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IoT Cloud Systems

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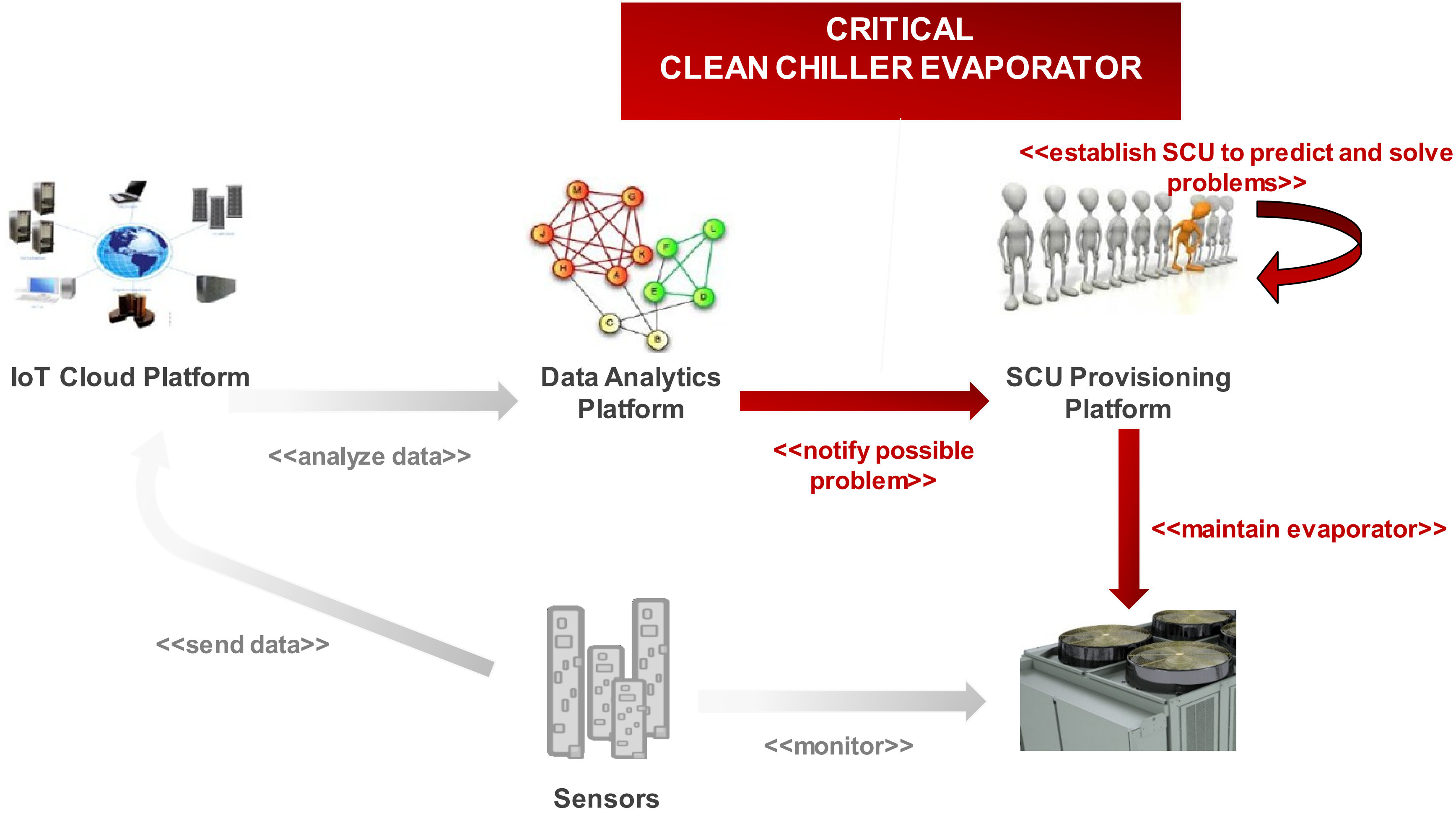
Distributed Systems Group

Outline

- Cloud computing
- Internet of Things (IoT)
- IoT and Cloud integration models
- IoT Cloud Systems
- Services Engineering for IoT cloud systems

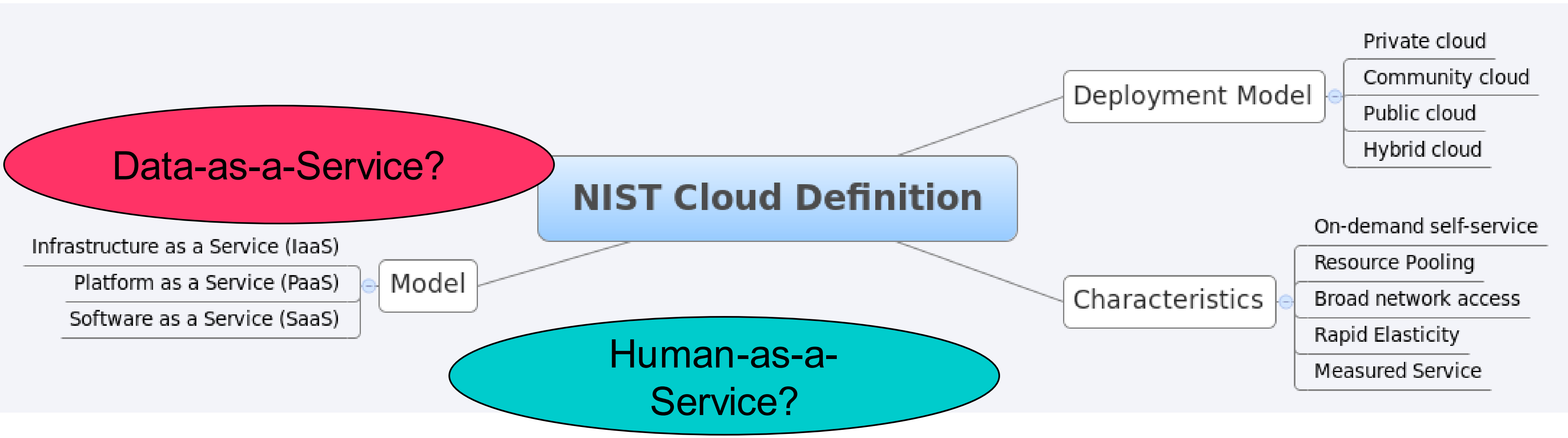
Example: Predictive Maintenance



NIST Cloud definitions

"This cloud model promotes availability and is composed of five essential **characteristics**, three **service models**, and four **deployment models**."

Source: NIST Definition of Cloud Computing v15, http://csrc.nist.gov/groups/SNS/cloud-computing/cloud-def-v15.doc



Some enabling techniques

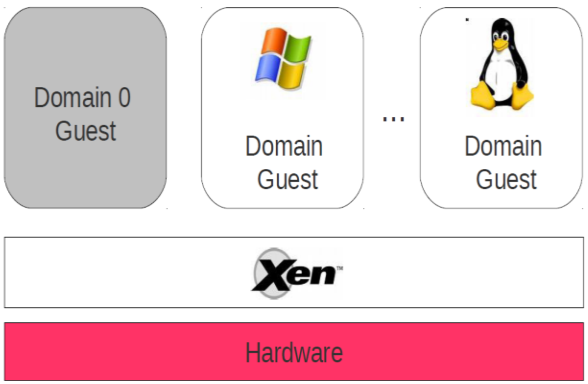
- On-demand self- services
  - Self-*, automatic service composition
- Resource pooling
  - Virtualization, Cluster/Grid techniques, data center management
- Broad network access
  - SOA, mobile, Internet technologies, interoperability APIs
- Rapid elasticity
  - Self-*, resource management, performance monitoring
- Measured service
  - Service contract, monitoring, billing

Key engineering techniques

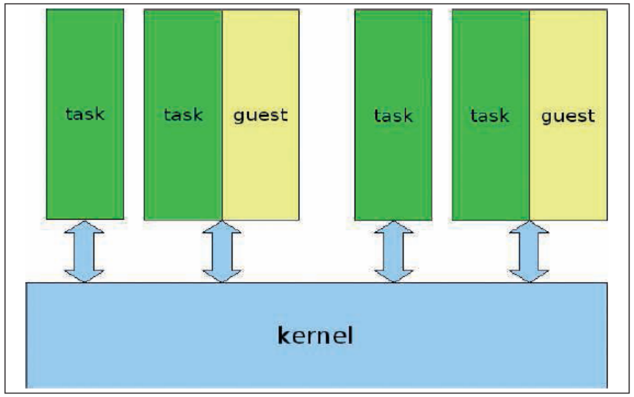
- Virtualization
  - Compute resources (VMs, containers), networks, data, etc.
- Composition and orchestration
  - REST/SOAP services, scalable protocols and rich sets of connectors for integration
  - Private, Public and Hybrid clouds
  - Complex topologies of resources/services
- On demand and pay-per-use
  - Dynamic and runtime features (for virtualization, composition, and orchestration)
  - Hot deployment techniques, fine-grained monitoring
- Elasticity engineering
  - Resources, quality and cost based on customer-specific runtime constraints

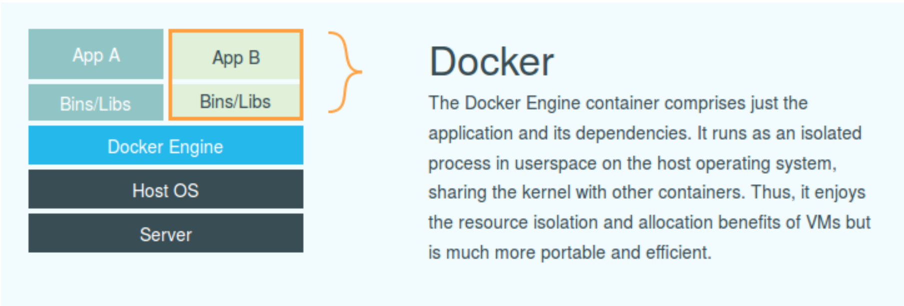
Virtualization of machines using hypervisors

Source: The XEN Hypervisor (http://www.xen.org/)



Source: Kernel-based Virtual Machine (http://www.linux-kvm.org/page/Main_Page)





Virtualization is a powerful concept: we can apply virtualization techniques virtually for everything!

Hybrid and Multi Clouds

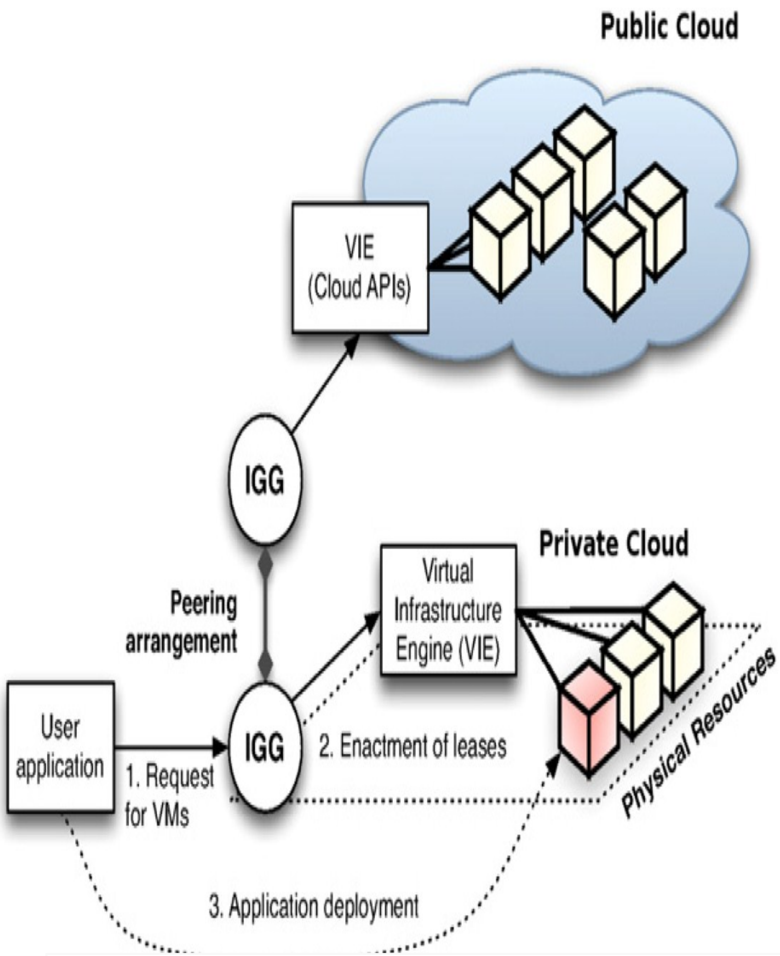
NIST on Hybrid clouds: *"The cloud infrastructure is **a composition of two or more clouds (private, community, or public)** that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds)."*

- Multi-cloud environments/federated clouds
  - Switch and combine multiple clouds
  - May or may not be "*bound together by standardized or proprietary technology*"

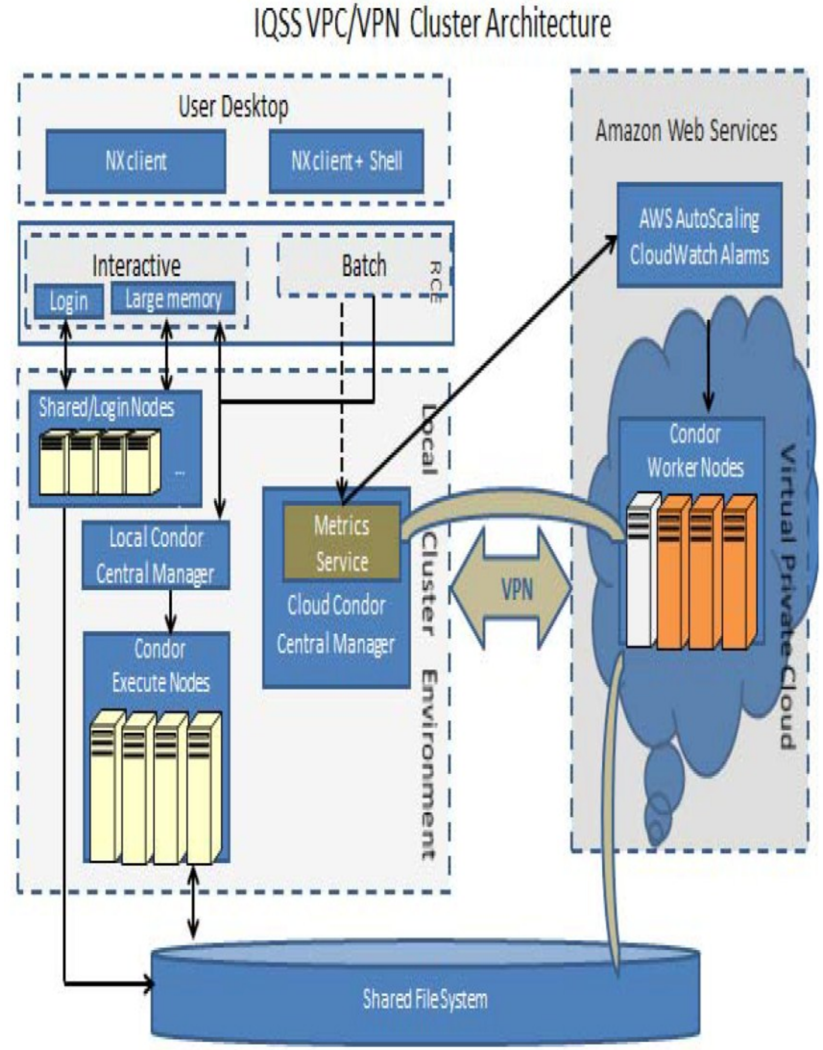
Engineering your services on top of distributed clouds

- Interoperability protocols for multiple level of abstractions
  - Virtual machines, networks, cloud management APIs
- Security cross multiple domains
- Complex data governance policies and service contracts
- Complex billing and monitoring
- Which resource models you need?
  - Cloud bursting
  - Multi-cloud distributed services

Examples



Source: Bahman Javadi, Jemal Abawajy, Rajkumar Buyya, Failure-aware resource provisioning for hybrid Cloud infrastructure, Journal of Parallel and Distributed Computing, Volume 72, Issue 10, October 2012, Pages 1318-1331, ISSN 0743-7315,



Source: Steven Abramson, William Horka, and Leonard Wisniewski. 2014. A Hybrid Cloud Architecture for a Social Science Research Computing Data Center. In Proceedings of the 2014 IEEE 34th International Conference on Distributed Computing Systems Workshops (ICDCSW '14). IEEE Computer Society, Washington, DC, USA, 45-50

Hybrid cloud process

Source:
Neal Leavitt. 2013. Hybrid Clouds Move to the Forefront. Computer 46, 5 (May 2013), 15-18.

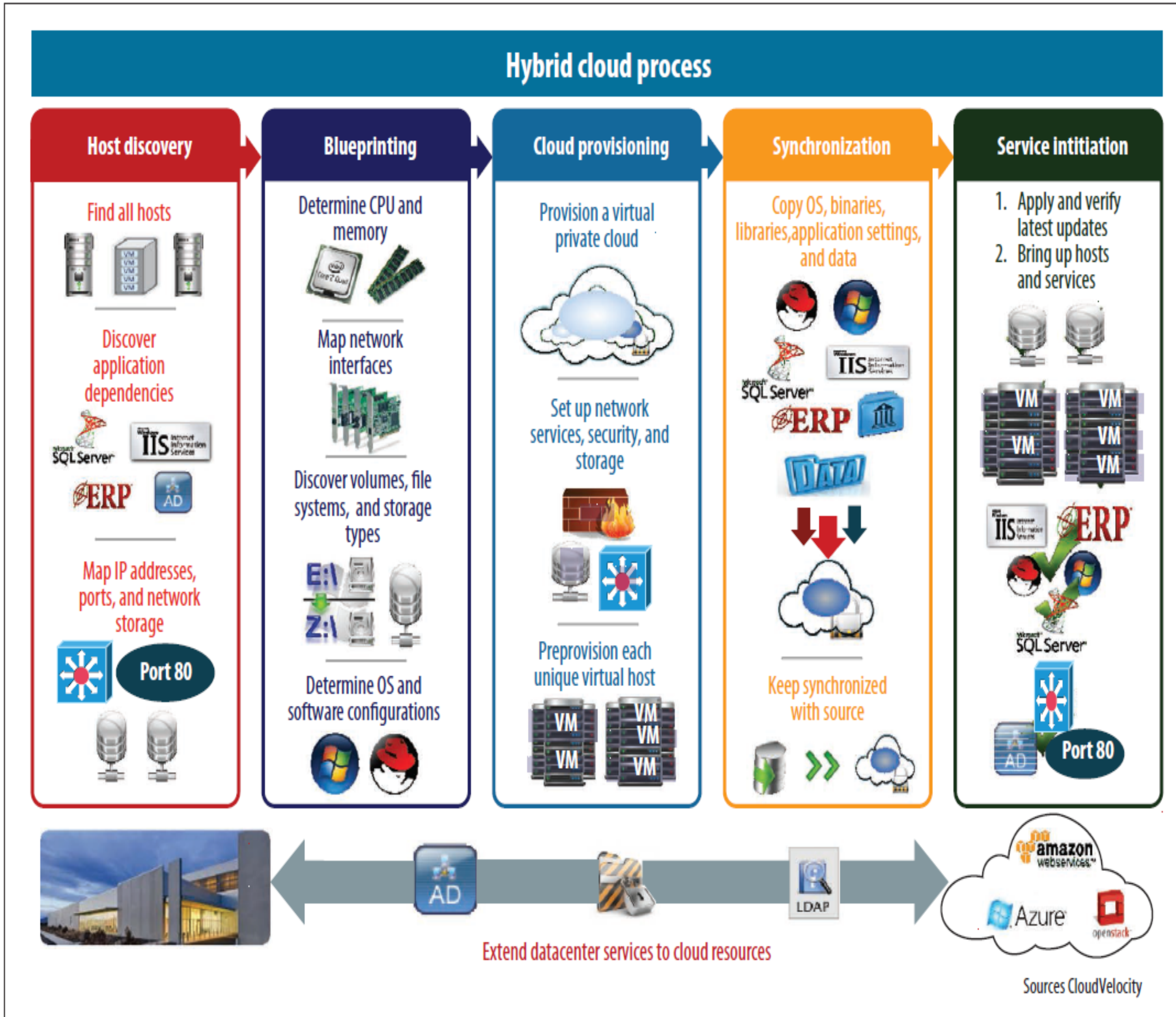
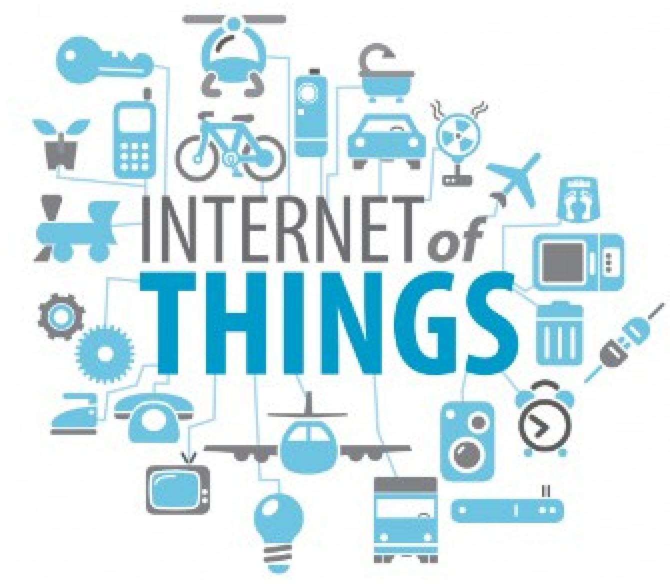


Figure 1. Critical steps for deploying a hybrid-cloud operating model for use with a traditional multitier application.

INTERNET OF THINGS (IOT)

Internet of Things (IoT)

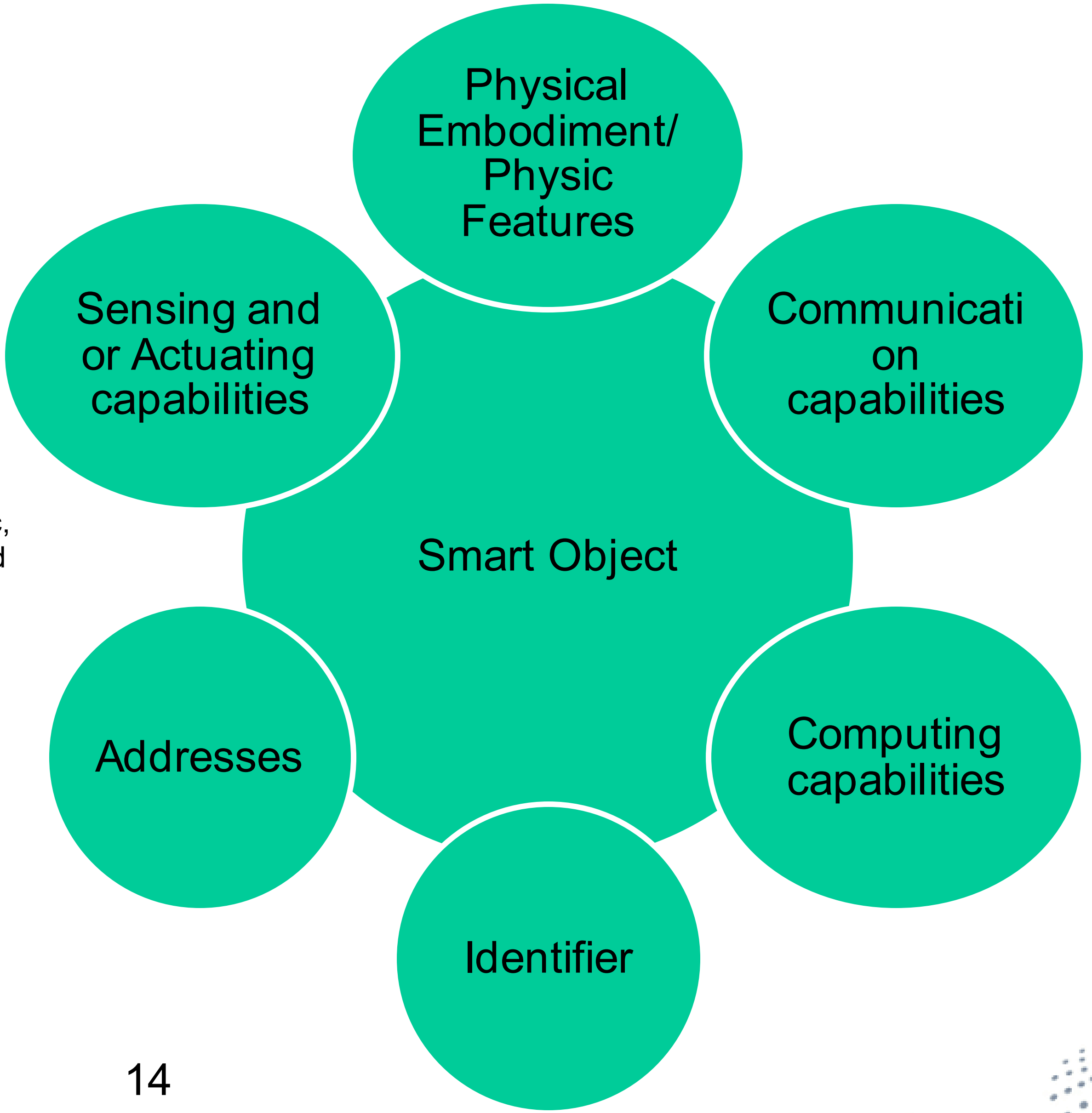
- Things and Objects
  - Home
  - Official Business,
  - Hospital
  - Factory
  - Infrastructure



http://www.control4.com/blog/2014/03/the-internet-of-things-and-the-connected-home

- How to make such things and objects being connected and interacting each other? To be part of the Internet?
  - Why do we need this?

Smart Object Encapsulating Thing

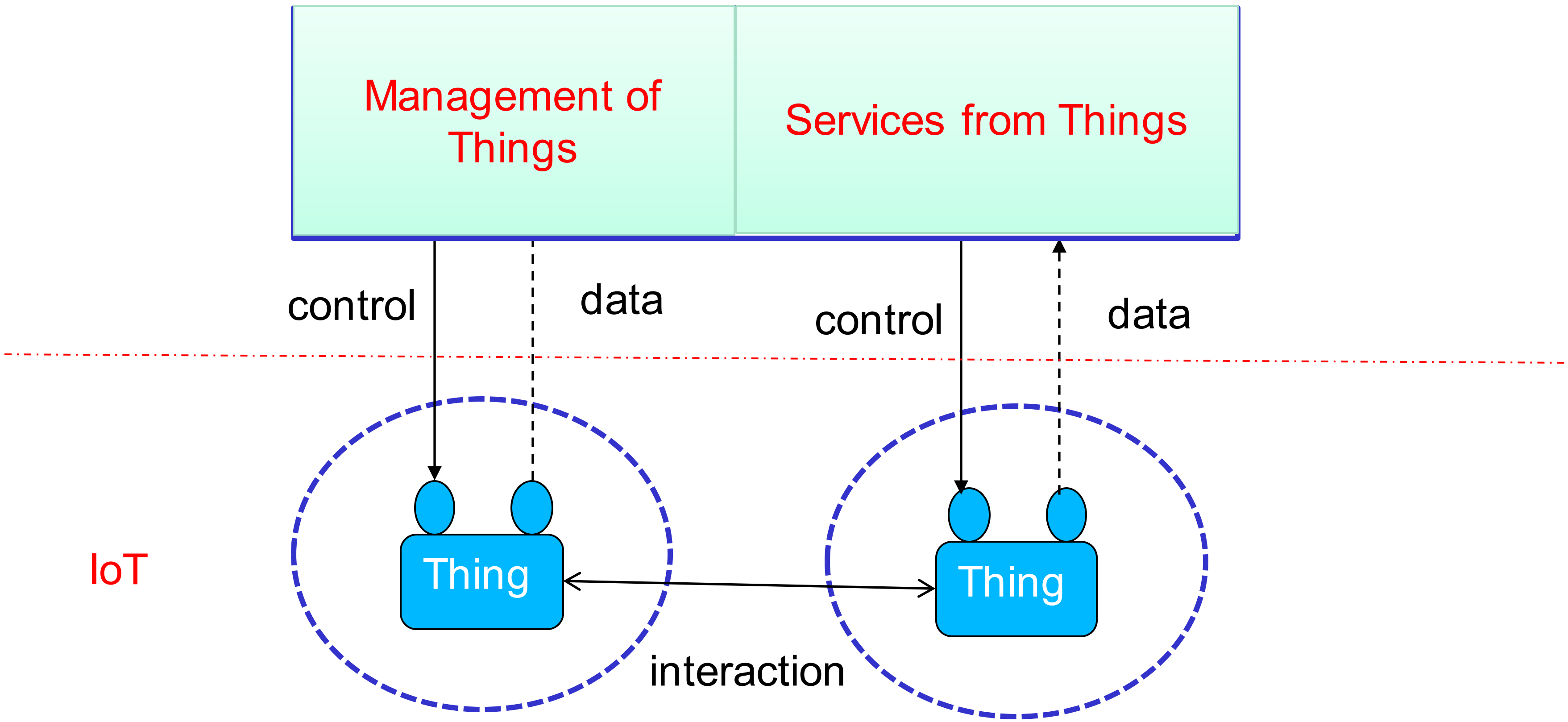


Daniele Miorandi, Sabrina Sicari, Francesco De Pellegrini, Imrich Chlamtac, Internet of things: Vision, applications and research challenges, Ad Hoc Networks, Volume 10, Issue 7, September 2012, Pages 1497-1516

Key properties

- Diversity
  - Networks: Bluetooth, Ethernet, GPRS, LoRa, ZigBee, Wi-Fi, NFC/RFID, GPS, LonWorks, Modbus, RS-232, RS-485, etc.
  - Application protocols (HTTP, MQTT, CoAP, etc.)
- Scale
  - Network scale: Body → Home → City → Internet-scale!
  - Vertical/horizontal domain objects to be studied/managed
- Complexity
  - Software stack, Network topology

Management versus Service Offering



Connecting Things to Services

Conceptual view

Where is the boundary between IoT and clouds?

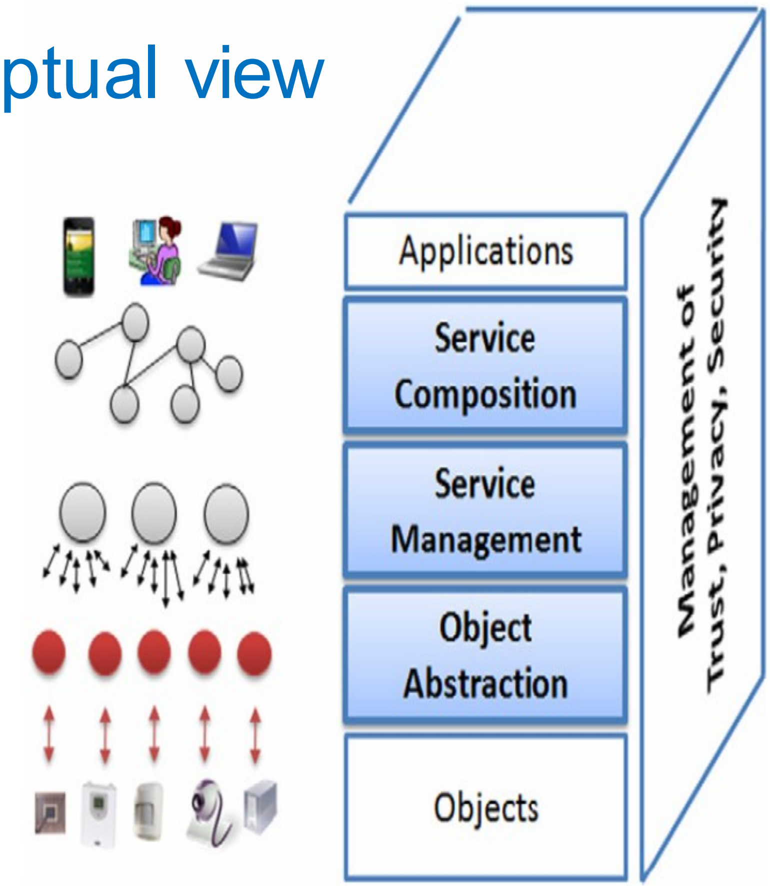


Fig. 2. SOA-based architecture for the IoT middleware.

Source: Luigi Atzori, Antonio Iera, Giacomo Morabito, The Internet of Things: A survey, Computer Networks, Volume 54, Issue 15, 28 October 2010, Pages 2787-2805, ISSN 1389-1286

Common Interactions

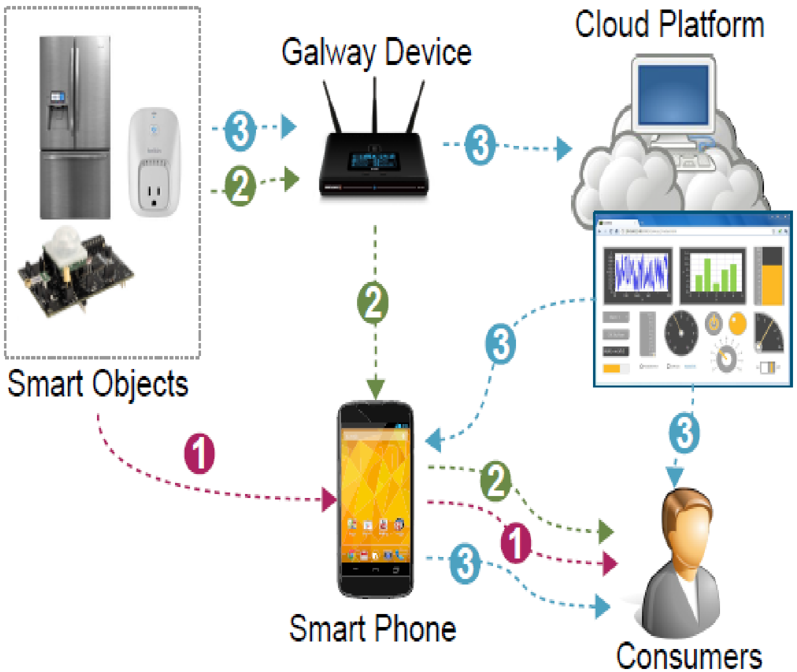
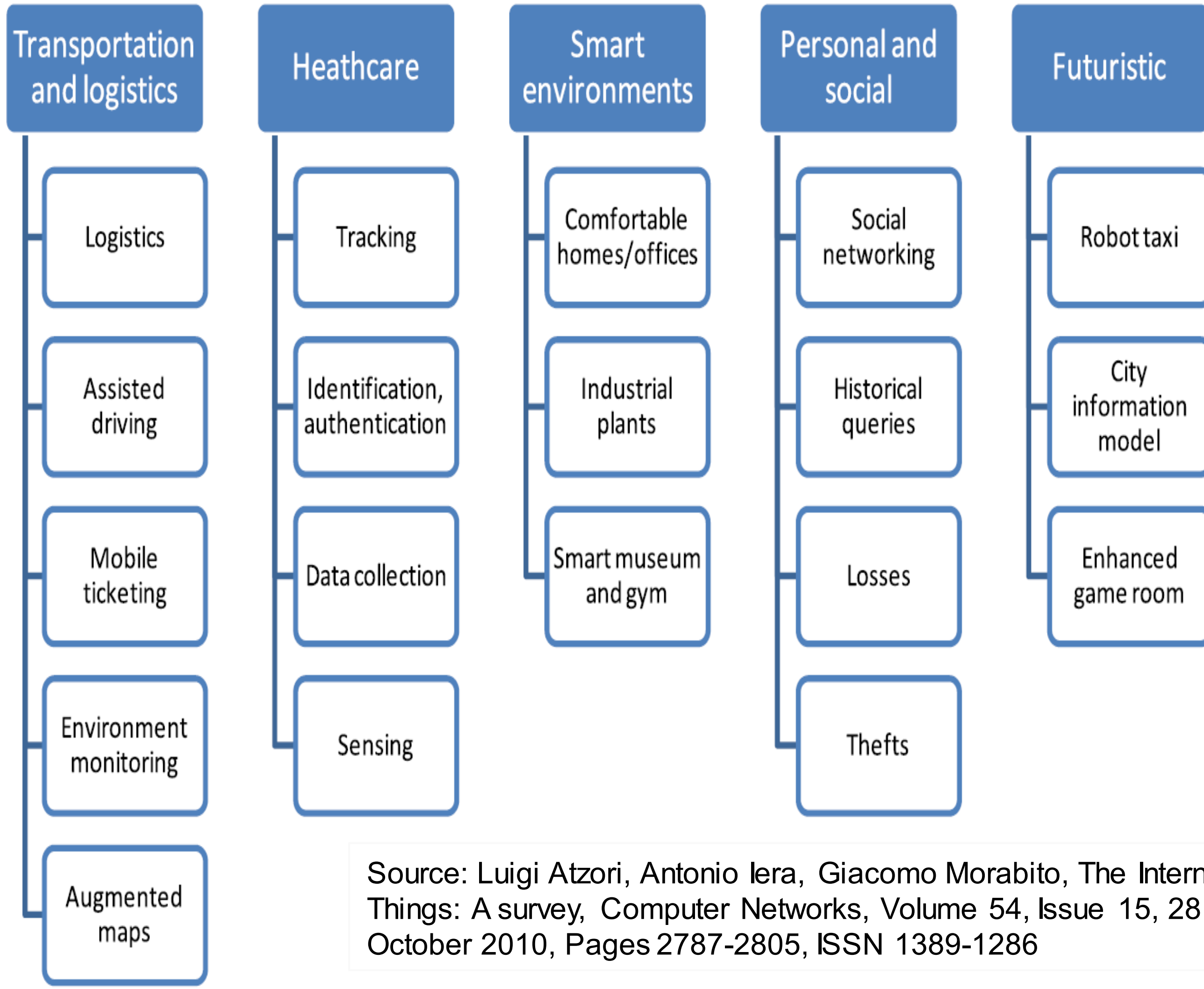


Fig. 2. Common Communication Patterns in IoT Applications. There are mainly three types of common patterns

Source: Charith Perera, Chi Harold Liu, Srimal Jayawardena: The Emerging Internet of Things Marketplace From an Industrial Perspective: A Survey. IEEE Trans. Emerging Topics Comput. 3(4): 585-598 (2015)

Application domains

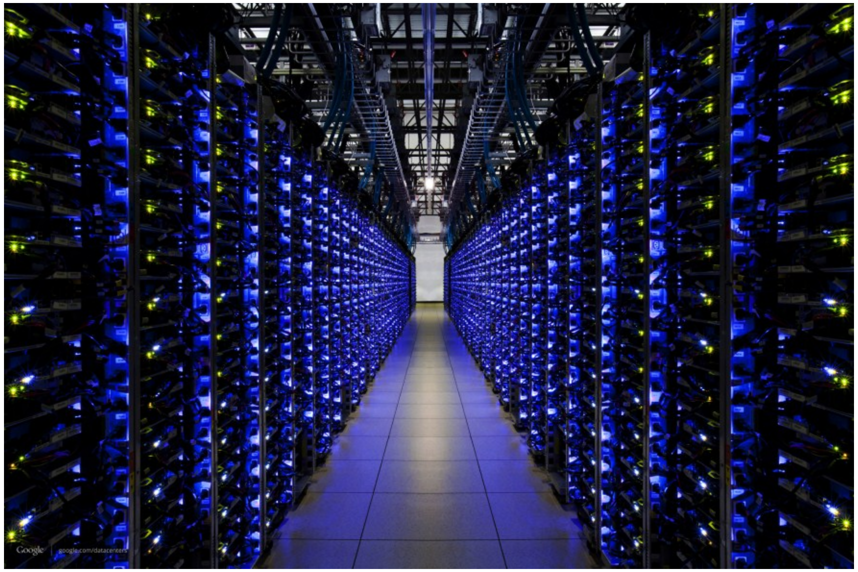


Source: Luigi Atzori, Antonio Iera, Giacomo Morabito, The Internet of Things: A survey, Computer Networks, Volume 54, Issue 15, 28 October 2010, Pages 2787-2805, ISSN 1389-1286

IOT + CLOUD INTEGRATION

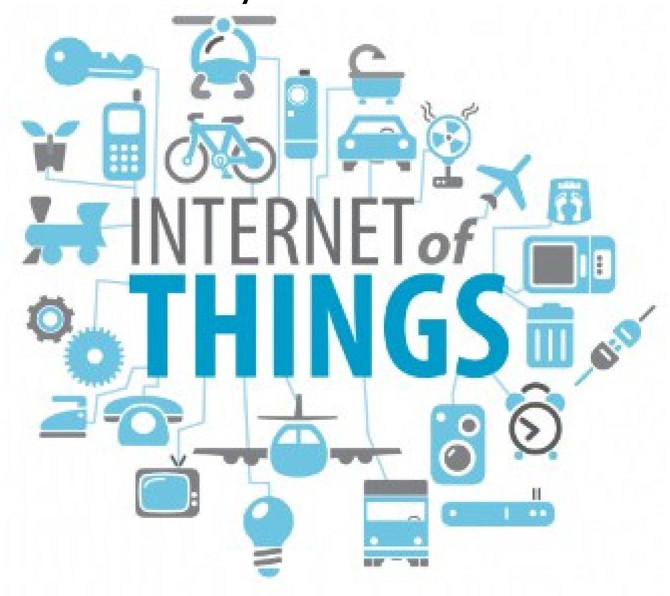
Connecting data centers to IoT

Data Center: Processing, Storage, Networking, Management, Distribution



Source: http://www.infoescola.com/wp-content/uploads/2013/01/datacenter-google.jpg

IoT devices: Gateways, Sensors, Actuators, Topologies of Gateways



Source: http://www.control4.com/blog/2014/03/the-internet-of-things-and-the-connected-home

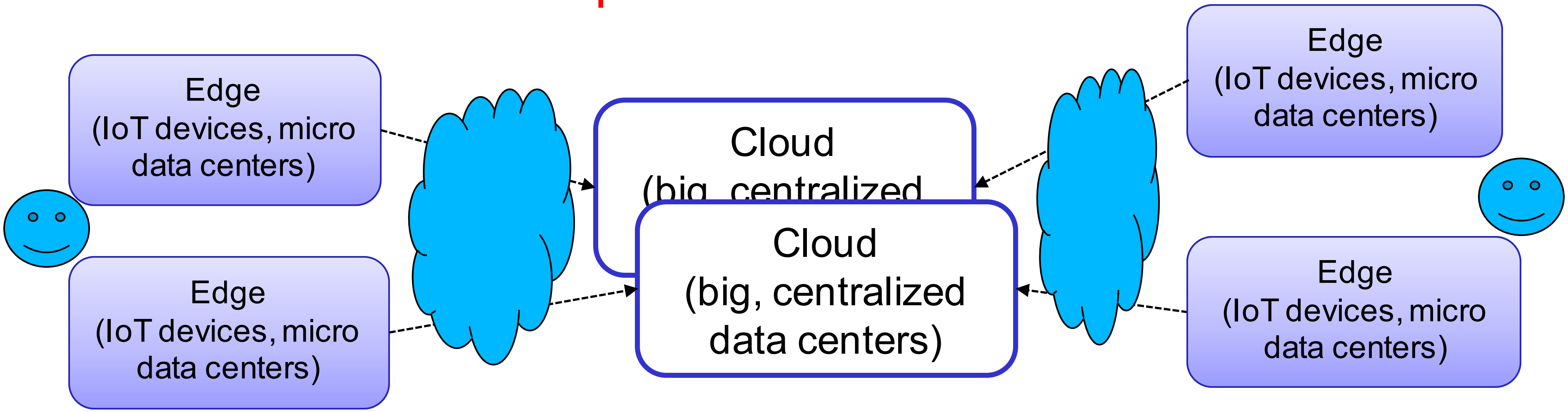
IoT and Clouds

- IoT elements at the edge
  - Software sensors and actuators interfacing "Things"
  - IoT Gateways: processing, relaying and controlling
    - lightweighted hardware/software acting as intermediate nodes between sensors/actuators and back-end cloud services
- Cloud services at (big) centralized data centers
  - Software services and data: complex event processing, data services, data analytics, etc.
- Connectivity
  - Network middleware and protocols within/among IoT and clouds
- IoT-to-Cloud
  - Several systems in the middleware

Current trends in IoT/CPS and Clouds

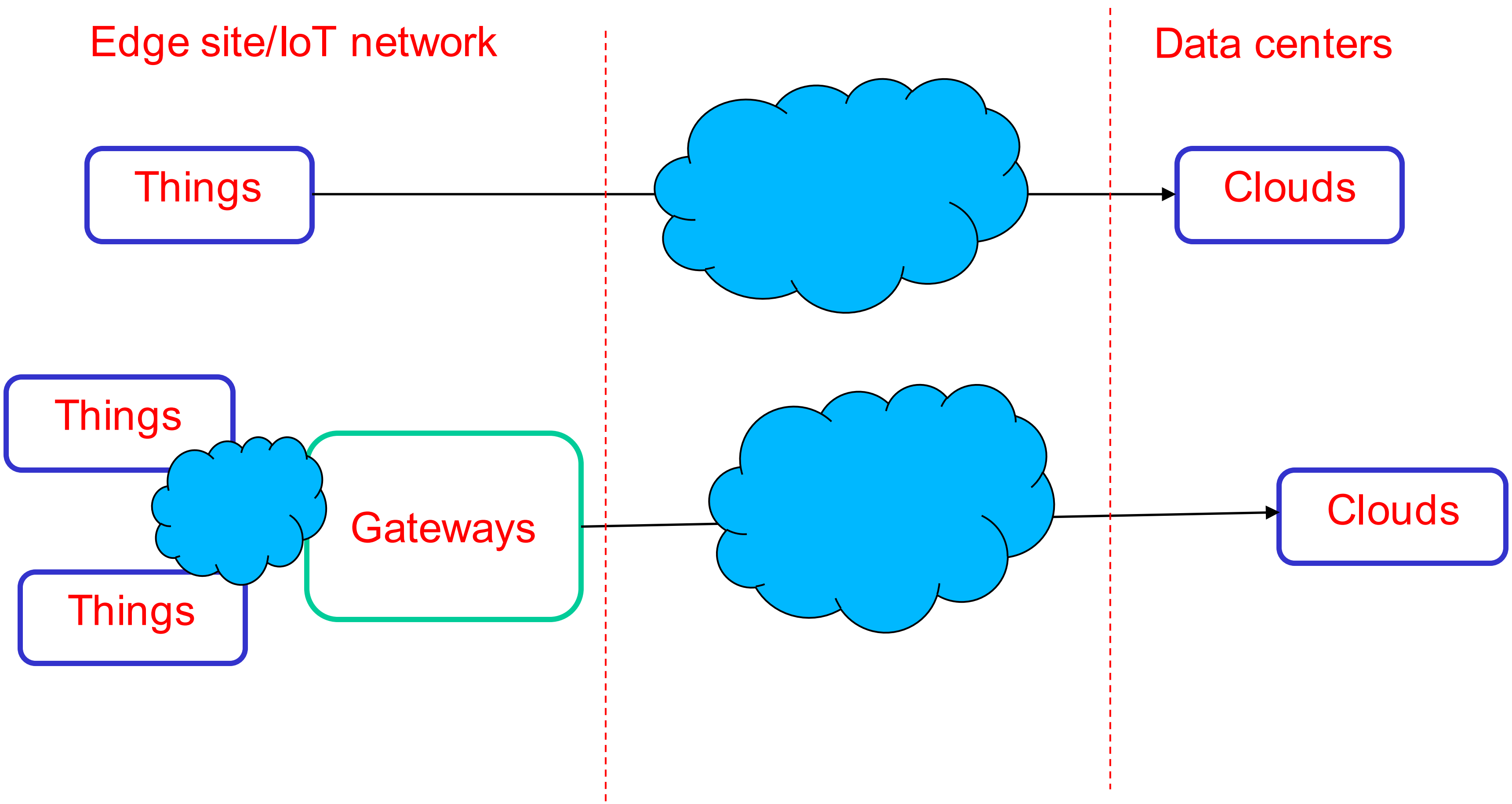
- Terms or buzz-words?
  - Fog computing, edge computing, Mobile-Edge Computing, Edge-centric computing, cloudlets, Cloud of IoTs, distributed clouds (centralized data centers and micro data centers), cloud-assisted IoT, etc.

Simple view



Cloud-assisted IoT

Cloud-centric IoT approach

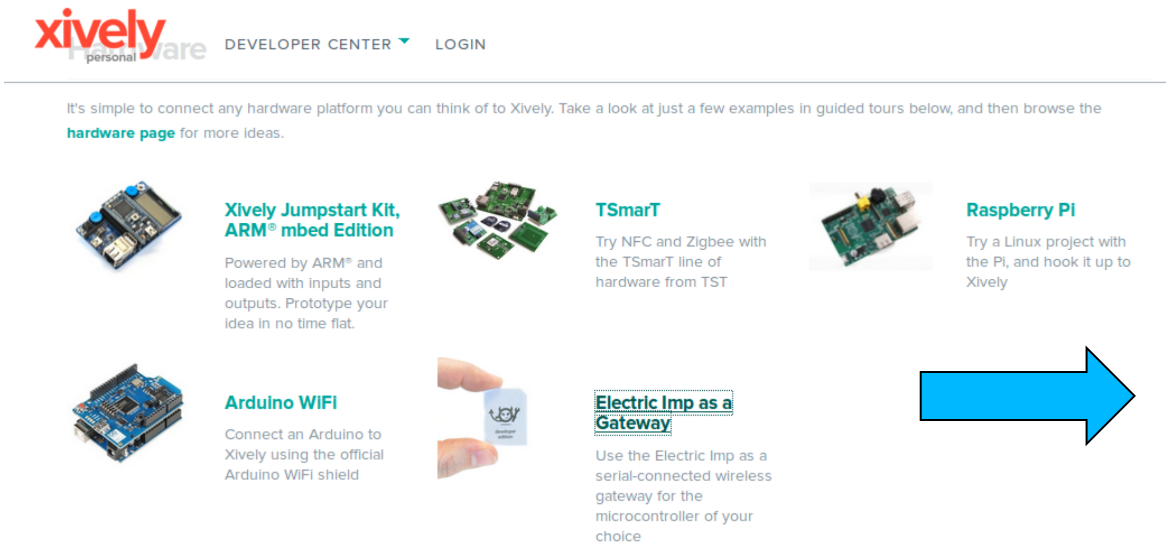


Industrial systems

ThingWorx
A PTC Business

xively
by LogMeIn

Example – Look at the Internet



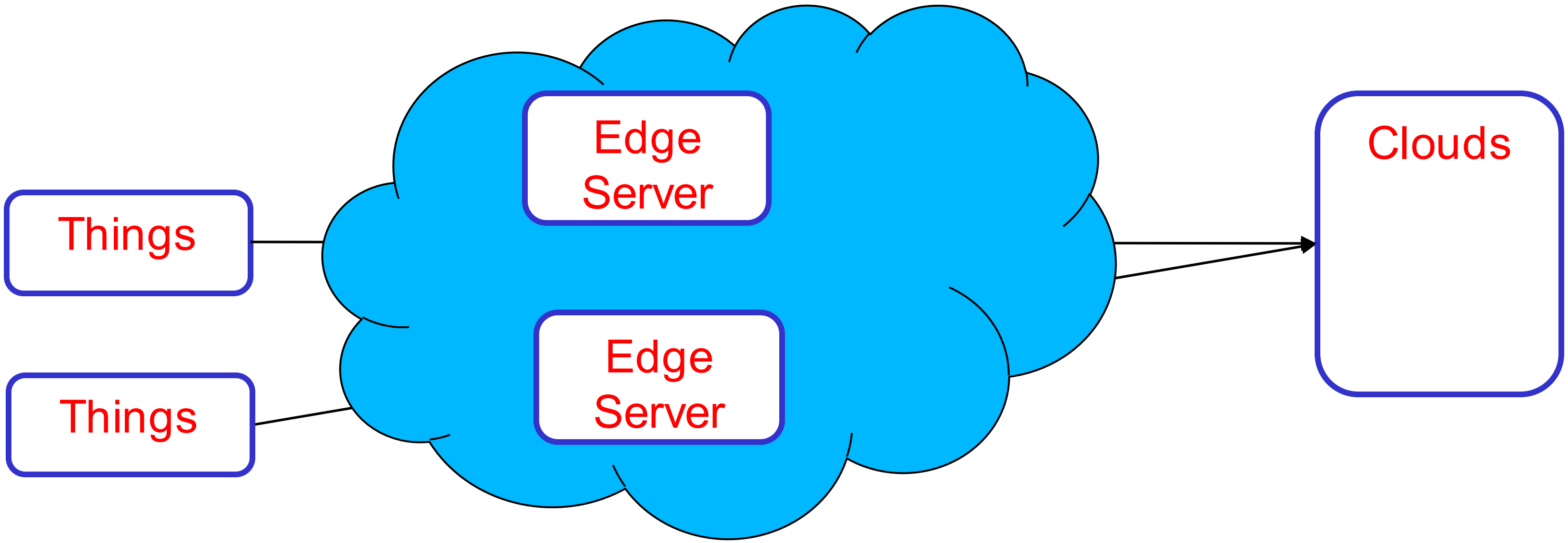
Xively Platform in Cloud

http://www.ptc.com/File%20Library/Axeda/whitepapers/Axeda_WP_Platform_TechOverview_011714_singles_PRINT_no_crops.pdf

Read: Alessio Botta, Walter de Donato, Valerio Persico, Antonio Pescapè: On the Integration of Cloud Computing and Internet of Things. 23-30

Mobile-Edge computing/Fog Computing

Edge-centric IoT approach



Edge server: network functions, storage, processing, etc

Mobile Edge Computing

"Mobile Edge Computing provides an IT service environment and cloud computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers. The aim is to reduce latency, ensure highly efficient network operation and service delivery, and offer an improved user experience."

Source ETSI, http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp11_mec_a_key_technology_towards_5g.pdf

Video analytics + business applications/public security

Use Case 3: Video Analytics

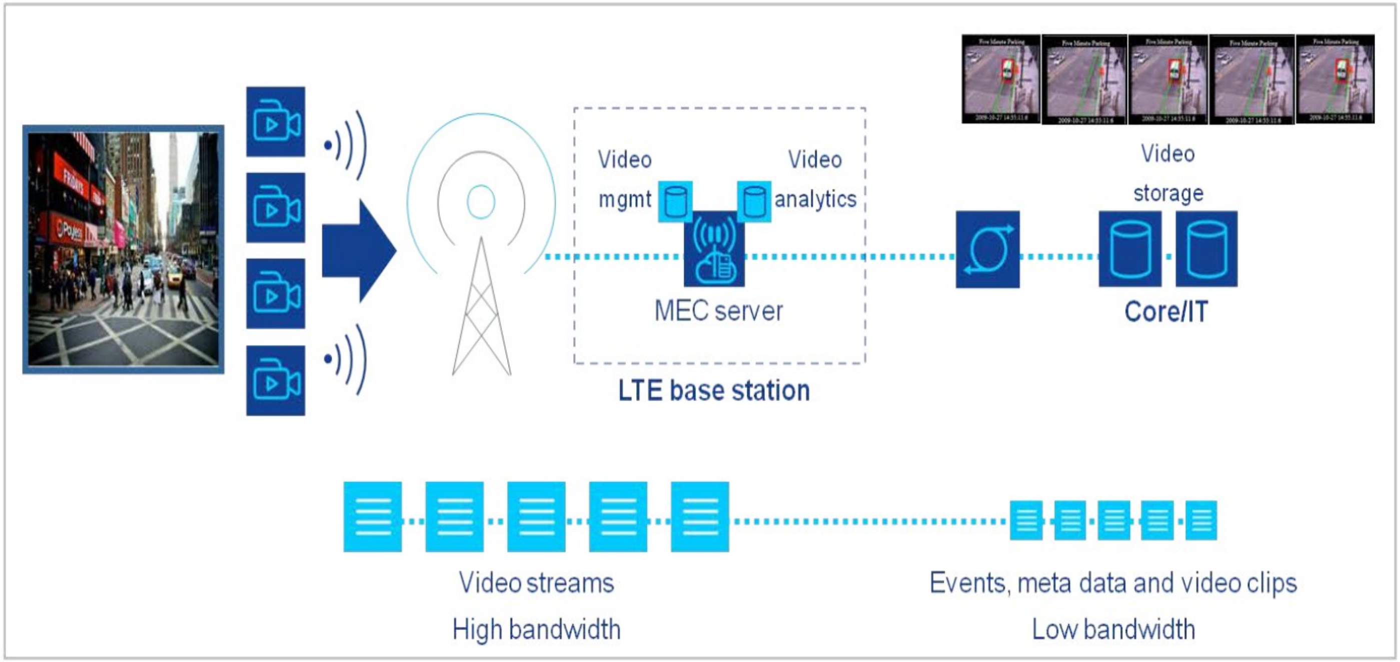


Figure 4: Example of video analytics

Figure source:
https://portal.etsi.org/portals/0/tbpages/mec/docs/mobile-edge_computing_-_introductory_technical_white_paper_v1%2018-09-14.pdf

Micro data center

Source:Mohammad Aazam, Eui-Nam Huh:
Fog Computing Micro Datacenter Based Dynamic Resource Estimation and Pricing Model for IoT. AINA 2015: 687-694

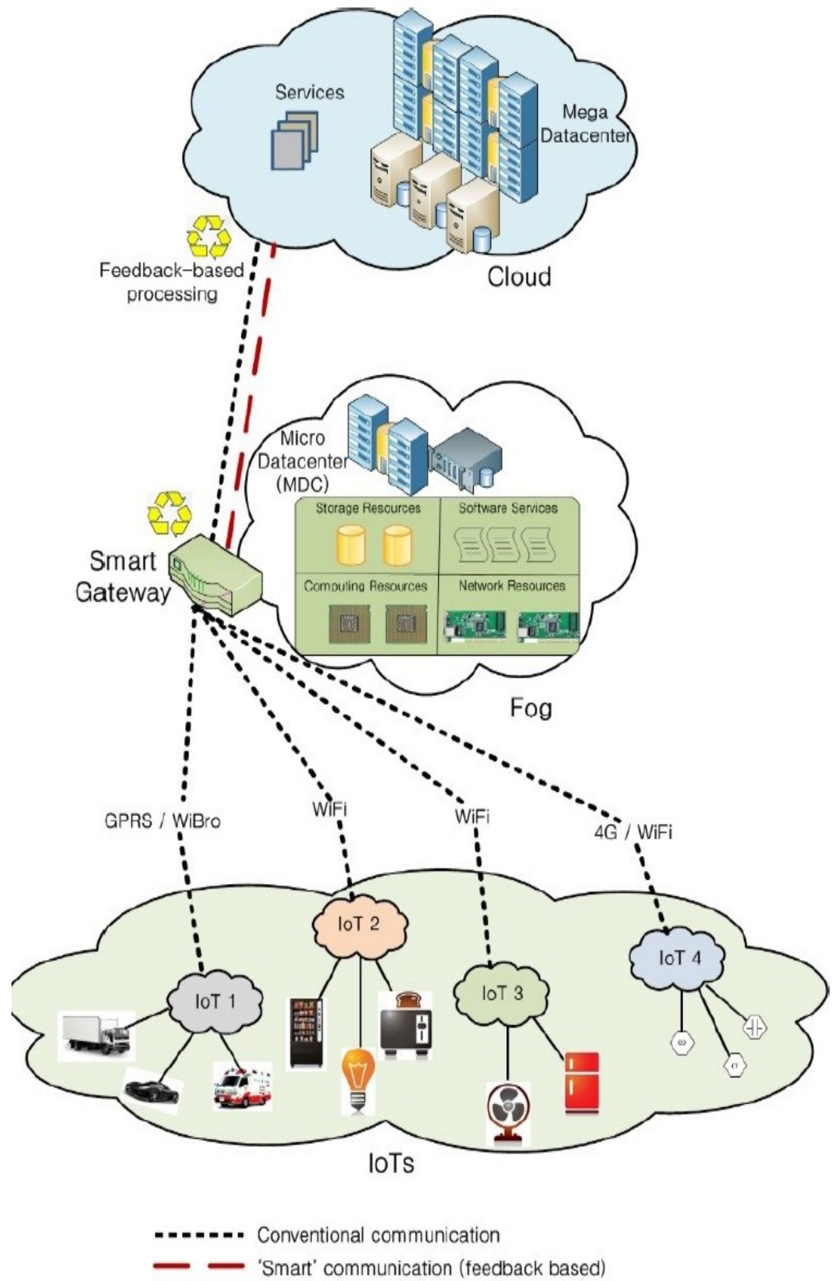
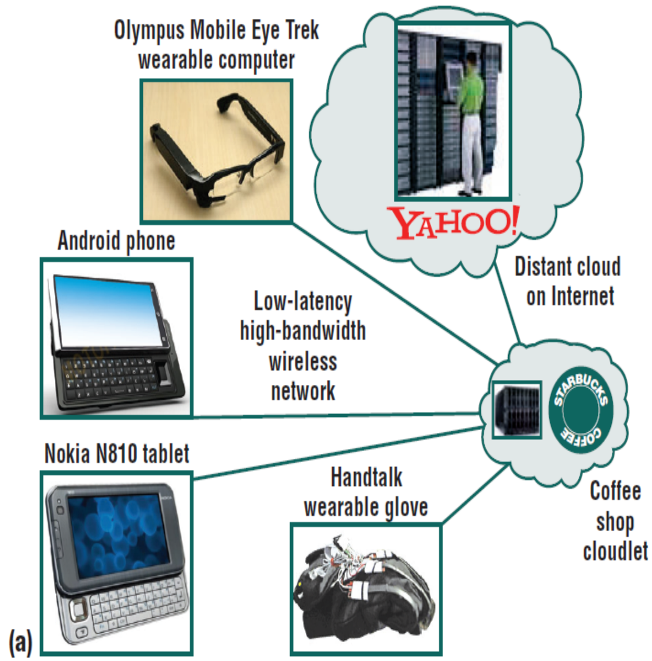


Figure 1. Smart Gateway with Fog computing.

Cloudlet



(b)

	Cloudlet	Cloud
State	Only soft state	Hard and soft state
Management	Self-managed; little to no professional attention	Professionally administered, 24X 7 operator
Environment	"Datacenter in a box" at business premises	Machine room with power conditioning and cooling
Ownership	Decentralized ownership by local business	Centralized ownership by Amazon, Yahoo!, etc.
Network	LAN latency/ bandwidth	Internet latency/ bandwidth
Sharing	Few users at a time	100s-1000s of users at a time

Figure 4. What is a cloudlet? (a) The cloudlet concept involves proximate computing infrastructure that can be leveraged by mobile devices; it has (b) some key differences with the basic cloud computing concept.

Source: Mahadev Satyanarayanan, Paramvir Bahl, Ramón Cáceres, Nigel Davies:
The Case for VM-Based Cloudlets in Mobile Computing. IEEE Pervasive Computing 8(4): 14-23 (2009)

Cloudlet

Mahadev Satyanarayanan, Pieter Simoens, Yu Xiao, Padmanabhan Pillai, Zhuo Chen, Kiryong Ha, Wenlu Hu, Brandon Amos:
Edge Analytics in the Internet of Things. IEEE Pervasive Computing 14(2): 24-31 (2015)

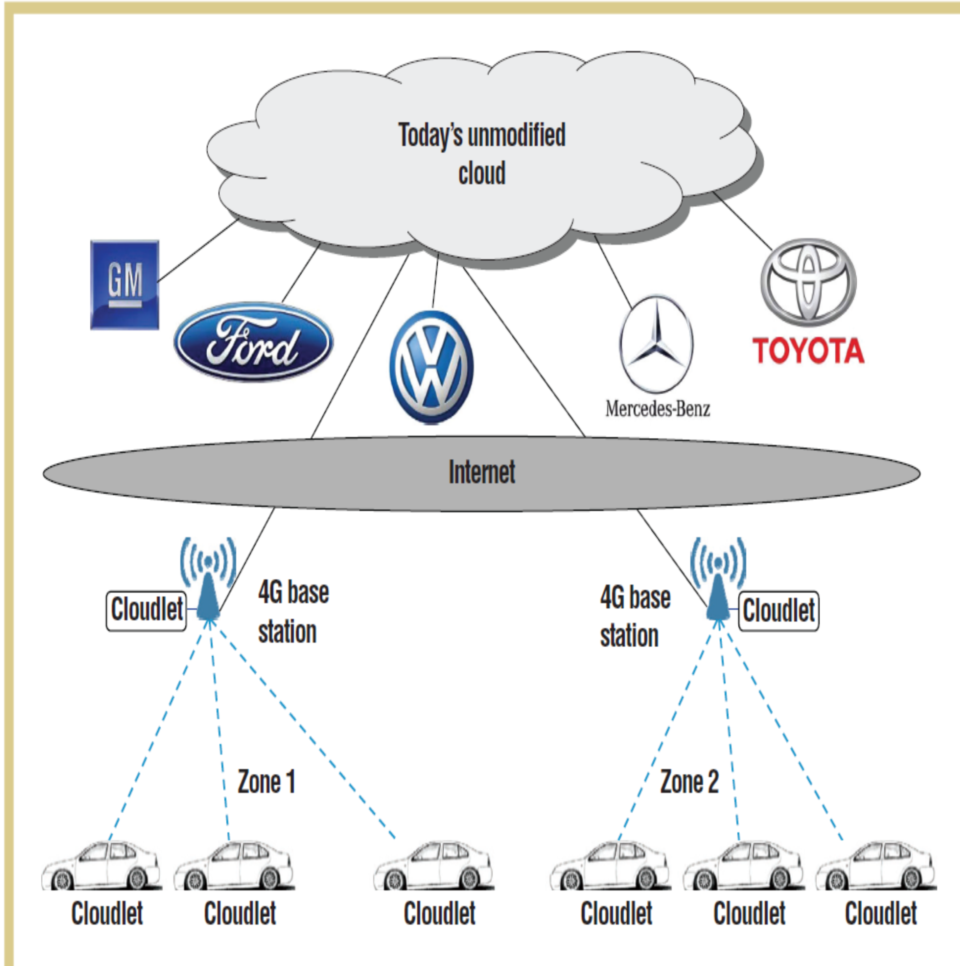


Figure 4. GigaSight for cars. Continuous capture and real-time analytics of car-mounted video cameras can help to improve road safety when shared via cell tower cloudlets.

Today‘s cyber-physical systems

“Cyber-physical systems integrate computation, communication, sensing, and actuation with physical systems to fulfill time-sensitive functions with varying degrees of interaction with the environment, including human interaction.”,

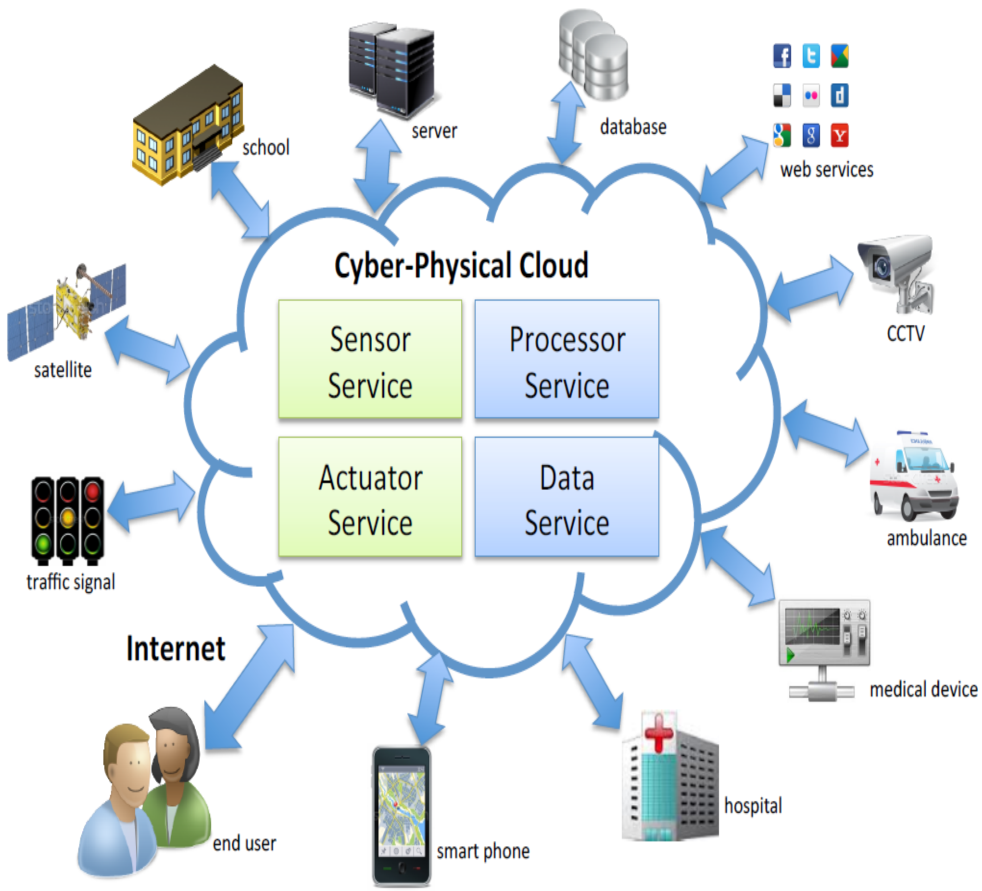
Source NIST, http://www.cpspwg.org/Portals/3/docs/CPS%20PWG%20Draft%20Framework%20for%20Cyber-Physical%20Systems%20Release%200.8%20September%202015.pdf

Today‘s cyber-physical systems

- Physical systems:
  - Things/physical entities
  - Network, sensors, actuators
- Cyber systems
  - Networked services/Cloud services
- Similar to IoT+Cloud?
- But:

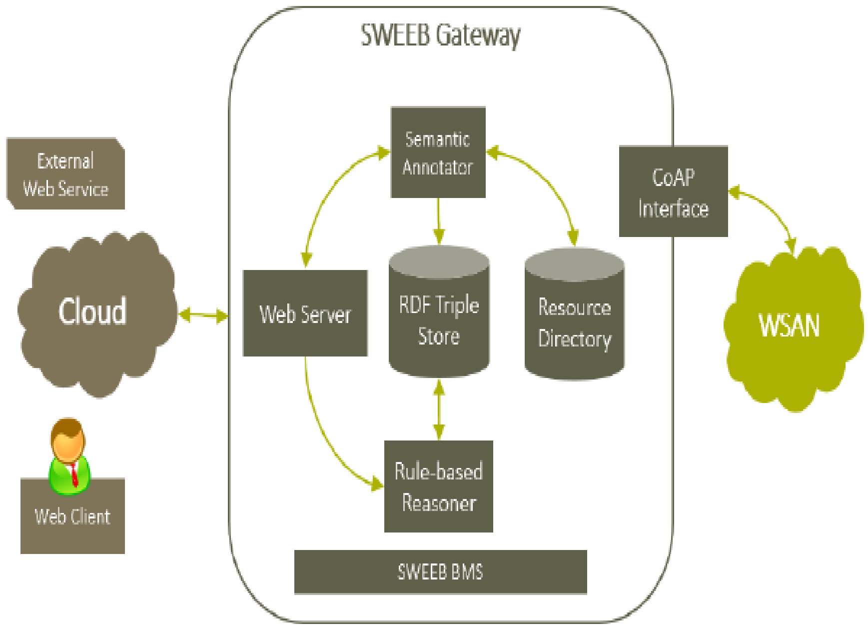
Higher degree of combination and coordination between physical and cyber entities, especially control flows.

Example (1)

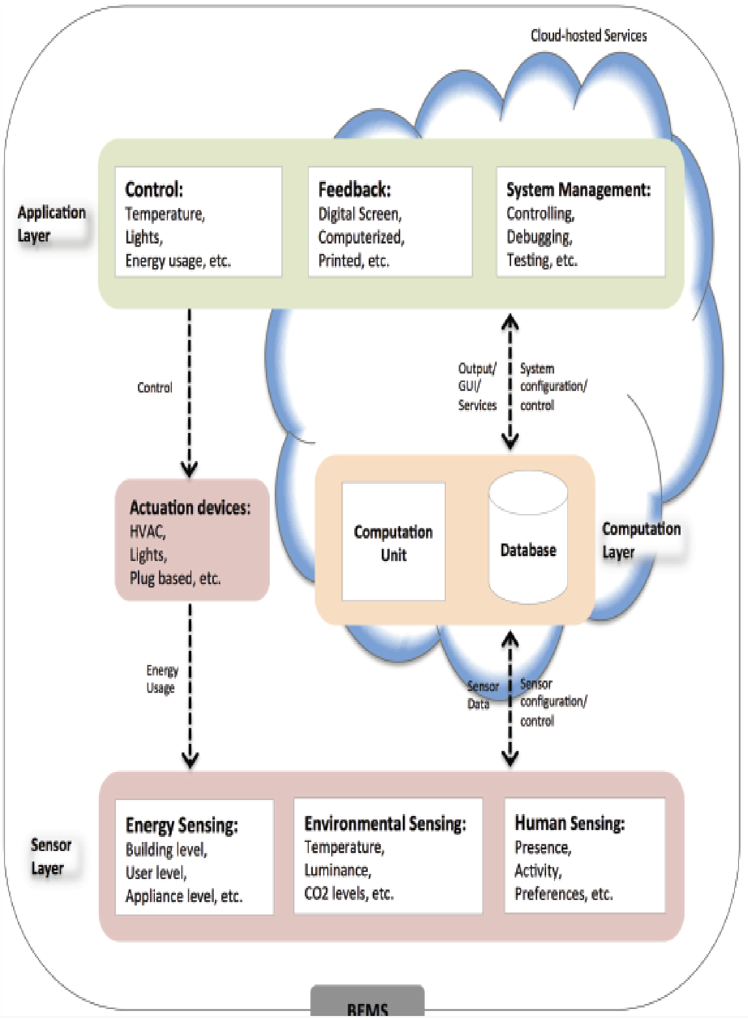


Source: Eric D. Simmon; Kyoung-sook Kim; Eswaran Subrahmanian; Ryong Lee; Frederic J. de Vaulx; Yohei Murakami; Koji Zettsu; Ram D. Sriram, A Vision of Cyber-Physical Cloud Computing for Smart Networked Systems, August 26, 2013, http://www.nist.gov/manuscript-publication-search.cfm?pub_id=914023

Example (2)



Source: SWEEB: Semantic Web-enabled Energy Efficient Buildings
Niccolo' De Caro (Vrije Universiteit Brusse
sensys.acm.org/2013/sensys13DC/decaro.pdf



Source: Aqeel H. Kazmi, Michael J. O'grady, Declan T. Delaney, Antonio G. Ruzzelli, and Gregory M. P. O'hare. 2014. A Review of Wireless-Sensor-Network-Enabled Building Energy Management Systems. ACM Trans. Sen. Netw. 10, 4, Article 66 (June 2014), 43 pages. DOI=10.1145/2532644 http://doi.acm.org/10.1145/2532644

IoT + Cloud integration models

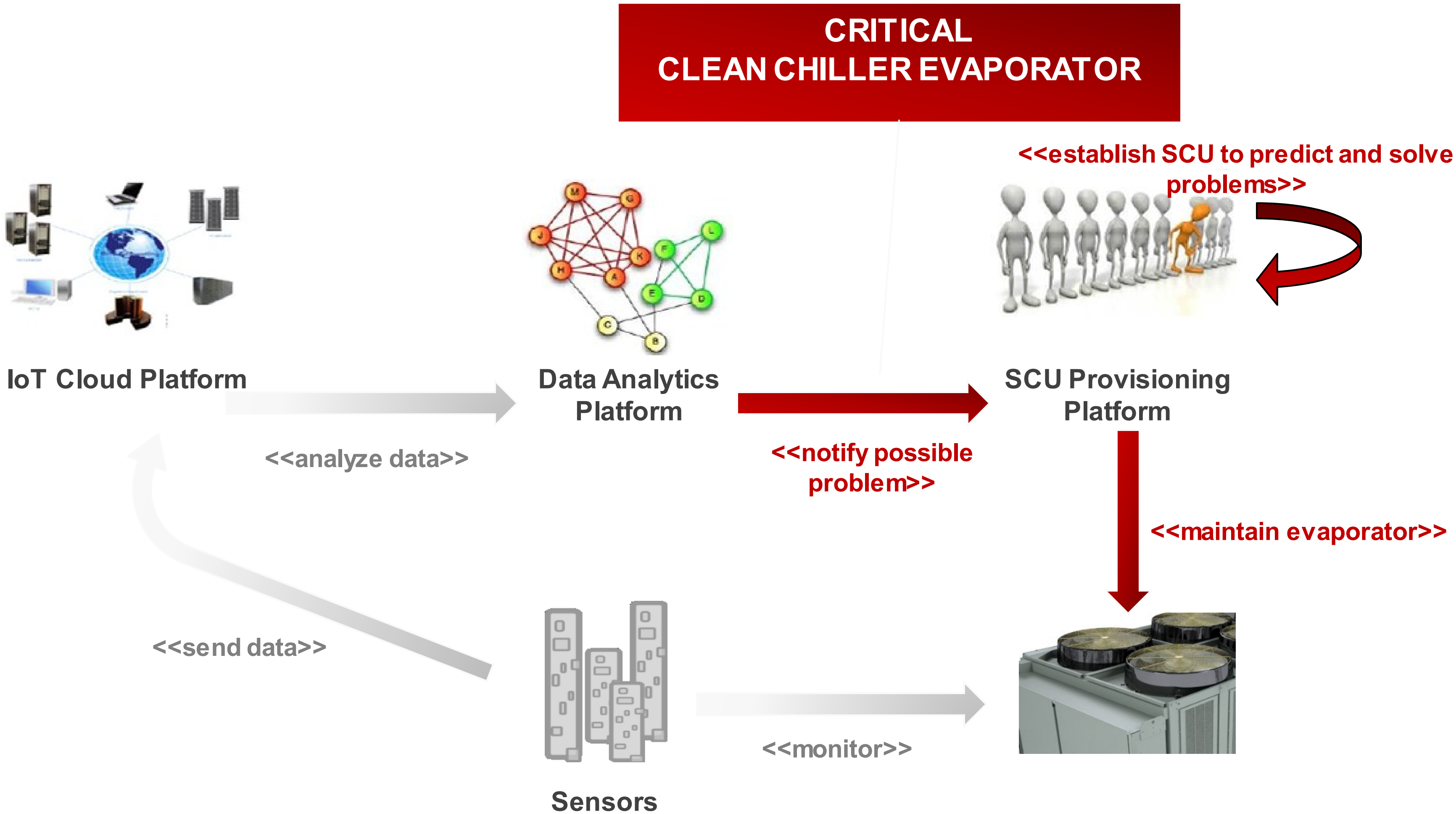
- What are common network structures?
- What are common data and control flows or interactions between IoT and clouds?
- What are common types of applications?
- What are common data models for IoT?
- Quality attributes: Performance, scalability, security, privacy, etc.

IOT CLOUD SYSTEMS

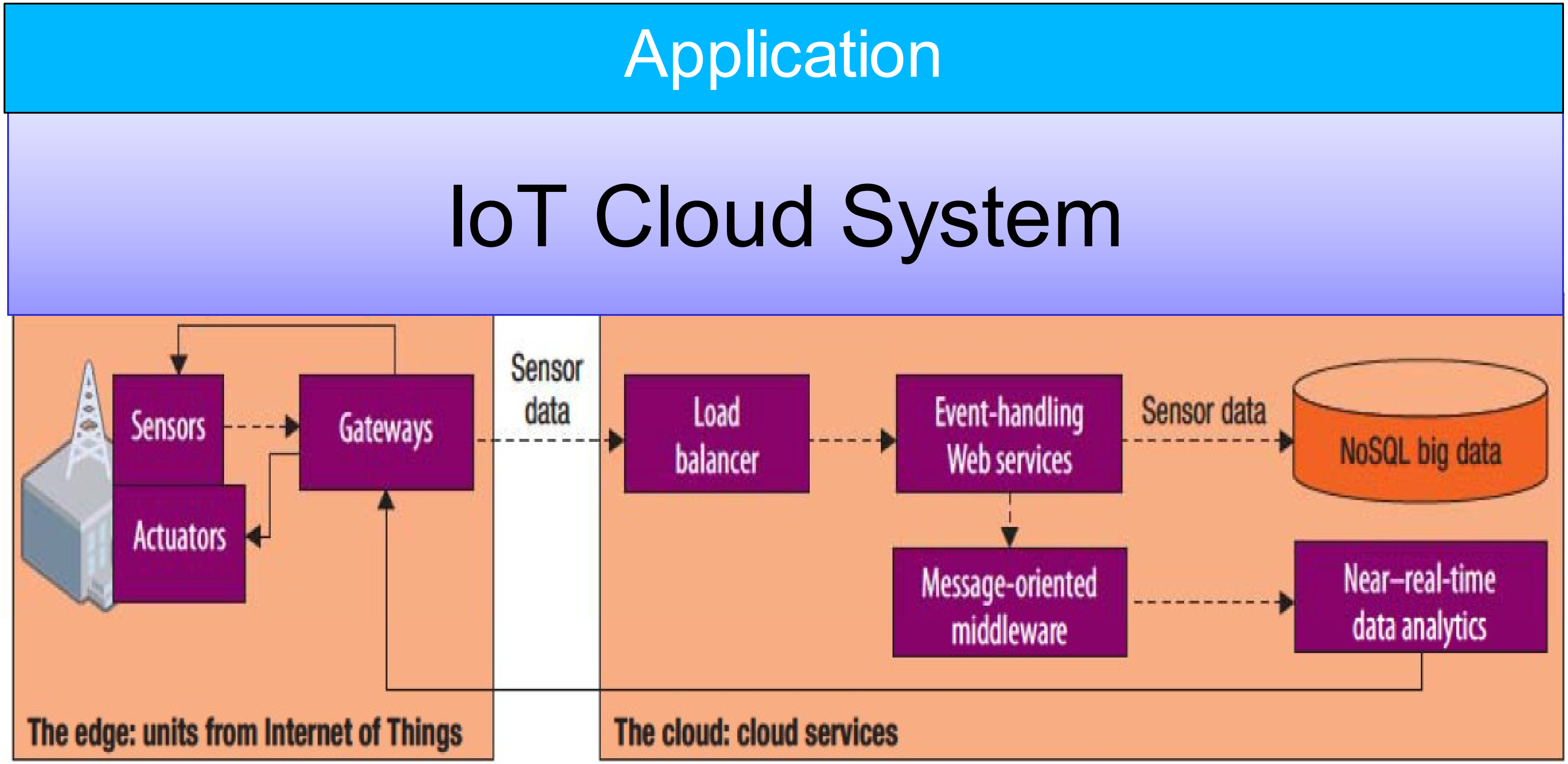
Key views

- Neither edge-centric nor cloud-centric approach
  - Should depending on application scenarios
- Resources from IoT, network functions and clouds are blending.
- Data and control follows
  - Edge → cloud
  - Cloud → edge
- Depending on the situation:
  - edge-centric or cloud-centric usage

Recall: Predictive Maintenance



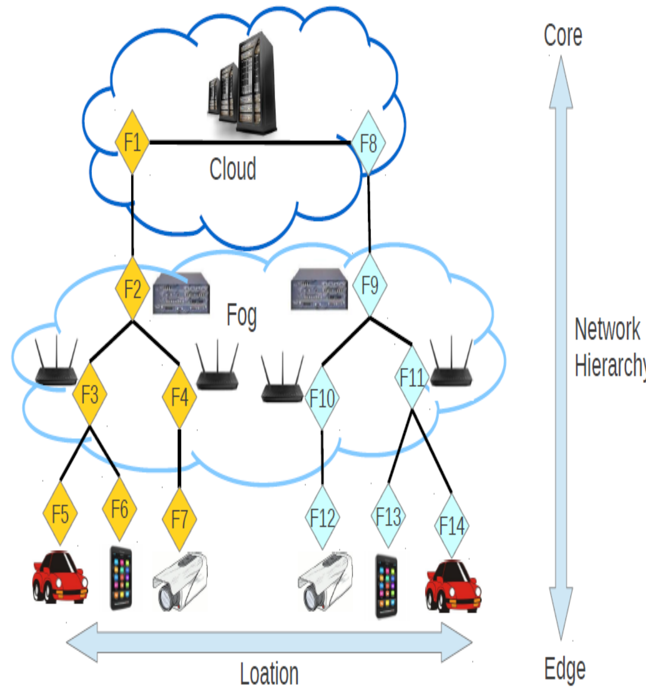
Our view on IoT Cloud System



- But we do not want a separation!
- How to build a coherent view!

Example of an application model atop IoT Cloud

When we need to run application components across IoT and clouds



Source: Kirak Hong, David Lillethun, Umakishore Ramachandran, Beate Ottenwälder, and Boris Koldehofe. 2013. Mobile fog: a programming model for large-scale applications on the internet of things. In Proceedings of the second ACM SIGCOMM workshop on Mobile cloud computing (MCC '13). ACM, New York, NY, USA, 15-20.

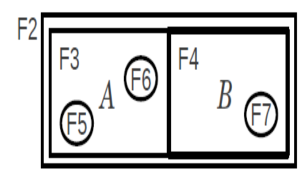


Figure 1: A logical structure of an application

Lifting IoT software stack

- Software artifact management
- Virtualization
  - Virtualization of software components for certain requirements: e.g., for a single application/domain
- Composition and orchestration
  - Complex topologies of IoT components
- Software-defined capabilities
  - Management done via APIs at runtime
- Cloud connectivity
  - Hide low level network stuffs

IoT Marketplaces

IoTapplications and components can be bought and deployed from marketplaces

similar to VMs, docker, and software services in the cloud

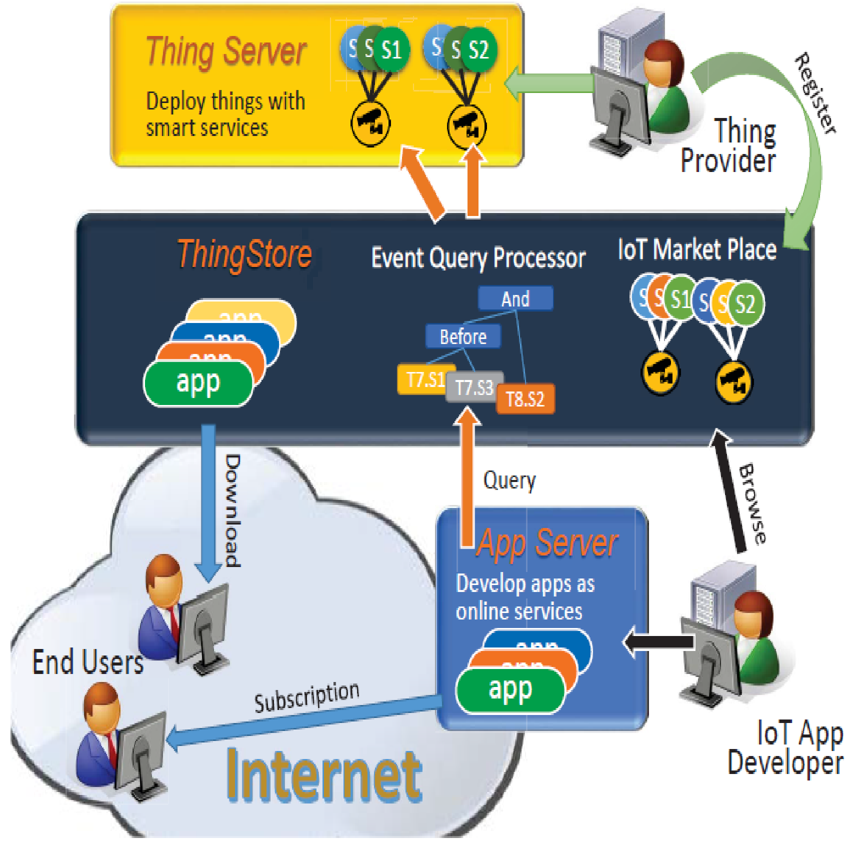
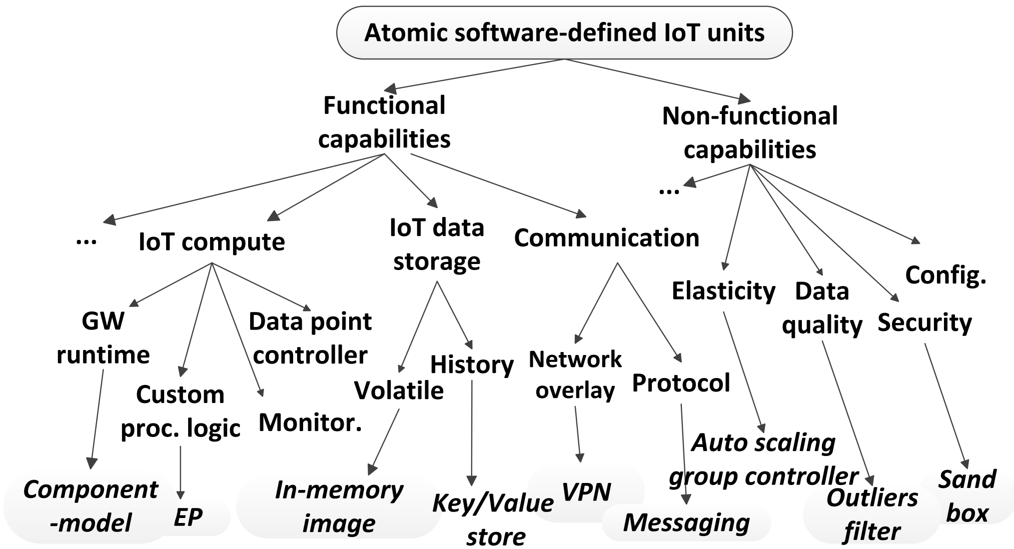
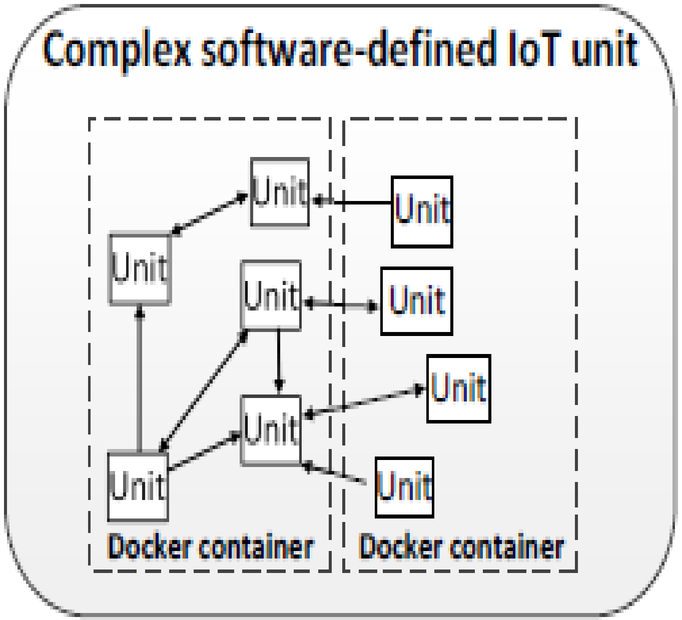


Figure 1: The IoT environment and ThingStore

Source: Kutalmis Akpinar, Kien A. Hua, Kai Li: ThingStore: a platform for internet-of-things application development and deployment. DEBS 2015: 162-173

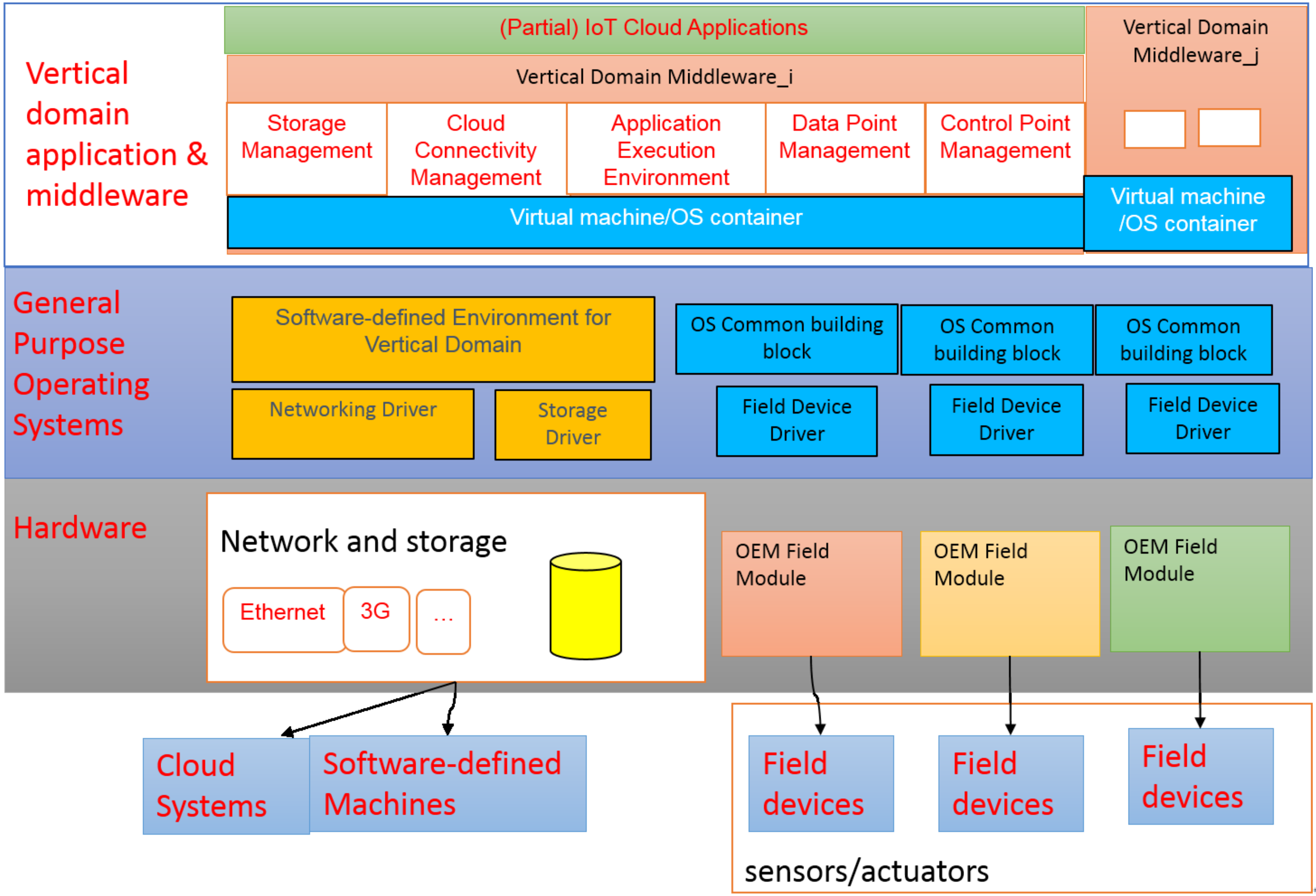
Example of composition and virtualization techniques





Stefan Nastic, Sanjin Sehic, Duc-Hung Le, Hong Linh Truong, Schahram Dustdar: Provisioning Software-Defined IoT Cloud Systems. FiCloud 2014: 288-295

Abstract software-defined machines (SDMs) for IoT

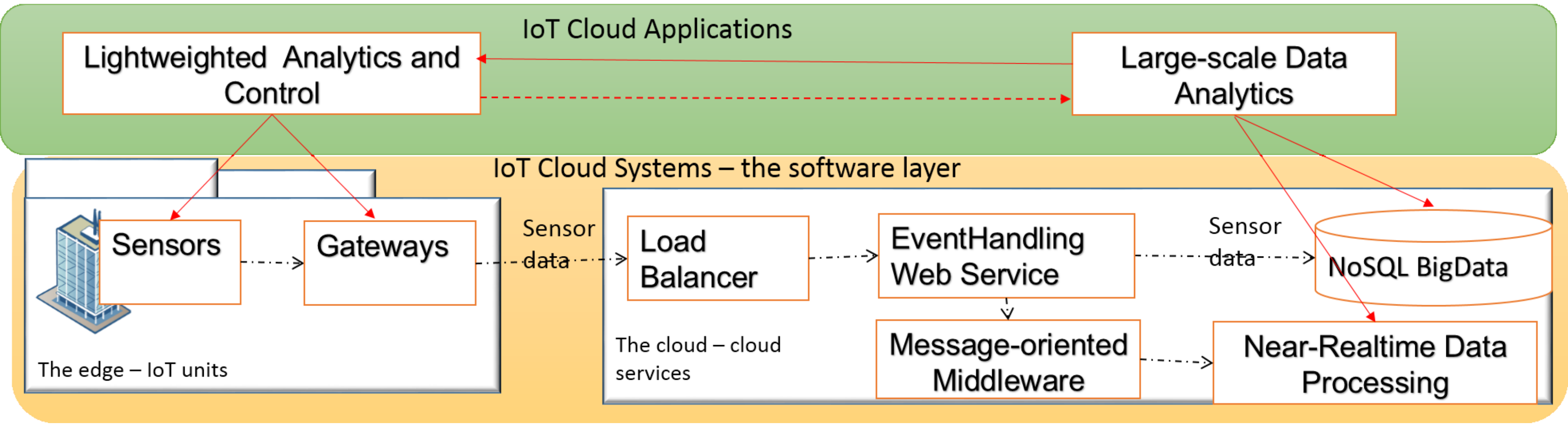


Can be build SDM with current technologies? with e.g. Raspberry Pi, docker, routers?

If we have virtualization and composition and software-defined capabilities in both IoT and Cloud

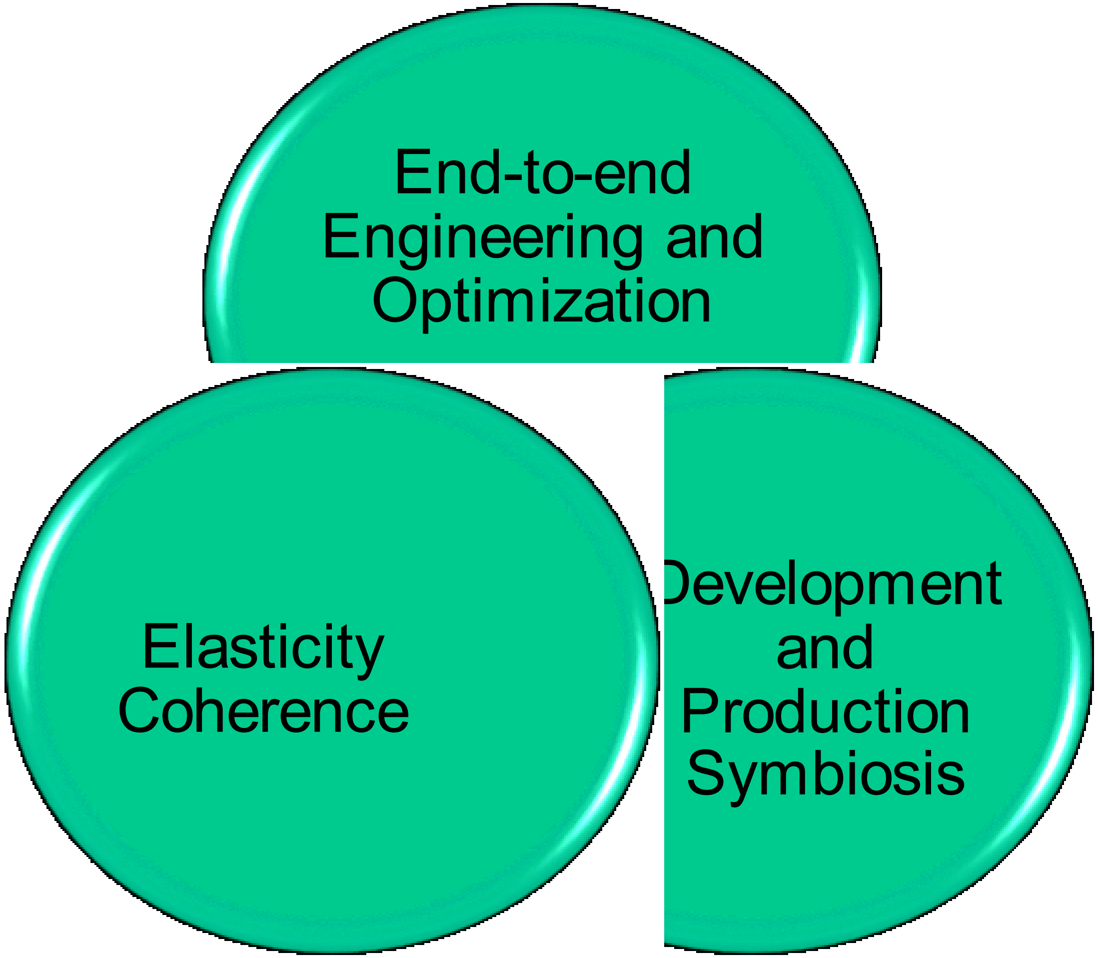
IoT Cloud System as a continuum environment

- Enable a continuum execution environment across IoT and clouds
- Utilize similar techniques to deal with composition, provisioning, deployment, control, etc



Challenges for Engineering Analytics

Engineering perspectives



Hong Linh Truong, Schahram Dustdar: Principles for Engineering IoT Cloud Systems. IEEE Cloud Computing 2(2): 68-76 (2015)

Challenges

1. Enable virtualization and composition of IoT components as unit

   Selection, composition, pay-per-use

2. Enable emulated/simulated IoT parts working with production IoT/cloud services

   Symbiotic development and operation

3. Enable dynamic provisioning of IoT and cloud service units through uniform marketplaces and repositories for multiple stakeholders

Challenges (2)

4. Provide multi-level software stack deployment and configuration

5. Provide software-defined elasticity and governance primitive functions for all IoT units and cloud service units

6. Provide monitoring and analysis for an end-to-end view on elasticity and dependability properties

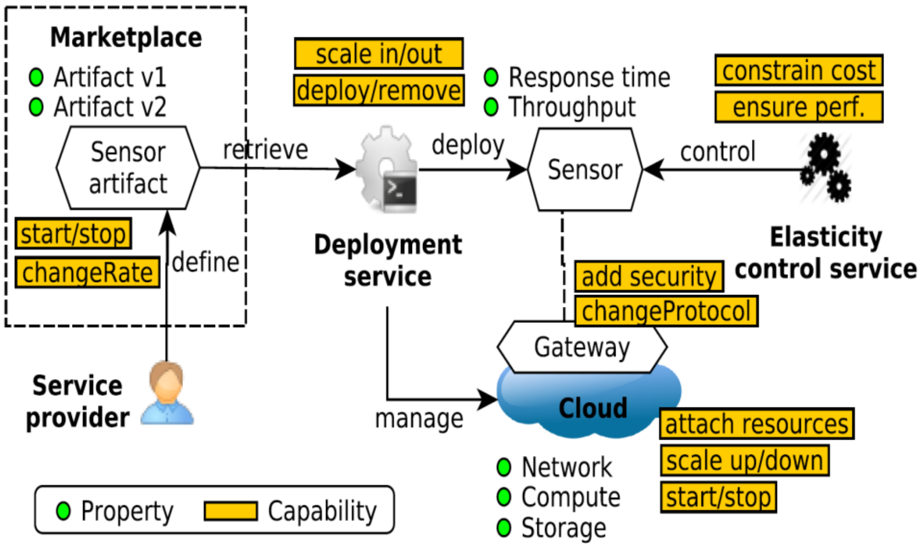
Challenges (3)

7. Coordinate elasticity to enable a coherent elastic execution through the whole IoT cloud systems

8. Deal with uncertainties

9. Assure security and privacy during system on-demand provisioning and elasticity

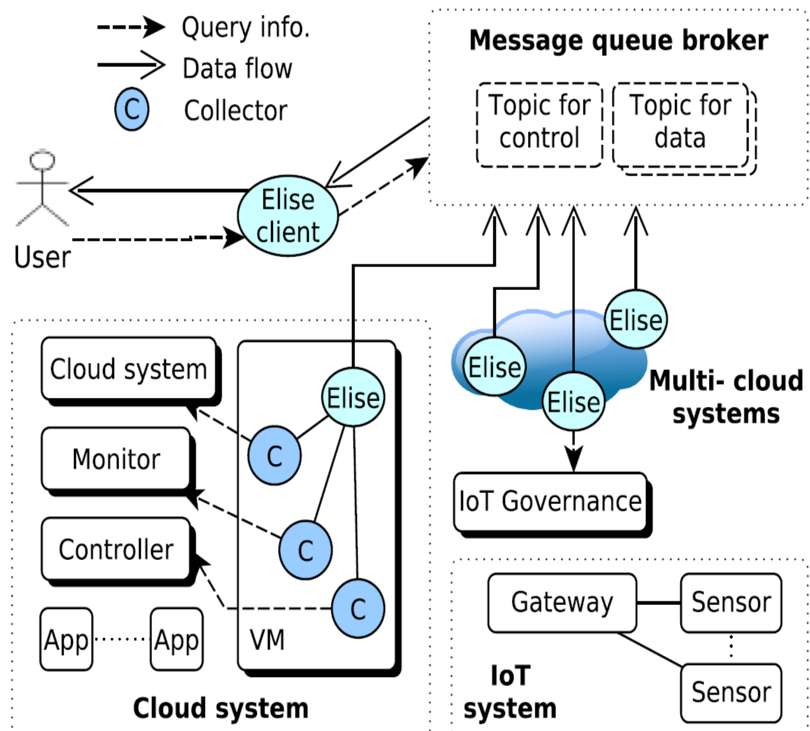
Creating an IoT Cloud system



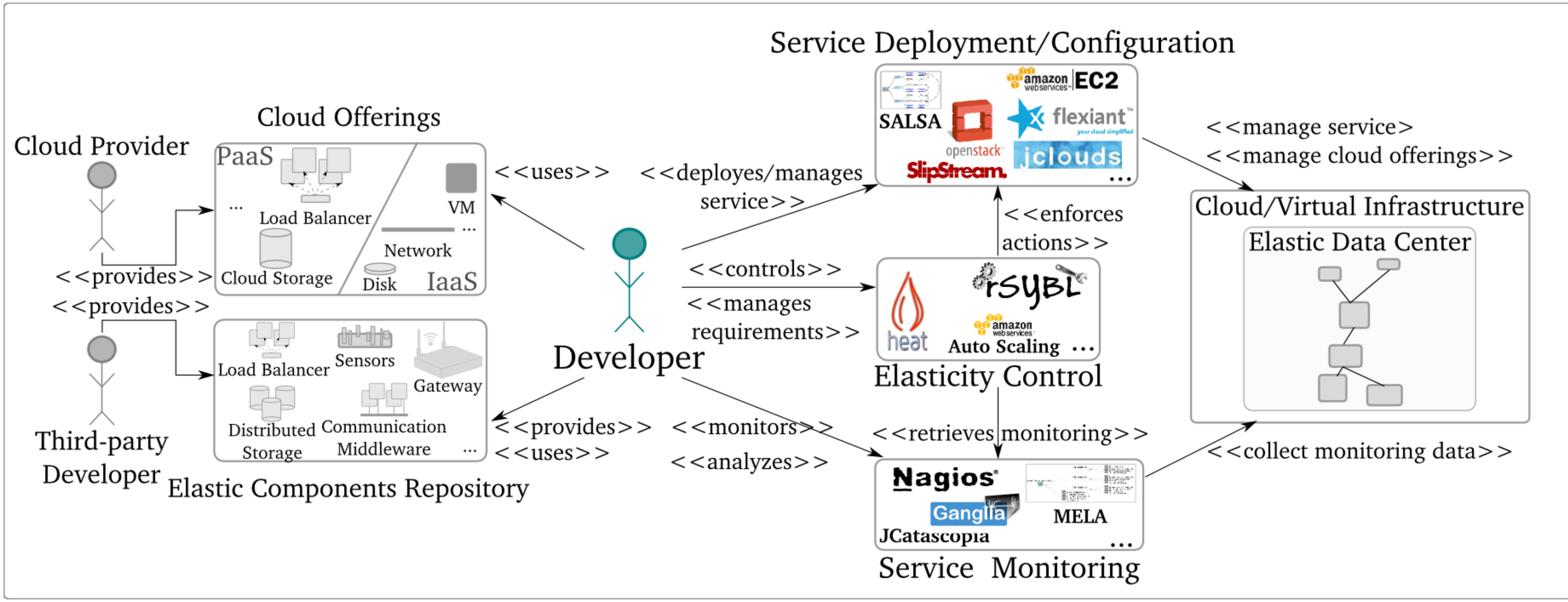
Deployment and configuration

https://github.com/tuwiendsg/SALSA

Collecting resource information

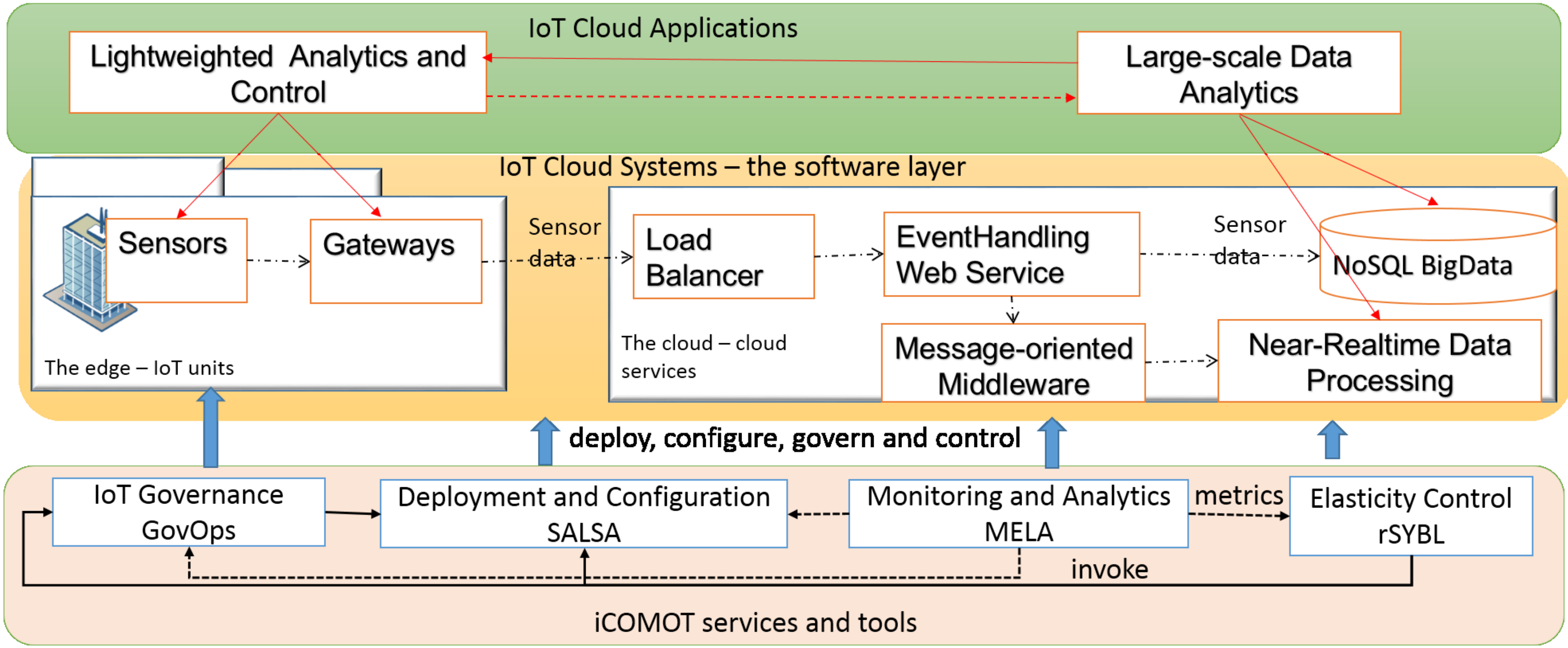


Development Tools and Actions



Hong Linh Truong, Georgiana Copil, Schahram Dustdar, Duc-Hung Le, Daniel Moldovan, Stefan Nastic : On Architecting and Developing Elastic IoT Cloud Platforms -- The iCOMOT Approach, Working paper, 2015

iCOMOT – IoT Cloud Monitoring, Control and Testing



Check: http://tuwiendsg.github.io/iCOMOT/

Exercises

- Read papers mentioned in slides
- Check services mentioned in examples
- Program some simple sensors sending data to public clouds

Important notes

- 2nd assignment released today
  - Due on 21 April 2016
- Scenario and service design presentation
  - On 15 April 2016 (not a backup date anymore)
  - Provide 2-3 slides of your talk until 17pm 14 April
- Submission through TUWEL
- Check the exact deadlines from TUWEL

Thanks for your attention

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