events
  - Metadata, e.g.
    - Min, max for numbers and integers
    - Read-only or read-write
    - Required and optional
      - Properties and action arguments
    - Units of measure including scale factors
    - Whether static or changeable
    - Cardinality for collections
  - Metadata for given IoT platforms
  - Mapping of enumerated values, property names etc. to IDs
    - Resilience to changes in models
      - Google protocol buffers

Web of Things should avoid protocol specific data representations, e.g. bit fields

# Syntactic Modularity

- Specifications like to define things in a modular way
  - Reusable definitions, e.g. enumerations
  - A set of interfaces (e.g. oneM2M's modules)
    - Some set of properties, actions, events, metadata and named type definitions
  - A means to combine this when defining devices
    - e.g. refrigerator with freezer and cooler compartments using common interface models for sensors and controls
  - Syntactic modularity analogous to C++ #include
    - At the level of a thing or a thing's properties

# Semantic Modularity

- Not used by any of the IoT platforms covered so far in the survey
  - Useful for semantic search and semantic interoperability
- For each device state what semantic classes it conforms to
- Each semantic class defines requirements in terms of
  - other semantic classes
  - properties, actions, events, metadata
- Can be validated to check for semantic interoperability
  - Ensuring that services share the same meaning, interfaces and data types
- Can also be used abductively to generate a thing description from a set of semantic classes and additional constraints
  - Involves making guesses based upon past experience

# Open Questions

- Is it worth extending the survey to cover the communication patterns supported by different IoT platforms and the use cases that motivate these patterns?
  - This would help with respect to guidance on how to bind the Web of thing to particular IoT platforms
- The need to examine what kinds of IoT platform metadata is needed as part of the application contract?
  - This should be sufficient to meet the means for the application platform to make the connection
  - It can also provide a basis for negotiating quality of service
  - But risk of tightly coupling apps to particular IoT platforms

# Next Steps

- I plan to flesh out this survey as a CreateIoT report whilst also extending it to a broader range of IoT platforms
  - My highest priority is OPC-UA
  - Other targets include Apple HomeKit, Android Things, OMA's LwM2M, OMG's DDS, Hypermedia Controls and a wide range of Web services
  - Any suggestions for platforms to look at?
- To be complemented with a companion survey on end to end security across different platforms and through the lifecycle

# Thank you

Questions?