How to make the interoperability of IoT data

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IoT standards are no doubt the key enablers for IoT industries. But the growth looks a bit “wild” and still extending.
Technologies in IoT Stack

<table>
<thead>
<tr>
<th>Applications</th>
<th>Custom IoT Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Layer</td>
<td>dotdot</td>
</tr>
<tr>
<td>aka</td>
<td>OPENCONNECTIVITY</td>
</tr>
<tr>
<td>Service Platform</td>
<td>ALLSEEN</td>
</tr>
<tr>
<td>Middleware</td>
<td>Alliance</td>
</tr>
<tr>
<td>Enablement Platform</td>
<td>brokerage</td>
</tr>
<tr>
<td>Service Layer</td>
<td>CoAP</td>
</tr>
<tr>
<td>Service Platform</td>
<td>RTPS</td>
</tr>
<tr>
<td>Middleware</td>
<td>HTTP</td>
</tr>
<tr>
<td>Enablement Platform</td>
<td>WebSocket</td>
</tr>
</tbody>
</table>

**Protocols**

- **CoAP**: REST over UDP
- **RTPS**: Real-time protocol over UDP
- **HTTP**: Hypertext Transfer Protocol
- **WebSocket**: Web socket protocol
- **DTLS / UDP**: Datagram Transport Layer Security over UDP
- **TLS / TCP**: Transport Layer Security over TCP
- **IEEE 802.1TSN**: Time-Sensitive Networking Protocol
- **IEEE 802.11**: Wireless Fidelity
- **IEEE 802.3**: Ethernet
- **IEEE 802.15.4**: Low-Rate Wireless Personal Area Network
- **3GPP**: Third Generation Partnership Project
- **Wi-Fi**: High-Speed Wireless Networking
- **LoRa**: Low-Rate Wide Area Network
- **IEEE 802.1TSN Wired**: Industrial Non-IP

**Source:** 3rd oneM2M Industry Day, How oneM2M fits into the landscape of IoT technologies, 2017

**Nanjing, China**

27-29 November 2017
ETSI White Paper: Achieving Technical Interoperability

Technical Interoperability is usually associated with hardware/software components, systems and platforms that enable machine-to-machine communication to take place. This kind of interoperability is often centred on (communication) protocols and the infrastructure needed for those protocols to operate.

Semantic Interoperability is usually associated with the meaning of content and concerns the human rather than machine interpretation of the content.

Syntactical Interoperability is usually associated with data formats. Certainly, the messages transferred by communication protocols need to have a well-defined syntax and encoding, even if it is only in the form of bit-tables. However, many protocols carry data or content, and this can be represented using high-level transfer syntaxes such as HTML, XML or ASN.1.

Organizational Interoperability is the ability of organizations to effectively communicate and transfer (meaningful) data (information) even though they may be using a variety of different information systems over widely different infrastructures, possibly across different geographic regions and cultures. Organizational interoperability depends on successful technical, syntactical and semantic interoperability.

Figure 1: Different levels of interoperability
oneM2M Technical View on Interworking

- Multi-access
- Multi-service/Cross-domain
- Reuse Network Capabilities

Platform (IN)
- IN-CSE
- Protocol/Bindings
- Integration

Underlying Networks
- Cellular
- fixed, ...

Gateway (MN)
- MN-CSE
- IPE
- SDT3.0 based HAIM

Area Network Interworking
- non-oneM2M
- oneM2M device

Field Domain (Edge)

Infrastructure Domain (Cloud)

- Cellular
- fixed, ...

Nanjing, China
27-29 November 2017
oneM2M flexible framework of interworking from transparent, translucent to semantic

To make different technologies working smoothly together and build a converged ecosystem

• **Transparent Interworking**: encapsulate the data model of one technology into another (as a pipe)
• **Translucent Interworking**: data model structures are mapped, while semantics/data types are not
• **Semantic Interworking**: mapping not only protocols, but also full data models and semantics

**Figure 1: Different levels of interoperability**

OCF IoT Scope

Vertical Profiles
- Smart Home
- Industrial
- Healthcare
- ...

Baseline Functionality
- Group management
- ID & Addressing
- Protocol Bridge/GW
- Security
- CRUDN
- Device management
- Discovery
- Messaging
- Streaming

Connectivity
- Wi-Fi
- BT/BLE
- Thread
- ...

Controller
- Remote Access
- Cloud Interface
- Controller App
- Cloud Servers
- service #1 domain
- service #2 domain
- Cloud Servers
- Controller
- Controller
- Things
- Local Control
- Remote Control
- Server to Server
OCF consider for Interoperability

- **Full interoperability** from the connectivity layer up to the service layer is the only way to truly guarantee a satisfactory UX.
- Interoperability at the Connectivity and/or Platform layer only provides partial interoperability which can ultimately lead to fragmentation.

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1. **Connectivity Level Interoperability**
   - Vertical Services
   - Platform
   - Connectivity

2. **Platform Level Interoperability**
   - Vertical Services
   - Platform
   - Connectivity

3. **Service Level Interoperability**
   - Vertical Services
   - Platform
   - Connectivity
OCF Core Framework Spec

① **Discovery**: Common method for device discovery (IETF CoRE)

② **Messaging**: Constrained device support as default (IETF CoAP) as well as protocol translation via bridges

③ **Common Resource Model**: Real world entities defined as data models (resources)

④ **CRUDN**: Simple Request/Response mechanism with Create, Retrieve, Update, Delete and Notify commands

⑤ **ID & Addressing**: OCF IDs and addressing for OCF entities (Devices, Clients, Servers, Resources)

⑥ **Protocol Bridge/GW**: Handled by the Bridging Spec with some implications on the Core

Security is fundamental to the OCF ecosystem and applies to all elements.
OCF Bridge Specification

- Specifies a framework for bi-directional translation between devices in OCF and non-OCF ecosystems.
- Specifies general requirements for translation between OCF and non-OCF ecosystems
  - Requirements for resource discovery, message translation, security, and handling of multiple bridges.
- Specifies specific requirements for translation between OCF and AllJoyn ecosystems
  - Requirements for mapping core resources, propagating errors, and algorithmically translating custom resource types.
  - Refers to OCF to AllJoyn Mapping specification for translating well-known resource types.
OCF to AllJoyn Mapping

- Models the interworking between OCF and AllJoyn
- Makes use of derived model syntax
- Defines the mapping in terms of:
  - Device Type equivalency
  - Resource <-> Interface equivalency
  - Detailed Property by Property mapping on a per Interface Basis (Derived Models)

<table>
<thead>
<tr>
<th>Classification</th>
<th>ASA Device Type</th>
<th>OCF Device Type</th>
<th>OCF Device Type ID</th>
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</thead>
<tbody>
<tr>
<td>Air Care</td>
<td>Air Conditioner</td>
<td>Air Conditioner</td>
<td>oic.d.airconditioner</td>
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<tr>
<td></td>
<td>AirPurifier</td>
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<td>AirQualityMonitor</td>
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<td>Dehumidifier</td>
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<td>Humidifier</td>
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<td></td>
<td>ElectricFan</td>
<td>Fan</td>
<td>oic.d.fan</td>
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<td></td>
<td>Thermostat</td>
<td>Thermostat</td>
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<td>Fabric Care</td>
<td>Clothes Washer</td>
<td>Washer</td>
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<td></td>
<td>Clothes Dryer</td>
<td>Dryer</td>
<td>oic.d.dryer</td>
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<tr>
<td></td>
<td>Cloths Washer-Dryer</td>
<td>Washer-Dryer</td>
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<td></td>
<td>Ice Maker</td>
<td>Ice Maker (Resource)</td>
<td>oic.r.iceremaker</td>
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<td>Freezer</td>
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<td>Food Preservation</td>
<td>Oven</td>
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<td>oic.d.oven</td>
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<td></td>
<td>Cooktop</td>
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<td></td>
<td>Cookerhood</td>
<td>Cooker Hood</td>
<td>oic.d.cookerhood</td>
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<tr>
<td></td>
<td>Foodprobe</td>
<td>Food Probe</td>
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<td>Dishwasher</td>
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<td>Floor Care</td>
<td>Robot Cleaner</td>
<td>Robot Cleaner</td>
<td>oic.d.robotcleaner</td>
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<td>Entertainment</td>
<td>TV</td>
<td>Television</td>
<td>oic.d.tv</td>
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<tr>
<td></td>
<td>Set Top box (STB)</td>
<td>Set Top Box</td>
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</table>

<table>
<thead>
<tr>
<th>AllJoyn Interface</th>
<th>OCF Resource Type Name</th>
<th>OCF Resource Type ID</th>
<th>OCF Interface(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment.CurrentAirQuality</td>
<td>Air Quality Collection</td>
<td>oic.r.airqualitycollection</td>
<td>oic.if.s</td>
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<tr>
<td>Environment.CurrentAirQualityLevel</td>
<td>Air Quality Collection</td>
<td>oic.r.airqualitycollection</td>
<td>oic.if.s</td>
</tr>
<tr>
<td>Environment.CurrentHumidity</td>
<td>Humidity</td>
<td>oic.r.humidity</td>
<td>oic.if.s</td>
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<tr>
<td>Environment.CurrentTemperature</td>
<td>Temperature</td>
<td>oic.r.temperature</td>
<td>oic.if.s</td>
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<tr>
<td>Environment.TargetHumidity</td>
<td>Humidity</td>
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<td>oic.if.a</td>
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<td></td>
<td></td>
<td>oic.r.selectablelevels</td>
<td></td>
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<tr>
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<td>Temperature</td>
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<td>oic.if.a</td>
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<td>Operation.AudioVolume</td>
<td>Audio Controls</td>
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<td>oic.if.a</td>
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<td>Operation.Channel</td>
<td>Not mapped</td>
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<td></td>
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<td>Operation.ClimateControlMode</td>
<td>Mode</td>
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<td>oic.if.a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation.ClosedStatus</td>
<td>Door</td>
<td>oic.r.door</td>
<td>oic.if.s</td>
</tr>
<tr>
<td>Operation.CycleControl</td>
<td>Operational State</td>
<td>oic.r.operationalstate</td>
<td>oic.if.s</td>
</tr>
<tr>
<td>Operation.FanSpeedLevel</td>
<td>Air Flow</td>
<td>oic.r.airflow</td>
<td>oic.if.a</td>
</tr>
<tr>
<td>Operation.HeatingZone</td>
<td>Heating Zone Collection</td>
<td>oic.r.heatingzonecollection</td>
<td>oic.if.s</td>
</tr>
<tr>
<td>Operation.HvacFanMode</td>
<td>Mode</td>
<td>oic.r.mode</td>
<td>oic.if.a</td>
</tr>
<tr>
<td>Operation.OnOffStatus</td>
<td>Binary Switch</td>
<td>oic.r.switch.binary</td>
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</tr>
<tr>
<td>Operation.OvenCyclePhase</td>
<td>Operational State</td>
<td>oic.r.operationalstate</td>
<td>oic.if.s</td>
</tr>
</tbody>
</table>
IIC Industrial Internet Reference Architecture (IIRA)

IIRA Implementation Viewpoint

IIRA Functional Viewpoint

IIoT Connectivity Function: Ability to exchange information among endpoints in a system of interest, include: sensor updates, commands, alarms, events, status changes, configuration updates.
Interoperability is about sharing Data governed by Quality of Service (QoS)

Compatible meaning of **data models** in the context of the vertical application domain.

Compatible means of sharing **datatypes**. Be able to evolve those datatypes.

Compatible means of **signaling and protocols**

Interoperability requires a Suitable Connectivity Infrastructure for Meaningful Communications between...
IIoT Horizontal Interoperability

Relevant Connectivity Standards

IIoT Connectivity Stack
## Connectivity Core Standards Criteria Applied

<table>
<thead>
<tr>
<th>Core Standard Criterion</th>
<th>DDS</th>
<th>Web Services</th>
<th>OPC-UA</th>
<th>oneM2M</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Provide <strong>syntactic interoperability</strong></td>
<td>√</td>
<td>Need XML or JSON</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td><strong>2</strong> Open standard with strong <strong>independent, international governance</strong></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td><strong>3</strong> Horizontal and neutral in its applicability across industries</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td><strong>4</strong> Stable and deployed across multiple vertical industries</td>
<td>Software Integration &amp; Autonomy</td>
<td>√</td>
<td>Manufacturing</td>
<td>Home Automation</td>
</tr>
<tr>
<td><strong>5</strong> Have standards-defined <strong>Core Gateways to all other core connectivity standards</strong></td>
<td>Web Services, OPC-UA*, oneM2M*</td>
<td>DDS, OPC-UA, oneM2M</td>
<td>Web Services, DDS*, oneM2M*</td>
<td>Web Services, OPC-UA*, DDS*</td>
</tr>
<tr>
<td><strong>6</strong> Meet the connectivity framework <strong>functional requirements</strong></td>
<td>√</td>
<td>X</td>
<td>Pub-Sub in development</td>
<td>√</td>
</tr>
<tr>
<td><strong>7</strong> Meet <strong>non-functional requirements of performance, scalability, reliability, resilience</strong></td>
<td>√</td>
<td>X</td>
<td>Real-time in development</td>
<td>Reports not yet documented or public</td>
</tr>
<tr>
<td><strong>8</strong> Meet <strong>security and safety requirements</strong></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td><strong>9</strong> Not require any single component from any single vendor</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td><strong>10</strong> Have readily-available SDKs both <strong>commercial and open source</strong></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

**GREEN = Gating Criteria**  

* = work in progress  
√ = supported, X = not supported
OpenFog Smart Object prefer to reuse existing standards

The Fog/Cloud can be (dynamically) configured to process/analyze, route, cache and archive data in multiple tiers of the Fog. Data, devices, and code are all smart objects in a registry which can be mapped onto physical locations.
OpenFog Interoperability, Interconnectivity, Interchangeability

OpenFog Interoperability Focus
- Application/Service Compatibility
- API Based
- Built from Service Bus / SW Backplane

OpenFog Interconnectivity Focus
- Information Interchange Capability
- Protocol Based
- Built from Network Layer (IP)
- Communications consider IIC Connectivity Framework

OpenFog Interchangeability Focus
- Device Function Compatibility
- Spec Based
- Built from Physical / Logical Device

Figure 1: Different levels of interoperability

Figure 2-2: The focus of this document is on connectivity layers above the network layer, namely the connectivity transport and the connectivity framework layers.
OpenFog Architecture to build a multi-vendor interoperable fog computing ecosystem

SWI-001: APIs for Application Microservices

SWI-002: Northbound APIs provided by the NM & SB layer
ETSI ISG CIM: establish an info-exchange layer on top of IoT platforms like oneM2M, especially targeting Smart City applications.

**Goal = interoperable exchange of data & metadata between systems**
ETSI ISG CIM overview IoT-related SDOs & Fora

De Jure SDOs

- ITU-T
- ITU-R
- JTC1

De Facto SDOs

- IEEE
- OSGi
- W3C
- OMA
- ECC
- LoRa
- AllSeen

National SDOs:

- CEN
- CENELEC
- ETSI
- SG-20
- CEN

Open-Source

- OMA
- OMA
- OMA
- OMA
- OMA
ETSI ISG CIM Features

- Flexible exchange of information between domains
  - Graph-based
  - Core concepts include Entities and Relationships
  - Entities can have Properties and Relationships
  - Relationships/Properties can also have Properties and Relationships
- Aim to be developer-friendly
  - Using familiar technologies (e.g. HTTP, JSON-LD)
  - Simple query interface
    - Based on entity type or identifier
    - Scoping of query (e.g. by time/geography)
    - Filtering of results
- API is agnostic to the deployed architecture
  - Applications need only know the URL where the API is exposed
  - Actual choice of architecture depends on (changeable) trade-offs
    - Centralised Architecture is simplest
    - Distributed architecture may be chosen to improve scalability
    - Federated architecture enables different organizational units to transparently integrate their information sources
- NOT yet another IoT/M2M standard
- NOT for low-layer protocol or network-centric connectivity
- NOT just a semantic annotation vocabulary
- NOT specific to one particular environment
- NOT restricted to one type of information source
- NOT dedicated to one particular type of application

- ETSI ISC CIM entities are represented by URIs
- Entities are "first class citizens" in the Information Model and API
- All entities must reference some ontology (to define their type)
Various Architectures possible using ETSI ISG CIM

Centralised

Federated

Distributed
ETSI ISG CIM maps to oneM2M Base Ontology
ETSI ISG CIM Data Model instantiation example:
- what information do CIM need to express?

Vehicle

- urn:c3im:Vehicle:A4567
- length: "4.333"

LegalEntity

- urn:c3im:Org:TownHall
- providedBy

OffStreetParking

- urn:c3im:OffStreetParking:Downtown1
- availableSlotNum: 121
- accuracy: 5%

Sensor

- urn:c3im:Sensor:Cam1
- providedBy
## Conclusion

<table>
<thead>
<tr>
<th>IoT SDO</th>
<th>IoT focus area</th>
<th>Technical Interoperability</th>
<th>Syntactic Interoperability</th>
<th>Semantic Interoperability</th>
<th>Pragmatic Interoperability</th>
<th>Dynamic Interoperability</th>
<th>Conceptual Interoperability</th>
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</thead>
<tbody>
<tr>
<td>oneM2M Telecom platform</td>
<td>√</td>
<td>√</td>
<td>V (OIC, Alljoyn, LWM2M, DDS, OPC-UA, OSGI, Modbus, etc)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>OCF</td>
<td>Smart home</td>
<td>√</td>
<td>√</td>
<td>V(Alljoyn)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IIC</td>
<td>Industry, Manufacturing</td>
<td>√</td>
<td>√(Web service)</td>
<td>V(oneM2M, DDS, OPC-UA)</td>
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<td>openfog</td>
<td>Fog/edge computing</td>
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<td>√ starting</td>
<td>√ starting</td>
<td></td>
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<td>ideal</td>
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<tr>
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<td>√</td>
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<td>Better solution?</td>
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