Fog Computing

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Fog computing?

Pervasive IoT …

Domotics

Android wearables

Amazon Echo

Google Nest

Amazon Dash buttons

Pervasive IoT …

- The Cloud alone cannot support the **IoT momentum**
- Need to **filter** and **process** data *before* the Cloud

So much data, really?

www.leverege.com/calculator

Resources Used

Data Transfer
145800.74
MB / month

146 GB/month

Cloud Storage
437402.21
MB / month

437 GB/month
5.2 TB/year

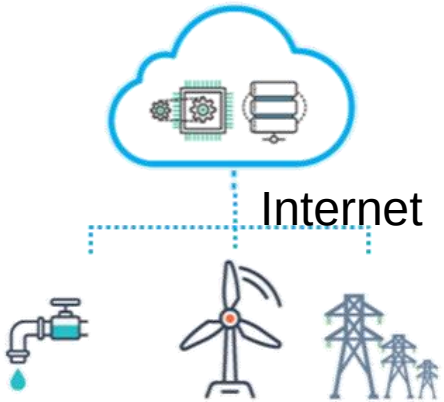
Updates
~2.68 M
per month

Deployment models

IoT+Edge

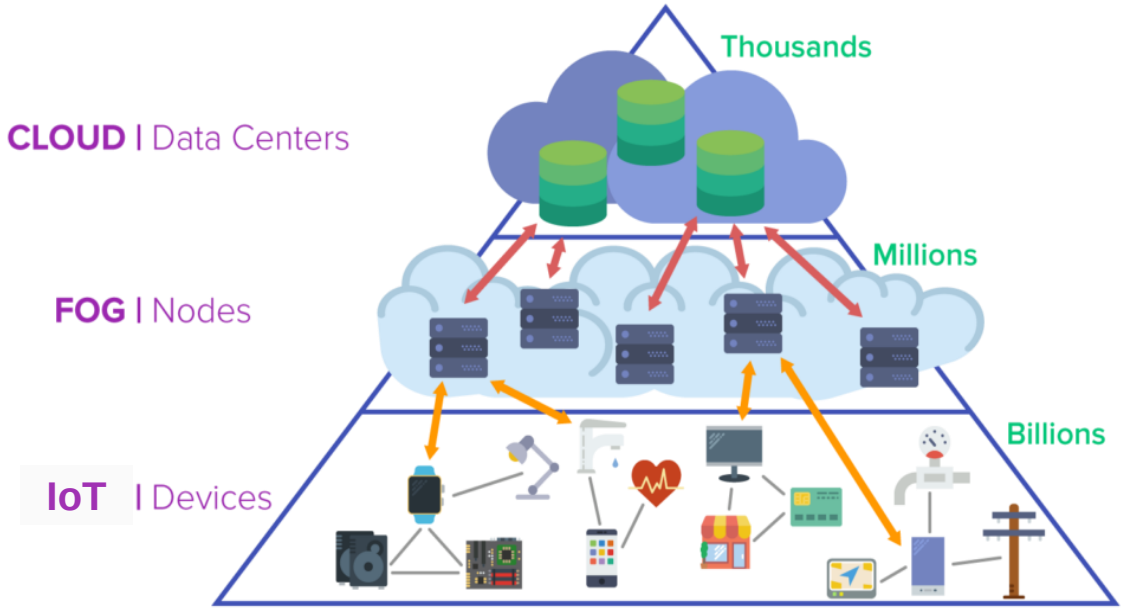
- **Process data *in situ* at the Edge**
- Low latencies but
- Limited capabilities
- Difficulties in sharing data

IoT+Cloud



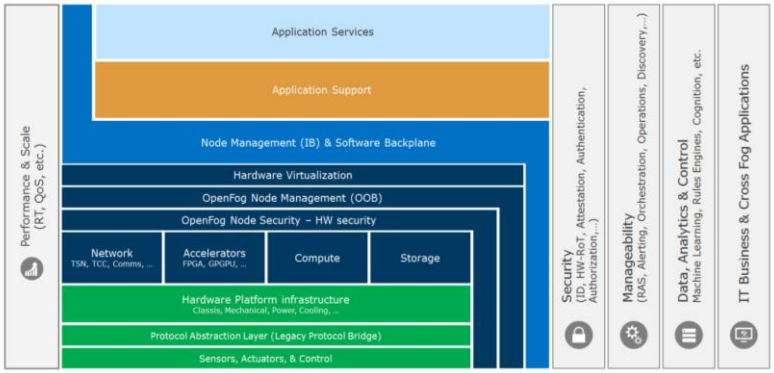
- **Send data to Cloud for processing**
- Huge computing power but
- Mandatory connectivity
- High latencies
- Bandwidth bottleneck

Fog Computing



Fog computing aims at extending the Cloud towards the IoT to better support **latency-sensitive** and **bandwidth-hungry** IoT applications

Fog Computing

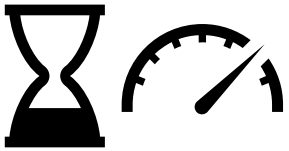


*«A system level horizontal architecture that distributes resources and services of **computing**, **storage**, **control** and **networking** anywhere **along the continuum from Cloud to Things**, thereby **accelerating** the velocity of **decision making**.»*

OpenFog (60+ companies, founded by ARM, Cisco, Dell, Intel, Microsoft, Princeton University)

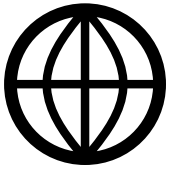

Fog is...
ENERGY MANAGEMENT

Fog Characteristics



Low latency &
bandwidth savings

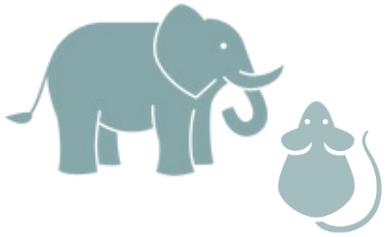
Location- &
context-awareness



Pervasiveness &
geo-distribution

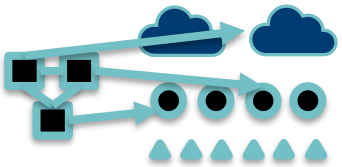
Fog & Things
Mobility

Collaboration &
interoperability

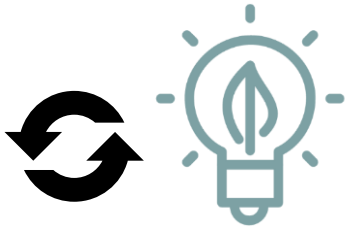


Heterogeneity
of devices

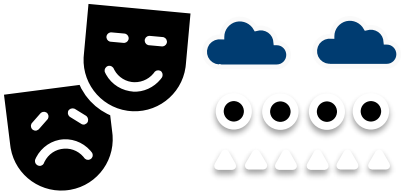
Research Challenges



Application Deployment



Resource & Energy Management



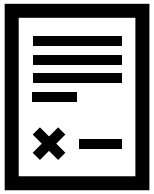
Infrastructure & Interfaces

Fog and IoT: An Overview of Research Opportunities

Mung Chiang, *Fellow, IEEE*, and Tao Zhang, *Fellow, IEEE*

Architecture is about functionality allocation [1]: deciding who does what and how to "glue" them back together. Unlike the more mature technology fields such as serial computation, digital communication, and the Internet, where strong and solid architectural foundation has been laid, we are still searching for architectural principles for many emerging systems and applications such as IoT, cyber-physical systems, and embedded artificial intelligence (AI). We need to make fundamental decisions ranging from where to compute and where to store data along the "cloud-to-things" continuum to how to map computation tasks into a substrate of heterogeneously capable and variably available nodes.

Security & Privacy



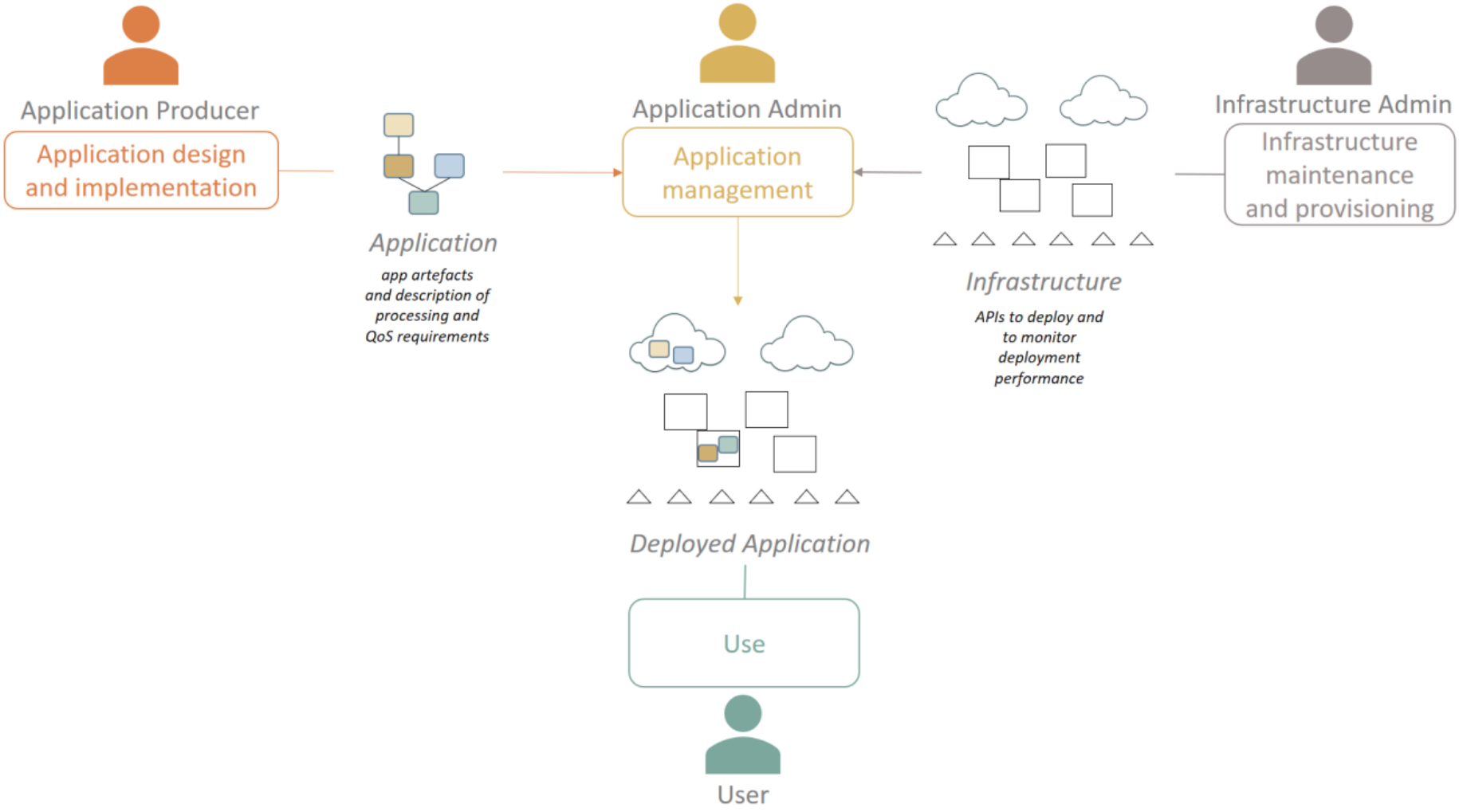
Business Aspects


Fog computing?
Deploying apps through the Fog

Deploying composite applications in a QoS- and context-aware manner over the continuum from Things to Cloud is challenging

App requirements	Fog infrastructure
• Hardware • Software • QoS	• Heterogeneous • Large • Dynamic*

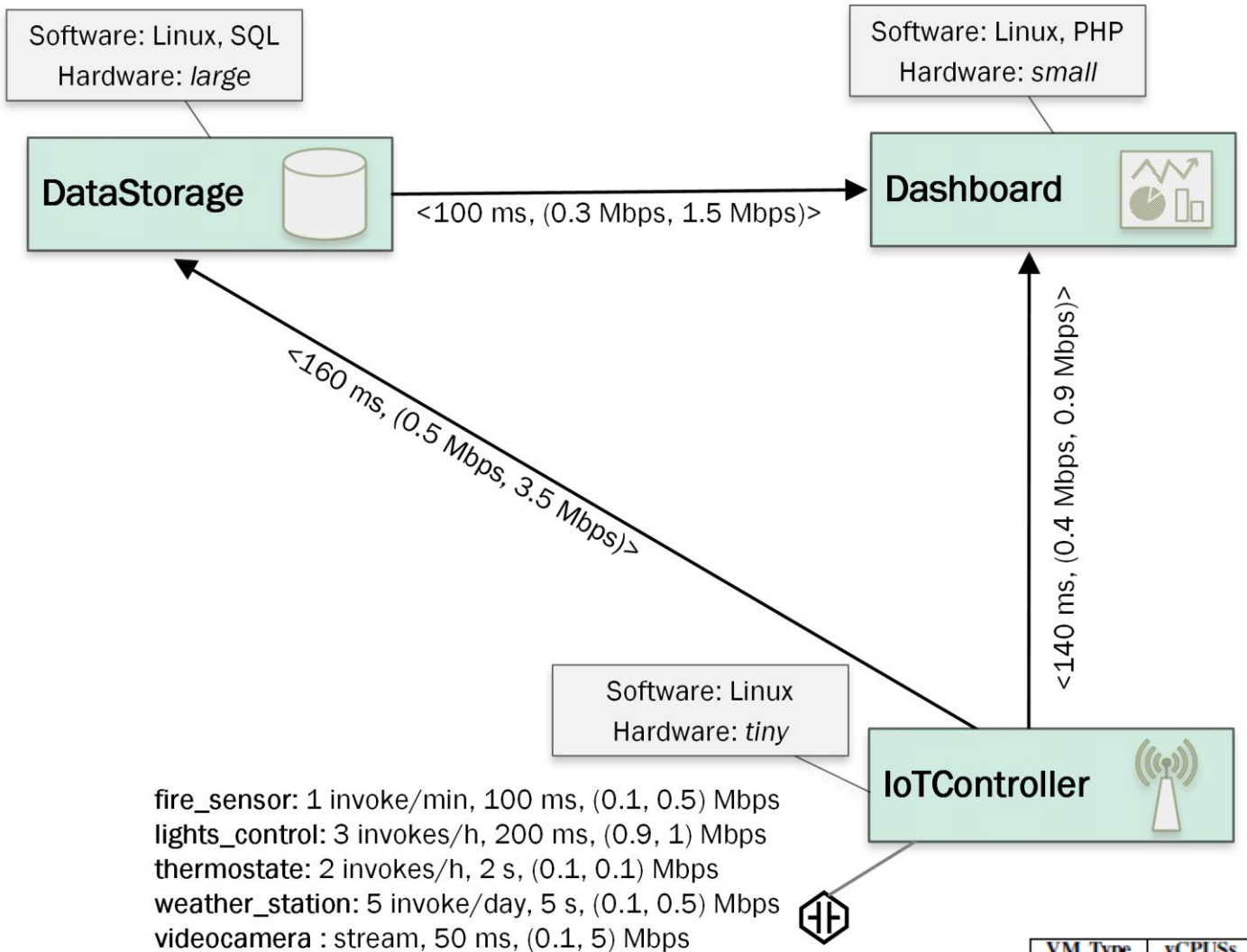
- *How many and how powerful fog nodes do I need to **adequately deploy** my application?*
- *Should I deploy this component on the **cloud**, on the **fog-as-a-service** available in my city or on my **premises gateway**?*
- *Is there any component I should better deploy on a different node after this **link/node failure**?*
- *Which are the eligible deployments that **comply most** with the required **qos**?*
- *Can I **reduce** resource consumption of some fog nodes, or **avoid** using them?*
- *Do I need to **upgrade** my infrastructure if the application requirements change?*
- *…*



One **stakeholder** can play more than one **role**:

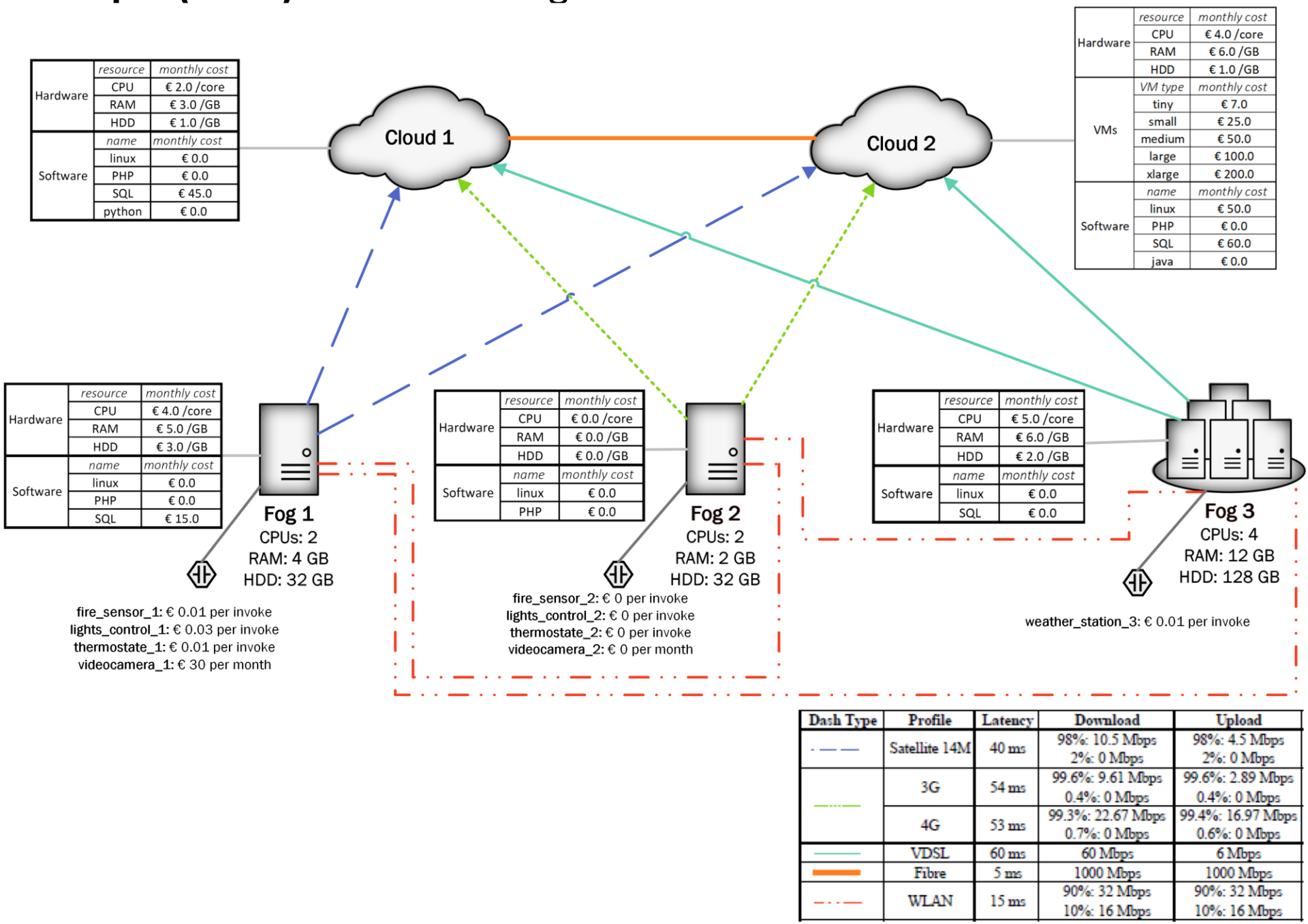
- DevOps: roles of application producer and administrator collapse
- Telecom provider providing IoT+Fog+Cloud infrastructure to its customers, and managing apps and services over the very same infrastructure
- User can act as infrastructure provider when sharing her home router as Fog capability for application deployment

Example - Simple Fog application that manages fire alarm, heating and AC systems, interior lighting, and security cameras of a smart building.



VM Type	vCPUSs	RAM (GB)	HDD (GB)
tiny	1	1	10
small	1	2	20
medium	2	4	40
large	4	8	80
xlarge	8	16	160

Example (cont.) – Available Fog infrastructure.



	resource	*monthly cost*
Hardware	CPU	€ 2.0 /core
	RAM	€ 3.0 /GB
	HDD	€ 1.0 /GB
	name	*monthly cost*
Software	linux	€ 0.0
	PHP	€ 0.0
	SQL	€ 45.0
	python	€ 0.0

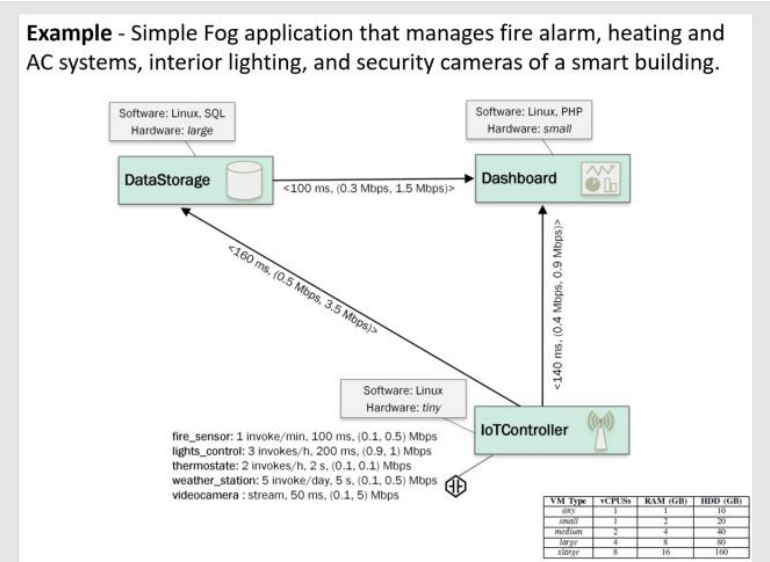
	resource	*monthly cost*
Hardware	CPU	€ 4.0 /core
	RAM	€ 6.0 /GB
	HDD	€ 1.0 /GB
	VM type	*monthly cost*
VMs	tiny	€ 7.0
	small	€ 25.0
	medium	€ 50.0
	large	€ 100.0
	xlarge	€ 200.0
	name	*monthly cost*
Software	linux	€ 50.0
	PHP	€ 0.0
	SQL	€ 60.0
	java	€ 0.0

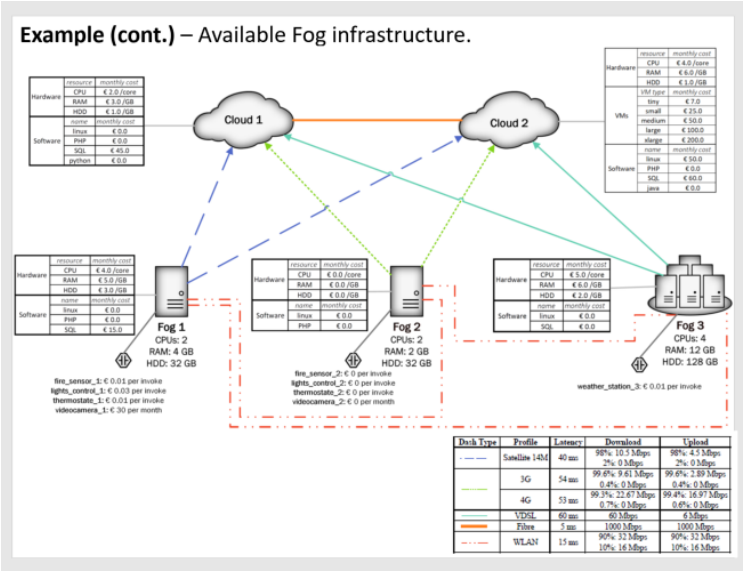
	resource	*monthly cost*
Hardware	CPU	€ 4.0 /core
	RAM	€ 5.0 /GB
	HDD	€ 3.0 /GB
	name	*monthly cost*
Software	linux	€ 0.0
	PHP	€ 0.0
	SQL	€ 15.0

	resource	*monthly cost*
Hardware	CPU	€ 0.0 /core
	RAM	€ 0.0 /GB
	HDD	€ 0.0 /GB
	name	*monthly cost*
Software	linux	€ 0.0
	PHP	€ 0.0

	resource	*monthly cost*
Hardware	CPU	€ 5.0 /core
	RAM	€ 6.0 /GB
	HDD	€ 2.0 /GB
	name	*monthly cost*
Software	linux	€ 0.0
	SQL	€ 0.0

Dash Type	Profile	Latency	Download	Upload
	Satellite 14M	40 ms	98%: 10.5 Mbps 2%: 0 Mbps	98%: 4.5 Mbps 2%: 0 Mbps
	3G	54 ms	99.6%: 9.61 Mbps 0.4%: 0 Mbps	99.6%: 2.89 Mbps 0.4%: 0 Mbps
	4G	53 ms	99.3%: 22.67 Mbps 0.7%: 0 Mbps	99.4%: 16.97 Mbps 0.6%: 0 Mbps
	VDSL	60 ms	60 Mbps	6 Mbps
	Fibre	5 ms	1000 Mbps	1000 Mbps
	WLAN	15 ms	90%: 32 Mbps 10%: 16 Mbps	90%: 32 Mbps 10%: 16 Mbps





Example (cont.) – Questions:

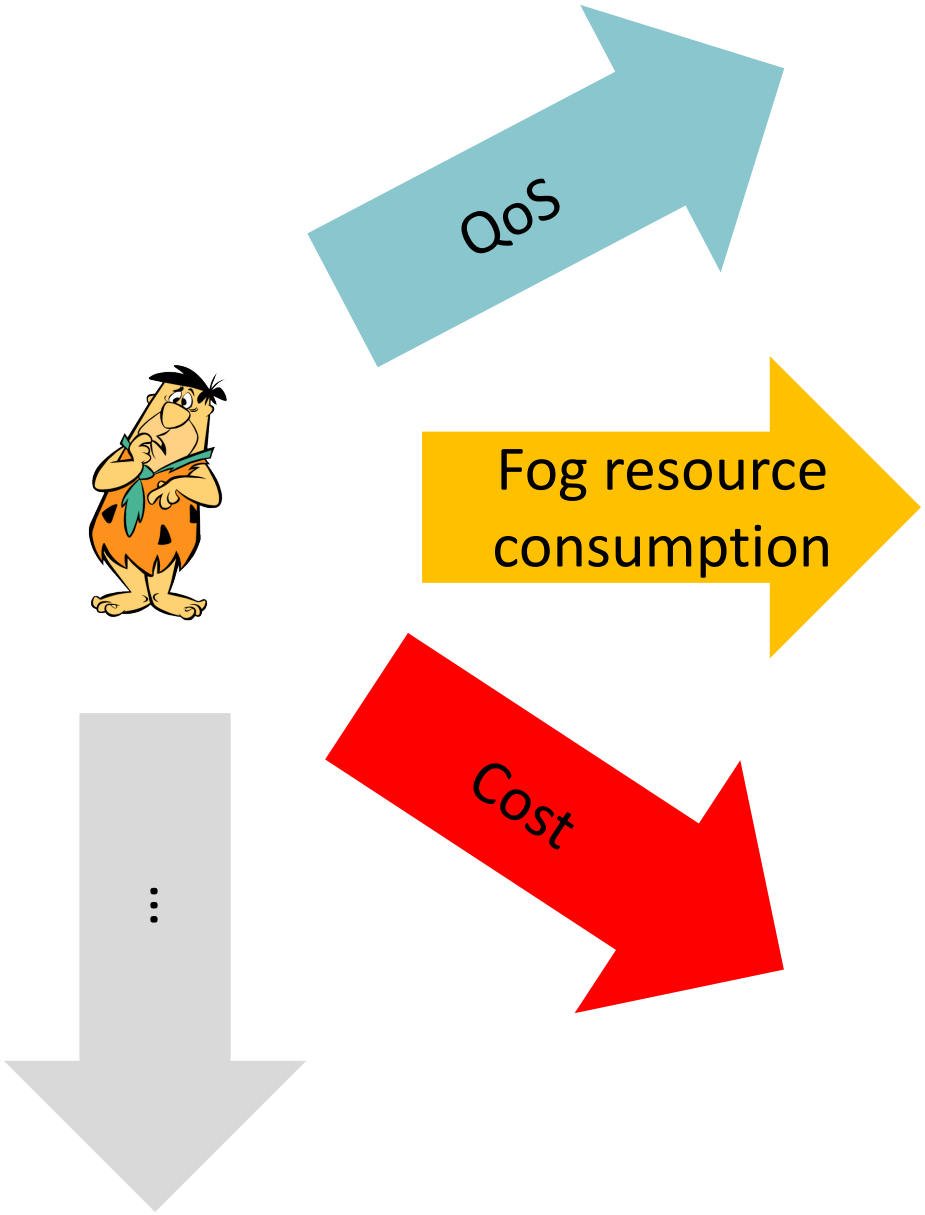
- *Q1 - Is there any eligible deployment of the application reaching the needed Things at Fog 1 and Fog 3, and meeting the financial (at most 850 euros/month) and QoS-assurance (at least 98% of the time) constraints?*
- *Q2 - Which eligible deployments minimise resource consumption in the Fog layer so to permit future deployment of services and sales of virtual instances to other customers?*
- *Q3 - Would there be any deployment that complies with all previous requirements and reduces financial cost and/or consumed Fog resources when upgrading from 3G to 4G at Fog 2?*

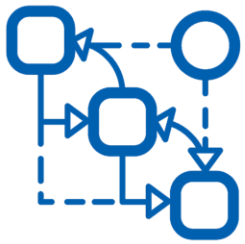
- How to decide *where* to «best» deploy each component of an application by exploiting QoS-, location-, and context-awareness?

- How to estimate the «goodness» of a candidate deployment?

- Especially challenging for mission-critical applications where
  - unpredictable performances cannot be tolerated
  - limited availability of resources of Fog devices make the management of application deployments intrinsically complex

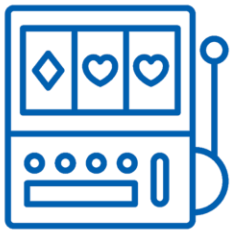
Need of **tools** helping to trade-off orthogonal dimensions





model and **algorithms**

QoS-aware Deployment of IoT Applications Through the Fog.
IEEE IoT Journal, 2017

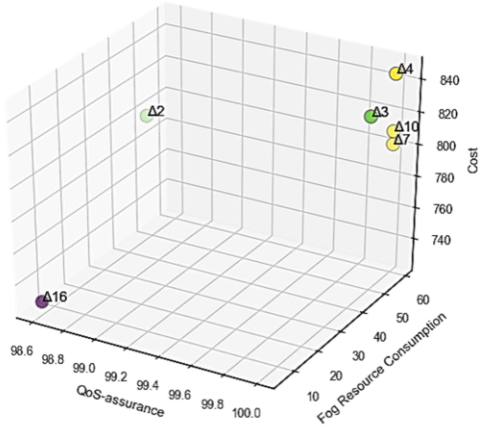


Monte Carlo simulation

How to best deploy your Fog applications, probably.
ICFEC17, Madrid, 2017

IoT+Fog+Cloud **cost model**

Deploying Fog applications: How much does it cost, by the way?
CLOSER18, Madeira, 2018



fogtorch Π

QoS-, context- and cost-aware deployments

https://github.com/di-unipi-socc/FogTorchPI

A. Brogi, G. Ferrari, S. Forti. ***Secure apps in the Fog: Anything to declare?*** *Cloudways, Como, 2018.*

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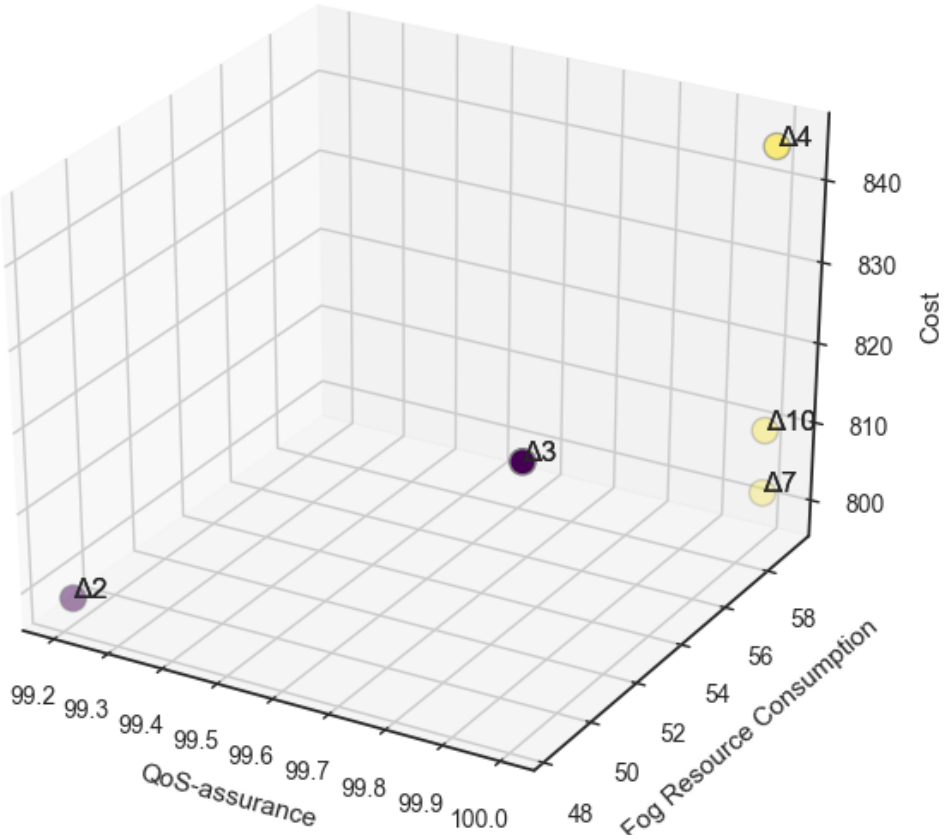


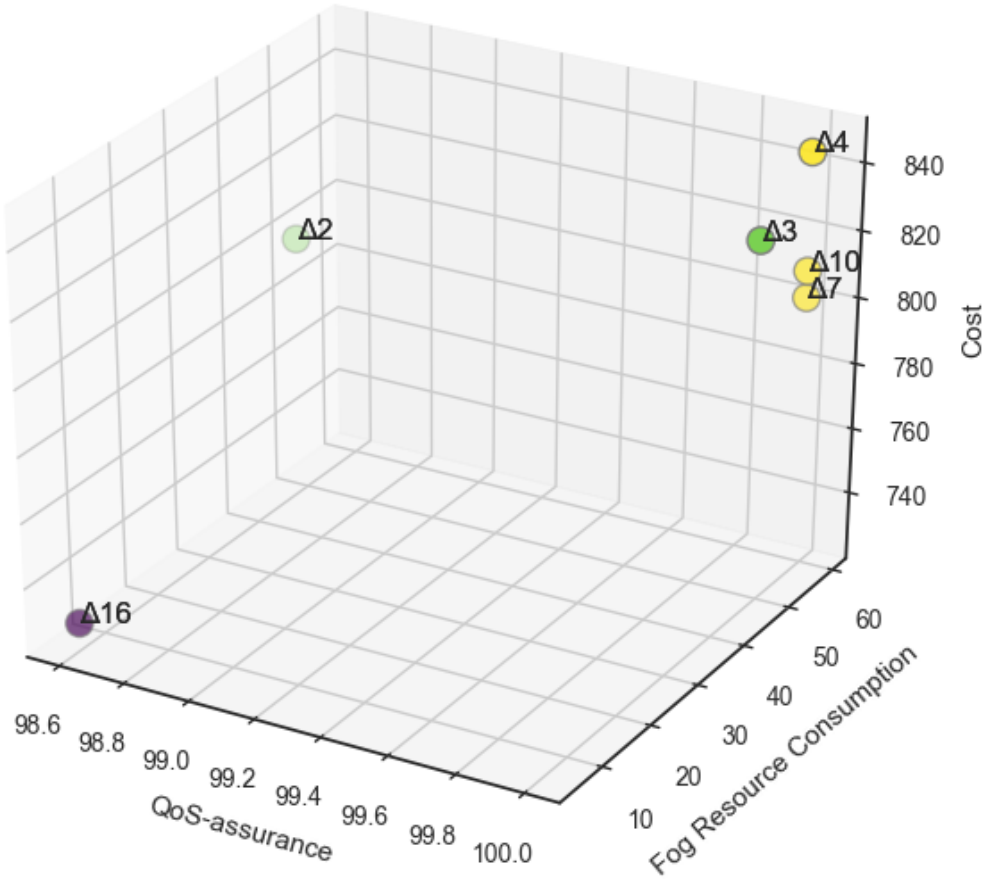
DeploymentID	IoTController	DataStorage	Dashboard
Δ1	Fog 2	Fog 3	Cloud 2
Δ2	Fog 2	Fog 3	Cloud 1
Δ3	Fog 3	Fog 3	Cloud 1
Δ4	Fog 2	Fog 3	Fog 1
Δ5	Fog 1	Fog 3	Cloud 1
Δ6	Fog 3	Fog 3	Cloud 2
Δ7	Fog 3	Fog 3	Fog 2
Δ8	Fog 3	Fog 3	Fog 1
Δ9	Fog 1	Fog 3	Cloud 2
Δ10	Fog 1	Fog 3	Fog 2
Δ11	Fog 1	Fog 3	Fog 1
Δ12	Fog 2	Cloud 2	Fog 1
Δ13	Fog 2	Cloud 2	Cloud 1
Δ14	Fog 2	Cloud 2	Cloud 2
Δ15	Fog 2	Cloud 1	Cloud 2
Δ16	Fog 2	Cloud 1	Cloud 1
Δ17	Fog 2	Cloud 1	Fog 1

Five output deployments satisfy the QoS and budget constraints imposed by the system integrators. 3, 4, 7 and 10 all feature 100% QoS-assurance

- Among them, 7 is the cheapest in terms of cost, consuming as much Fog resources as 4 and 10, although more with respect to 3
- On the other hand, 2, still showing QoS-assurance above 98% and consuming as much Fog resources as 3, can be a good compromise at the cheapest monthly cost of e800

Example (cont.) – Questions:

- *Q3 - Would there be any deployment that complies with all previous requirements and reduces financial cost and/or consumed Fog resources when upgrading from 3G to 4G at Fog 2?*



We change the Internet access at Fog 2 from 3G to 4G. This increases the monthly expenses by e20.
FogTorch now reveals six new eligible deployments in addition to the previous output.
Among those, only 16 turns out to meet also the QoS and budget constraints that the system integrators require.
Interestingly, 16 costs e70 less than the best candidate for Q1 (2), whilst sensibly reducing Fog resource consumption.
Hence, overall, the change from 3G to 4G would lead to an estimated monthly saving of e50 with 16 with respect to 2.


Fog computing?
Deploying apps through the Fog
Concluding remarks

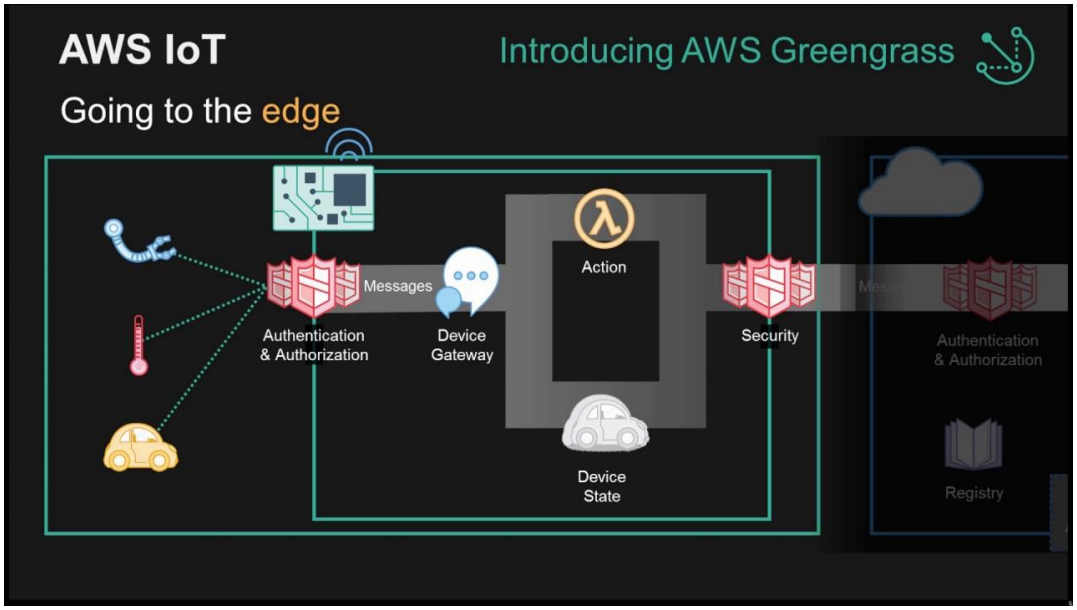
- Growing industrial and academic interest on fog computing (hype?)

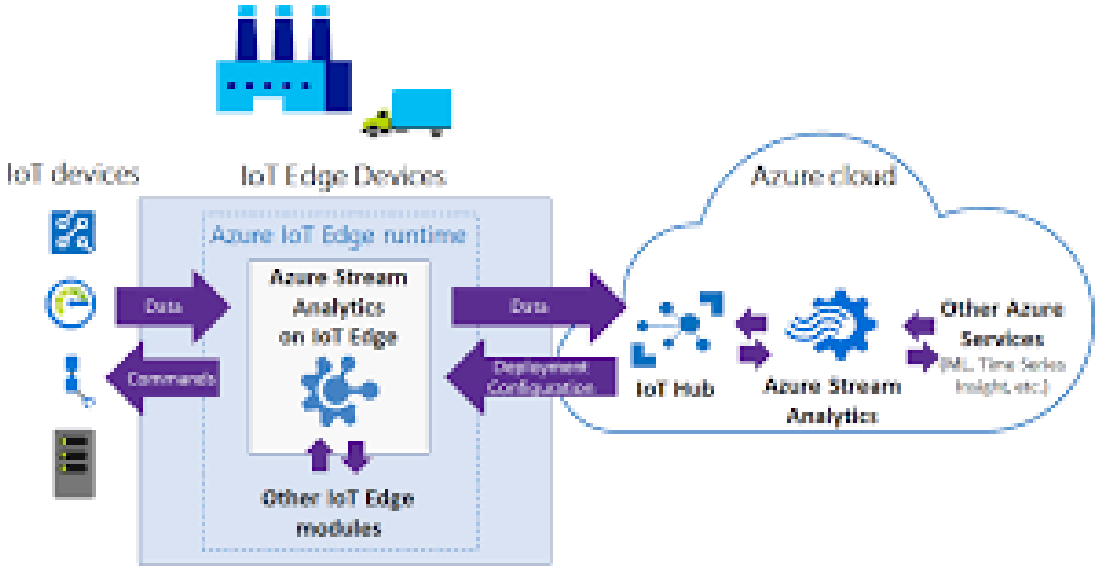
- Various open challenges:
  - Privacy and security
  - Faults
  - Mobility
  - (standardization of) F2F, F2C, F2T interfaces
  - Testbeds

- Business models

Through the Fog

University project aiming at devising new models and techniques to deploy existing applications over the fog, to program new fog applications and to support **fog computing**.


AWS IoT
Introducing AWS Greengrass
Going to the edge
Messages
Authentication & Authorization
Device Gateway
Action
Device State
Security
Authentication & Authorization
Registry


IoT devices
IoT Edge Devices
Azure cloud
Azure IoT Edge runtime
Azure Stream Analytics on IoT Edge
Data
Commands
Data
Deployment Configuration
IoT Hub
Azure Stream Analytics
Other Azure Services
Other IoT Edge modules


CISCO drones