Quality of Observation within Sensor Web systems: from theory to practice

Qualité des Observations pour les systèmes Sensor Webs : de la théorie à la pratique

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TéSA seminar

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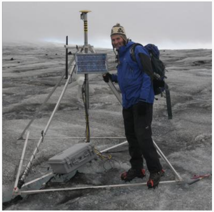
Context and Motivation

Context

A World of sensors



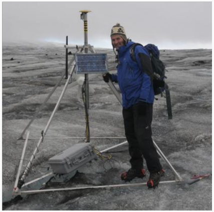
Temperature, humidity, wind speed, water salinity, GPS, accelerometers, etc.

How to discover, access and retrieve observations from all these sensors in an unified manner?

Context

A World of sensors



Temperature, humidity, wind speed, water salinity, GPS, accelerometers, etc.

How to discover, access and retrieve observations from all these sensors in an unified manner?

$\Rightarrow$ Short answer: by using sensor middlewares, a.k.a **Sensor Webs**!

What *was* a Sensor Web?

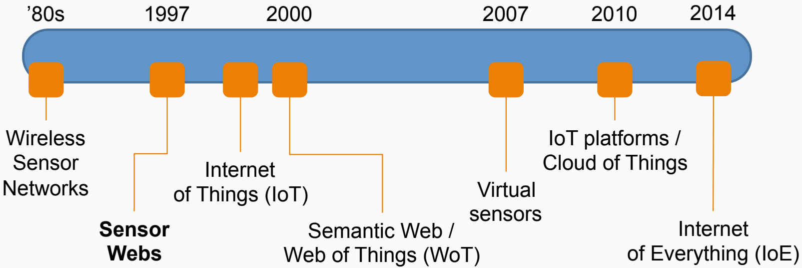
NASA JPL (1999)

Developmental collections of sensor pods that could be scattered over land or water areas or other regions of interest to gather data on spatial and temporal patterns of relatively slowly changing physical, chemical, or biological phenomena in those regions.

Back then, consumers:

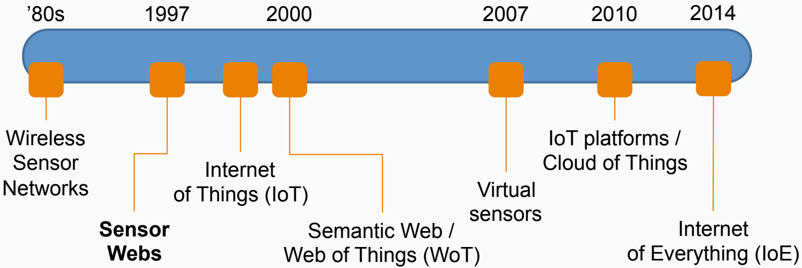
- had basic needs in terms of **Quality of Service (QoS)**
- were mainly interested in **physical** sensors
- had access to **dedicated** sensors

- New paradigms have emerged:



- Sensors, consumers and uses are changing
- 50+ billion Things will be connected to the Internet by 2020

- New paradigms have emerged:



- Sensors, consumers and uses are changing
- 50+ billion Things will be connected to the Internet by 2020

⇒ Sensors Webs need to evolve as well to cope with new issues

What *is* a Sensor Web? (update)

OGC SWE (2011)

Sensor Web is to sensor resources what the WWW is to general information sources - an infrastructure allowing users to easily share their sensor resources in a well-defined way. [Brö+11]

Guest Editors for a Sensor Web journal (2016)

Sensor Web can be defined as the paradigm that enables the integration of sensors/sensor networks and Web-based platforms.

Observations should be of **"good quality"** for each consumer

- Quality of Service (QoS) but…
- Quality of Experience (QoE) but…

Still insufficient to characterize all consumer needs!

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Still insufficient to characterize all consumer needs!

Quality of Information (QoI)

QoI is the collective effect of information characteristics (or attributes) that determine the degree by which the information is (or perceived to be) fit-to-use for a purpose. [Bis+09]

Within sensor-based networks, information $\equiv$ observations
$\Rightarrow$ **Quality of Observation (QoO)** to remain coherent

New challenges for modern Sensor Webs:

Integration

How to bridge the gap between sensor capabilities and consumer needs while reducing the complexity of end applications?

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How to provide fit-for-use observations in a consumer-specific fashion?

New challenges for modern Sensor Webs:

Integration

How to bridge the gap between sensor capabilities and consumer needs while reducing the complexity of end applications?

Quality of Observation (QoO)

How to provide fit-for-use observations in a consumer-specific fashion?

System adaptation

How to take into account context changeability over time?

We envision a new generation of Sensor Webs:

QoO-aware **A**daptive **S**ensor **W**eb **S**ystems (QASWS)

We proposed two contributions:

1. A generic framework for QASWS
2. A functional QASWS prototype

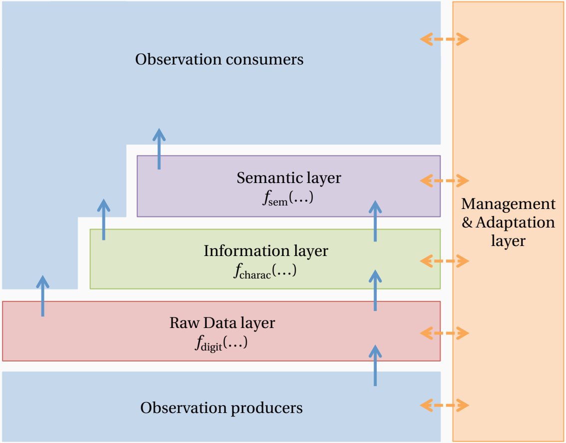
A generic framework for QASWS

⇒ Framework for researchers and developers who may want to conceive their own QASWS:

- Defined from **ISO/IEC/IEEE 42010 standard** (terminology and concepts)
- Platform-Independent Model (PIM), no technology or software is specified
- Should be **instantiated** to a specific use case (see iQAS)

Our framework is composed of:

1. A Reference **Model** (composed of several sub-models)
2. A Reference **Architecture** (composed of several views)
3. Reference **Guidelines**

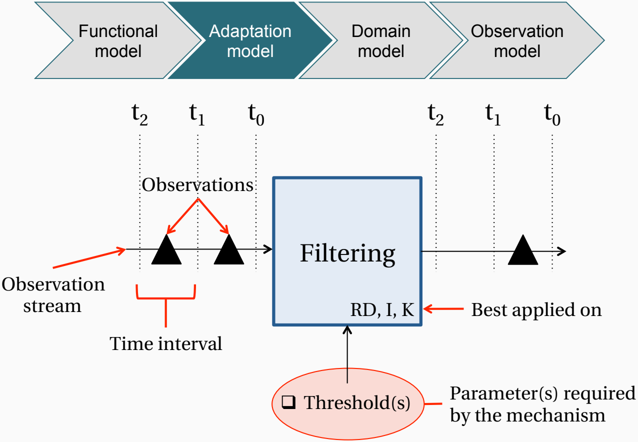


$f_{sem}(\text{Information}, \text{OntoModel}) = \text{Knowledge}$

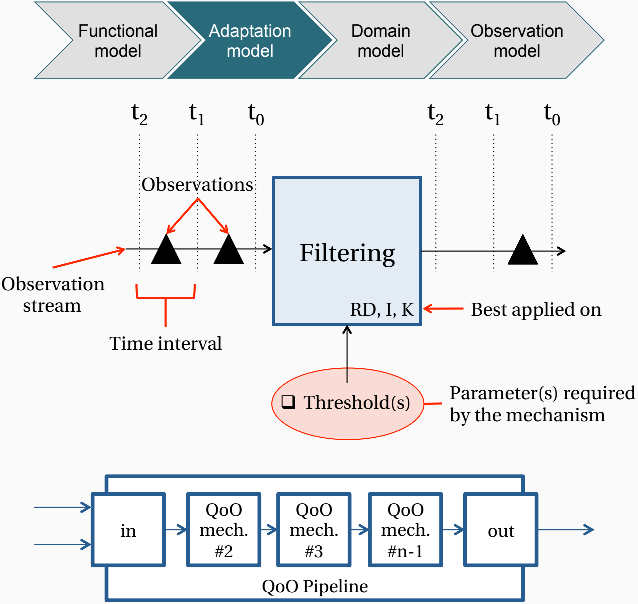
$f_{charac}(\text{Raw Data}, \text{Context}) = \text{Information}$

$f_{digit}(\text{Sensor outputs}) = \text{Raw Data}$

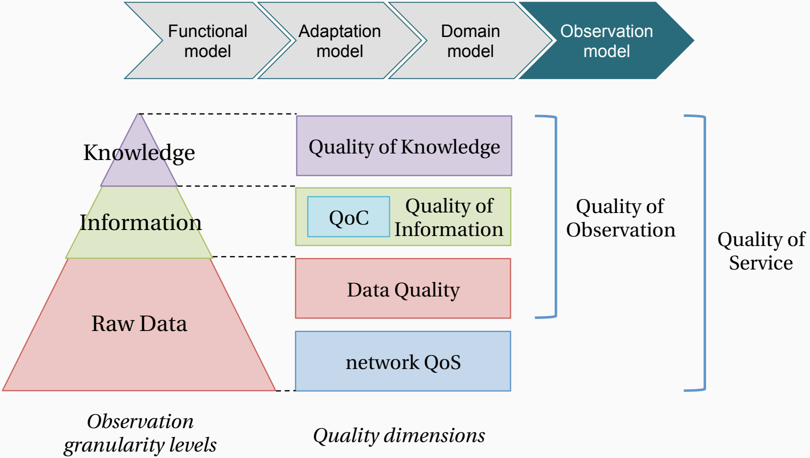
Generic framework for QASWS ► Reference Model



Generic framework for QASWS ▶ Reference Model



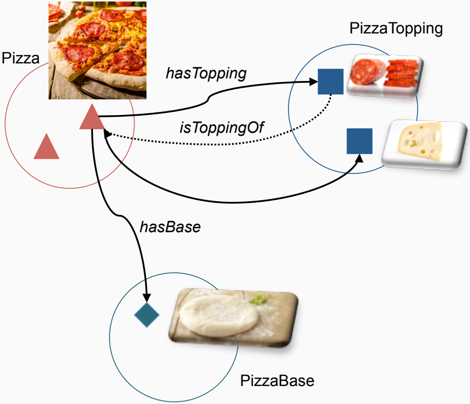
Generic framework for QASWS ► Reference Model



⇒ Use of **ontologies** to make the link between all concepts introduced by the different sub-models

Ontology

A formal explicit description of concepts, properties and restrictions in a domain of discourse.



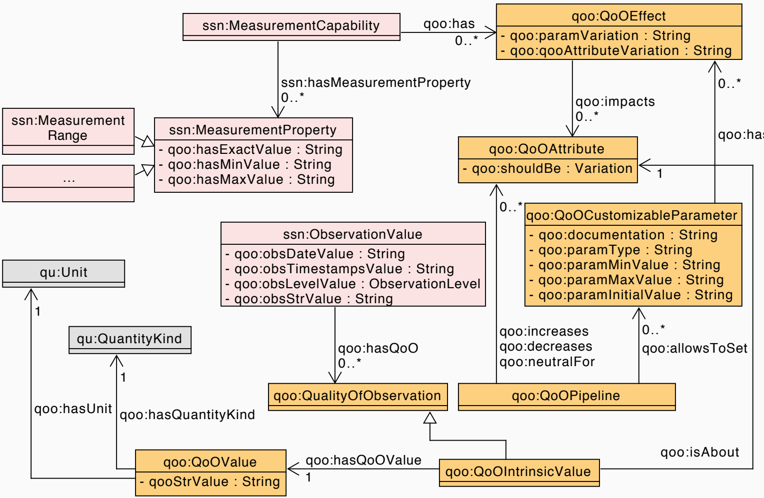
⇒ Why should we use ontologies?

- ✓ To **share** knowledge among people or software agents
- ✓ To enable **reuse** of domain knowledge
- ✓ To **separate** domain from operational knowledge
- ✓ To **analyze** domain knowledge

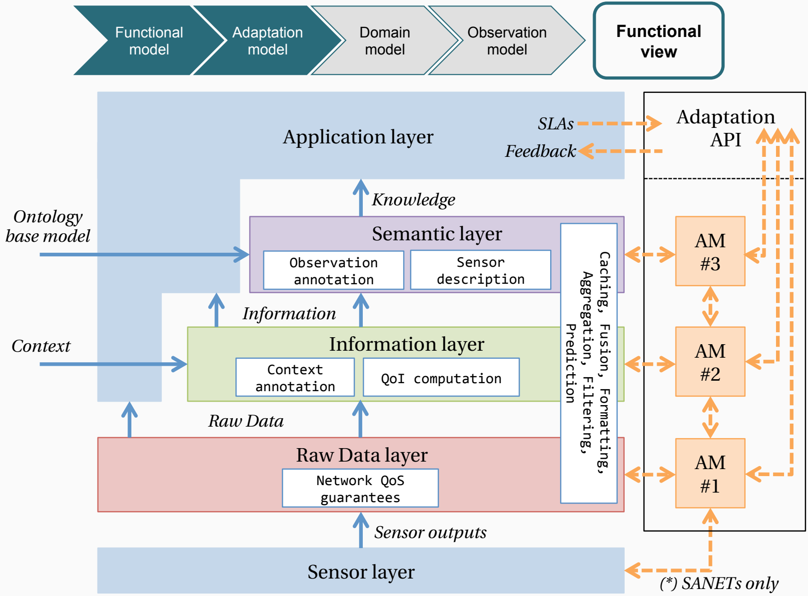
[Source: *Protégé*]

Generic framework for QASWS ▶ Reference Model

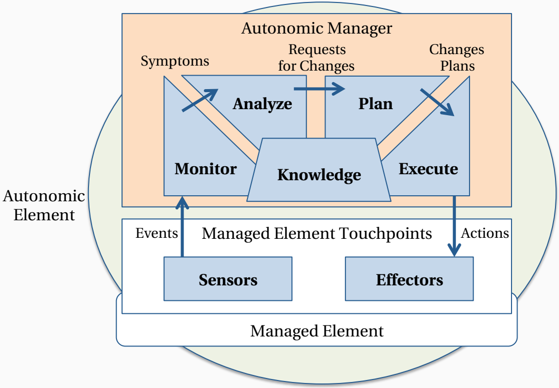
By reusing existing standards (W3C SSN), we propose the **QoOnto ontology** to describe sensors, mechanisms and pipelines:



Generic framework for QASWS ► Reference Architecture



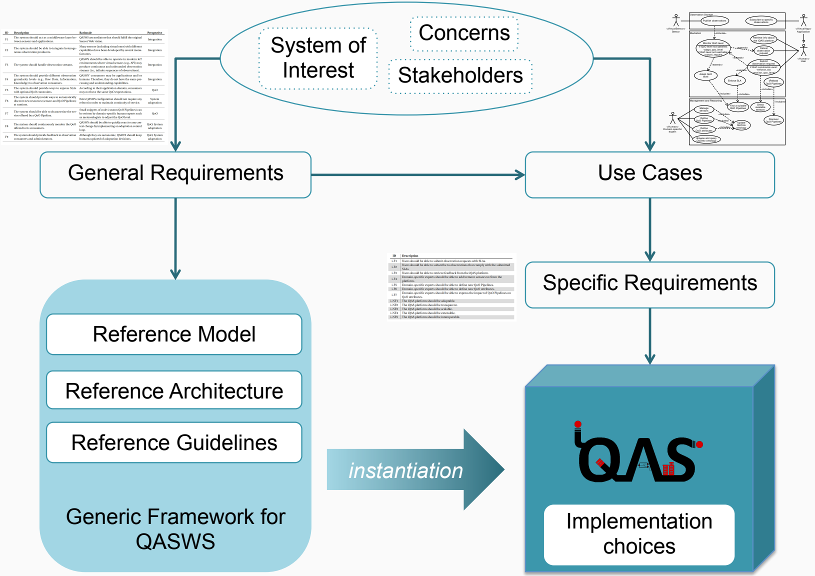
MAPE-K loop for enabling resource-based (sensors, pipelines) and QoO-based adaptation



- ✓ Specific adaptation per sensor/request/consumer
- ✓ Lazy adaptation strategy

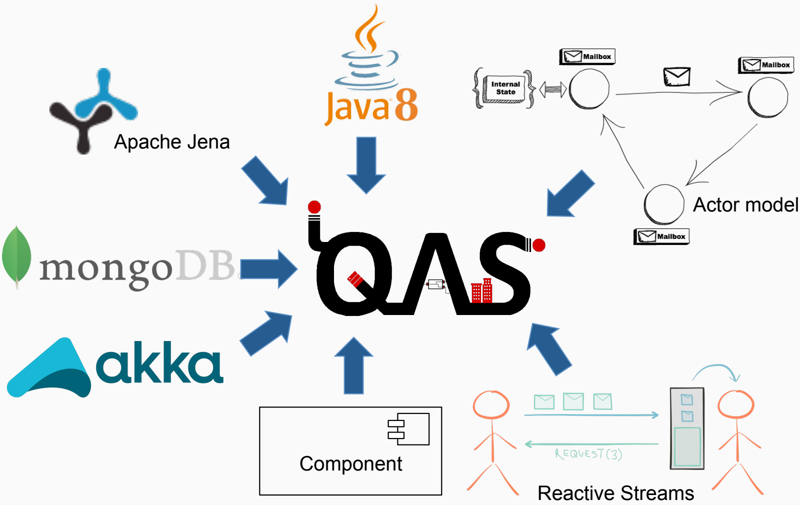
A functional QASWS prototype: the iQAS platform

The iQAS platform ▶ Instantiation process

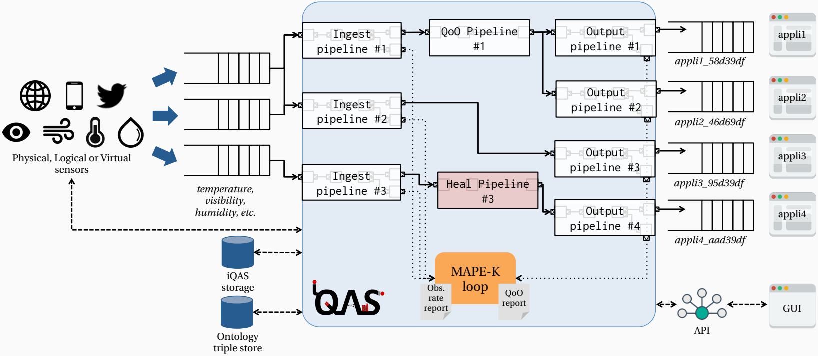


The iQAS platform ▶ Specific requirements

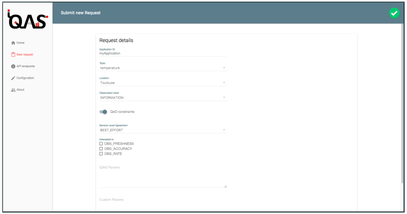
i-F1	Observation requests (SLAs)
i-F2	Observation retrieval
i-F3	Feedback provided by the platform
i-F4	Sensor “plug-and-play”
i-F5	Definition of new QoO Pipelines
i-F6	Definition of new QoO attributes
i-F7	Characterization of QoO Pipelines
i-NF1	Adaptability
i-NF2	Transparency
i-NF3	Scalability
i-NF4	Extensibility
i-NF5	Interoperability

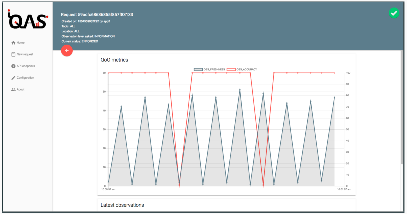

Apache Jena
Java 8
Internal State
Mailbox
Mailbox
Mailbox
Actor model
mongoDB
iQAS
akka
Component
REQUEST(3)
Reactive Streams

The iQAS platform ▶ High-level architecture



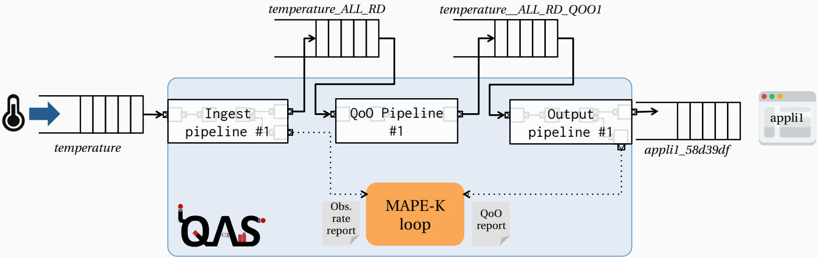
The iQAS platform ► Graphical User Interface





Software and its configuration may impact QoO...

⇒ Due to our implementation choices, iQAS performances are greatly impacted by **Apache Kafka** and its configuration (broker and clients)

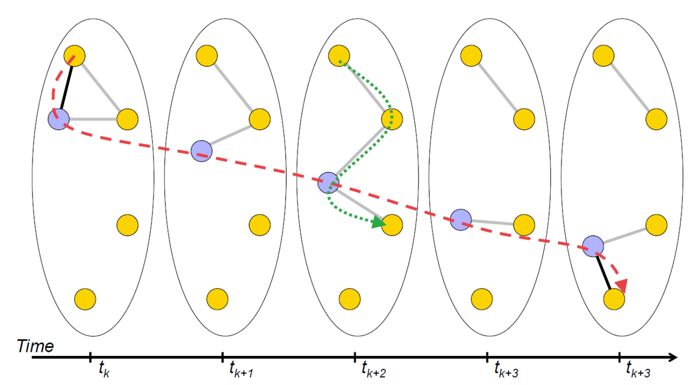


Use of Kafka without parallelism or replication (obs. streams)

A deployment scenario: QoO for challenging Internets

Delay-Tolerant Network (DTN)

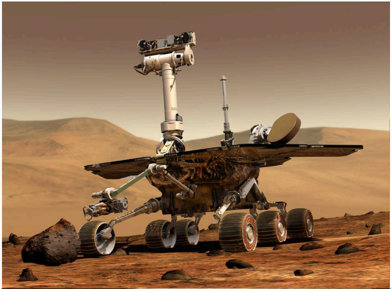
A network that may lack continuous network connectivity.

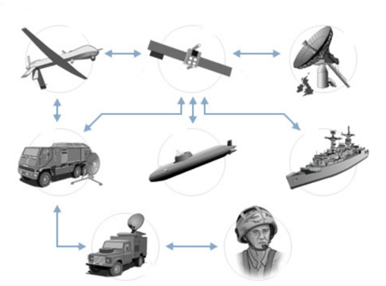


Opportunistic Networks further consider **human social characteristics** to perform routing and data sharing

Architecture can **fail**!

⇒ DTNs and OppNets as an alternative for challenging Internets





Our goals:

- Imagine a deployment scenario where QoO is of interest
- Study a QoO metric that can be impacted by both network QoS and iQAS processing time
- Show that network QoS and QoO are closely tied

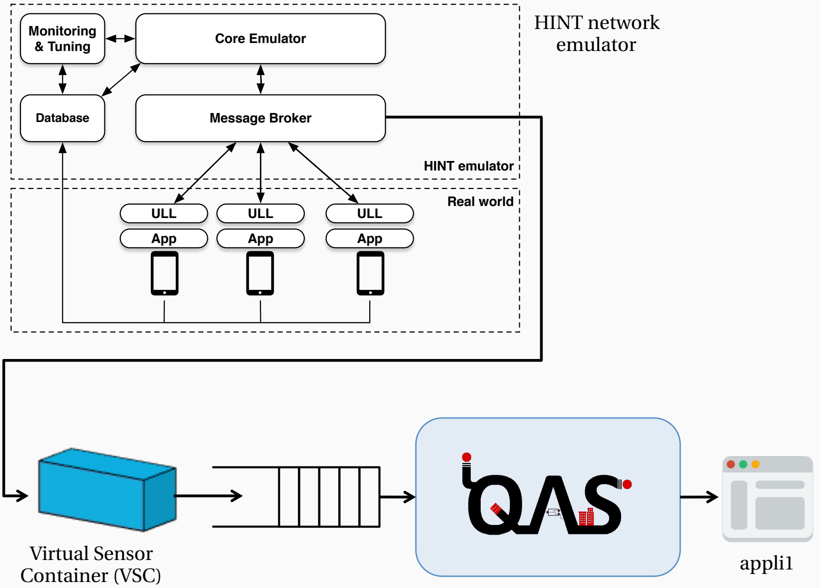
Our means:

✓ We investigated it from an **"Opportunistic Networking"** perspective

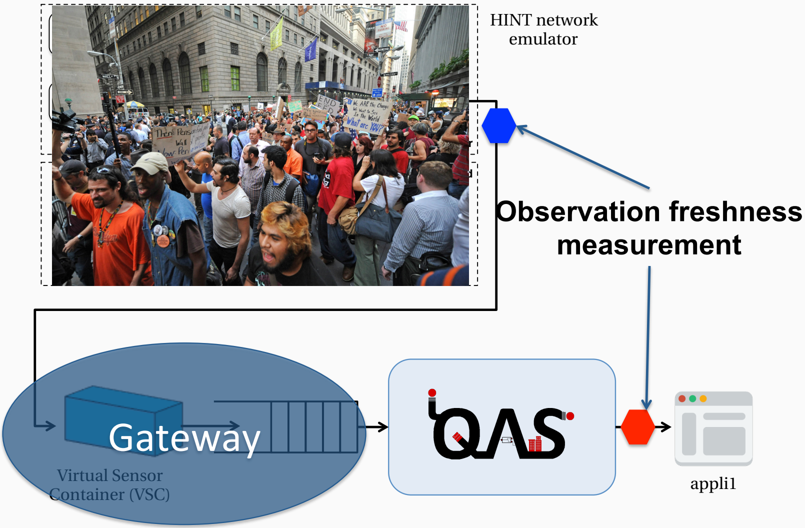
✓ We focused on the **"observation freshness"** attribute

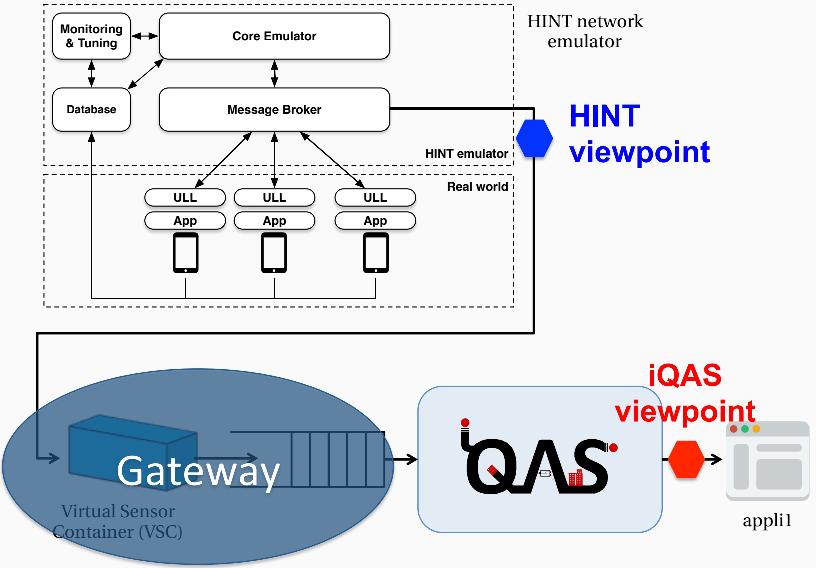
✓ We reused the **HINT emulator** from the DGAME project

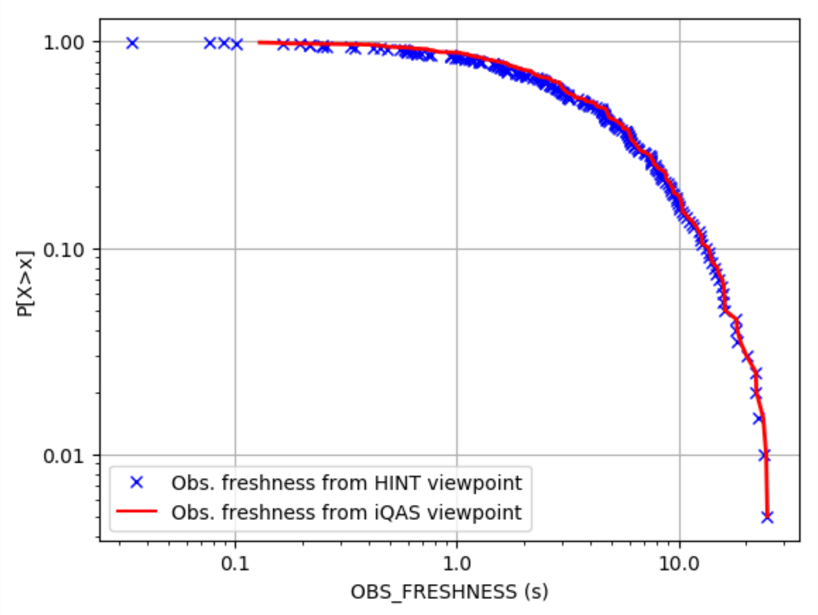
Deployment scenario ▶ Experimental setup

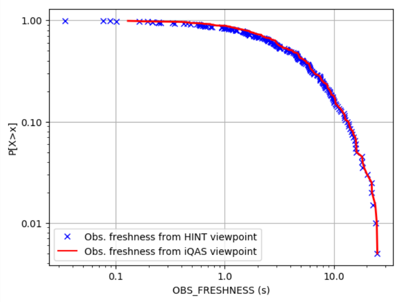


Deployment scenario ▶ Experimental setup




Monitoring & Tuning
Core Emulator
Database
Message Broker
HINT network emulator
HINT emulator
Real world
ULL
App
ULL
App
ULL
App
HINT viewpoint
iQAS viewpoint
Gateway
Virtual Sensor Container (VSC)
appli1


1.00
0.10
0.01
P[X>x]
0.1
1.0
10.0
OBS_FRESHNESS (s)
Obs. freshness from HINT viewpoint
Obs. freshness from iQAS viewpoint



- iQAS processing time is negligible compared to recollection time
- Some QoO constraints may be partially **translated** into network QoS constraints
- Network QoS guarantees should be ensured **first**

Conclusions and Perspectives

Conclusions

- ✓ The **Sensor Web** paradigm is in constant evolution
- ✓ **QoO** is one of the most important challenges that new Sensor Webs should cope with

- ✓ We proposed 2 contributions regarding the design and development of QoO-aware Adaptive Sensor Web Systems (**QASWS**)

- ✓ QoO is a complex but critical notion for **data-centric** systems
- ✓ QoO may be **impacted** by software and its configuration (Warning!)
- ✓ Network QoS and QoO may be used together to meet **consumer needs**

Perspectives

$\Rightarrow$ Keep studying the relationships between the different quality dimensions

$\Rightarrow$ How to describe the **capabilities** of a virtual sensor?

$\Rightarrow$ Improve and promote the iQAS platform (internship proposal at ISAE)

$\Rightarrow$ How can Sensor Webs **take advantage of** other paradigms regarding QoO? (Edge Computing, Blockchain, ML, etc.)

Publications

- Antoine Auger et al. “Towards the Internet of Everything: Deployment Scenarios for a QoO-aware Integration Platform”. In: *IEEE WF-IoT 2018*. Singapore, Singapore, 2018, pp. 504–509
- Antoine Auger et al. “Survey on Quality of Observation within Sensor Web Systems”. In: *IET Wireless Sensor Systems* 7 (6 2017), 163–177(14)
- Antoine Auger et al. “Sensor Observation Streams Within Cloud-based IoT Platforms: Challenges and Directions”. In: *20th ICIN Conference Innovations in Clouds, Internet and Networks*. Paris, FR, 2017, pp. 177–184
- Antoine Auger et al. “iQAS: an Integration Platform for QoI Assessment as a Service for Smart Cities”. In: *IEEE WF-IoT 2016*. Reston, VA, USA, 2017, pp. 88–93
- Antoine Auger et al. “A Generic Framework for Quality-based Autonomic Adaptation within Sensor-based Systems”. In: *ICSOC 2016 - ASOCA workshop*. Banff, CA, 2017, pp. 21–32
- Antoine Auger et al. “Using the HINT Network Emulator to Develop Opportunistic Applications: Demo”. In: *ACM CHANTS ’16*. New York City, NY, USA, 2016, pp. 35–36
- Gwilherm Baudic et al. “HINT: From Network Characterization to Opportunistic Applications”. In: *ACM CHANTS ’16*. New York City, NY, USA, 2016, pp. 13–18

Thank you for your attention.

Question time!

[Bis+09] C. Bisdikian et al. "A Letter Soup for the Quality of Information in Sensor Networks". In: *IEEE International Conference on Pervasive Computing and Communications, 2009. PerCom 2009*. Mar. 2009, pp. 1–6.

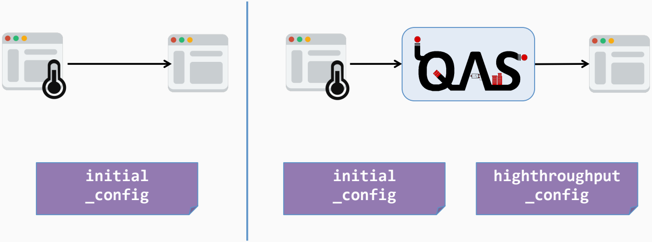
[Brö+11] Arne Bröring et al. "New Generation Sensor Web Enablement". In: *Sensors* 11.3 (2011), pp. 2652–2699.

We evaluated the iQAS footprint by defining **Key Primary Indicators (KPIs)**:

- iQAS overhead
- iQAS throughput
- iQAS response time

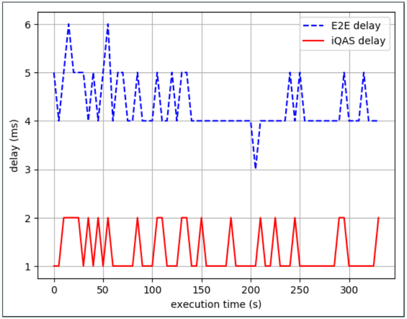
3-step methodology:

1. Identification of relevant parameters for Kafka configuration
2. Parameter tuning
3. Experiments



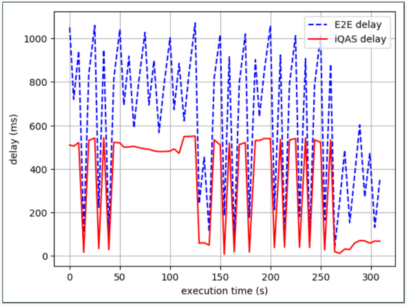
initial_config	Moderate batching, low limit for polling records, no linger time
highthroughput_config	Extreme batching, high limit for polling records, linger time

iQAS overhead (observation freshness)



`initial_config`

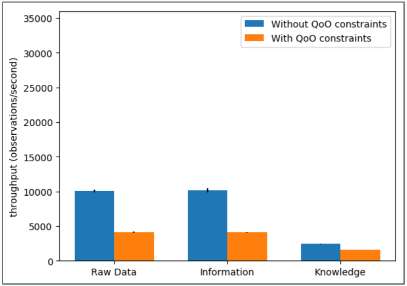
4 ms for E2E delay



`highthroughput_config`

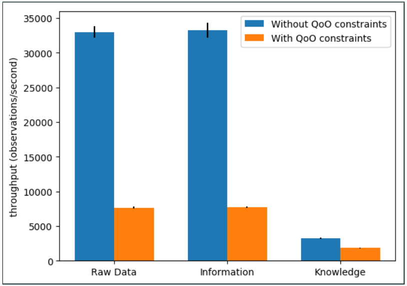
800 ms for E2E delay

iQAS throughput (observation rate)



`initial_config`

10 000 obs. / second

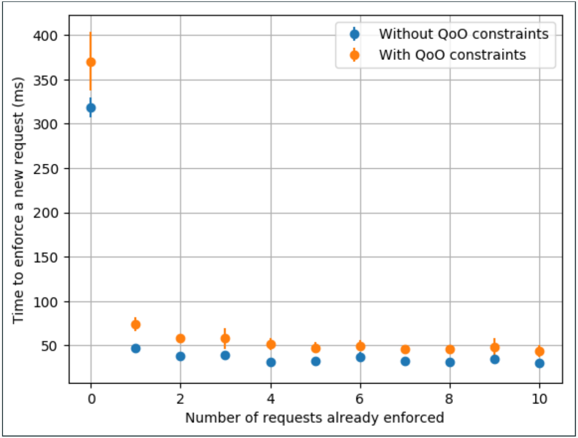


`highthroughput_config`

33 000 obs. / second

⇒ Tradeoffs between observation size, latency and throughput (see Queuing Theory)

iQAS response time (scalability)



⇒ For similar iQAS requests, only the first one is "costly"