Fog Computing: Beyond Mobile and Cloud Centric Internet of Things

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Mobile & Cloud Lab

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Main Research Activities

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Research

The research at the Mobile & Cloud Lab contributes to the following fields:

Cloud Computing

The research goal is to study the migration of enterprise applications to the cloud and to study their performance on the cloud.

Scientific Computing on the Cloud

The research goal is to study the migration of scientific computing applications to the cloud and to reduce these applications and algorithms to cloud computing frameworks like the MapReduce.

Mobile Computing

The research deals with developing mobile applications for various platforms and devices (e.g. Android, iOS, Windows Phone 7 etc). It also deals with acquiring and utilizing sensor data in building applications for different domains.

Mobile Cloud

The goal of the research is to investigate how to efficiently utilize cloud resources within the mobile applications (aka mobile cloud applications).

Mobile Web Services

This research theme deals with the invocation, provisioning, discovery and integration of web services from smart phones, in developing mobile applications.

Internet of Things

The goal of this research is to overcome the challenges of cyber-physical systems in the Internet of Things. The challenges include: interoperability, autonomous machine-to-machine communication, automatic configuration, energy efficiency, trustworthiness etc.

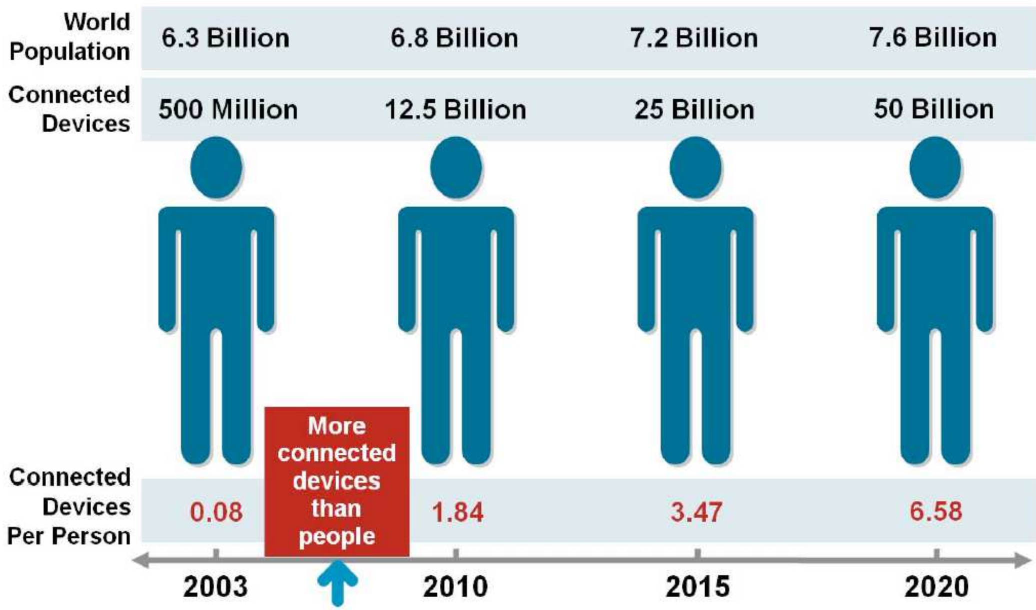
Outline

- Layers of Cloud-based Internet of Things (IoT)
- Mobile Web Services and Cloud Services
- Issues with Cloud-centric IoT
- Fog Computing & Research Roadmap

[Srirama, CSIICT 2017]

Internet of Things (IoT)

- IoT *allows people and things to be connected*
  - ***Anytime***, ***Anyplace***, *with* ***Anything*** *and* ***Anyone***, *ideally using* ***Any path/network*** *and* ***Any service***
    [European Research Cluster on IoT]
- More connected
- Cisco believes the
  trillion by 2025

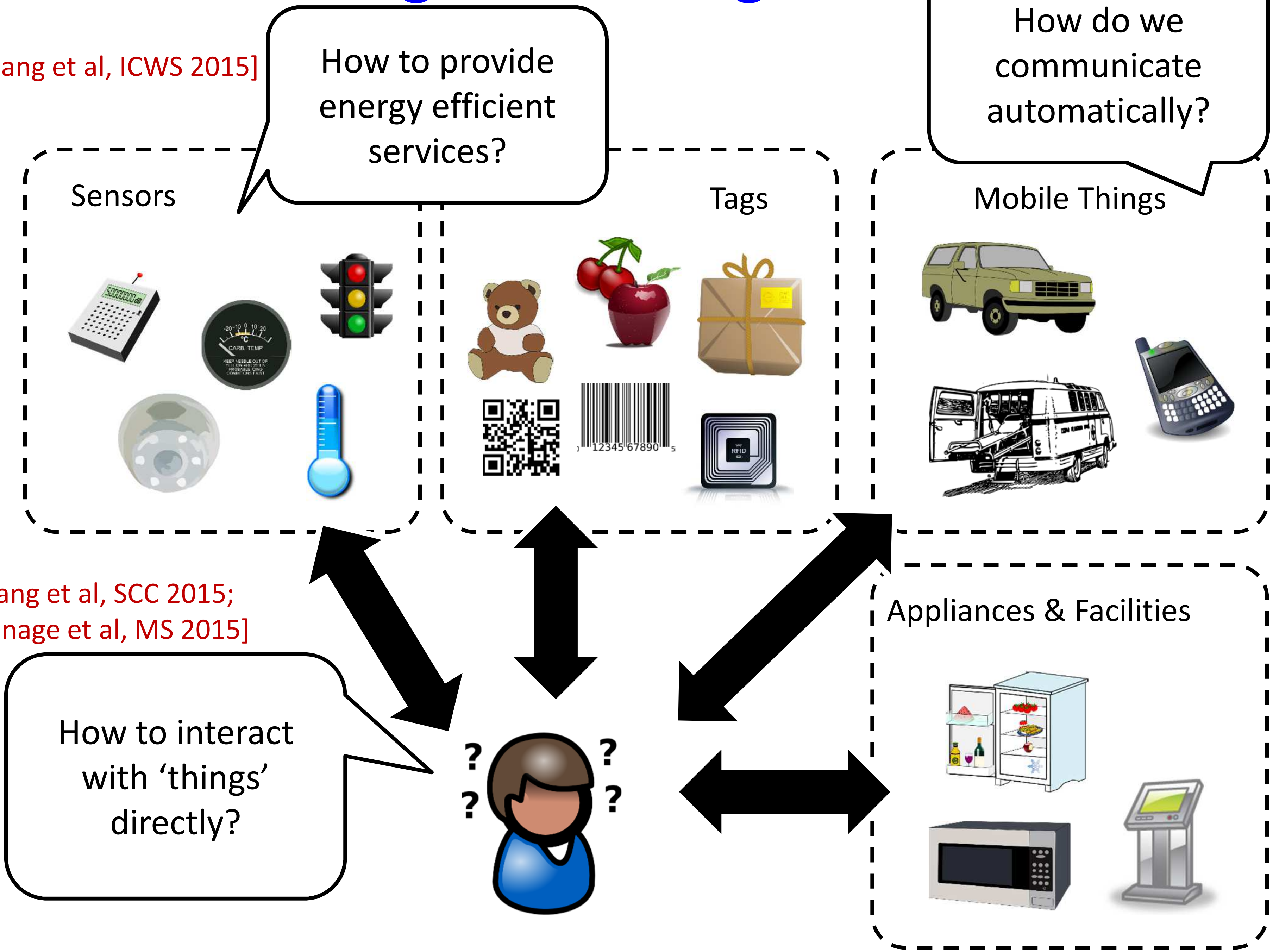


Source: Cisco IBSG, April 2011

Internet of Things – Challenges

[Chang et al, ICWS 2015]

[Chang et al, SCC 2015;
Liyanage et al, MS 2015]

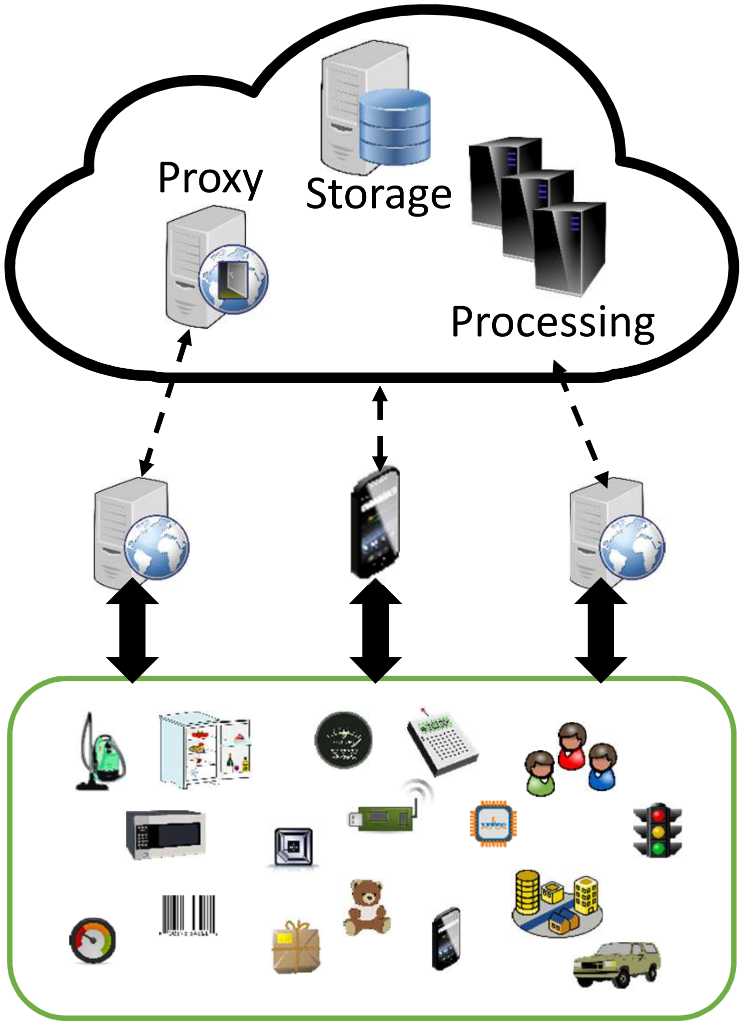


Layers of Cloud-based IoT

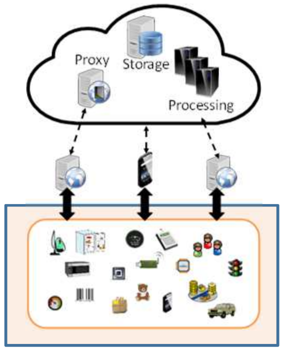
Remote Cloud-based processing

Connectivity nodes & Embedded processing

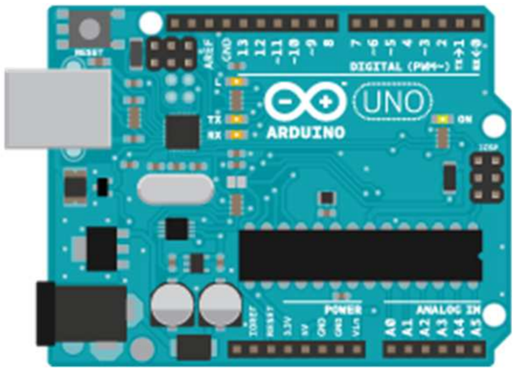
Sensing and smart devices



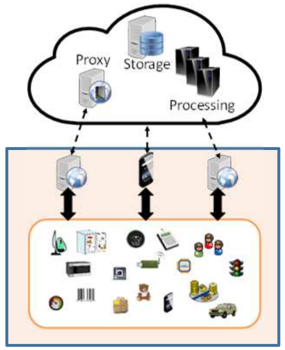
Sensing and Smart Devices



- IoT Devices
  - Sensors and actuators
  - Motion, Temp, Light, Open/Close, Video,
  Reading, Power on/off/dimm etc.
- Communication protocols
  - Wireless and wired
  - Protocols such as ZigBee, Z-Wave, Wi-Fi/Wi-Fi Direct, Bluetooth etc.
- Arduino & Raspberry PI
  - For rapid prototyping



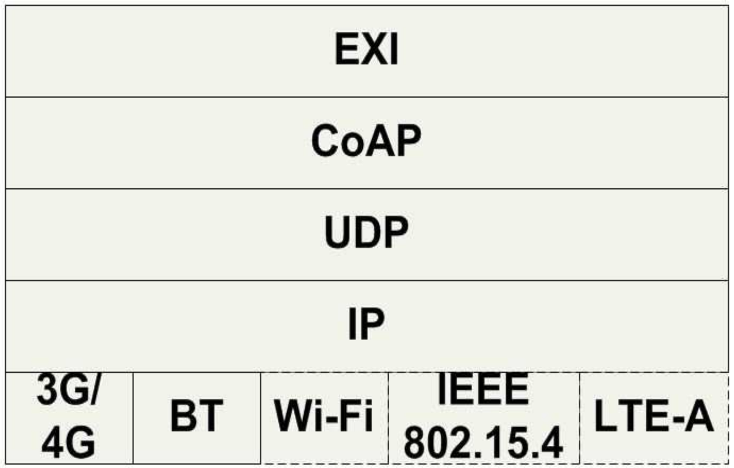
Gateway/Connectivity Nodes



- Primarily deals with the sensor data acquisition and provisioning
- Embedded processing saves the communication latencies
- Predictive analytics
  - Collect data only occasionally
- Mobiles can also participate
  - This brings in the scope of mobile web services and mobile cloud services for IoT

Light-weight Mobile Hosts for Sensor Mediation

- It is possible to provide services from smart phones [Srirama et al, ICIW 2006; Srirama, 2008]
- Mobile Host can directly provide the collected sensor information
  - Data can be collected based on need
- Ideal MWS Protocol Stack
  - Things have improved significantly over the years
  - Bluetooth Low Energy (BTLE) for local service discovery and interaction
  - UDP instead of TCP
  - Constrained Application Protocol (CoAP)
  - Efficient XML Interchange (EXI)



[Liyanage et al, MS 2015]

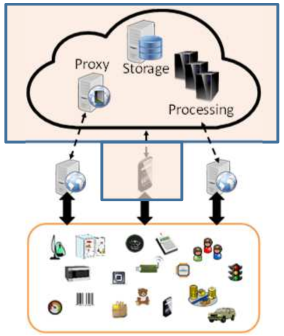
Limitations with Mobiles

- Longer battery life
  - Battery lasts only for 1-2 hours for continuous computing
- Same quality of experience as on desktops
  - Weaker CPU and memory
  - Storage capacity
- Still it is a good idea to take the support of external resources
  - For building resource intensive mobile applications
  - Brings in the scope for cloud computing

Mobile Cloud

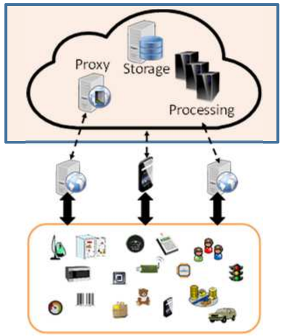
- Harness cloud computing resources from mobile devices

- Binding models
  - Task delegation [Flores and Srirama, JSS 2014]
  - Mobile code offloading [Flores et al, IEEE Communications Mag 2015; Zhou et al, TSC 2017]



- Ideal Mobile Cloud based system should take advantage of some of the key intrinsic characteristics of cloud efficiently
  - Elasticity & AutoScaling
  - Utility computing models
  - Parallelization (e.g., using MapReduce)

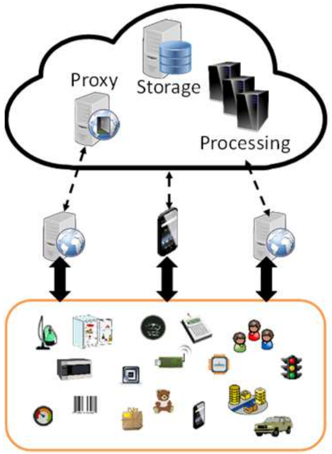
IoT Data Processing on Cloud



- Enormous amounts of unstructured data
  - In Zetabytes (10^{21} bytes) by 2020 [TelecomEngine]
  - Has to be properly stored, analysed and interpreted and presented
- Big data acquisition and analytics
- In addition to big data, IoT mostly deals with big streaming data
  - Message queues such as Apache Kafka to buffer and feed the data into stream processing systems such as Apache Storm
  - Apache Spark streaming

Issues with Cloud-centric IoT

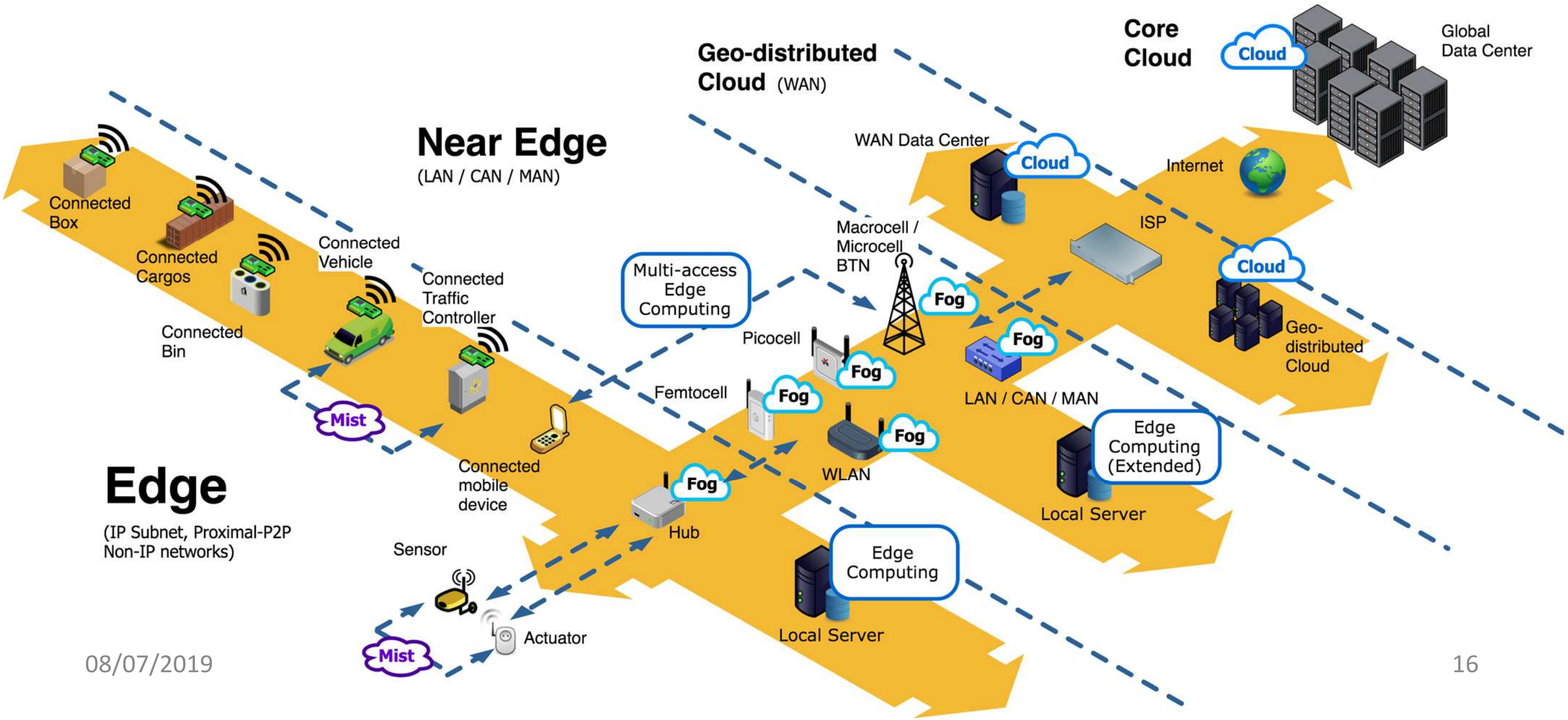
- Latency issues for applications with sub-second response requirements
  - Health care scenarios
  - Smart cities and tasks such as surveillance need real-time analysis with strict deadlines
- Network load
- Certain scenarios do not let the data move to cloud
  - Better security and deeper insights with privacy control



Fog Computing

- Processing across all the layers, including network switches/routers

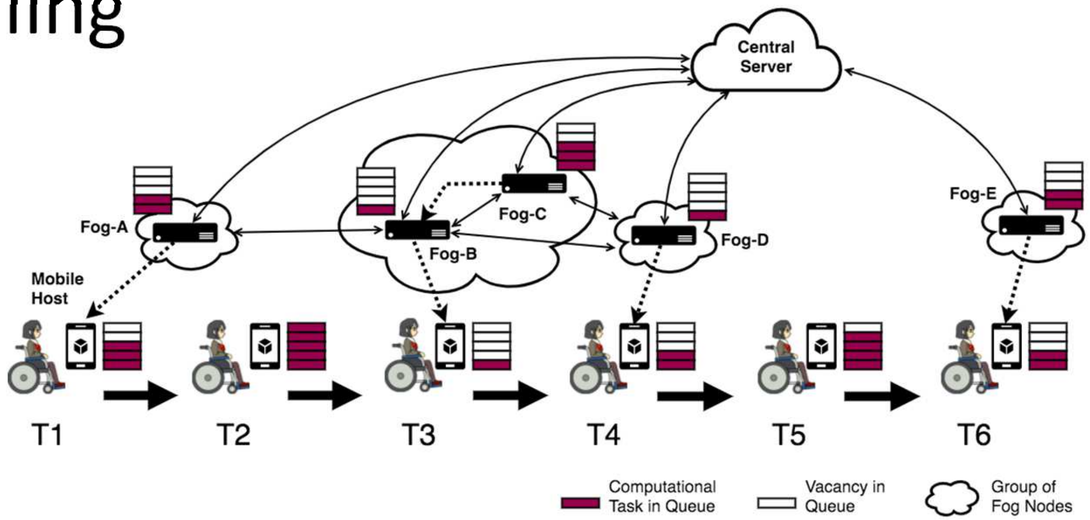
[Chang et al, AINA 2017; FEC 2019; Mass et al, SCC 2016; Liyanage et al, PDCAT 2016]



Fog Computing – Research Challenges

- Proactive Fog computing using resource-aware work-stealing

[Soo et al, IJMCMC 2017]



- Indie Fog [Chang et al, IEEE Computer 2017]
  - System architecture for enabling Fog computing with customer premise equipment

Fog Computing – Research Challenges - continued

- Dynamic Fog computing service discovery and accessing
- Distributed and fault-tolerant execution of Fog computing applications
  - Based on Actor programming model
  - Have implemented applications using the Akka framework

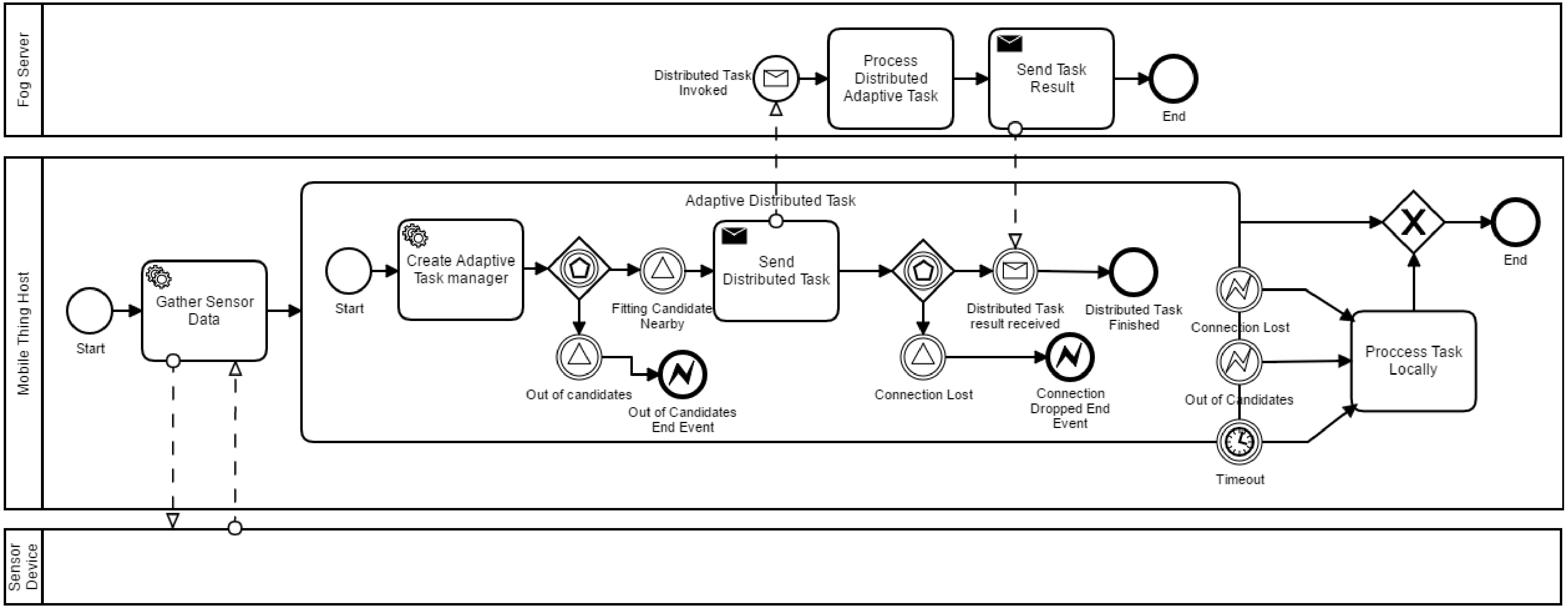
Fog Computing – Research Challenges - continued

- QoS & QoE-aware application placement across Fog topology [Mahmud et al, JPDC 2019]
  - Resource intensive tasks of IoT applications can be placed across the Fog topology
  - Latency-aware application module management
- The problem can also be formulated as multi-objective offloading strategy
  - Latency, energy-efficiency and resource management
  - Need to find ideal heuristics, metaheuristics etc.
  - Also have to consider the graph topology of the Fog nodes

QoS – Quality of Service
QoE – Quality of Experience

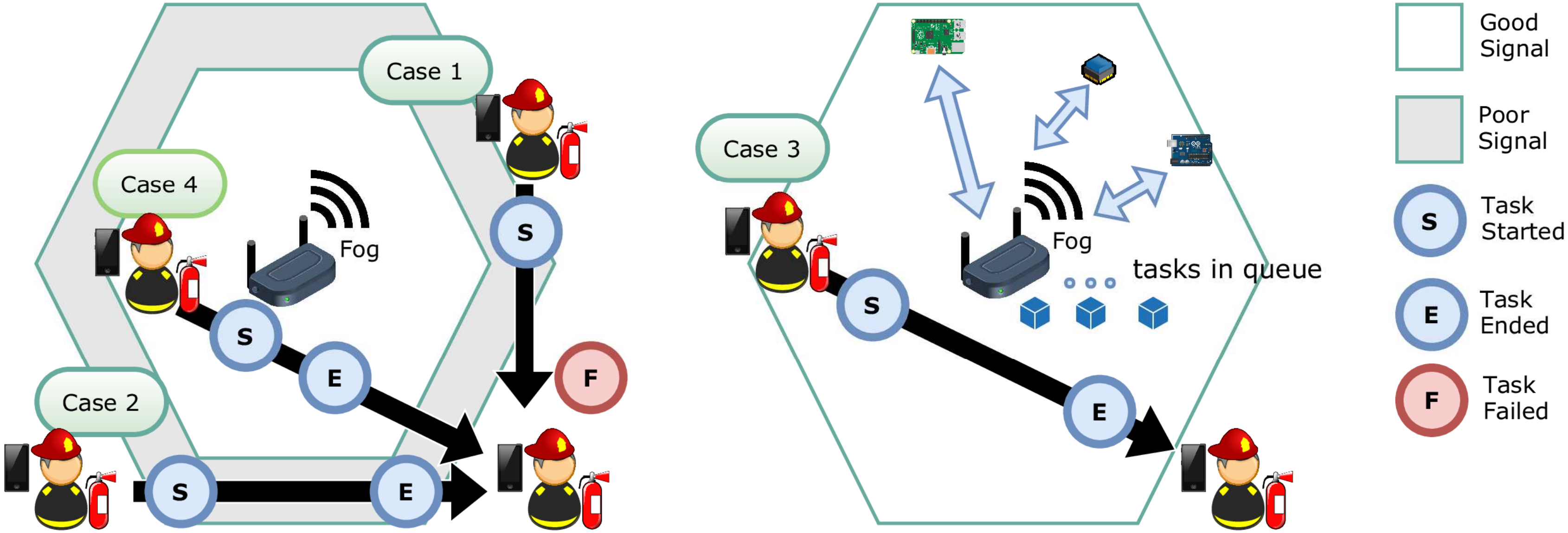
Fog Computing – Research Challenges - continued

- Process-driven Edge Computing in Mobile IoT
  [Mass et al, IoTJ 2019; CASA 2018; Chang et al, CSUR 2016]



Fog Computing – Research Challenges - continued

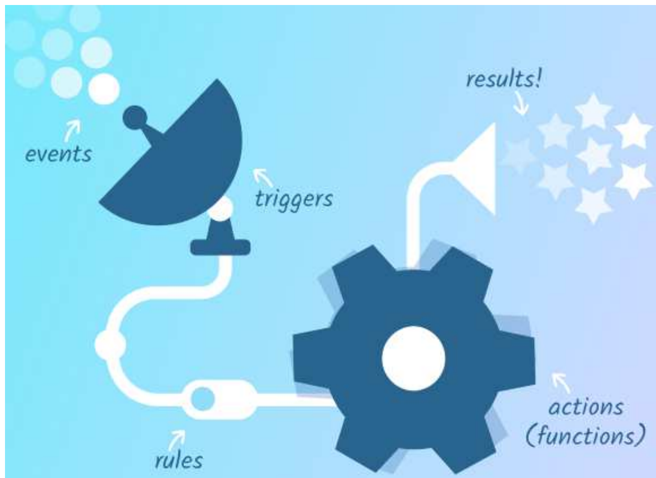
- Mobility also becomes critical in Fog computing [Mass et al, IoTJ 2019]



- STEP-ONE : Simulated Testbed for Edge Processes based on the Opportunistic Network Emulator
  - Extended the ONE simulator to simulate the Fog computing mobility aspects
  - Process execution based on Flowable BPMS

Serverless computing

- Event-action platforms to execute code in response to events
- Applications are charged by compute time (millisecond) rather than by reserved resources
- IoT workloads are a better fit for event driven programming
  - Execute app logic in response to sensor data
  - Similar tasks
    - Execute application logic in response to database triggers
    - Execute app logic in response to scheduled tasks etc.
- Serverless computing is ideal solution for fog processing
  - OpenFaaS, light-weight enough to place on Raspberry Pi



EU H2020 -RADON

- Rational decomposition and orchestration for serverless computing
  - Jan 2019 – Jun 2021
- Goal
  - Creating a DevOps framework to create and manage microservices-based applications
  - Tools that facilitate in designing and orchestrating data pipeline applications that involve serverless entities
  - OASIS - Topology and Orchestration Specification for Cloud Applications (TOSCA)
- Case studies
  - IoT application from healthcare
  - Tourism

Research Roadmap – IoT & Fog Computing

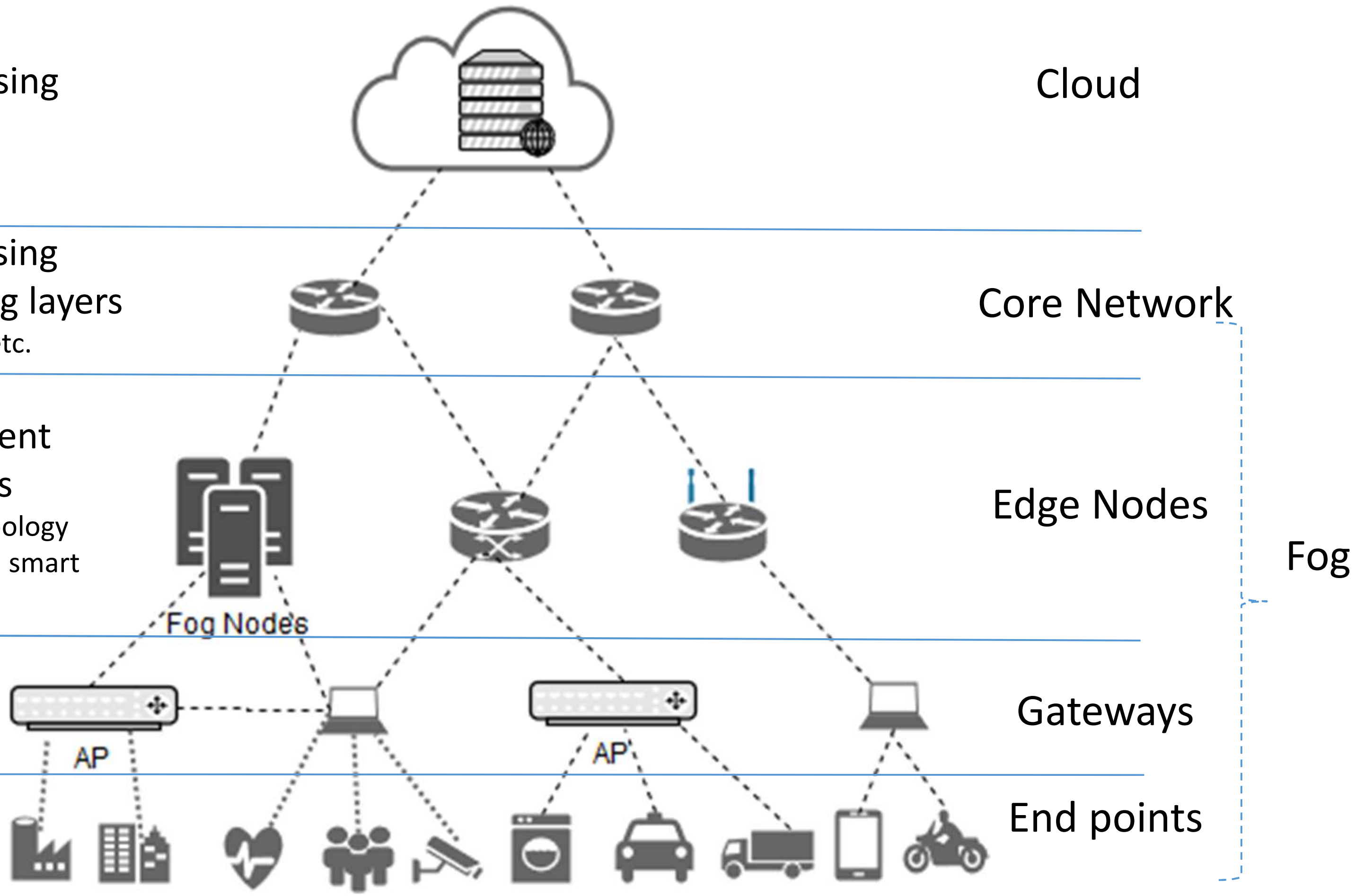
Distributed data processing on the Cloud
E.g. MapReduce, Spark

Distributed data processing across the Cloud and Fog layers
E.g. Personalized data, privacy etc.

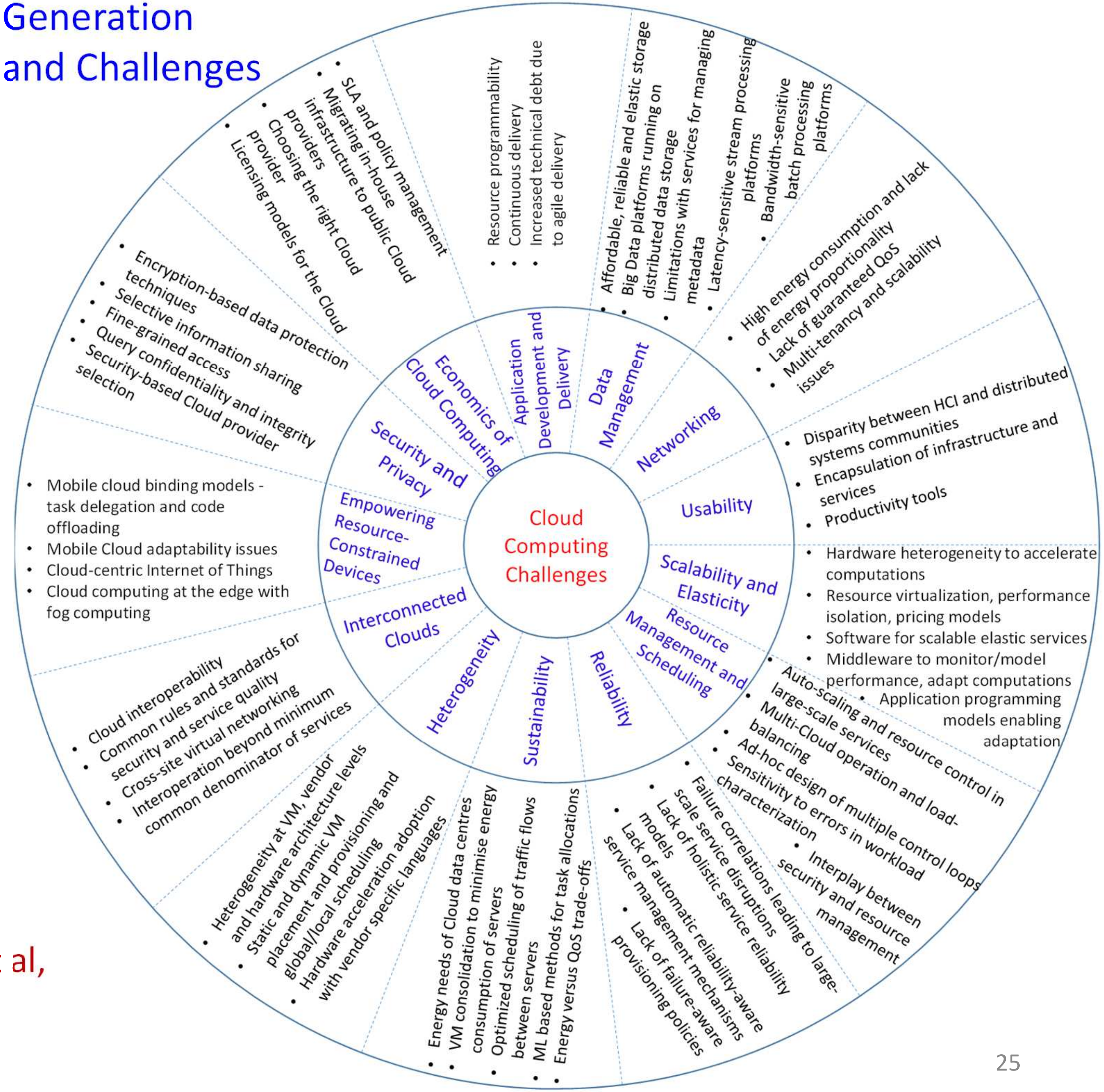
Fog topology management and scheduling the tasks
E.g. tasks run across the fog topology such as stream data processing, smart streetlights etc.

Edge analytics
E.g. filter, error detection, consolidation etc.

Intelligent sensors
E.g. vehicular networks



A Manifesto for Future Generation Cloud Computing: SOA and Challenges



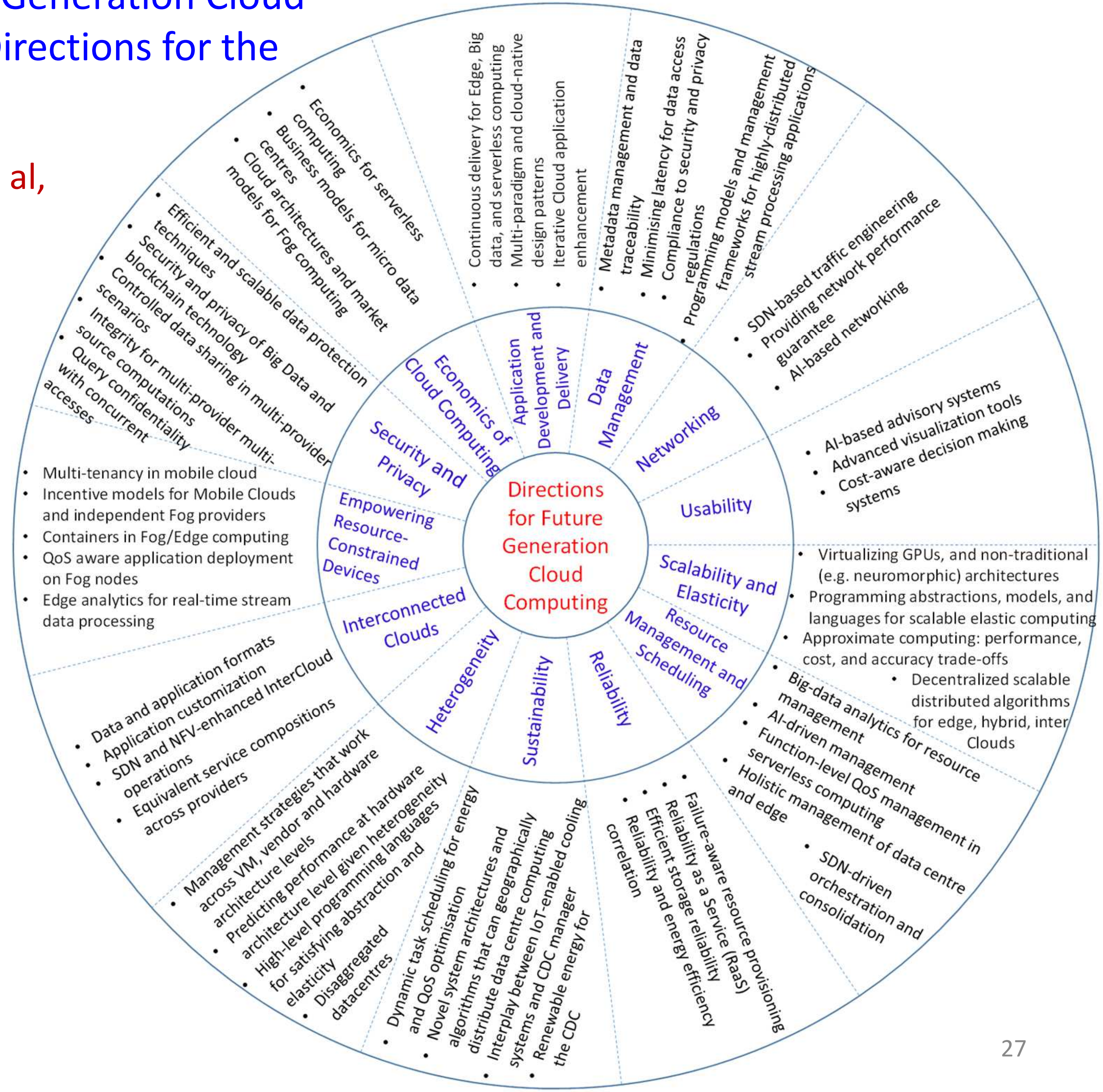
[Buyya, Srirama, Casale et al, ACM CSUR 2019]

Emerging trends and impact areas for cloud

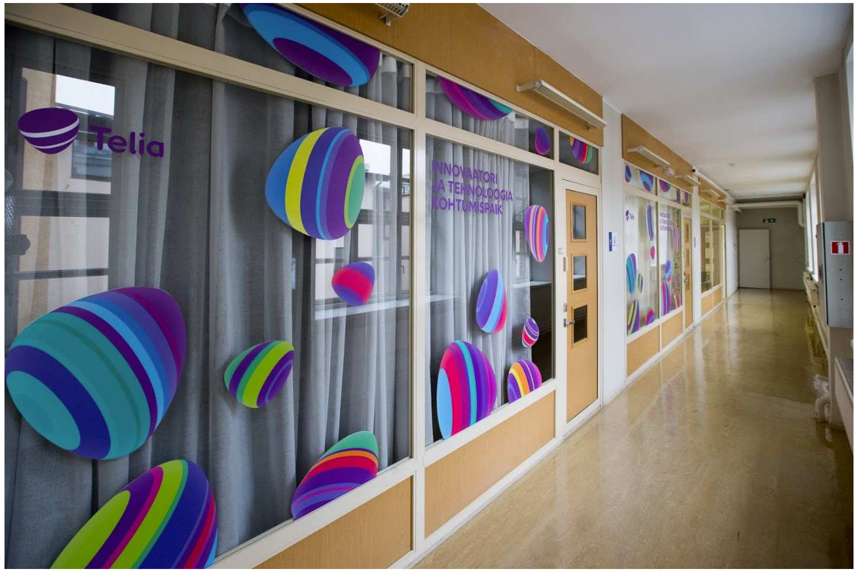
- Containers
- Fog Computing
- Big Data
- Serverless Computing
- Software-defined Cloud Computing
- Blockchain
- Machine and Deep Learning

A Manifesto for Future Generation Cloud Computing: Research Directions for the Next Decade

[Buyya, Srirama, Casale et al, ACM CSUR 2019]



IoT and Smart Solutions Laboratory



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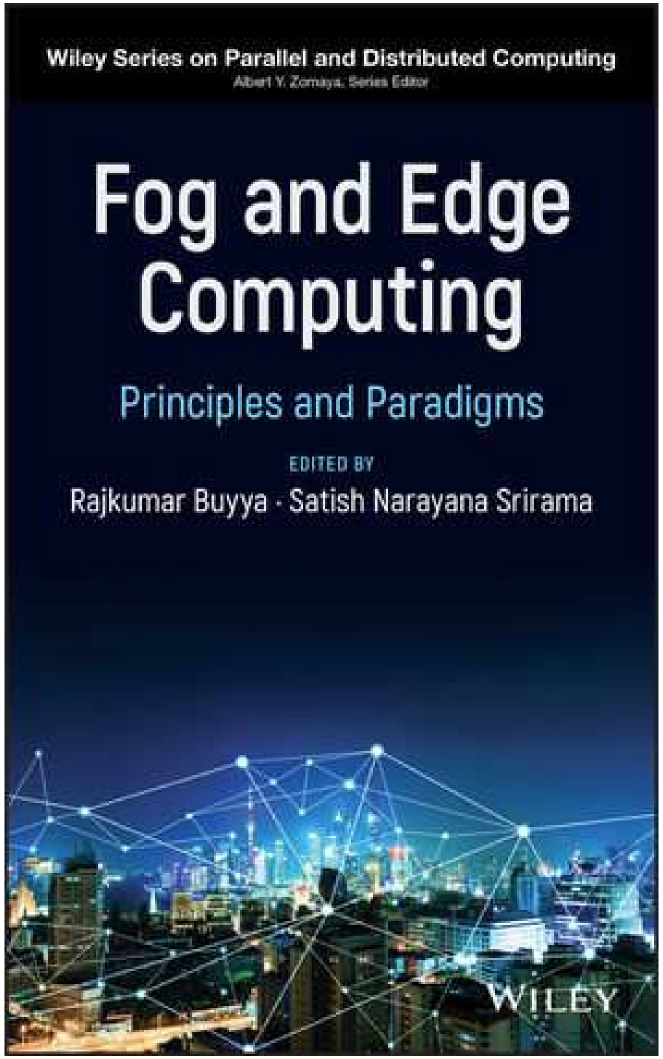

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