Towards Scalable, Reliable, and Resilient IoT Systems for Smart Cities

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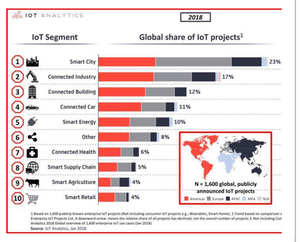
Introduction

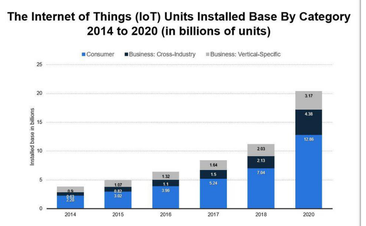
IoT systems have progressed from toy to commercial scale, encompassing hundreds of heterogeneous networked devices in buildings, industrial settings, and cities. Their complex, hybrid, cross-domain, and evolving nature poses a significant challenge for IoT applications that tend to outlive hardware. Subtle system changes can lead to catastrophic failures [2].

Fundamental Challenges

- Identification of IoT devices in software
  - Stable, human-friendly, contextual names
  - Combine device type & location
- Format & storage of IoT device metadata
  - Distributed & federated directory
- Resource discovery in evolving IoT systems
  - By aggregated queries
  - In long-lived software
- Rapid prototyping & testing
  - Without physical IoT devices
  - Without access to IoT systems



Source: bfconsulting.com



Approach

- Design location+type naming architecture & name resolver
- Manage metadata of devices as standard description profiles
- Store profiles into federated and distributed IoT directories
- Resolve names to objects by diverse queries
- Apply fine-grained access control combining roles and attributes

Metadata Directory

- An intermediate between IoT devices and Internet
- Gather metadata from local network IoT devices
- Preferably on edge computational nodes

```
"@context": "https://www.w3.org/2019/wot/td/v1",
"id": "urn:dev:ops:32473-WoTLamp-1234",
"title": "MyLampThing",
"securityDefinitions": {
    "basic_sc": {"scheme": "basic", "in":"header"}},
"security": ["basic_sc"],
"properties": {
    "status" : {
        "type": "string",
        "forms": [{"href": "https://mylamp.com/status"}]}},
"actions": {
    "toggle" : {
        "forms": [{"href": "https://mylamp.com/toggle"}]}},
"events":{
    "overheating":{
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```
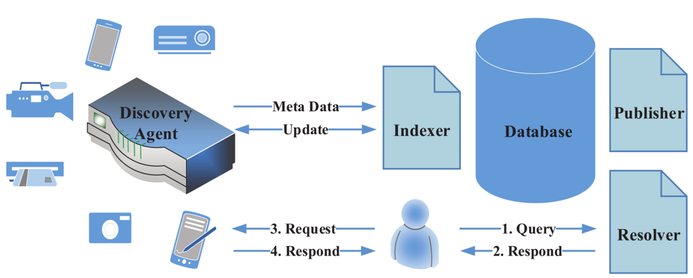

Source: W3C Thing Description



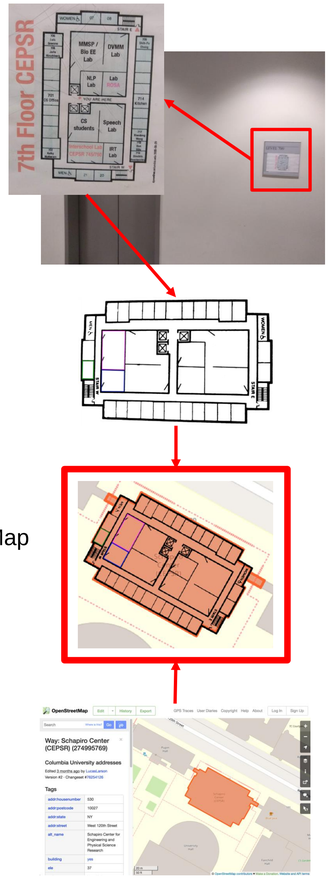
Functional modules of a local metadata directory

Geospatial Naming Database

- People often refer to physical objects by the object's location
  - "Light switch in the **living room**"
  - "**Kitchen** thermometer"
- Resolve human-readable name to machine-readable name
  - Owner, type, location, time
  - "Current status of my light switch in the living room"
- Intuitive IoT device names will likely have a geospatial component
- Needed: database of named geospatial objects

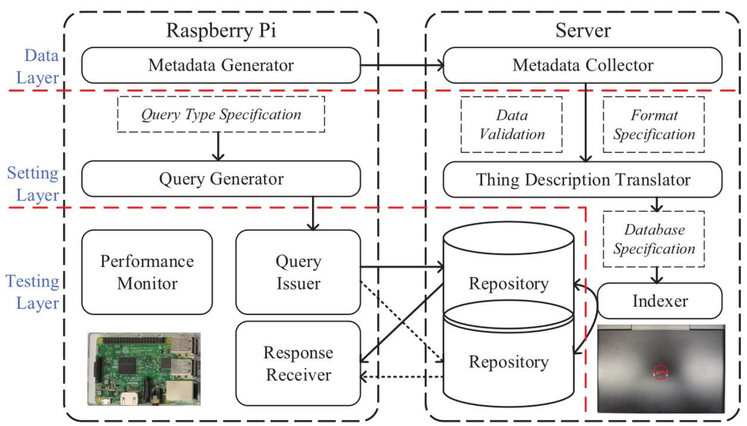
Approach

1. Obtain building object from OpenStreetMap (by address or location)
2. Digitize printed fire escape floor plan & adjust (contrast, colors, transparency)
3. Align floor plan with building polygon via reference coordinates
   - Find best projective transformation matrix via the least-square method
4. Aid user in defining and naming rooms, sections, and floors
   - Draw polygons over floorplan
   - Add labels to polygons



Testbed for Metadata Directory

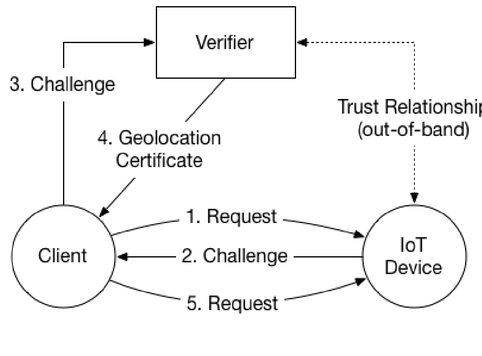
- Generate mock thing descriptions
- Using MongoDB and MySQL as selected data stores
- Analyze query performance

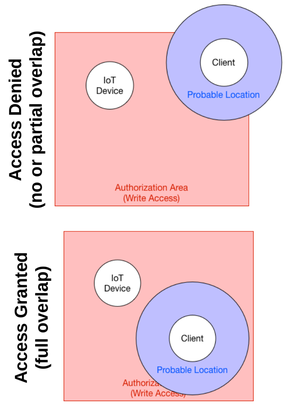


Geospatial IoT Access Control

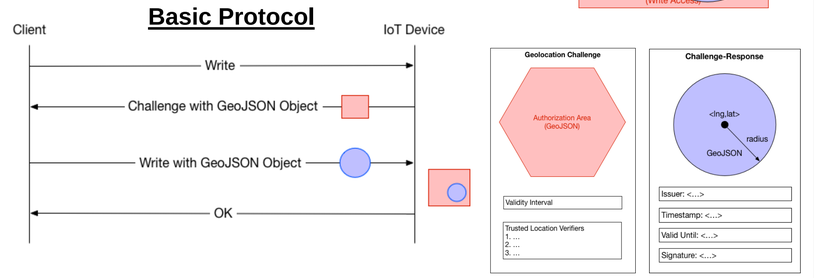
- Access control rules inspired by the physical world
  - People in a room can implicitly control light switches in the room
  - Access determined by client location relative to the controlled device
- Access control policies based on geospatial relationships
  - Write access if "near", otherwise read-only access
  - Write access if in the same room
  - Discoverable on campus

System Architecture





Basic Protocol



Challenges and Future Work

Name Resolution

- Real-time device profile update
- Name resolver prototype architecture

Access Control

- Represent the fine-grained and flexible access control
- Including dynamic properties (location) and rights ("min. query interval")
- Multi-owner issues

References

1. W3C Thing Description. https://www.w3.org/TR/wot-thing-description/
2. National Transportation Safety Board. Preliminary Report Pipeline: Over-pressure of a Columbia Gas of Massachusetts Low-pressure Natural Gas Distribution System. URL:https://www.ntsb.gov/investigations/AccidentReports/Pages/PLD18MR003- preliminary-report.aspx