Mobile and Cloud Centric Internet of Things

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Who am I

- Head of Mobile & Cloud Lab, Institute of Computer Science, University of Tartu, Estonia

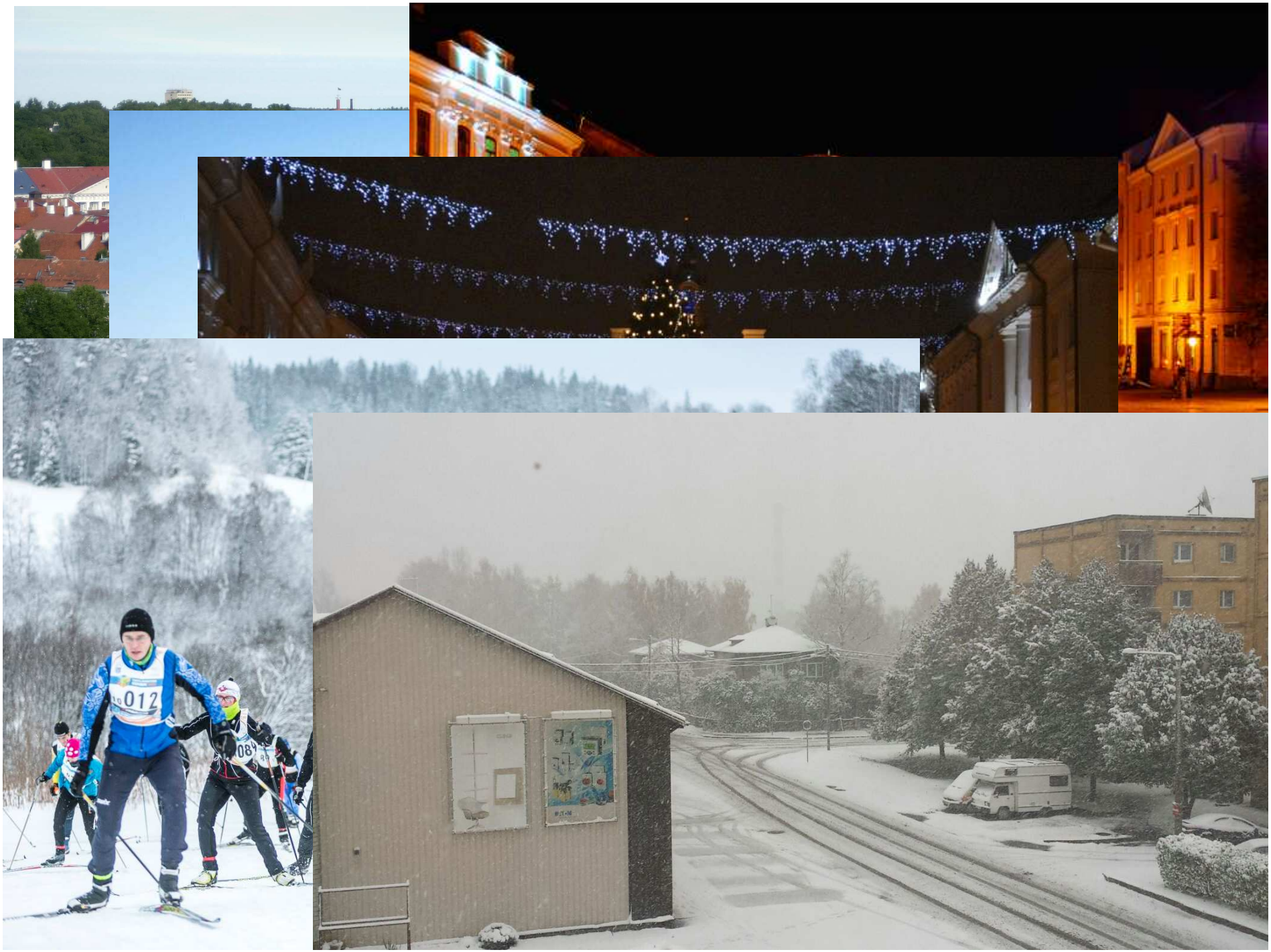
http://mc.cs.ut.ee

Mobile & Cloud Lab

Estonia pop: 1,300,000

TARTU

Pop: 100,000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Academic excellence since 1632

Main Research Activities

Mobile Cloud Lab

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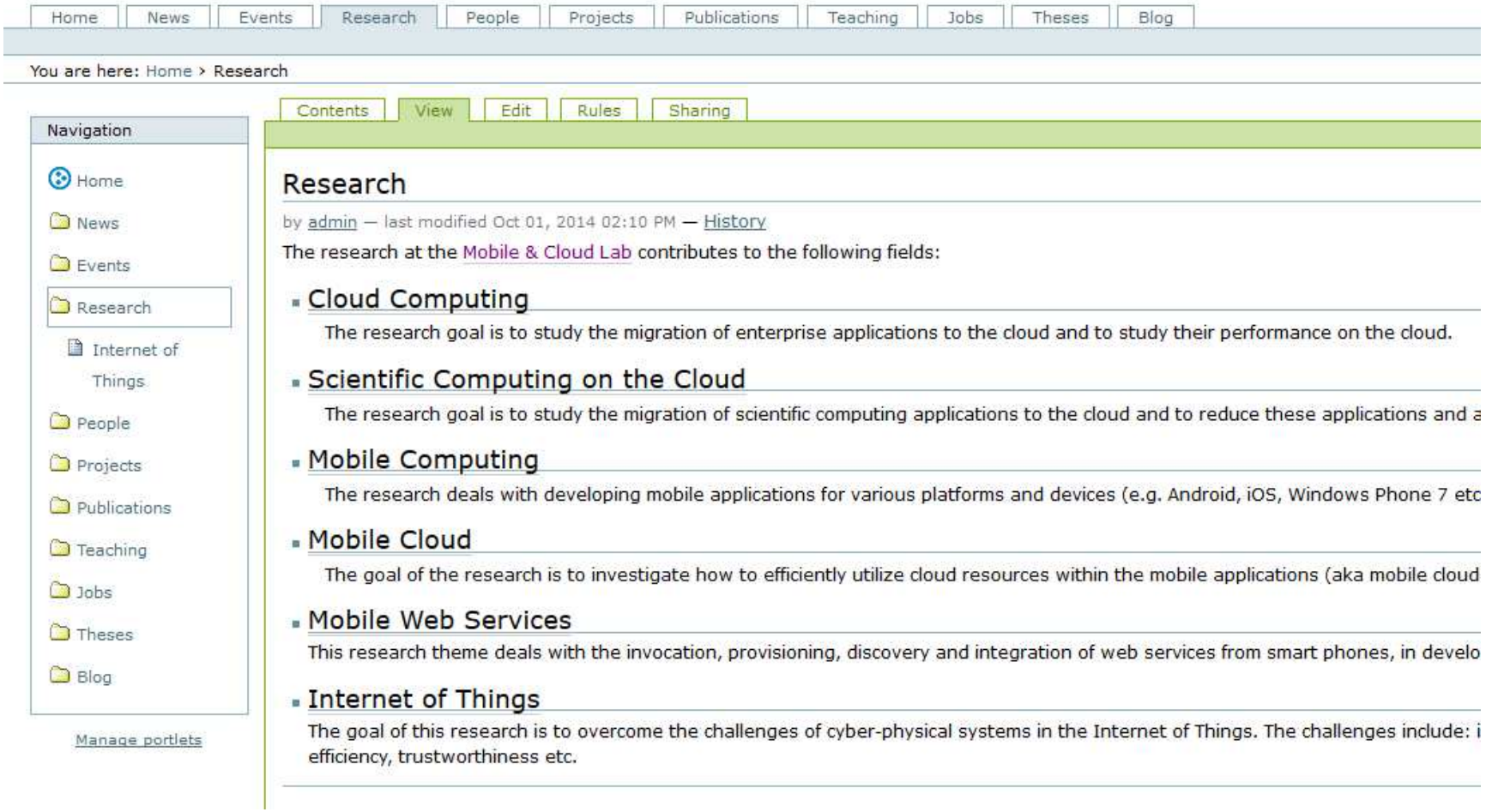
Institute of Computer Science
1632



Outline

- Layers of Cloud-based IoT
- Mobile Web Services
- Mobile Cloud Binding Models
  - Task delegation
  - Code offloading
- Cloud-based IoT Data Processing
- Research Roadmap

Cloud Computing

- Computing as a utility
  - Utility services e.g. water, electricity, gas etc
  - Consumers pay based on their usage

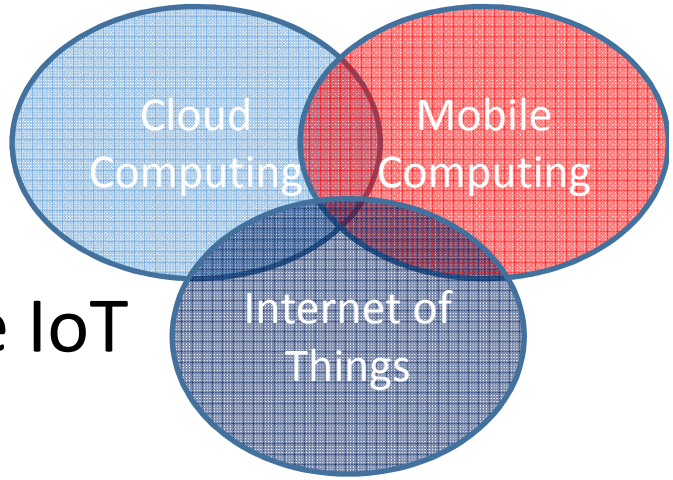
1969 – Leonard Kleinrock, ARPANET project

- "As of now, computer networks are still in their infancy, but as they grow up and become sophisticated, we will probably see the spread of 'computer utilities', which, like present electric and telephone utilities, will service individual homes and offices across the country"

- Cloud Computing characteristics
  - Illusion of infinite resources
  - No up-front cost
  - Fine-grained billing (e.g. hourly)

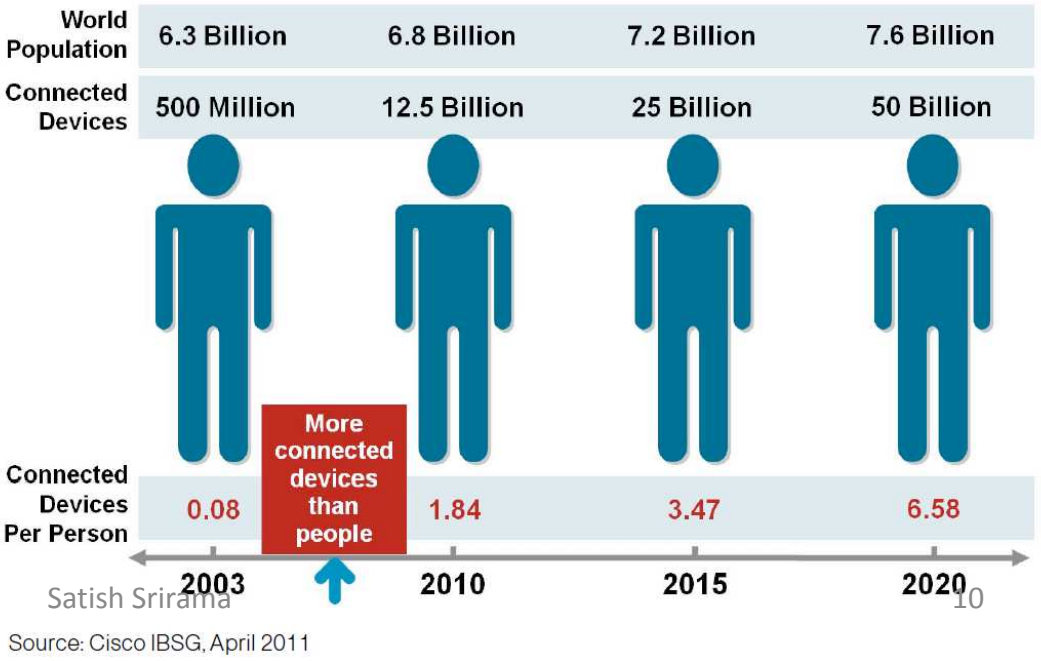
Potential of Cloud Computing

- Cloud computing has emerged as one of the most prominent platforms instigating
  - Enterprise applications
  - Social networking applications etc.
- Now IoT is emerging as another important domain
  - In realizing smart environment, smart cities, smart healthcare etc.
- Cloud has huge potential to drive IoT



Internet of Things (IoT)

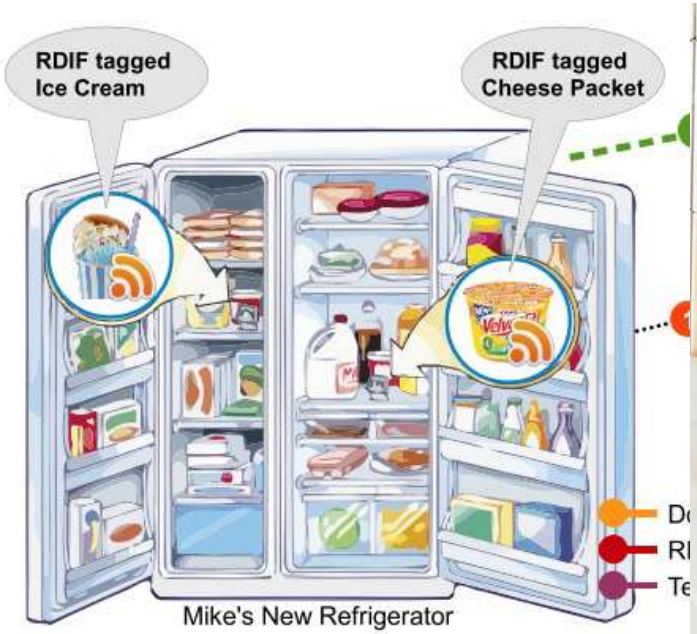
- IoT *allows people and things to be connected*
  - ***Anytime***, ***Anyplace***, *with* ***Anything*** *and* ***Anyone***, *ideally using* ***Any path/network*** *and* ***Any service***
    [European Research Cluster on IoT]
- More connected d
- Cisco believes the
  trillion by 2025

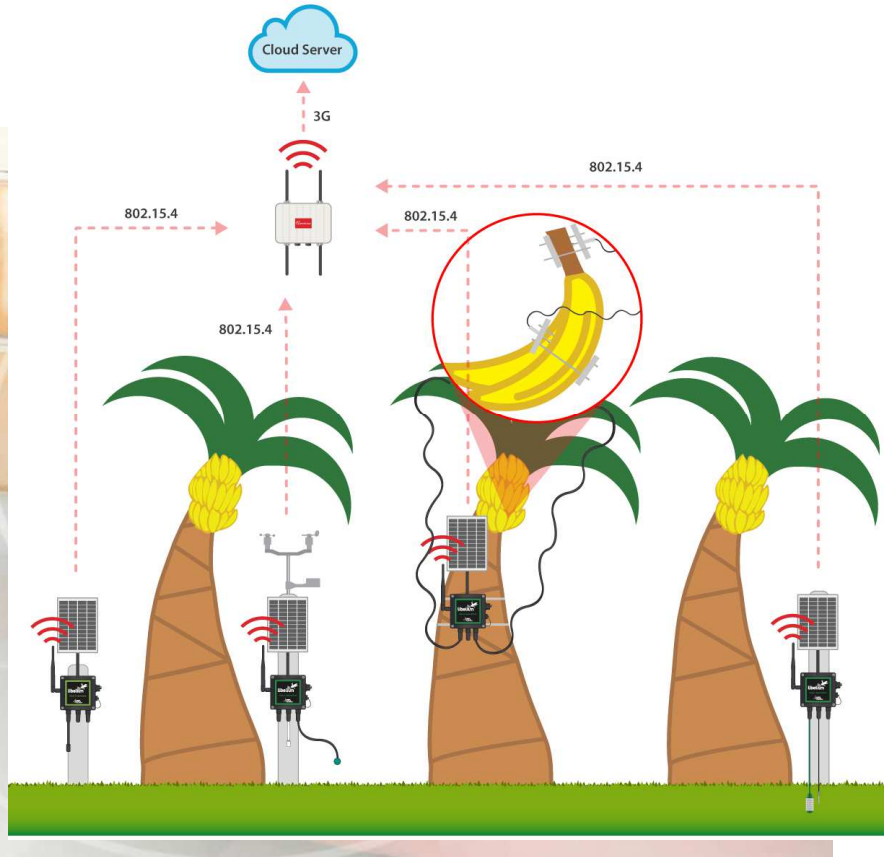


Source: Cisco IBSG, April 2011

IoT - Scenarios

- Environment Protection
- Smart Home
-
-





[Kip Compton]

[Perera et al, TETT 2014]

[http://www.libelium.com/improving-banana-crops-production-and-agricultural-sustainability-in-colombia-using-sensor-networks/]

Internet of Things – Challenges

[Chang et al, ICWS 2015]

How to provide energy efficient services?

How do we communicate automatically?

Sensors

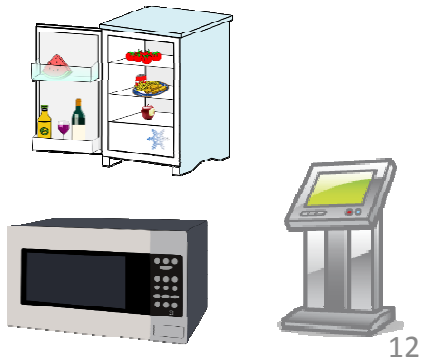
Tags

Mobile Things

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

How to interact with 'things' directly?

Appliances & Facilities

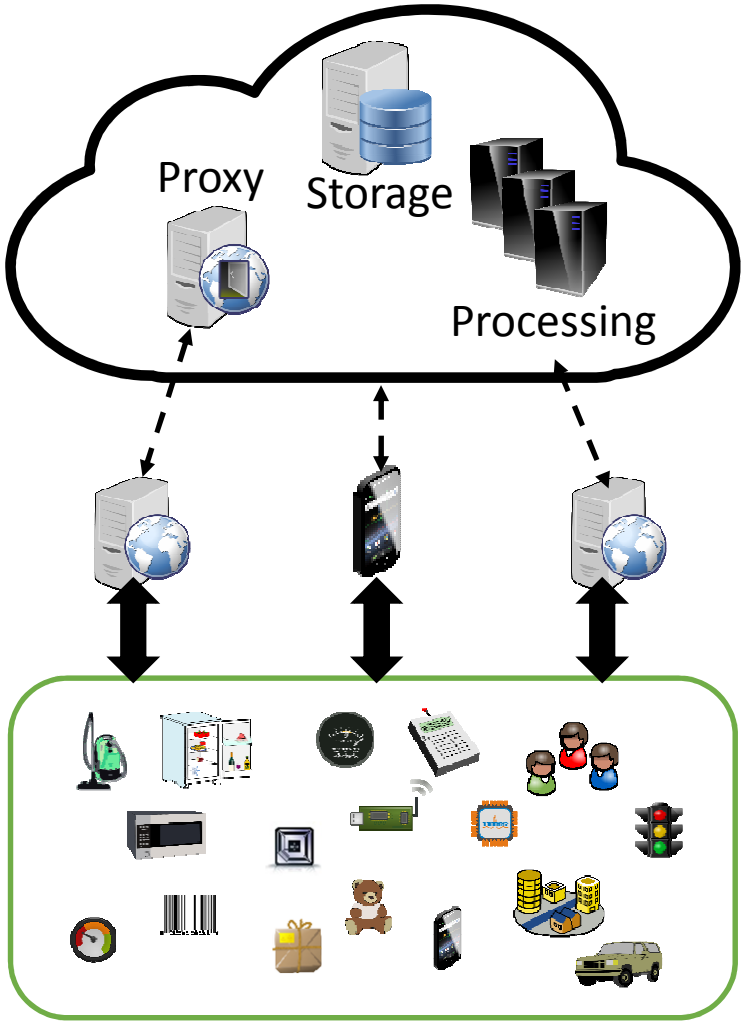


Layers of Cloud-based IoT

Remote Cloud-based processing

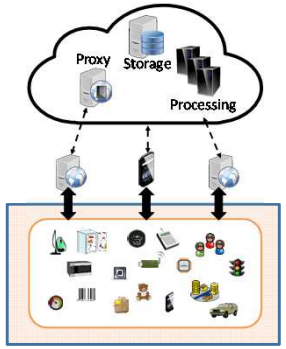
Connectivity nodes & Embedded processing

Sensing and smart devices

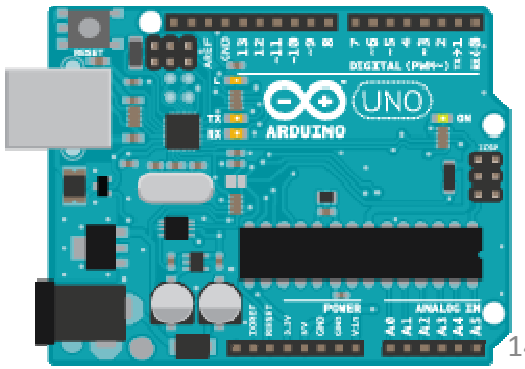


Sensing and Smart Devices

- IoT Devices
  - Sensors and actuators
  - Motion, Temp, Light, Open/Close, Video, Reading, Power on/off/dimm etc.

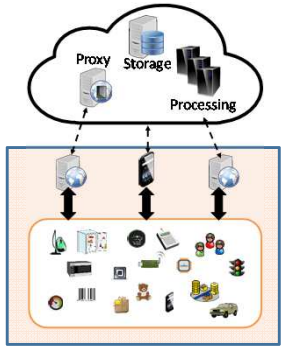


- Communication protocols
  - Wireless and wired
  - Protocols such as ZigBee, Z-Wave, Wi-Fi/Wi-Fi Direct, Bluetooth etc.
- Arduino & Raspberry PI
  - For rapid prototyping



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

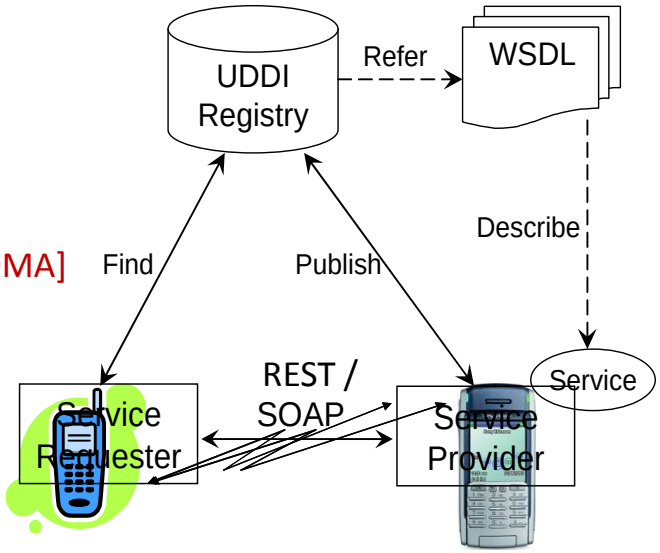


Advances in Mobile Technologies

- Mobile – The Seventh Mass Media Channel [Tomi T Ahonen]
- Embedded Hardware
  - Camera, Wifi, sensors such as accelerometer, magnetic field, etc.
- Higher data transmission and ubiquitous access to Internet
  - 3G, 4G, 5G, Wifi

Mobile Hosts in Enterprise Service Integration

- Web services (WS)
  - Enable enterprise integration
- Mobile web services (MWS) [LA, OMA]
  - Weather, search, maps etc.



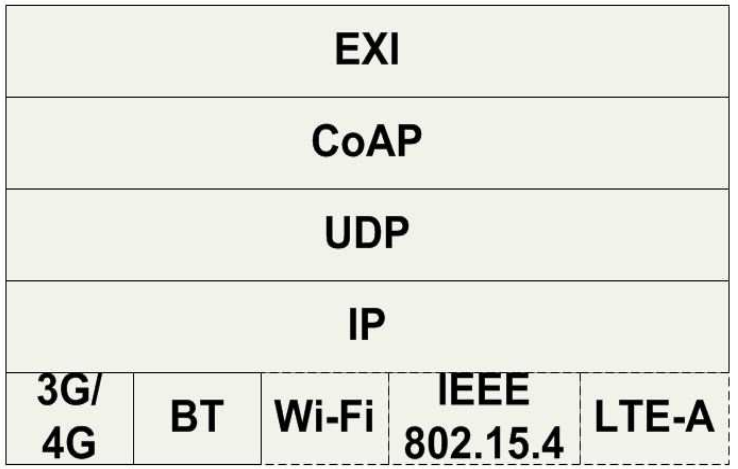
[Srirama et al, ICIW 2006; Srirama, 2008]

- Mobile Social Networks in proximity [Chang et al, ICSOC 2012; PMC 2014]

UDDI - Universal Description, Discovery and Integration
WSDL - Web Services Description Language

Light-weight Mobile Hosts for Sensor Mediation

- 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)



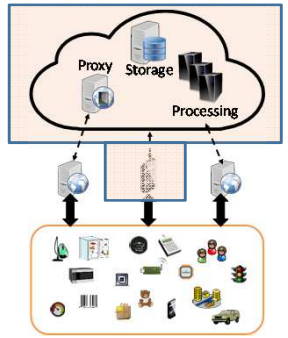
[Liyanage et al, MS 2015]

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 Applications

- Bring the cloud infrastructure to the proximity of the mobile user
- Mobile has significant advantage by going cloud-aware
  - Increased data storage capacity
  - Availability of unlimited processing power
  - PC-like functionality for mobile applications
  - Extended battery life (energy efficiency)

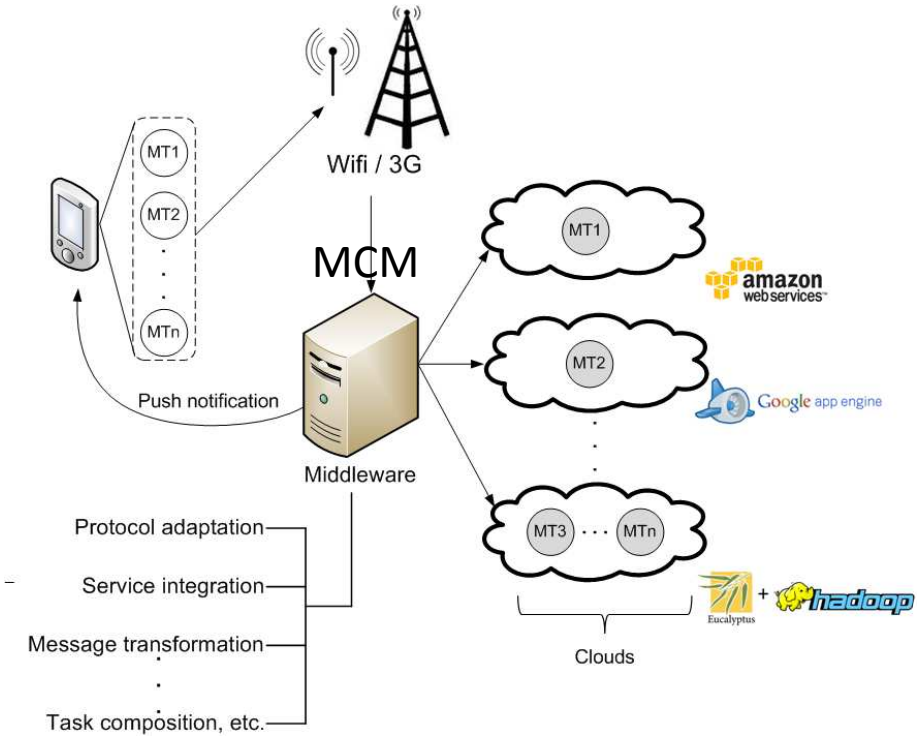


Mobile Cloud – Interpretation

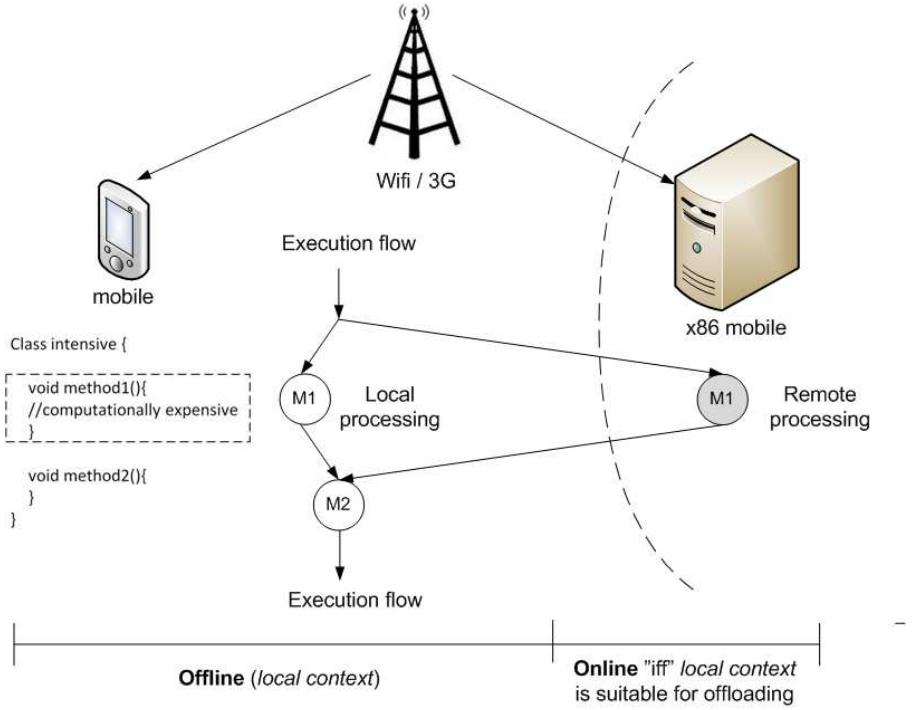
- We should not see Mobile Cloud to be just a scenario where mobile is taking the help of a much powerful machine!!!
- We should not see cloud as just a pool of virtual machines

- 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)

Mobile cloud - Binding models



Task Delegation



Code Offloading

[Flores and Srirama, JSS 2014]

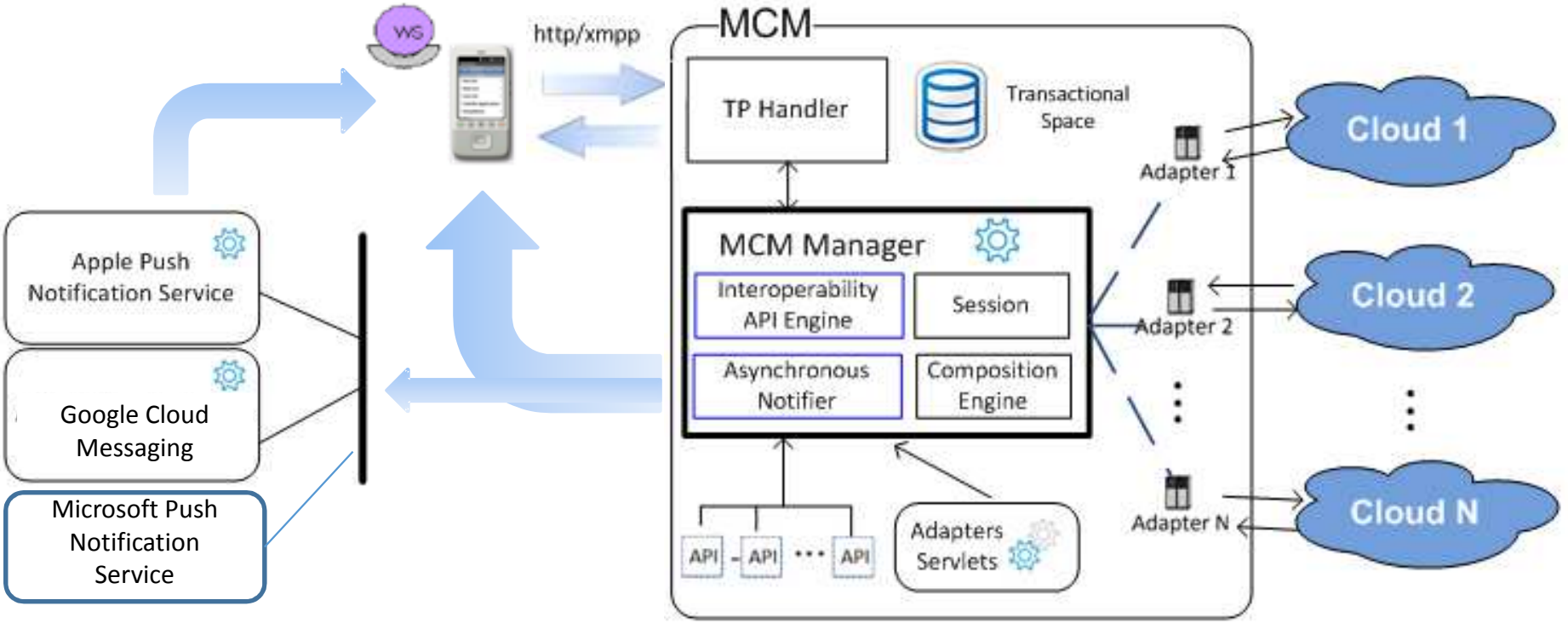
[Flores et al, IEEE Communications Mag 2015]

Task Delegation

- Follows traditional SOA model to invoke services
  - Similar to mobile Web service client
- Typical scenarios
  - Process intensive services
    - Face recognition, sensor mining etc.
  - Data Synchronization (SyncML, Funambol, Google Sync)
    - Calendar, contacts etc.
- Critical challenges were (~2010)
  - Cloud interoperability
  - Unavailability of standards and mobile platform specific API

Mobile Cloud Middleware

[Srirama and Paniagua, MS 2013]



[Warren et al, IEEE PC 2014]

[Flores et al, MoMM 2011; Flores and Srirama, JSS 2014]

MCM – enables

- Interoperability between different Cloud Services (IaaS, SaaS, PaaS) and Providers (Amazon, OpenStack, Eucalyptus, etc.)
- Provides an abstraction layer on top of API
- Composition of different Cloud Services
- Asynchronous communication between the device and MCM
- Means to parallelize the tasks and take advantage of Cloud's intrinsic characteristics

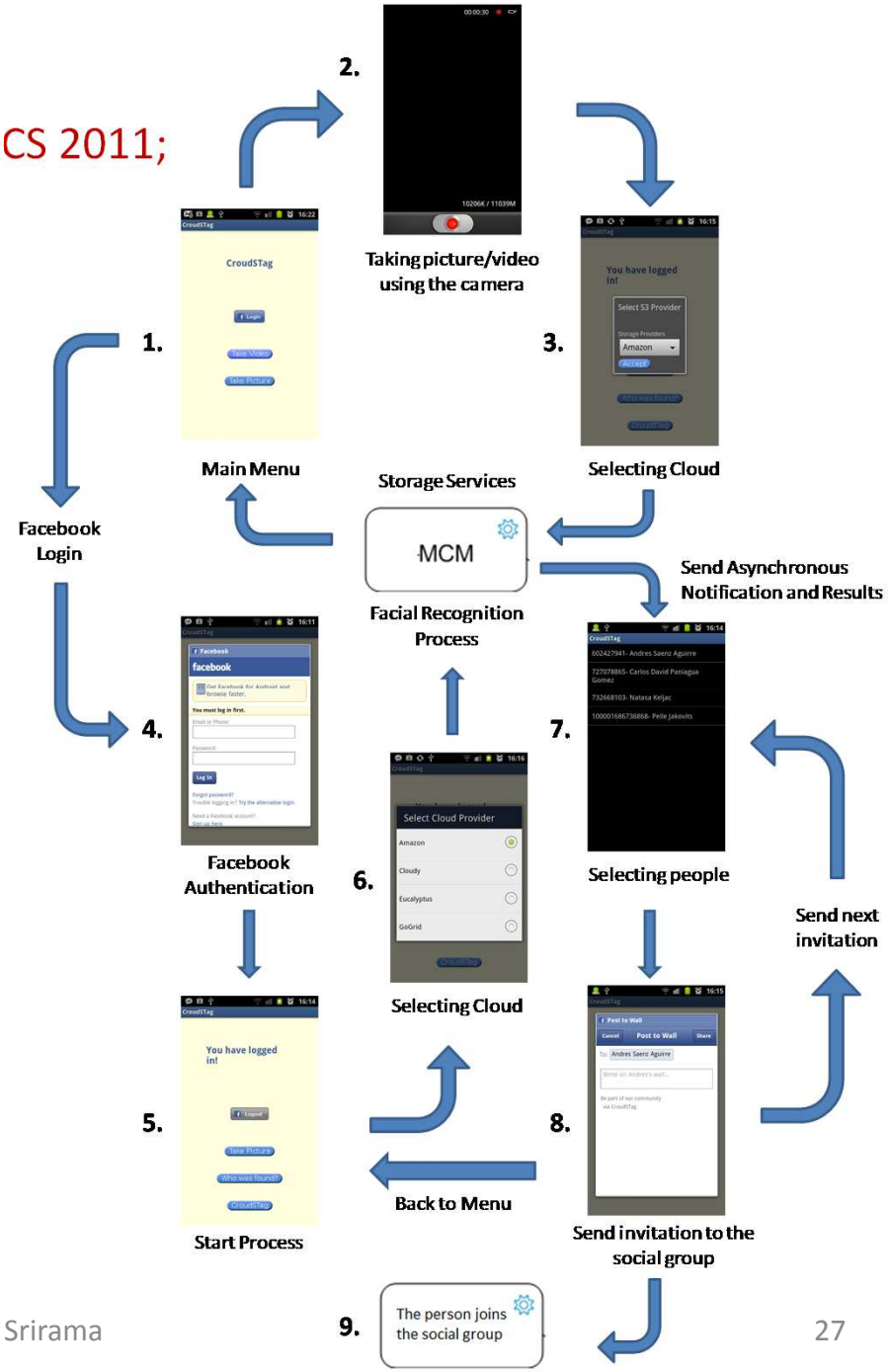
CroudSTag – Scenario

- CroudSTag takes the pictures/videos from the cloud and tries to recognize people
  - Pictures/Videos are actually taken by the phone
  - Processes the videos
  - Recognizes people using facial recognition technologies
- Reports the user a list of people recognized in the pictures
- The user decides whether to add them or not to the social group
- The people selected by the user receive a message in facebook inviting them to join the social group

[Srirama et al, PCS 2011; SOCA 2012]

CroudSTag [Srirama et al, PCS 2011; SOCA 2012]

- Cloud services used
  - Media storage on Amazon S3
  - Processing videos on Elastic MapReduce
  - face.com to recognize people on facebook
  - Starting social group on facebook



Other applications

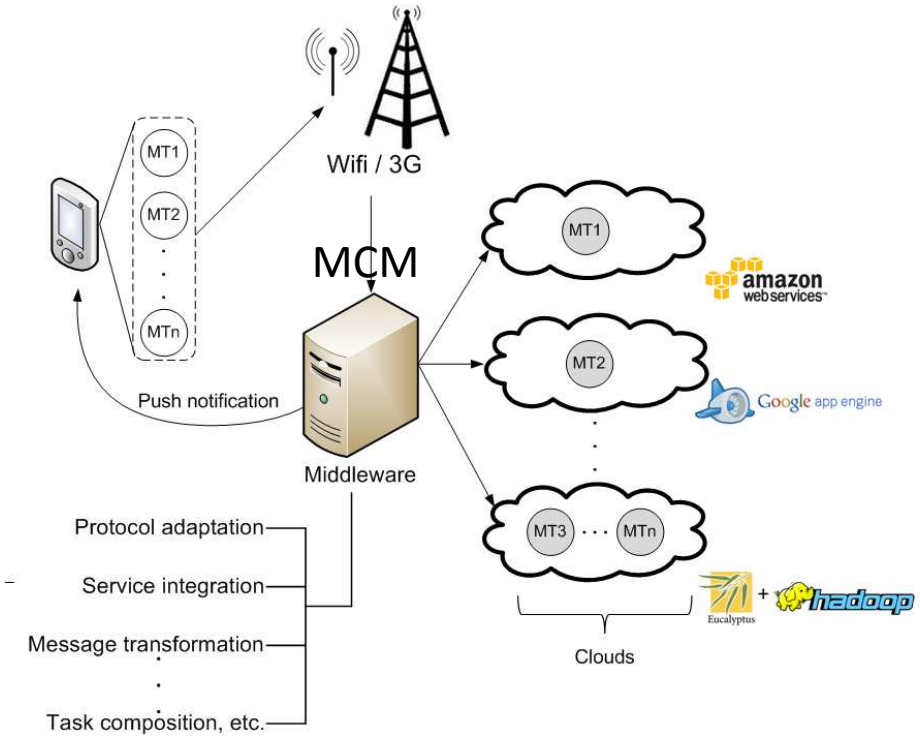
- Zompopo [Srirama et al, NGMAST 2011]
  - Intelligent calendar, by mining accelerometer sensor data
- Bakabs [Paniagua et al, iiWAS-2011]
  - Managing the Cloud resources from mobile
- Sensor data analysis
  - Human activity recognition
  - Context aware gaming
  - MapReduce based sensor data analysis [Paniagua et al, MobiWIS 2012]

- SPiCa: A Social Private Cloud Computing Application Framework [Chang et al, MUM 2014]

Adaptive Workflow Mediation Framework

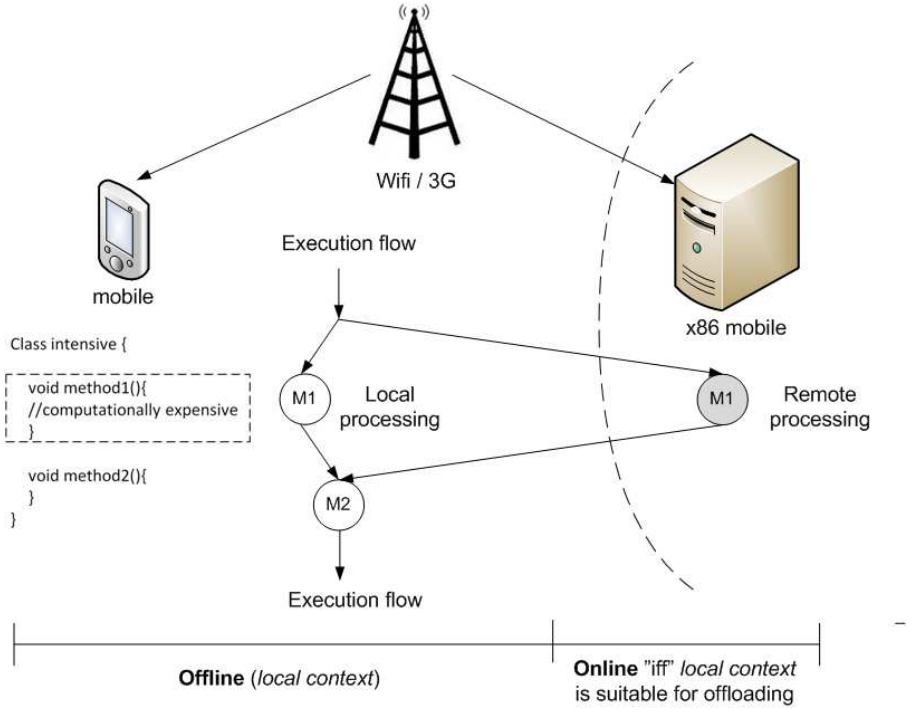
- Task delegation is a reality!!!
  - Cloud providers also support different platforms
- Mobile Host allows invocation of services on smartphones
- So Peer-to-Peer (P2P) communication is possible
- Extended the Mobile Host to also support workflow execution [Chang et al, ICSOC 2012; MUM 2014]
  - To address challenges of discovery and quality of service (QoS) [Srirama et al, MW4SOC 2007]
  - Tasks can move between mobile and middleware

Mobile cloud - Binding models



Task Delegation

[Flores and Srirama, JSS 2014]



Code Offloading

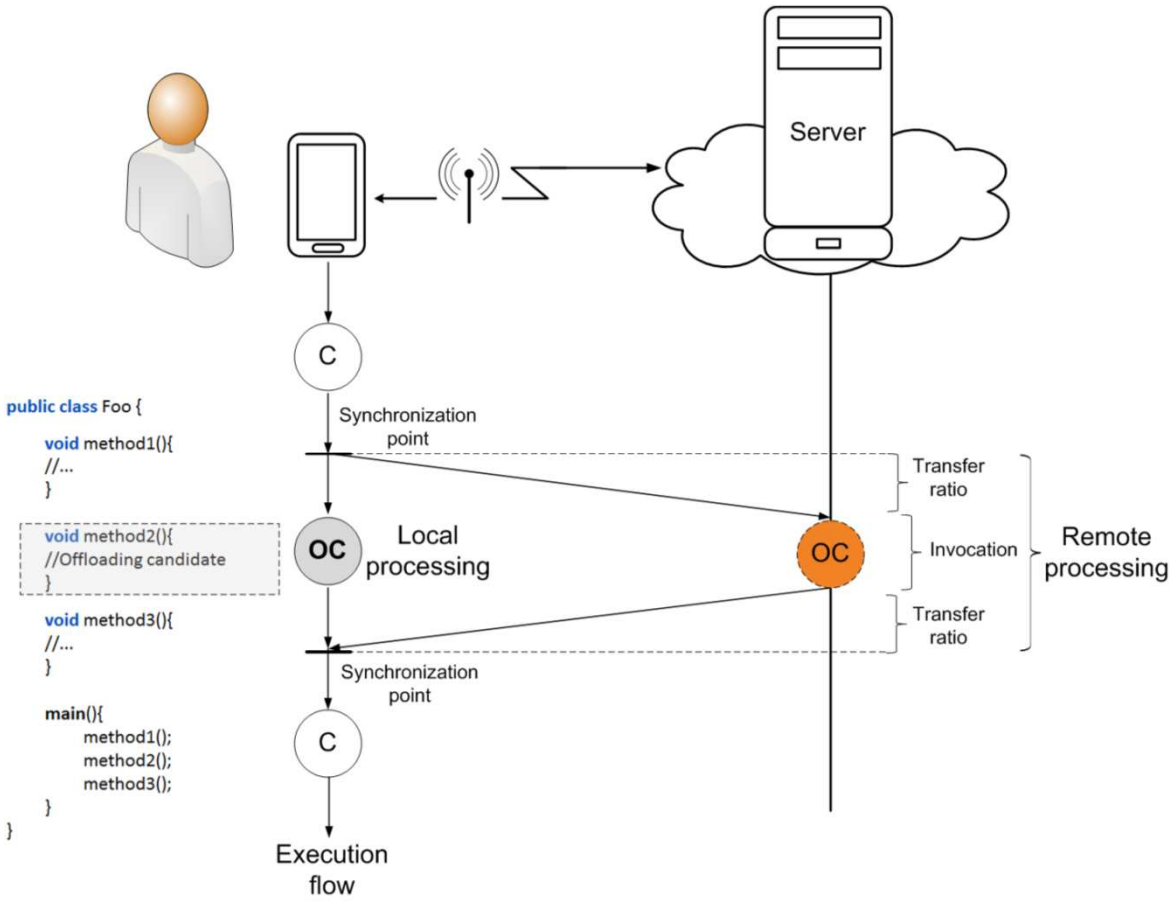
[Flores et al, IEEE Communications Mag 2015]

Code Offloading

- Also known as Cyber-foraging [M. Satyanarayanan et al, PC 2009]
- Mobile devices offload some of their heavy work to stronger surrogate machines
  - within the vicinity (Cloudlets)

Major Components

- Mobile
  - Code profiler
  - System profilers
  - Decision engine
- Cloud based surrogate platform
- Major research challenges
  - What, when, where and how to offload?



Some of the well known frameworks

- MAUI
  - Manual annotations [Cuervo et al., 2010]
- CloneCloud
  - Code profilers & Automated process [Chun et al., 2011]
- ThinkAir
  - Manual annotations and scalability [Kosta et al, 2012]
- EMCO [Flores and Srirama, MCS 2013]
  - Improved offloading by analysing the traces
- mCloud [Zhou et al, Cloud 2015; TSC 2016] & etc.
  - A context-aware offloading framework for heterogeneous mobile cloud

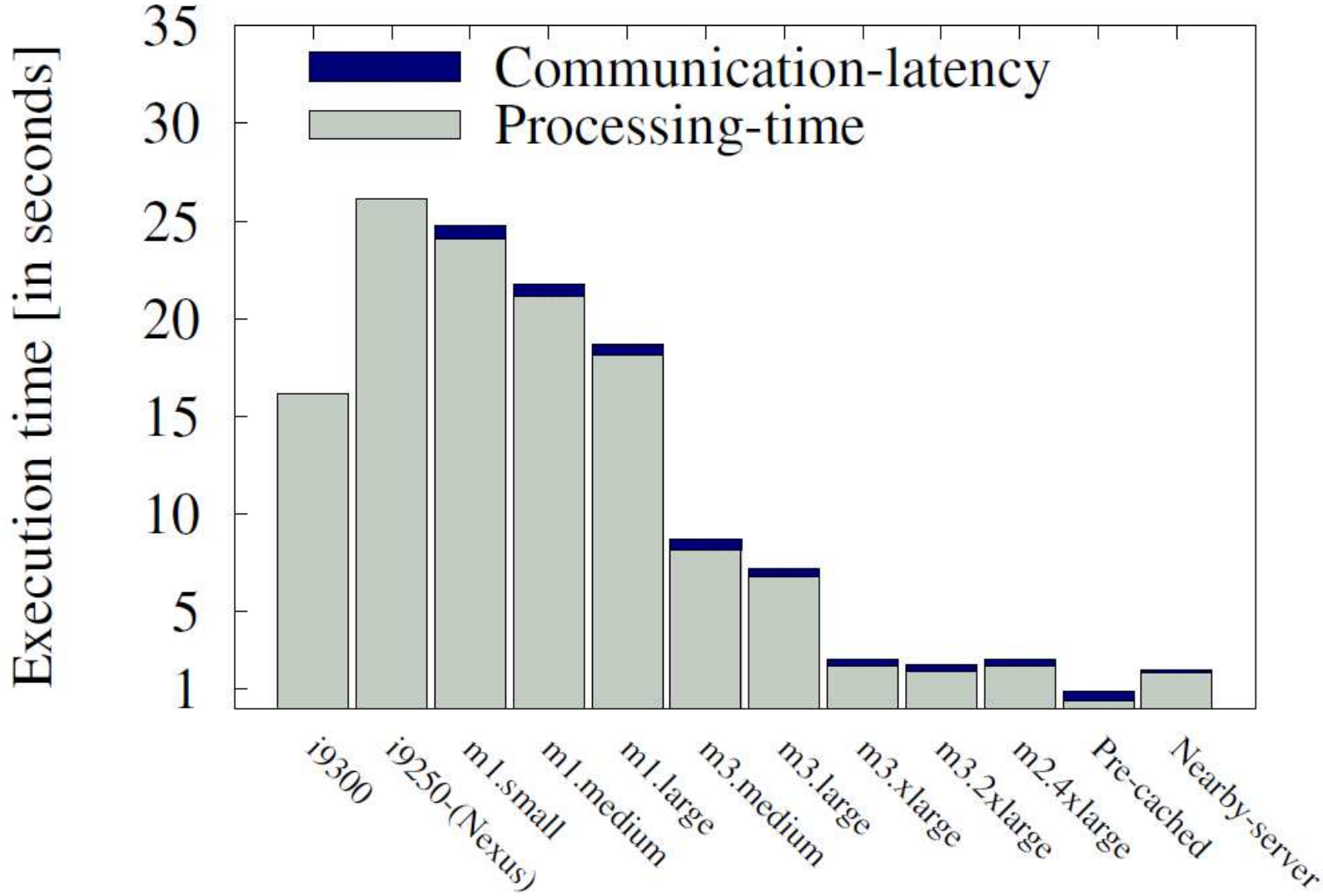
- Work in controlled environments like nearby servers
  - However, none can be adapted for real life applications

Challenges and technical problems

- Inaccurate code profiling
  - Code has non-deterministic behaviour during runtime
    - Based on factors such as input, type of device, execution environment, CPU, memory etc.
  - Some code cannot be profiled (e.g. REST)
- Integration complexity
  - Surrogate should have similar execution environment
- Dynamic configuration of the system
- Offloading scalability and offloading as a service
  - Should also consider about resource availability of Cloud

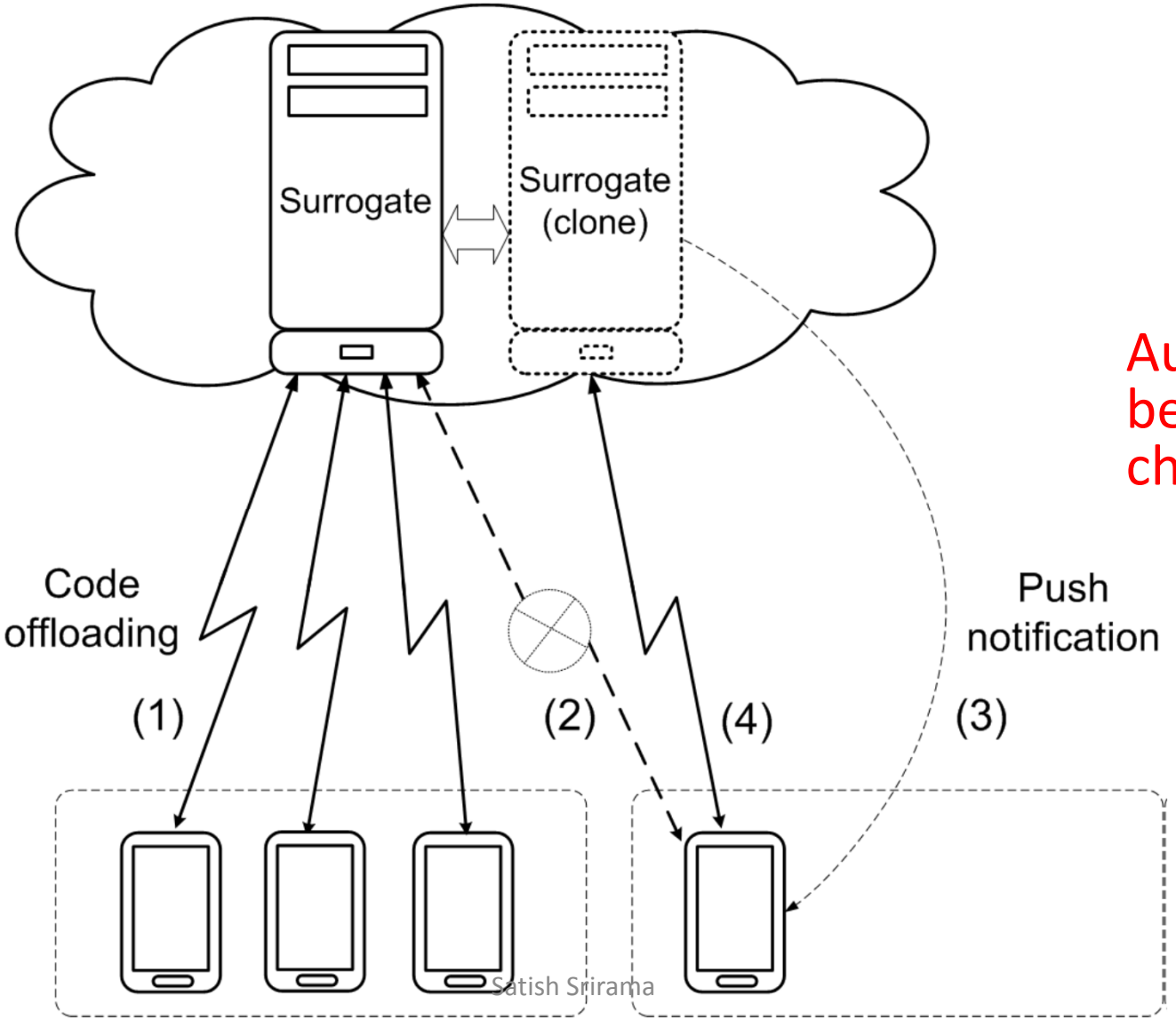
[Flores et al, IEEE Communications Mag 2015]

Practical adaptability of offloading



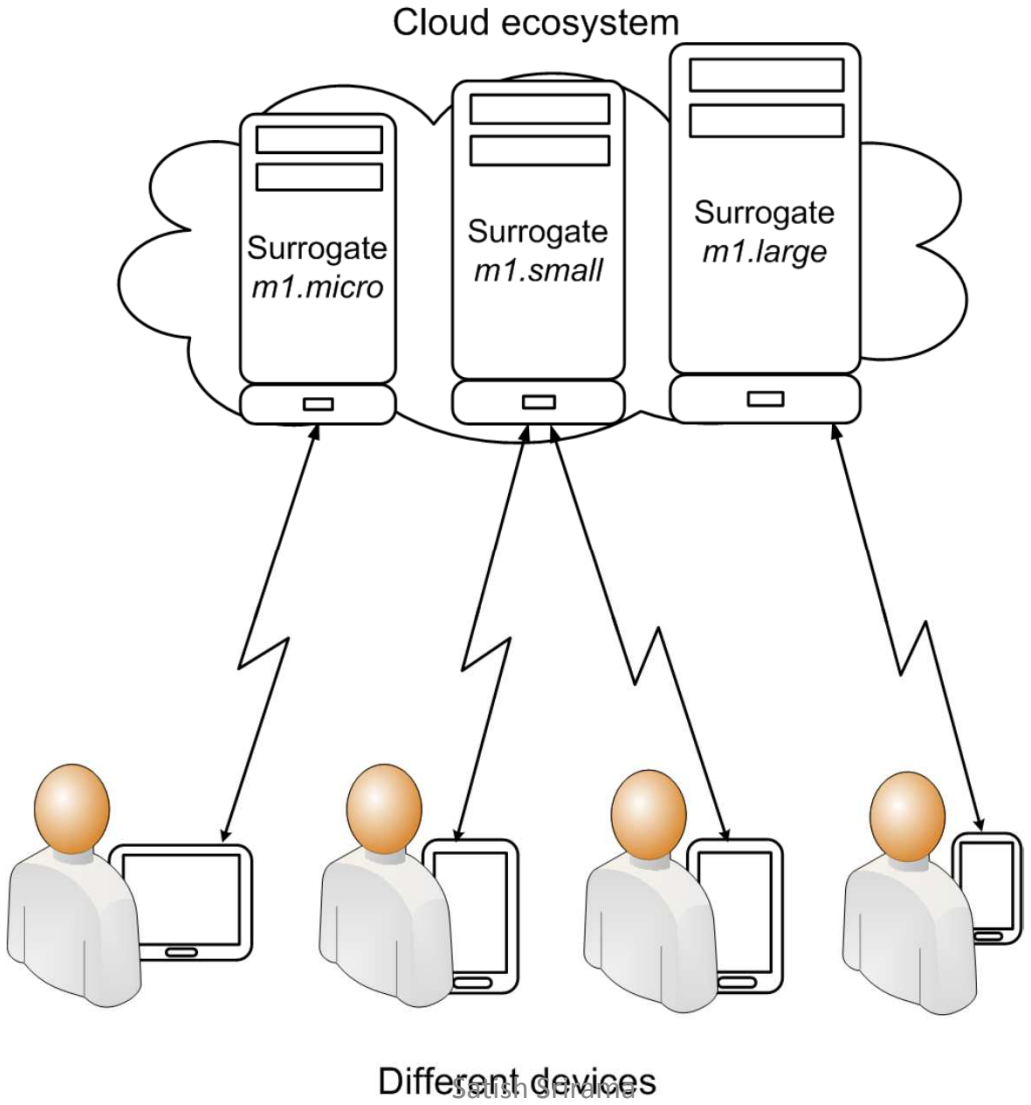
Applications that can benefit became limited with increase in device capacities

Multi-tenancy for code offloading



Auto-scaling becomes a challenge

Dynamic configuration

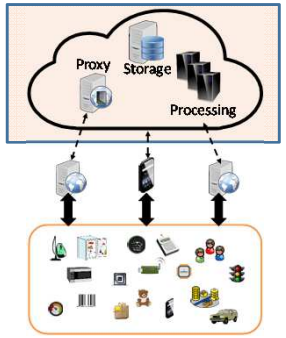


Vast resource allocation choices in the cloud ecosystem and the large diversity of smartphones make the context very variable

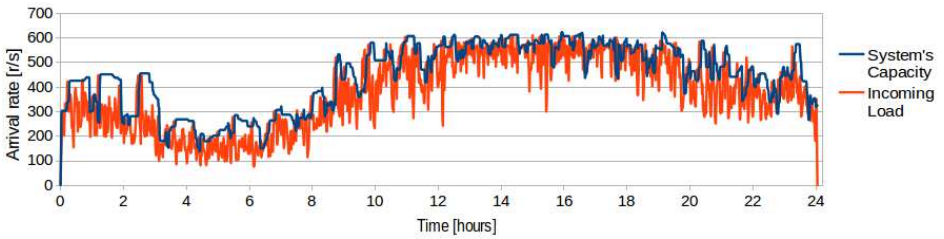
Remote Cloud-based Processing - Challenges

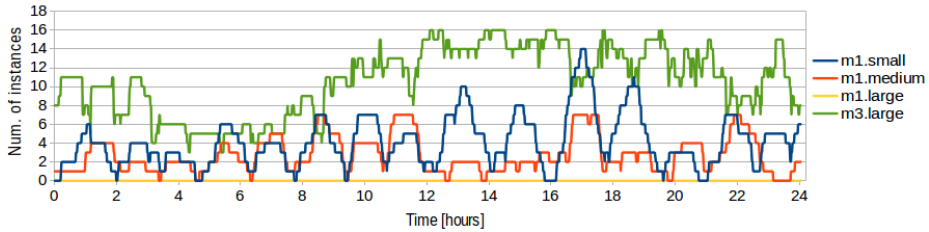
- Dynamic deployment of applications on cloud
  - Standardization efforts from CloudML

    [REMICS EU FP7; MODAClouds EU FP7; Srirama et al, Cloud 2016]



- Auto-scaling & Resource provisioning
  - Taking advantage of cloud heterogeneity
  - Cloud cost models of fine-grained billing (e.g. hourly) [Srirama and Ostovar, CloudCom 2014]





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
- Economics of Cloud Providers
  - Cloud Computing providers bring a shift from high reliability/availability servers to commodity servers
  - Replication of data and computation
    - MapReduce [Dean and Ghemawat, ACM 2008]

Adapting computing problems to cloud

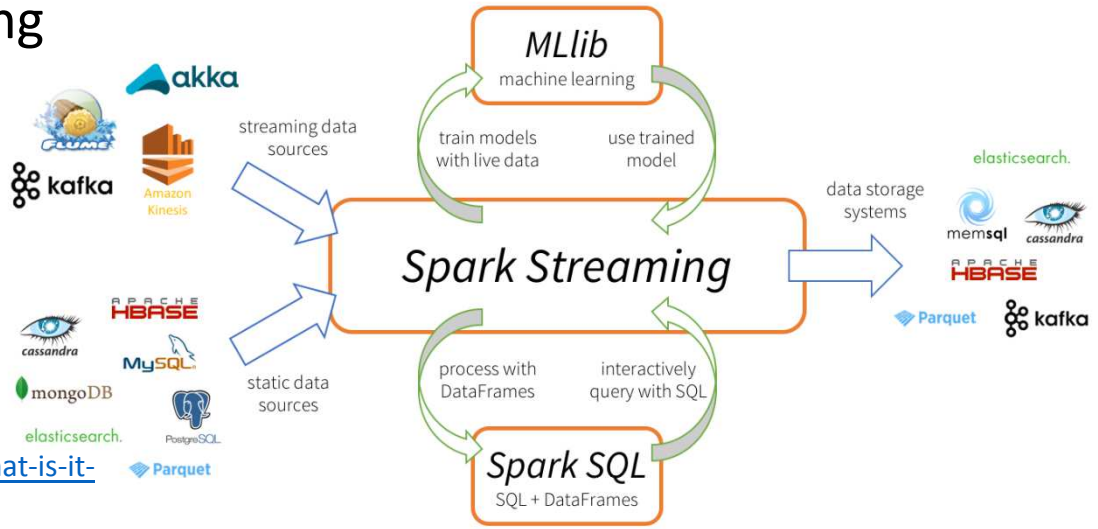
- However, MapReduce is ideal only for a subset of computing problems [Srirama et al, FGCS 2012]
  - Algorithm → single MapReduce job
    - Monte Carlo, RSA breaking
  - Algorithm → *n* MapReduce jobs
    - CLARA (Clustering), Matrix Multiplication
  - Each iteration in algorithm → single MapReduce job
    - PAM (Clustering)
  - Each iteration in algorithm → *n* MapReduce jobs
    - Conjugate Gradient
- Applicable especially for Hadoop MapReduce

Alternative approaches

- Restructuring algorithms into non-iterative versions
  - CLARA instead of PAM [Jakovits and Srirama, Nordicloud 2013]
- Alternative MapReduce implementations that are designed to handle iterative algorithms [Jakovits and Srirama, HPCS 2014]
  - E.g. Twister, HaLoop, Spark
- Alternative distributed computing models
  - Bulk Synchronous Parallel model [Valiant, 1990] [Jakovits et al, HPCS 2013]
  - Built a fault-tolerant BSP framework (NEWT) [Kromonov et al, HPCS 2014]
- Dynamic Algorithm Modeling Application (DAMA)

IoT Data Processing on Cloud - continued

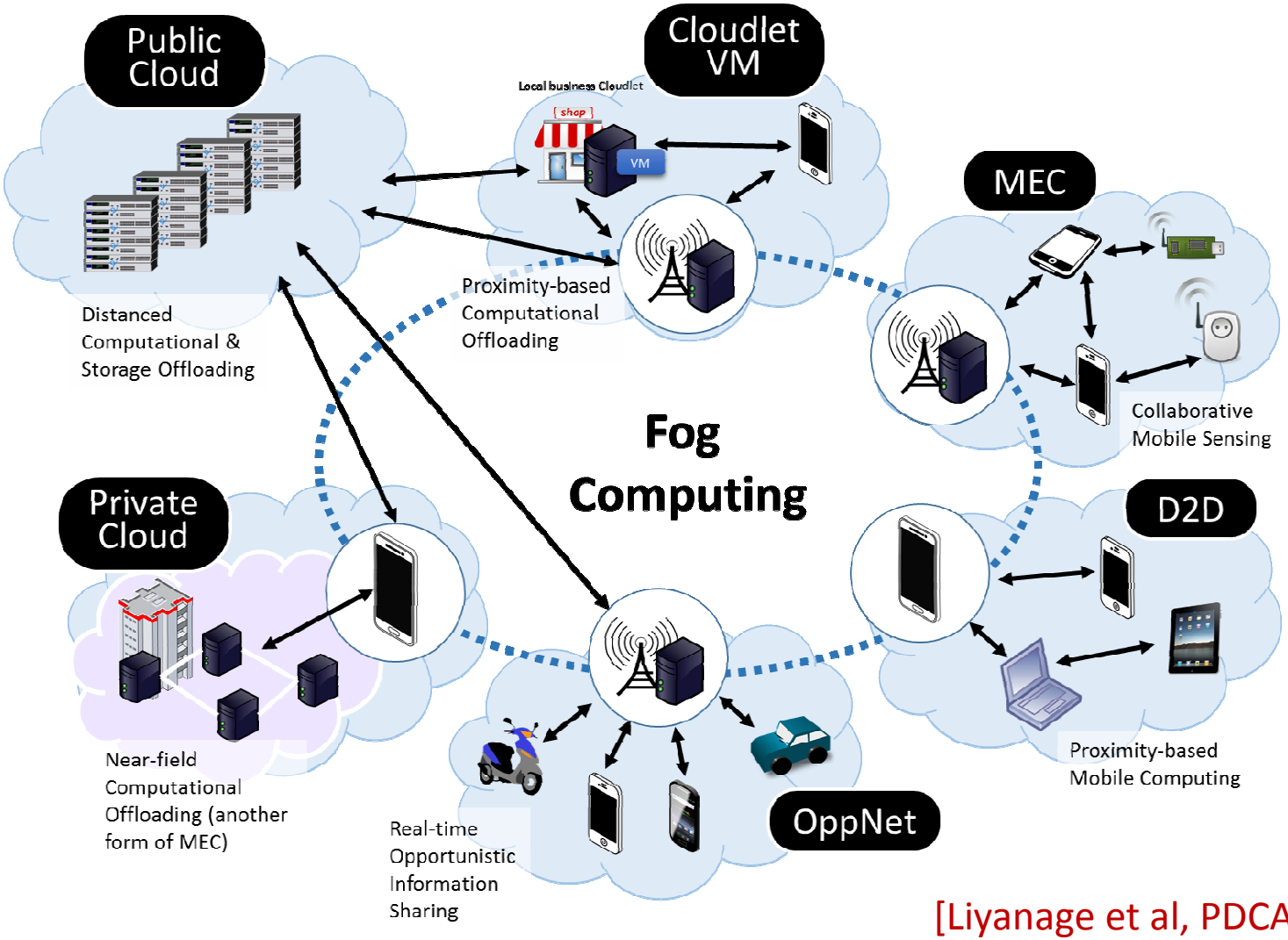
- IoT mostly deals with streaming data
  - Message queues such as Apache Kafka to buffer and feed the data into stream processing systems such as Apache Storm
  - Apache Spark streaming



https://www.datanami.com/2015/11/30/spark-streaming-what-is-it-and-whos-using-it/

- How to ensure QoS aspects such as security of data?
  - Anonymization and Expiry of data?
    - Especially for the personal data

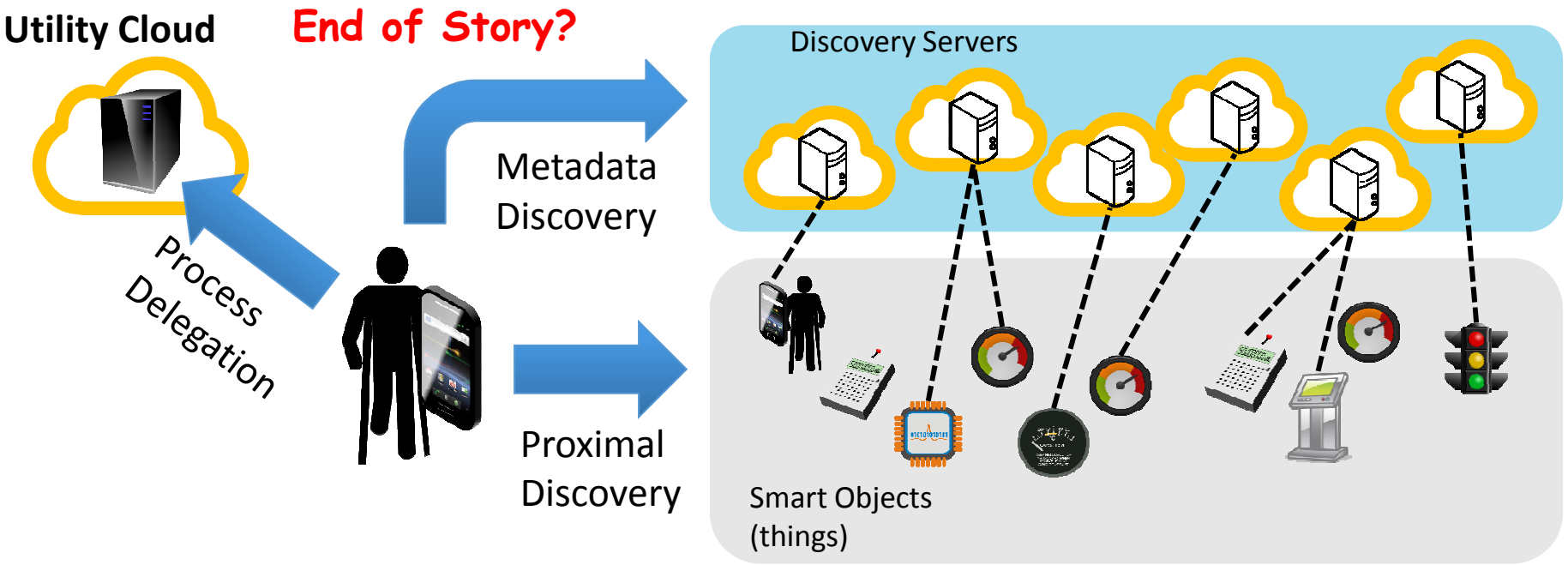
Fog Computing



[Liyanage et al, PDCAT 2016]

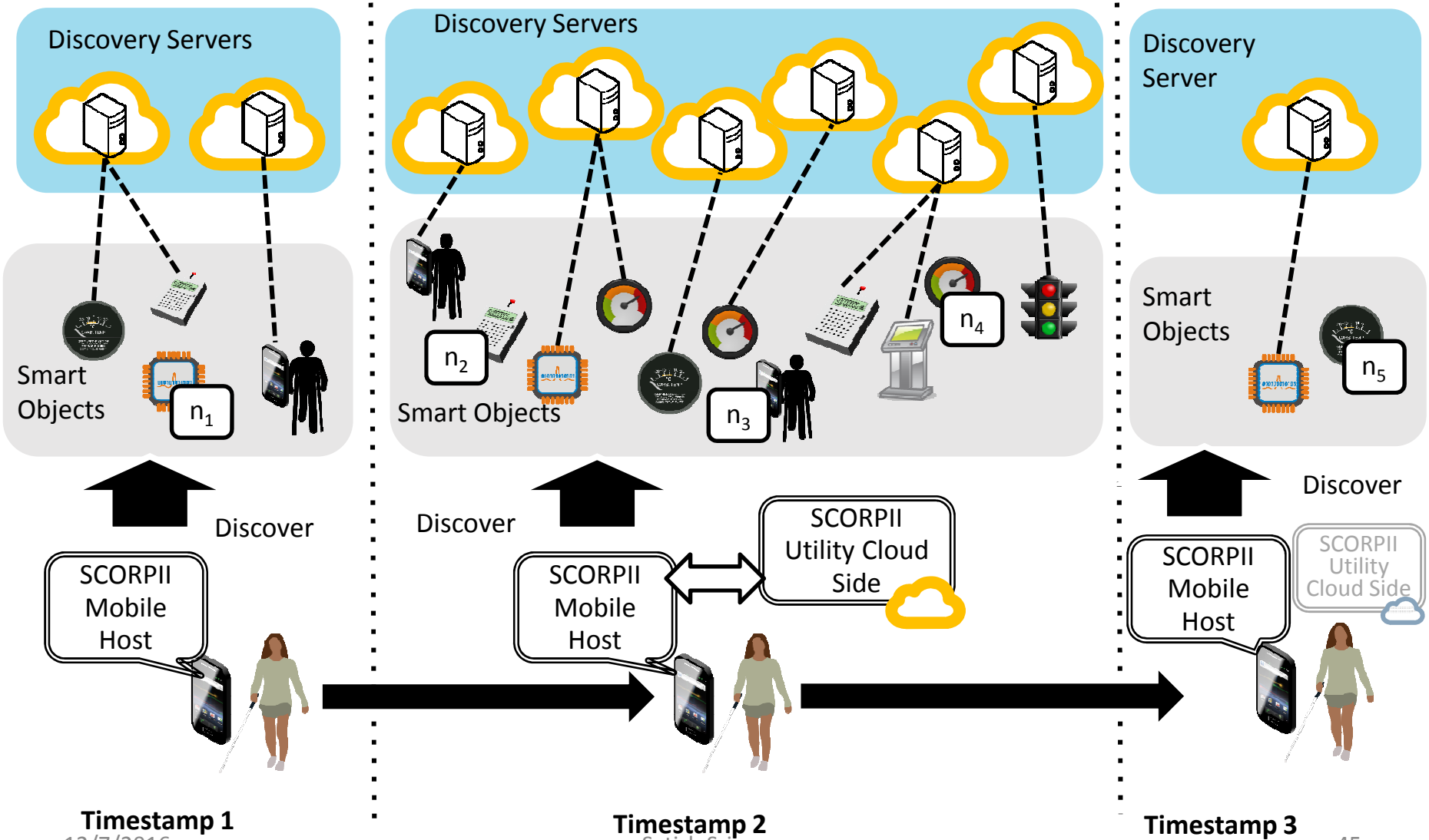
Scenario: Disabled Person Trying to Avoid Crowd in Urban Areas

- Let us assume everything we discussed so far works!



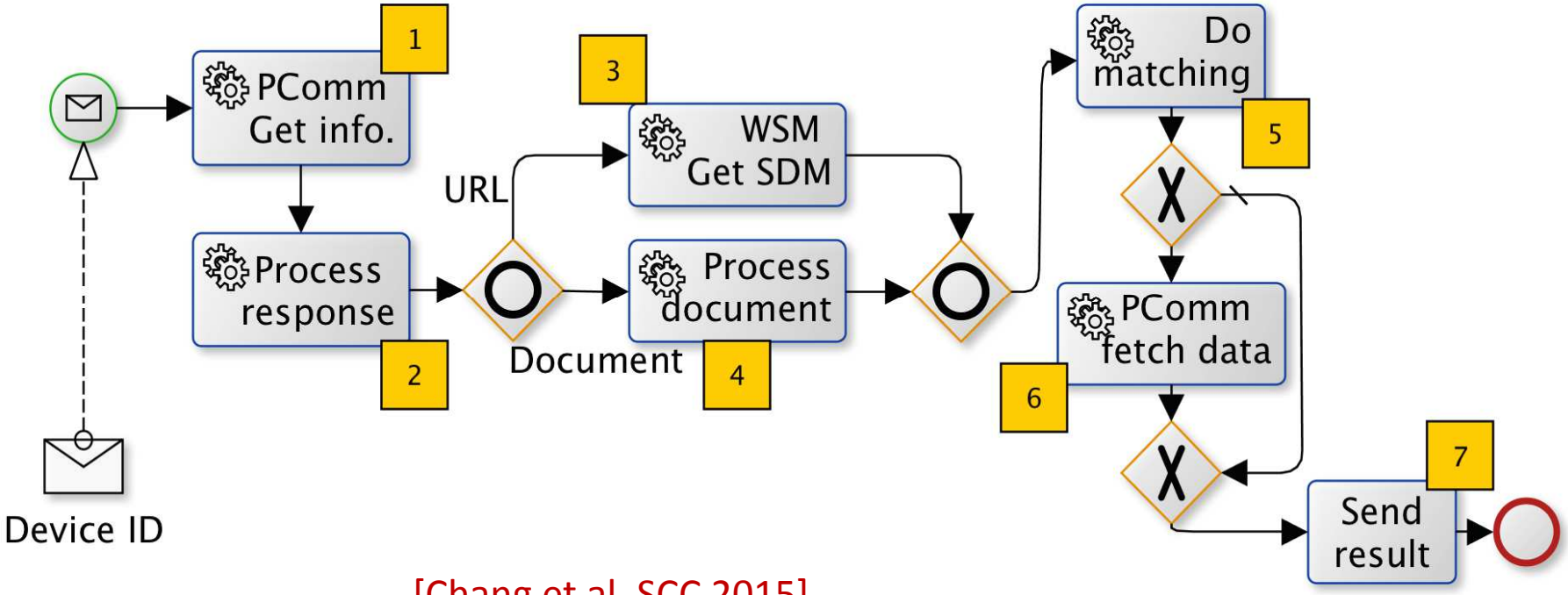
Real-time IoT Service Discovery

[Chang et al, SCC 2015]



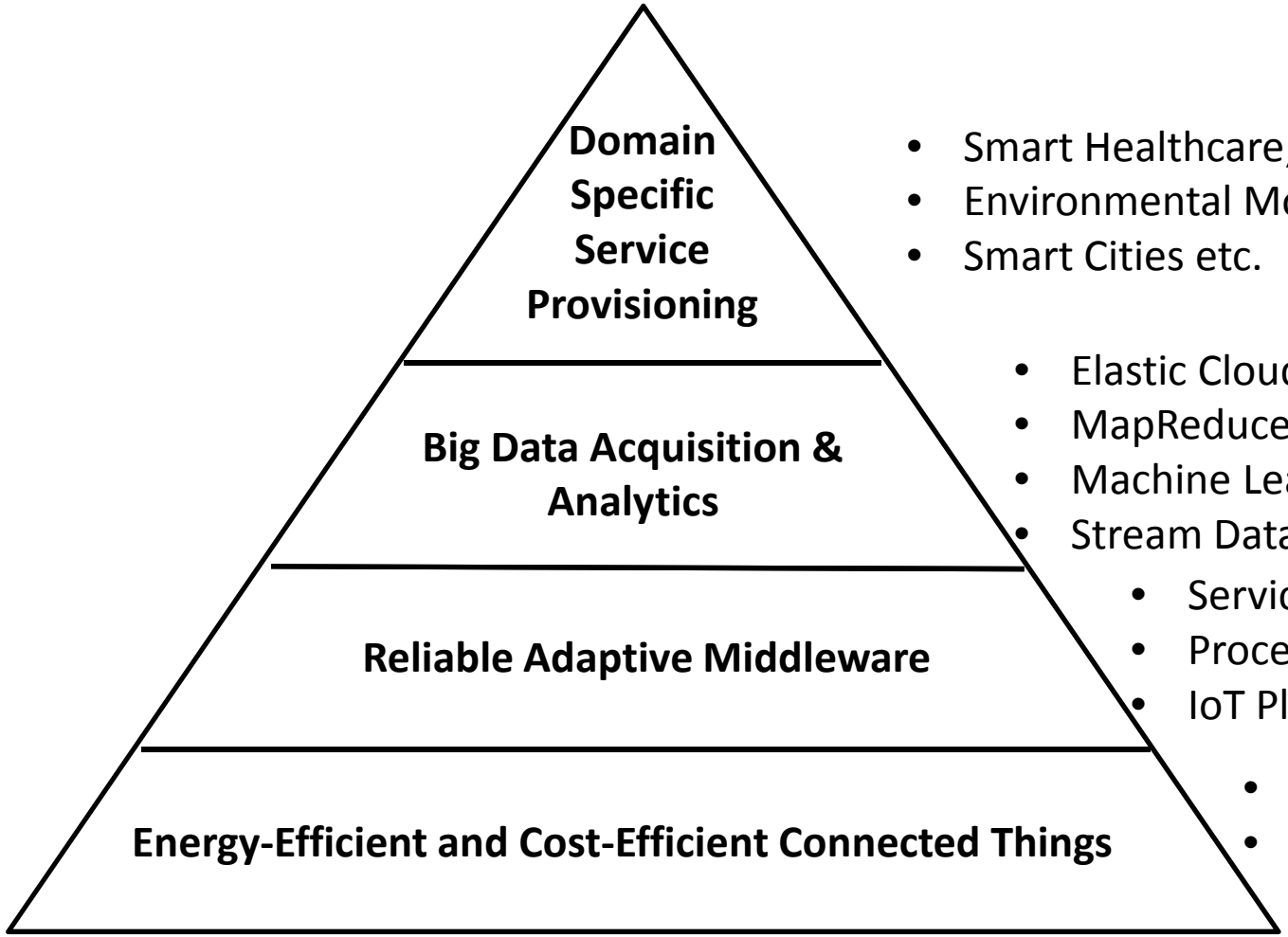
Discovery Workflow

- Workflow approach selection
- Fuzzy sets and Cost Performance Index



[Chang et al, SCC 2015]

Research Roadmap - IoT



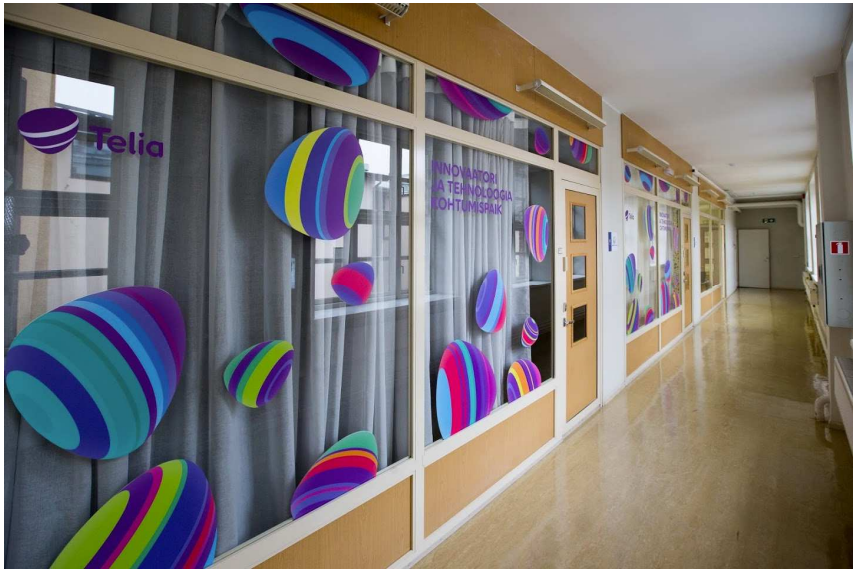
- Smart Healthcare;
- Environmental Monitoring;
- Smart Cities etc.

- Elastic Cloud Processing;
- MapReduce & Apache Hadoop Ecosyster
- Machine Learning;
- Stream Data Processing;

- Service-Oriented Computing;
- Process Management;
- IoT Platforms & Fog Computing;

- Mobile Computing;
- Wireless Sensor & Actuator Networks;

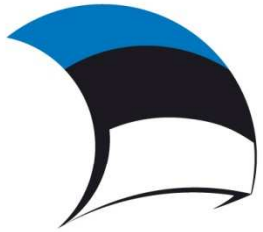
IoT and Smart Solutions Laboratory



Mobile & Cloud Lab

Telia

European Union
Regional Development Fund



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