Revisiting SoA for the IoT
A Middleware Perspective

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Agenda

1. The IoT: An Introduction
2. A Service-Oriented IoT: Why & How
3. SoA for the IoT: Some Middleware Insight
4. Conclusion: What’s Next
But what is the Internet of Things?
The Internet of (Every)Things

Revisiting Service-oriented Architecture for the IoT, Issarny et al.
When the Virtual absorbs the Physical World

Matrix trailer

Not yet there… hopefully 😊
When the Virtual & Physical Worlds Connect

Why bother? It’s already there!
But the Physical World is Complex

And so is the IoT!
The Pollution Monitoring use Case

Fixed Sensing
- High cost
  - but accurate

Mobile Crowdsensing
- Low cost &
  - high redundancy
  - but low accuracy &
    - high diversity

Social Sensing
- Qualitative add-on
  - but highly subjective

https://www.youtube.com/watch?v=Yw_Er8fMmMw
Challenges

- Ultra-large scale
  - # Things
  - # Data
- Deep heterogeneity
  - Technical
  - Functional
  - Social
- Physical knowledge
  - Time-dependency
- High dynamics
- Privacy & security
What if…

Everything connects and contributes to urban knowledge

Urban middleware with hybrid sensing/actuation

Middleware tames high heterogeneity, scale & dynamics

And QoS @ large – cf Elisa’s keynote on security & privacy
Learning from an Urban Scale Experiment

Ambiciti App informing about individual and collective exposure to urban pollution

Noise pollution monitoring in Paris since summer 2015

Scale, Heterogeneity, Physical, Dynamics, Privacy, …
The 2 Ends of the Spectrum

- Fixed Sensors
- Mobile Sensors
- Citizens
- Social Networks
The 2 Ends of the Spectrum

- Fixed Sensors
- Mobile Sensors
- Citizens
- Social Networks

Connect  
Cooperate  
To bring new services on the fly  
Toward an open Internet of Things  
SoA to the Rescue

Revisiting Service-oriented Architecture for the IoT, Issarny et al.
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Toward a Service-oriented IoT?
Service-oriented Architecture Meets the IoT

Service Abstraction
Discovery, Composition
& Access

BUT
Ultra-large scale
Continuous data streams
Multi-paradigm interactions
A Rich State of the Art

- Ultra-large scale
  - Cloud of Things, In-network processing
  - Continuous processing, Map-reduce
- Heterogeneity
  - SoA, WoT, Virtualization
  - Ontology, Semantic WoT
- Physical knowledge
  - Sensor data streams
- Dynamics
  - Dynamic discovery
- Privacy & security
A Thing-based SoA

Service abstraction for Things
- Connect with the physical world
- Semantic knowledge
- Functional & non-functional
- Discrete & continuous
A Thing-based SoA

Discrete service

Operation

Client

Service provider

Discrete result

Service consumer

Continuous service

Output port

Client

Data producer

Data consumer

invocation

access

diffusion
A Thing-based SoA

Things Abstraction

Thing discovery
- Query for real-world phenomena
- Mobile and fixed things
- Diversity of the connected things
- Redundancy
A Thing-based SoA

Things Abstraction, Discovery

Thing composition

- Complexity of the physical world
- Diversity of the connected things
- Sense & actuate continuous real-world phenomena

Revisiting Service-oriented Architecture for the IoT, Issarny et al.
A Thing-based SoA

Things Abstraction, Discovery, Composition

Thing access

- Resource-constraints
- Proxy/gateway
- Thing node
- Diversity of access protocols for the tiny to the wealthy things
A Thing-based SoA

Tame the heterogeneity

Discrete & continuous

Registries

Service Consumer

IoT-based Service-oriented Middleware (SOM)

Service Provider

Tame the #
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Middleware for a Service-oriented IoT
Middleware Solutions for a Thing-based SOA
Sensing the Physical World

- **Discovery** in the ultra-large scale IoT
- **Composition** in the Dynamic resource-constrained IoT
- **Access** in the Heterogeneous IoT
Service Discovery in the Ultra-large Scale IoT

Probabilistic discovery for the mobile IoT
Probabilistic Discovery for the Mobile IoT

Design Rationale
- Do not register redundant Things to reduce number
- Leverage user mobility knowledge

Jardin des Tuileries
Probabilistic Discovery: How

Centralized Approach
- Compute decision on Registry as search problem
- Using global displacement knowledge
- But computation time increases linearly
Probabilistic Discovery: How

Distributed Approach
- Compute decision on Thing
- Estimate displacements of registered Things using mobility models (e.g., TLW)

Jardin des Tuileries
Service Discovery in the Ultra-large Scale IoT

Probabilistic registration & lookup for the mobile IoT

Composing the discovered things
Service Composition in the Resource-constrained IoT

- **Consumer**
  - +consume(item)

- **Producer**
  - +produce():item

- **Processor**
  - +initialize()
  - +work(item):item-list
  - +finalize():item-list

- **Storage**
  - +store(item)
  - +produce(query):item-list

Transform → Consume → store

[Billet et al., JISA'2014]
Logical Mashup Graph

Producer → Processor → Processor → Processor → Processor → Consumer

[Billet et al., MASS’2014]
Logical Mashup Graph Example

1. Particle Sensor
2. NO₂ Sensor
3. Stream
4. Stream
5. Component
6. Speed Limiter
7. Control Center (GUI)
8. Stream

Components and Streams:
Deploying the Graph

Energy, Resource-constraints, Load balancing, Timeliness
Modeling Tasks and Things for Physical Mapping

Solving the problem optimally & approximately
Physical Composition of the Resource-constrained Things Example

[Diagram showing physical composition of resource-constrained things with nodes and arrows representing sensors and control center.]
Dioptase Middleware for Things

Dioptase is one solution…
Service Access in the Heterogeneous IoT

Dioptase  DPWS  MQTT  CoAP  ...

Streaming  Discrete  Sync  Async  Pus/sub  ...

[Georgantas et al., ESOCC’2013]
Service Bus for the IoT

4 basic operations:

- One-way sender operation
- One-way receiver operation
- Two-way asynchronous client operation
- Two-way asynchronous server operation
- Two-way synchronous client operation
- Two-way synchronous server operation
- Stream consumer operation
- Stream producer operation

Each operation represented as combination of *post* and *get* primitives

*post* and *get* primitives mapped to each protocol: SOAP, REST, CoAP, MQTT, etc.

Reconciling multi-paradigm interactions
VSB: The eVolution Service Bus
VSB Development & Run-time Environments

**VSB at development time:**

\[ < h, p, r, op, in, out > \]

*GIDL for Thing \( i \)*

**Bus protocol \( b_i \):**

- \( h \): host address
- \( p \): thing protocol
- \( r \): role type
- \( op \): list of operations
- \( in \): input data types
- \( out \): output data types

**VSB at runtime:**

[Diagram showing interactions between different components including BC Synthesis and implementations’ pool with detailed connections to Things 1, 2, and 3.]
An Urban Middleware Leveraging the IoT?
What’s next?
Contributions so far…

A perspective on SoA for the IoT
A flavor of SoA but…

Middleware solutions to tame the complex IoT
Scale, heterogeneity, …

But the centralized approach remains the winner…
What’s next…
Next generation Internet of Things

- Security & Privacy
- Reliability & Dependability
- Usability, Management, Interoperability
- Software architecture
- Information-centric networking
- Closed-loop operation
- Testing & Evaluation

http://anrg.usc.edu/ngiot16/

Is it all about Big Data…?
Thank you!

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