Mobile Cloud Computing

Concepts, applications and beyond

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Mobile & Cloud Lab

Cloud+/GPU Computing 2016
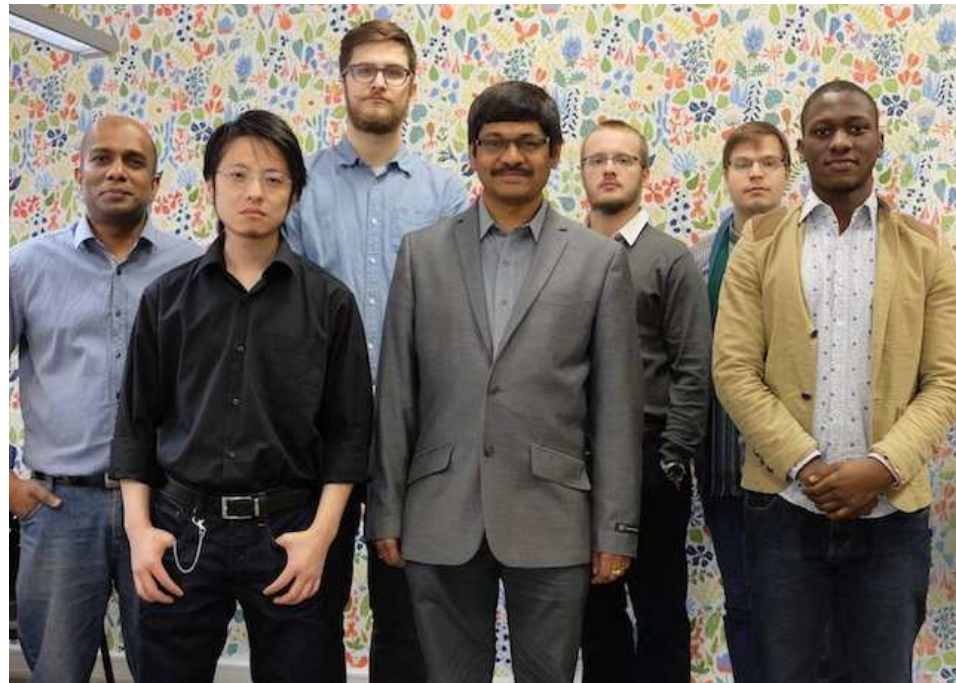Dept of CSE, UCEK, JNTU Kakinada
8th August 2016

Who am I

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

http://mc.cs.ut.ee

Mobile & Cloud Lab

Satish Srirama

Estonia pop: 1,300,000

TARTU

Pop: 100,000
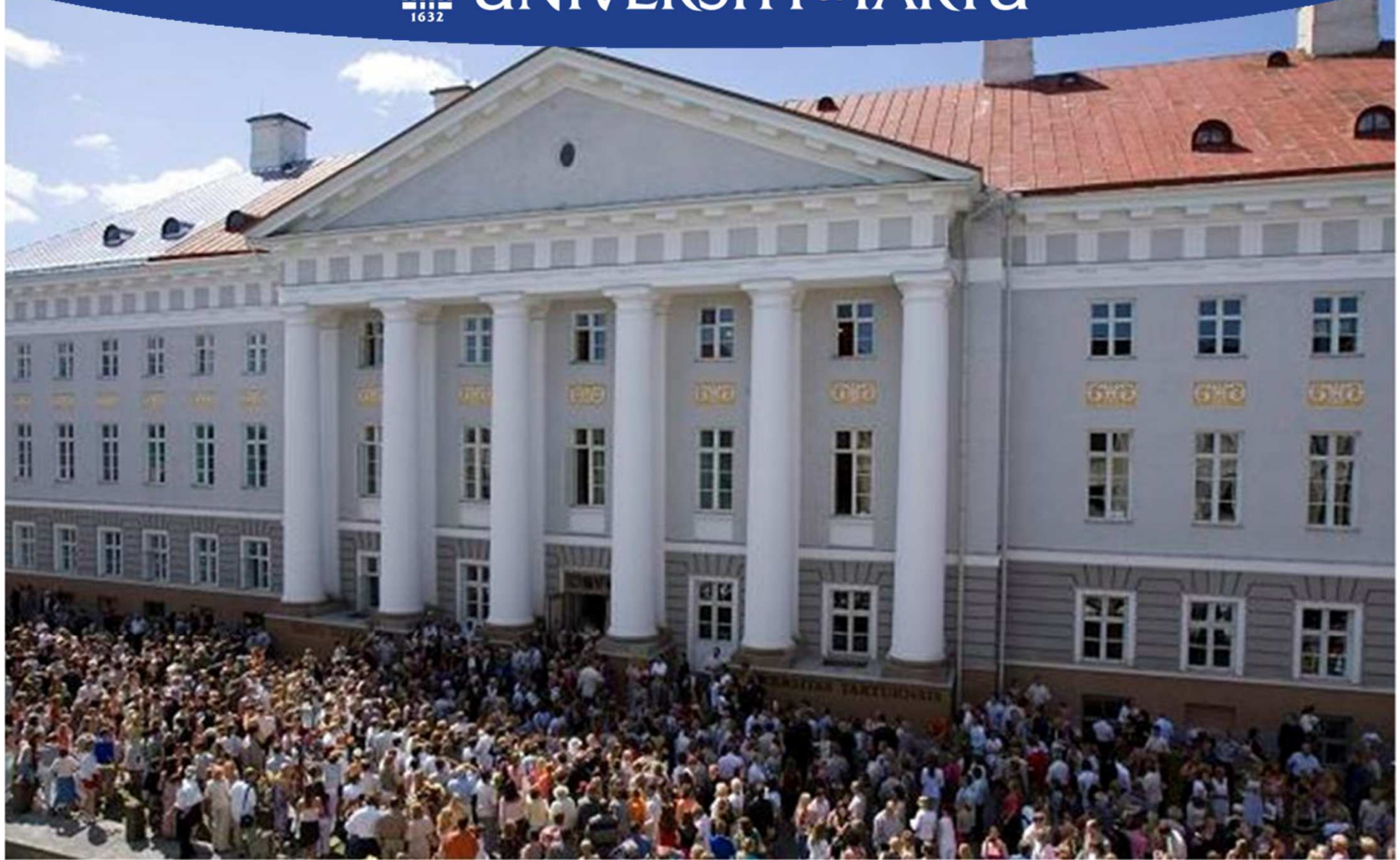
Academic excellence since 1632

Main Research Activities

Mobile Cloud Lab

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Institute of Computer Science
1632

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Manage portlets

Research

by admin — last modified Oct 01, 2014 02:10 PM — History

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 a

Mobile Computing

The research deals with developing mobile applications for various platforms and devices (e.g. Android, iOS, Windows Phone 7 etc

Mobile Cloud

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

Mobile Web Services

This research theme deals with the invocation, provisioning, discovery and integration of web services from smart phones, in develo

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: i efficiency, trustworthiness etc.

Outline

- Mobile computing
- Cloud computing
- Mobile Cloud Binding Models
  - Task delegation
    - Internet of Things (IoT)
  - Code offloading
- Conclusions and Future work

Mobile – The Seventh Mass Media Channel

The Seven Mass Media

First Mass Media Channel - **Print** from the 1500s

Second Mass Media Channel - **Recordings** from 1900s

Third Mass Media Channel - **Cinema** from 1910s

Fourth Mass Media Channel - **Radio** from 1920s

Fifth Mass Media Channel - **TV** from 1950s

Sixth Mass Media Channel - **Internet** from 1990s

Seventh Mass Media Channel - **Mobile** from 2000s

[Tomi T Ahonen]

Rank	Country or region	Number of mobile phones	Population	Phones per 100 citizens	Data evaluaton date
-	World	6,800,000,000+	7,012,000,000[1]	87	2013[2][3]
01	China	1,206,553,000[4]	1,349,585,838[5]	89.2	September 2013[4]
02	India	867,800,000	1,220,800,359[6]	70.72	30 April 2013[7]
03	United States	327,577,529	310,866,000[8]	103.9	June 2013[9]
04	Brazil	268,440,423	192,379,287[10]	135.4	August 2013[11]
05	Russia	256,116,000	142,905,200[10]	155.5	July 2013[12]
06	Indonesia	236,800,000	237,556,363	99.68	September 2013[10]
07	Pakistan	129,583,076	178,854,781[13]	72.45	September 2013[14]
08	Japan	121,246,700	127,628,095	95.1	June 2013[15]
09	Nigeria	114,000,000	165,200,000	69	May 2013[16]
10	Bangladesh	110,675,000	165,039,000	73.8	September 2013[17]
11	Germany	107,000,000	81,882,342	130.1	2013[18]
12	Philippines	106,987,098	94,013,200	113.8	October 2013[19]
13	Iran	96,165,000	73,973,000	130	February 2013[20]
14	Mexico	92,900,000	112,322,757	82.7	Dec. 2011[21]
15	Italy	88,580,000	60,090,400	147.4	Dec. 2013[22]
16	United Kingdom	75,750,000	61,612,300	122.9	Dec. 2013[23]

9/8/2016

Advances in Mobile Technologies

- Embedded Hardware
  - Camera, Wifi, sensors such as accelerometer, magnetic field, etc.
- Higher data transmission and ubiquitous access to Internet
  - 3G, 4G, 5G and Wifi
- Marketing models of applications
  - Apple Store
  - Android Market – Google Play

Popular consumer mobile applications

- ## Location-based services (LBSs)
  - Deliver services to users based on his location
- ## Mobile social networking
  - Most popular social networking platforms have apps for mobiles
- ## Mobile instant messaging (MIM)
  - Skype for mobiles, WhatsApp
- ## Mobile payment & Mobile commerce
  - Near field communication (NFC) payment

Popular consumer mobile applications - continued

- Context-aware services
  - Context means person's interests, history, environment, connections, preferences etc.
  - Proactively serve up the most appropriate content, product or service
- It is also possible to make the mobile a service provider
  - Mobile web service provisioning [Srirama et al, ICIW 2006; Srirama and Paniagua, MS 2013; Liyanage et al, MS 2015]
  - Challenges in security, scalability, discovery and middleware are studied [Srirama, PhD 2008]
  - Mobile Social Network in Proximity [Chang et al, ICSOC 2012; PMC 2014]

However, we still have not achieved

- 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

What is Cloud Computing?

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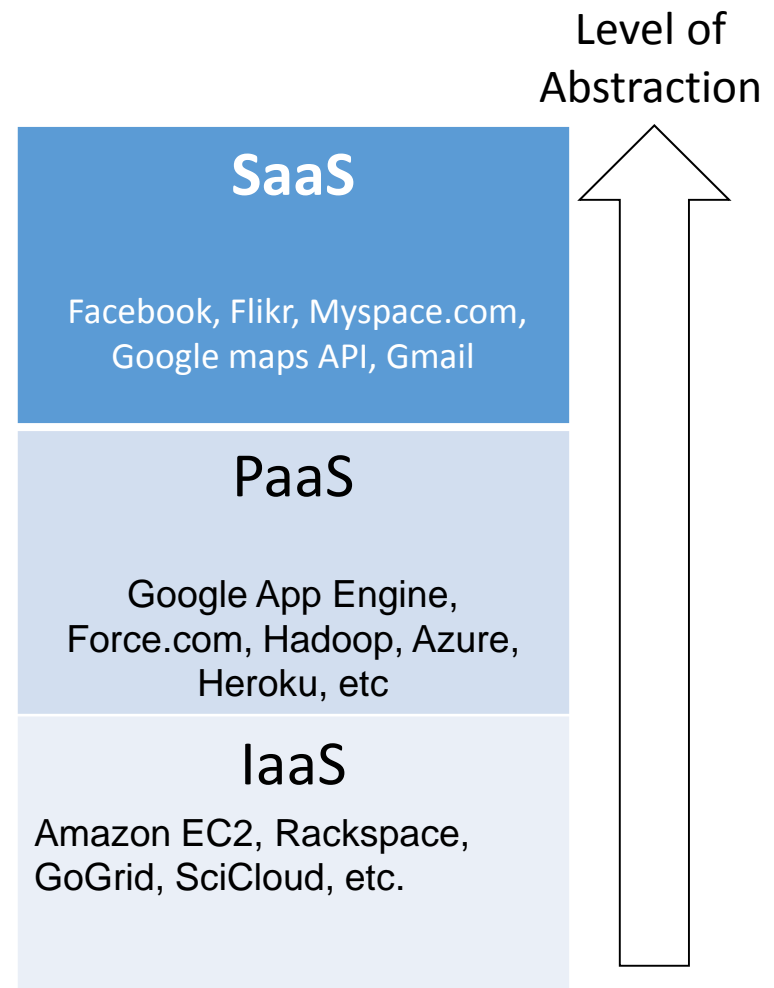 - Utility services e.g. water, electricity, gas etc
  - Consumers pay based on their usage

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)

Cloud Computing - Services

- Software as a Service – SaaS
  - A way to access applications hosted on the web through your web browser

- Platform as a Service – PaaS
  - Provides a computing platform and a solution stack (e.g. LAMP) as a service

- Infrastructure as a Service – IaaS
  - Use of commodity computers, distributed across Internet, to perform parallel processing, distributed storage, indexing and mining of data
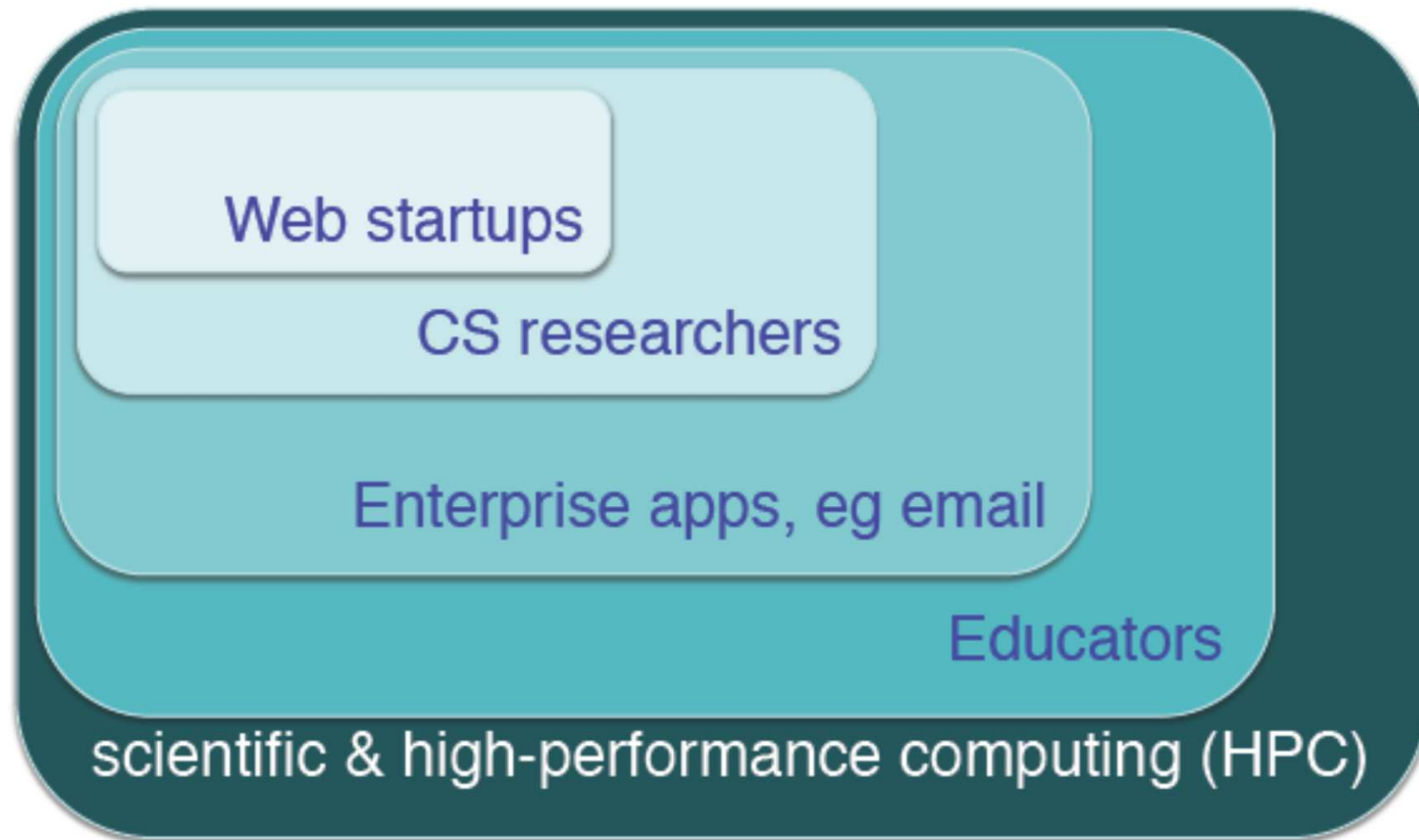 - Virtualization

SaaS

Facebook, Flikr, Myspace.com, Google maps API, Gmail

PaaS

Google App Engine, Force.com, Hadoop, Azure, Heroku, etc

IaaS

Amazon EC2, Rackspace, GoGrid, SciCloud, etc.

Level of Abstraction

Cloud Computing - Themes

- Massively scalable
- On-demand & dynamic
- Only use what you need - Elastic
  - No upfront commitments, use on short term basis
- Accessible via Internet, location independent
- Transparent
  - Complexity concealed from users, virtualized, abstracted
- Service oriented
  - Easy to use SLAs

SLA – Service Level Agreement

Economics of Cloud Providers

- Cloud Computing providers bring a shift from high reliability/availability servers to commodity servers
  - At least one failure per day in large datacenter
- Why?
  - Significant economic incentives
    - much lower per-server cost
- Caveat: User software has to adapt to failures
  - Very hard problem!
- Solution: Replicate data and computation
  - This is how MapReduce & Distributed File System jump into the Cloud domain

Cloud Computing Progress

Web startups

CS researchers

Enterprise apps, eg email

Educators

scientific & high-performance computing (HPC)

[Armando Fox, 2010]

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 is the future

Report: Mobile cloud to grow beyond $11 billion in 2018

Written by CopperEgg // July 12, 2012 // No Comment // Cloud Performance

The proliferation of smartphones, tablets and other mobile devices is contributing to change in the private sector, as businesses continue to leverage these gadgets in an attempt to enhance efficiency and potentially gain a competitive advantage. According to a new report by Global Industry Analysts, the evolution of mobility is also changing the cloud computing landscape, pushing the mobile cloud market to generate more than $11 billion in revenue by 2018.

Maribel Lopez, Contributor
I track how mobile changes engagement and business strategies
+ **Follow** (87)

TECH | 4/18/2012 @ 7:43AM | 18,825 views

Verizon's Stratton: The Future Of IT Is Mobile And Cloud

+ Comment Now   + Follow Comments

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

[Flores and Srirama, JSS 2014]

Code Offloading
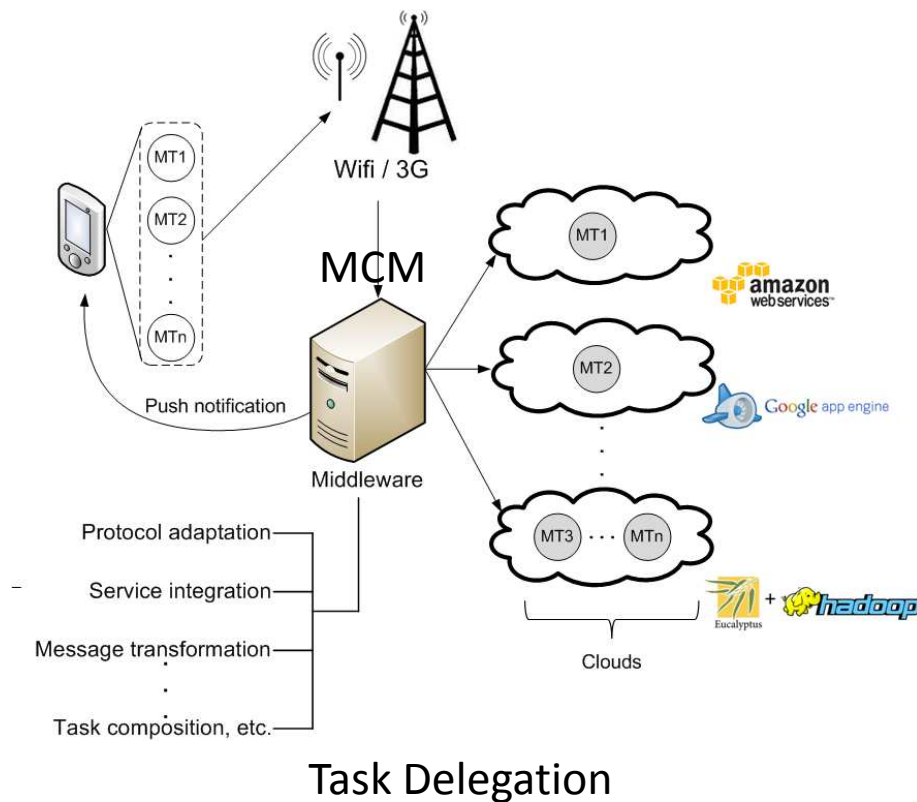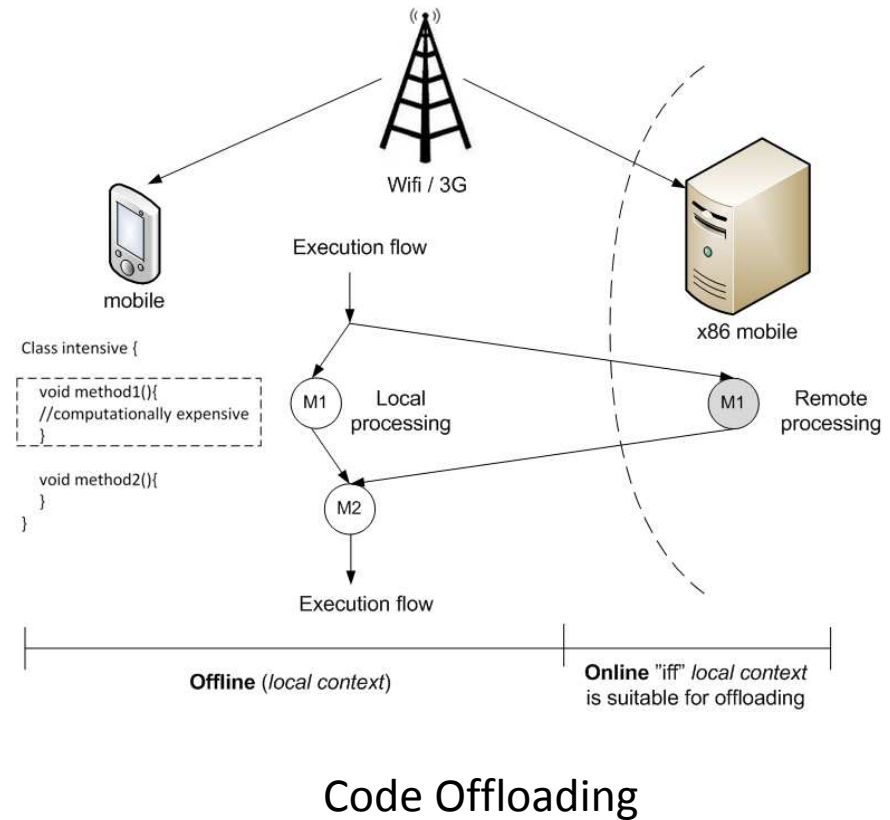
[Flores et al, IEEE Communications Mag 2015]

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]
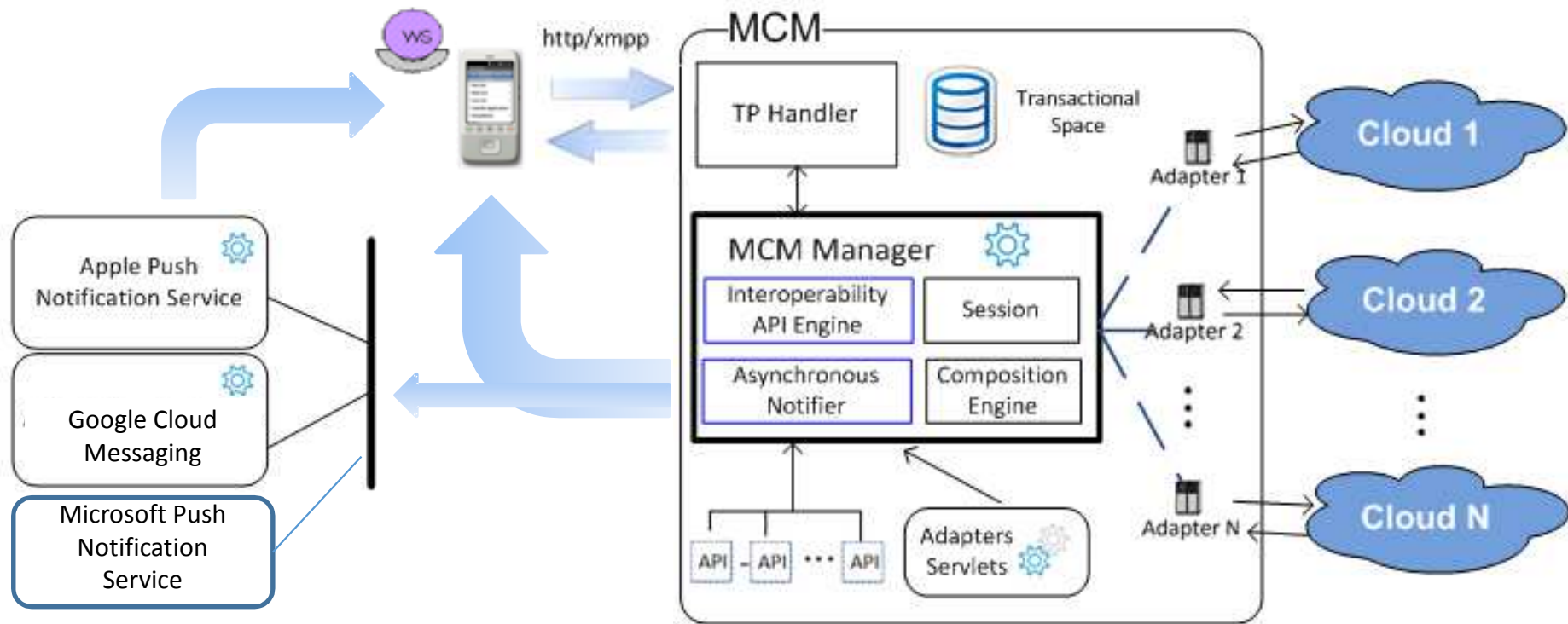
[Warren et al, IEEE PC 2014]

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

MCM – enables

- Interoperability between different Cloud Services (IaaS, SaaS, PaaS) and Providers (Amazon, 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

MCM - Scalability

MCM

Load Balancer

[Flores & Srirama, JSS 2014]
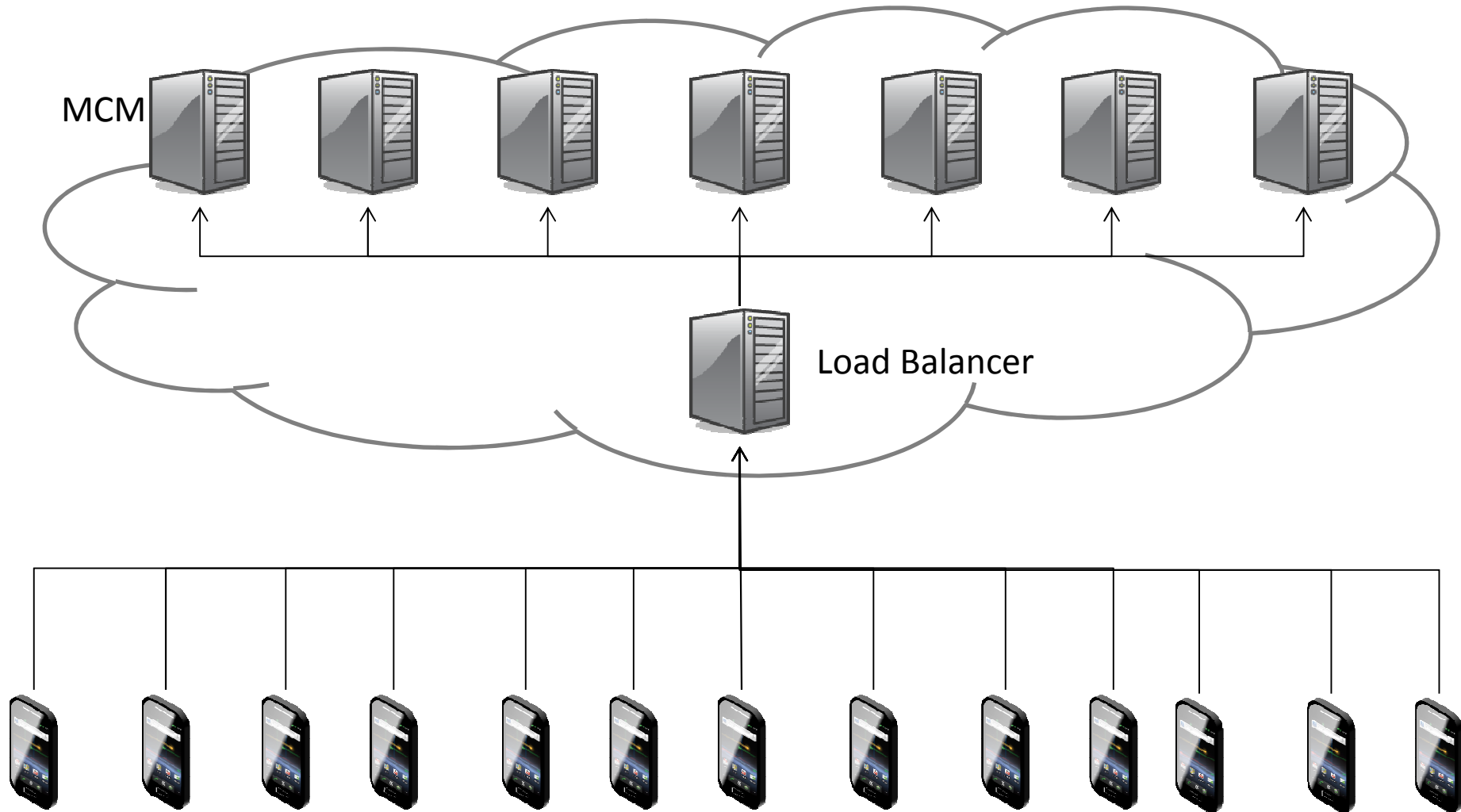
CroudSTag – Scenario

- 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
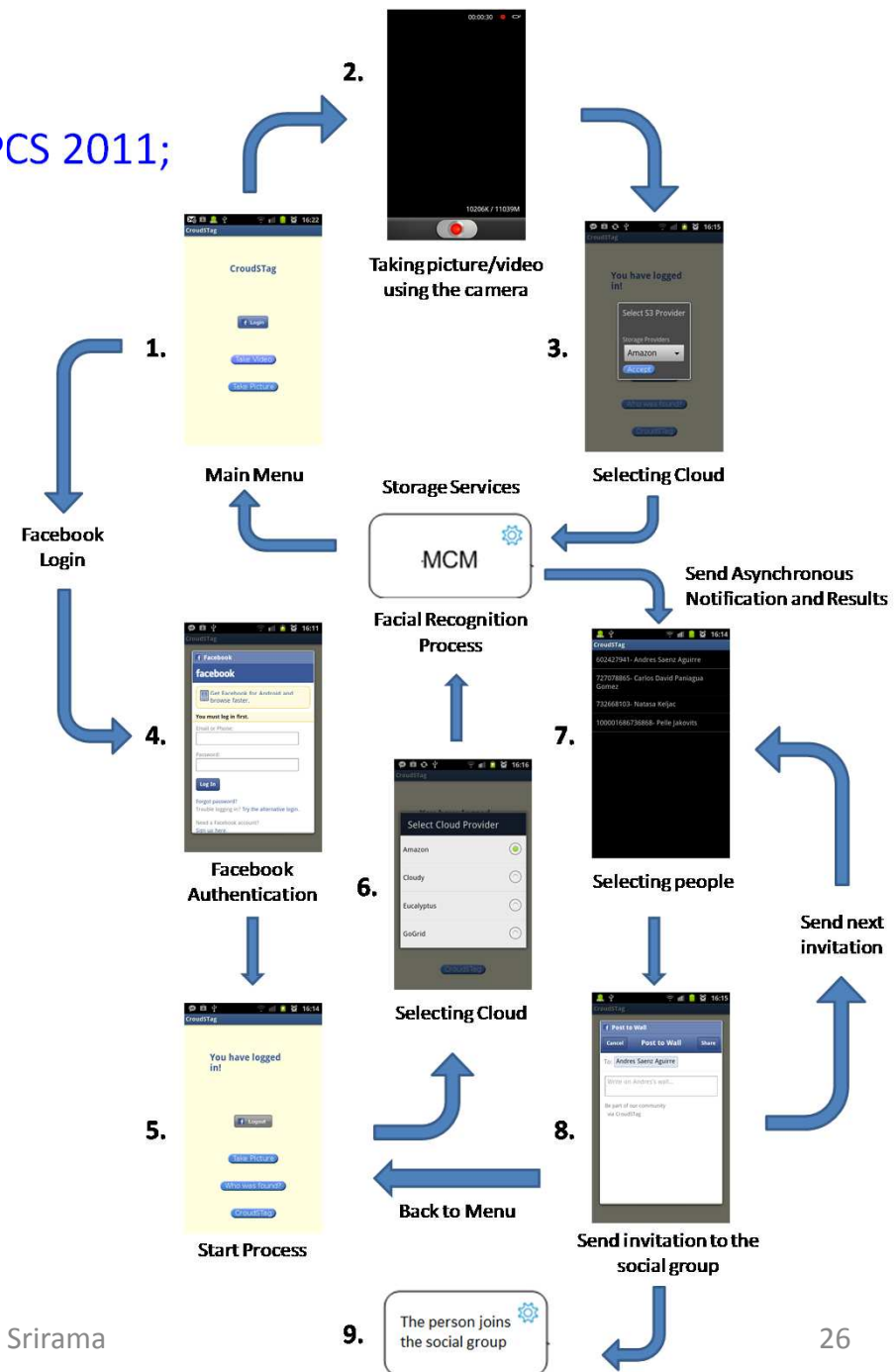
Other applications

- **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 for IoT [Chang et al, PMC 2014]

- 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
  - Very handy in the IoT context

Internet of Things (IoT)

- *"The Internet of Things 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

	2003	2010	2015	2020
World Population	6.3 Billion	6.8 Billion	7.2 Billion	7.6 Billion
Connected Devices	500 Million	12.5 Billion	25 Billion	50 Billion
Connected Devices Per Person	0.08	1.84	3.47	6.58

More connected devices than people

Source: Cisco IBSG, April 2011

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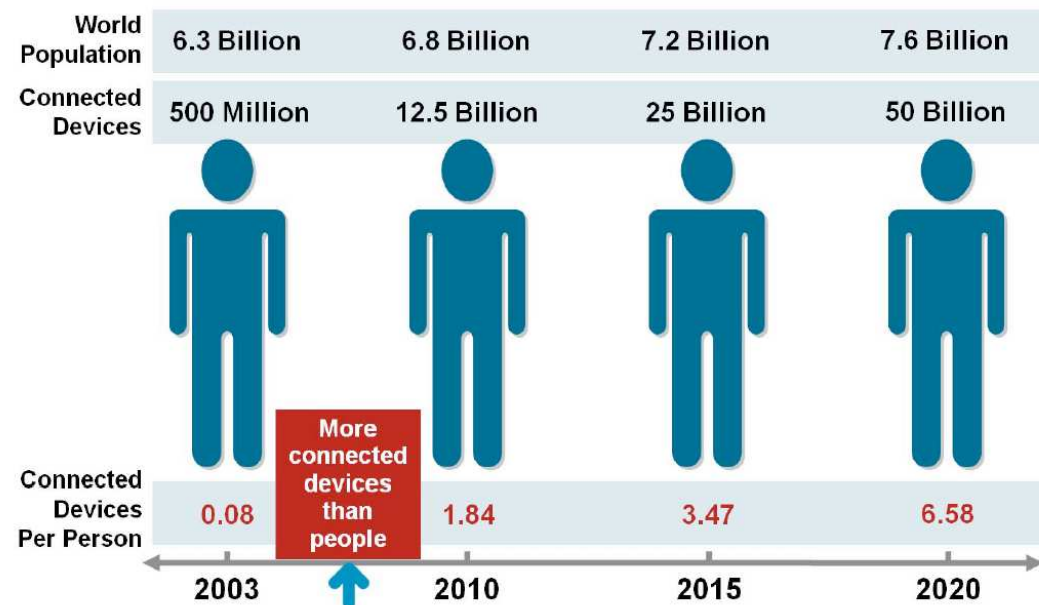
IoT - Scenarios

- Environment Protection
- Smart Home
-
-

RDIF tagged
Ice Cream

RDIF tagged
Cheese Packet

Mike's New Refrigerator
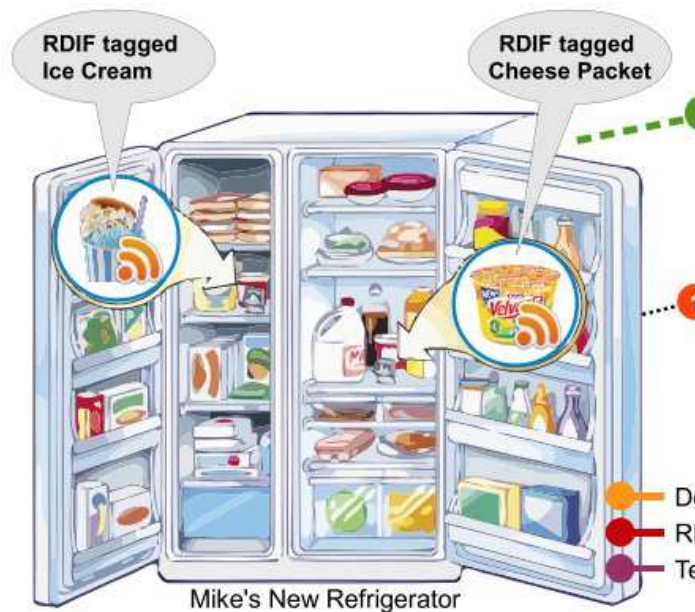
[Kip Compton]
[Perera et al, TETT 2014]

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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
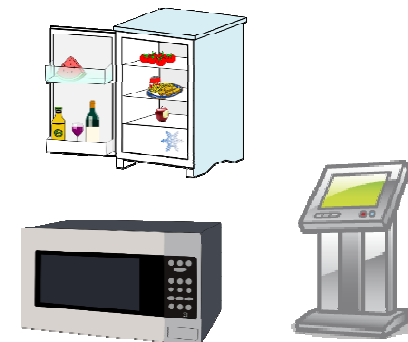
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Cloud-based IoT

Remote Cloud-based processing

Connectivity nodes & Embedded processing

Sensing and smart devices

Satish Srirama
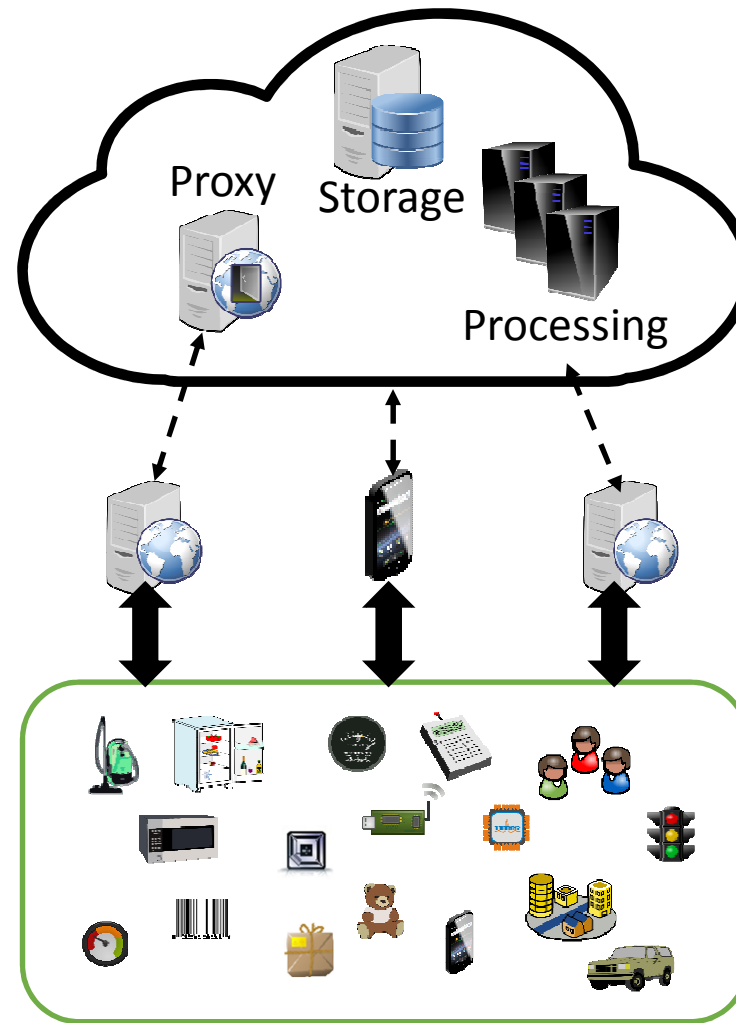
Demo – IoT and Smart solutions Laboratory

Smart Home

Scenario: Disabled Person Trying to Avoid Crowd in Urban Areas

- Mobile Host and MCM enable moving tasks between mobile and the middleware
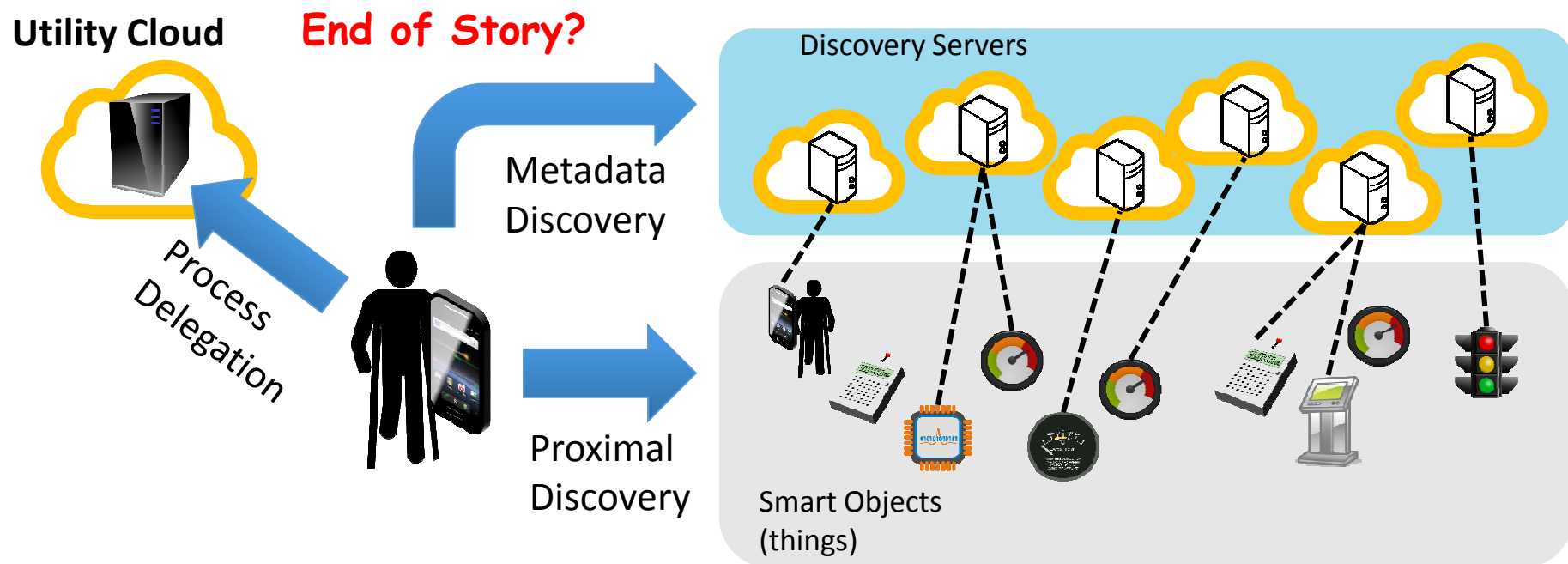
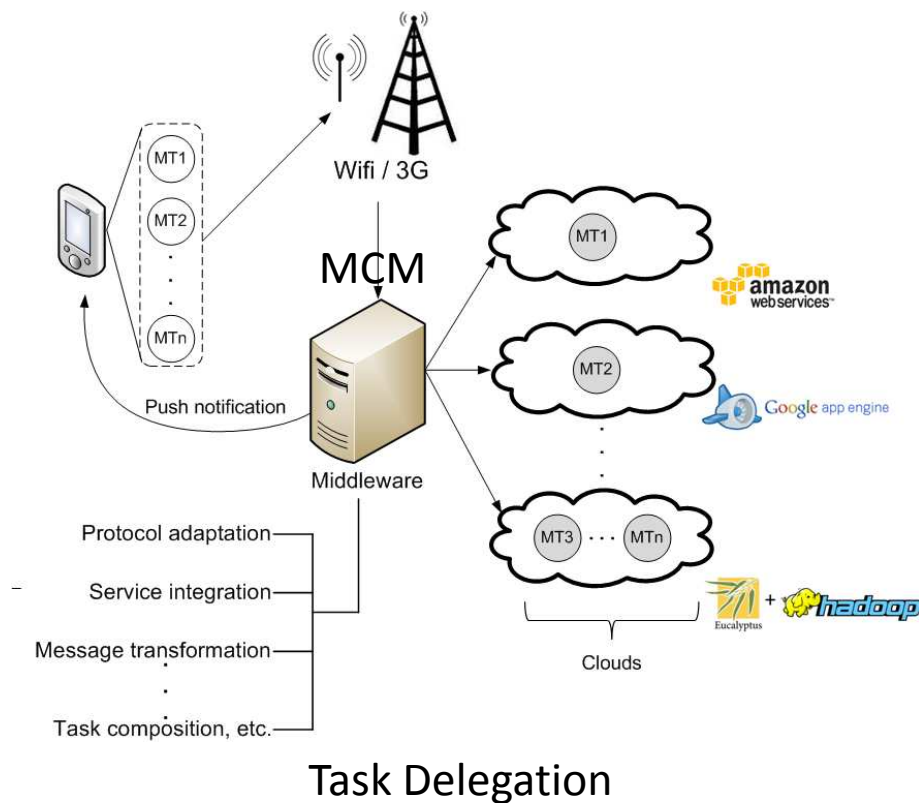# Real-time IoT Service Discovery
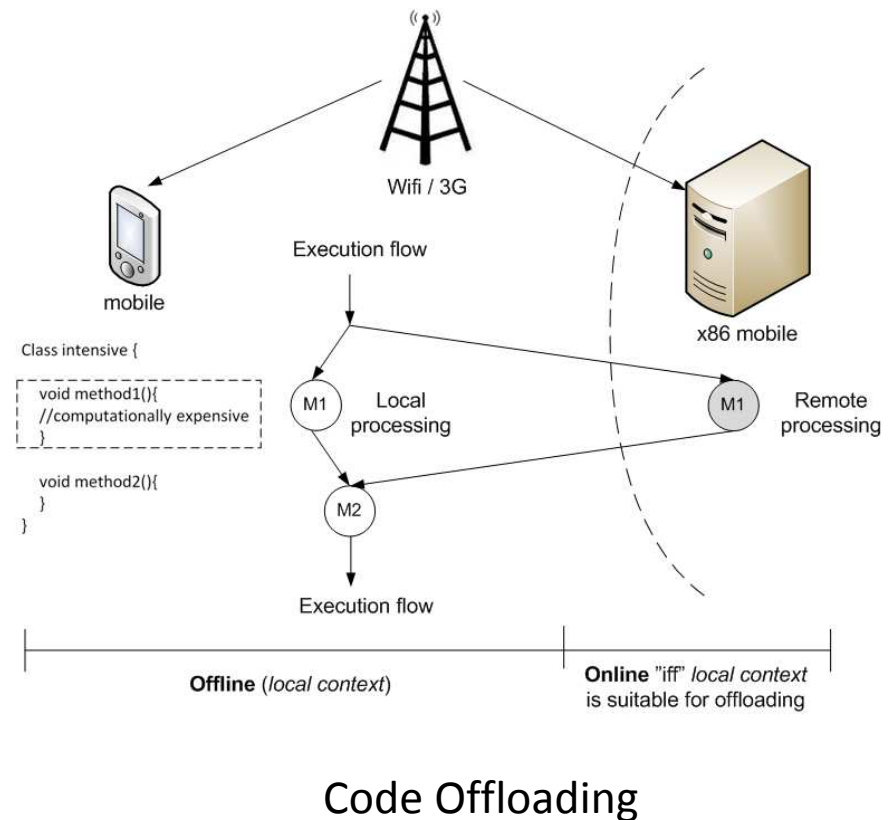
[Chang et al, SCC 2015]
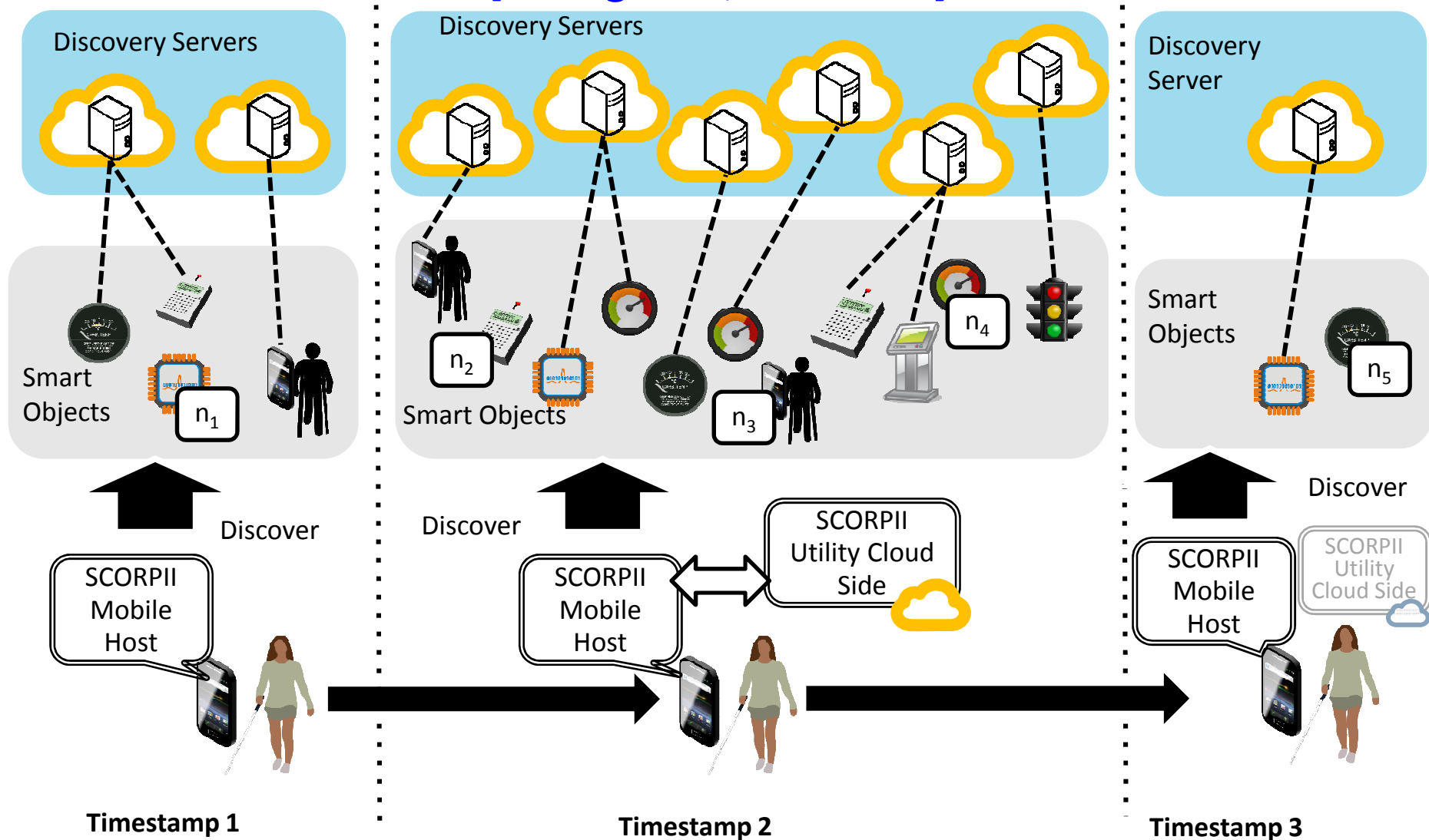
Discovery Workflow

- Workflow approach selection
- Fuzzy sets and Cost Performance Index

Mobile cloud - Binding models

Task Delegation
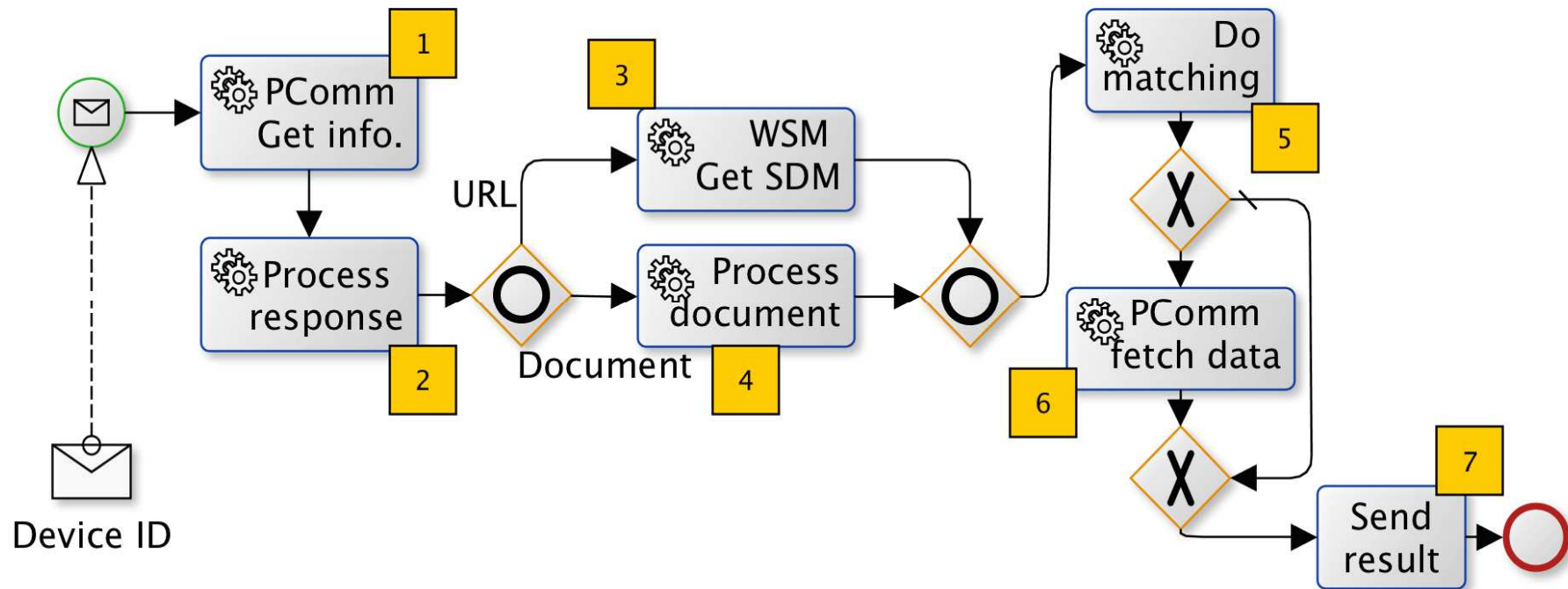
Code Offloading

[Flores and Srirama, JSS 2014]

[Flores et al, IEEE Communications Mag 2015]

Code Offloading

- Also known as Cyber-foraging [M. Satyanarayanan, 2001]
- Mobile devices offload some of their heavy work to stronger surrogate machines in the vicinity (Cloudlets)
- Major research challenges
  - What, when, where and how to offload?

Major Components

- Mobile
  - Code profiler
  - System profilers
  - Decision engine
- Cloud based surrogate platform
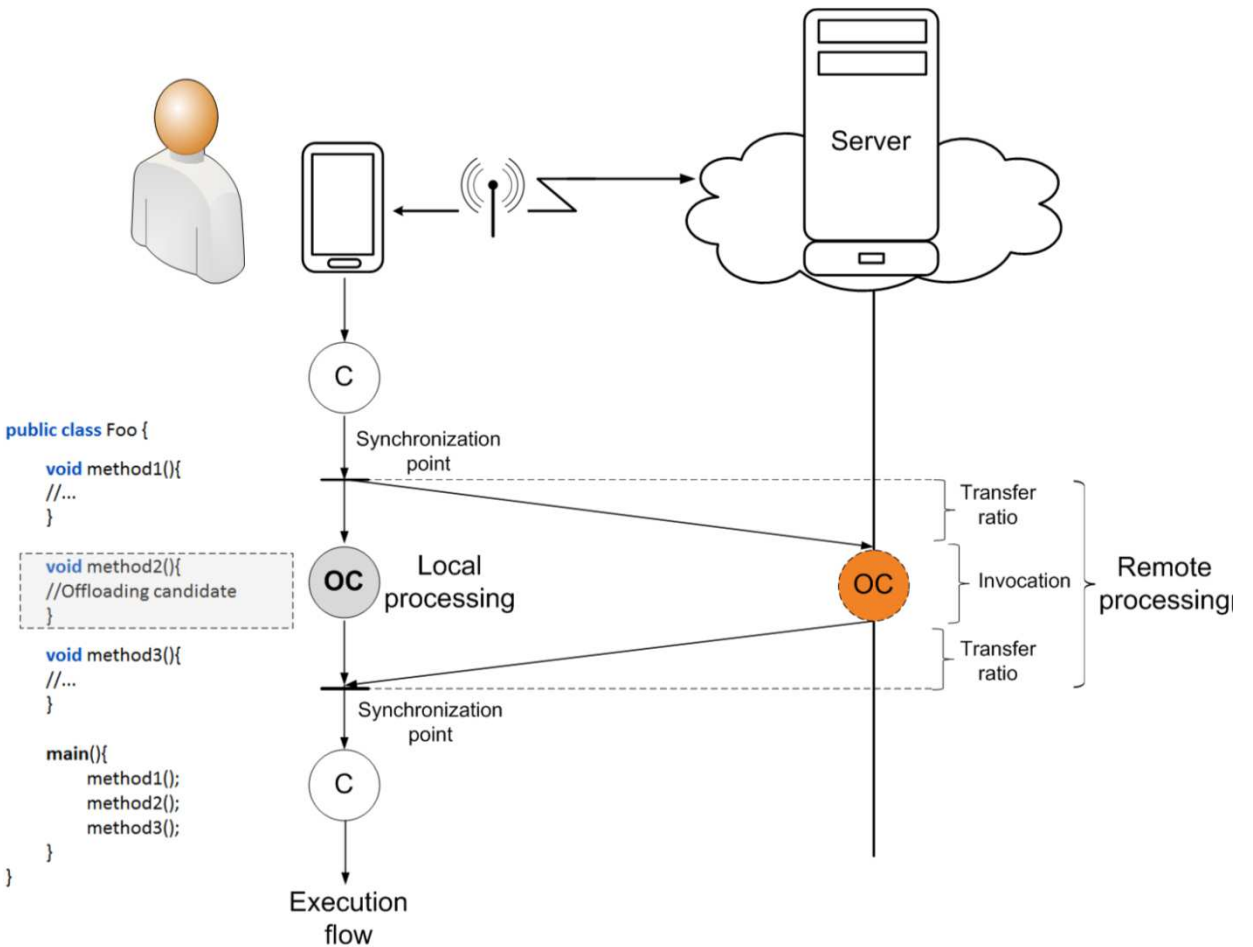
# Some of the well known frameworks

- 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] & etc.
  - Improved offloading by analysing the traces
- mCloud [Zhou et al, Cloud 2015; TSC 2016]
  - 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
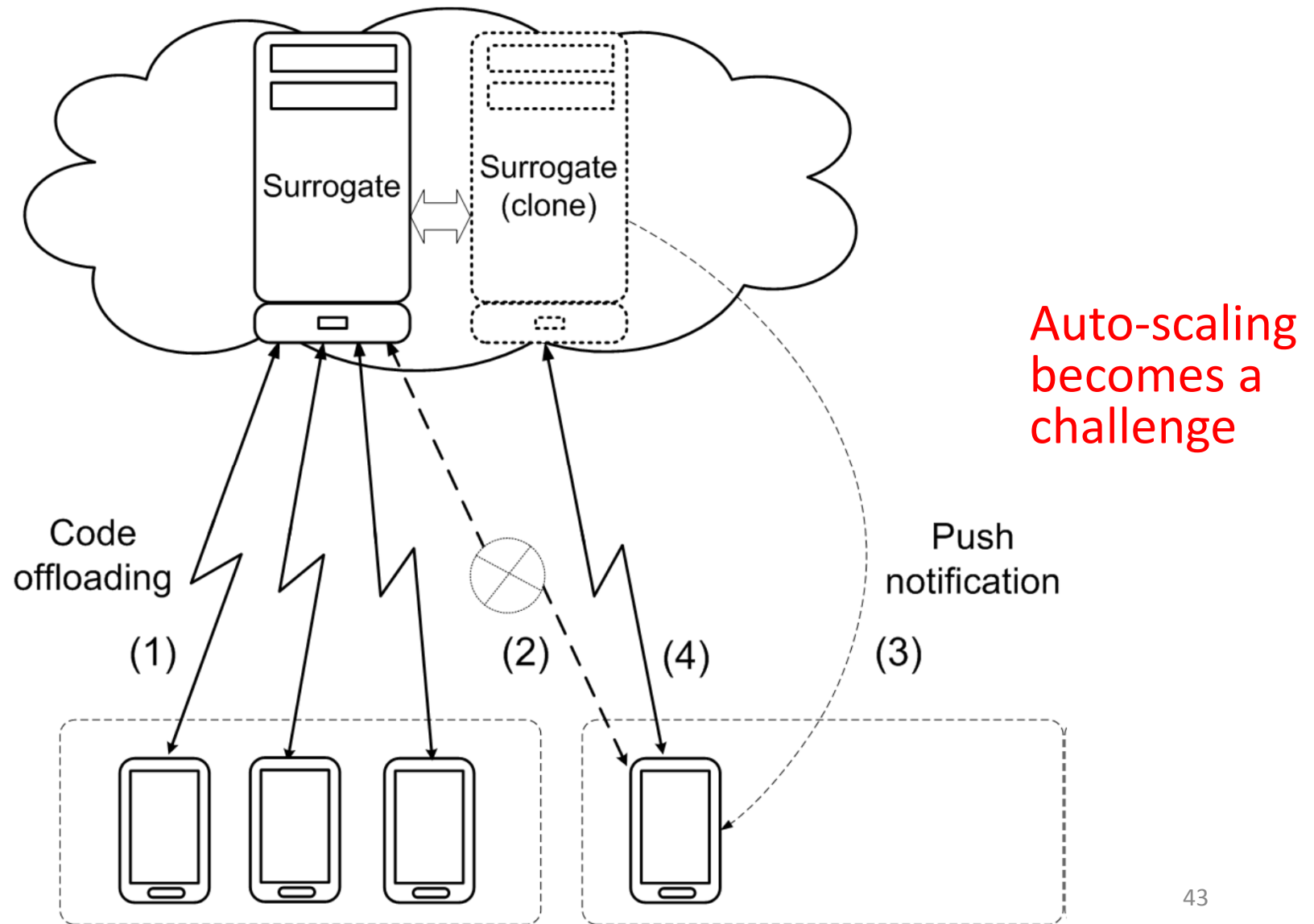 - Should also consider about resource availability of Cloud

[Flores et al, IEEE Communications Mag 2015]
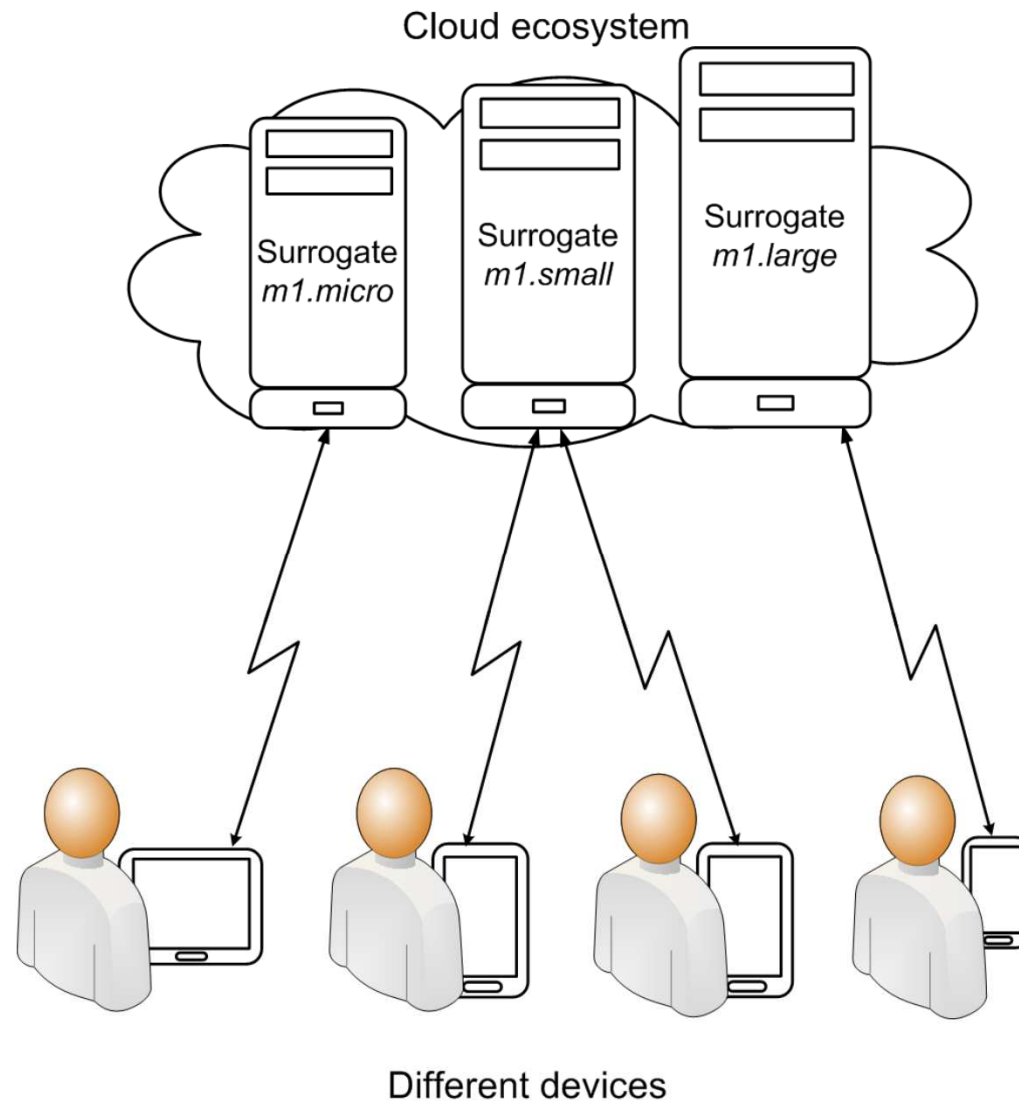
Practical adaptability of offloading
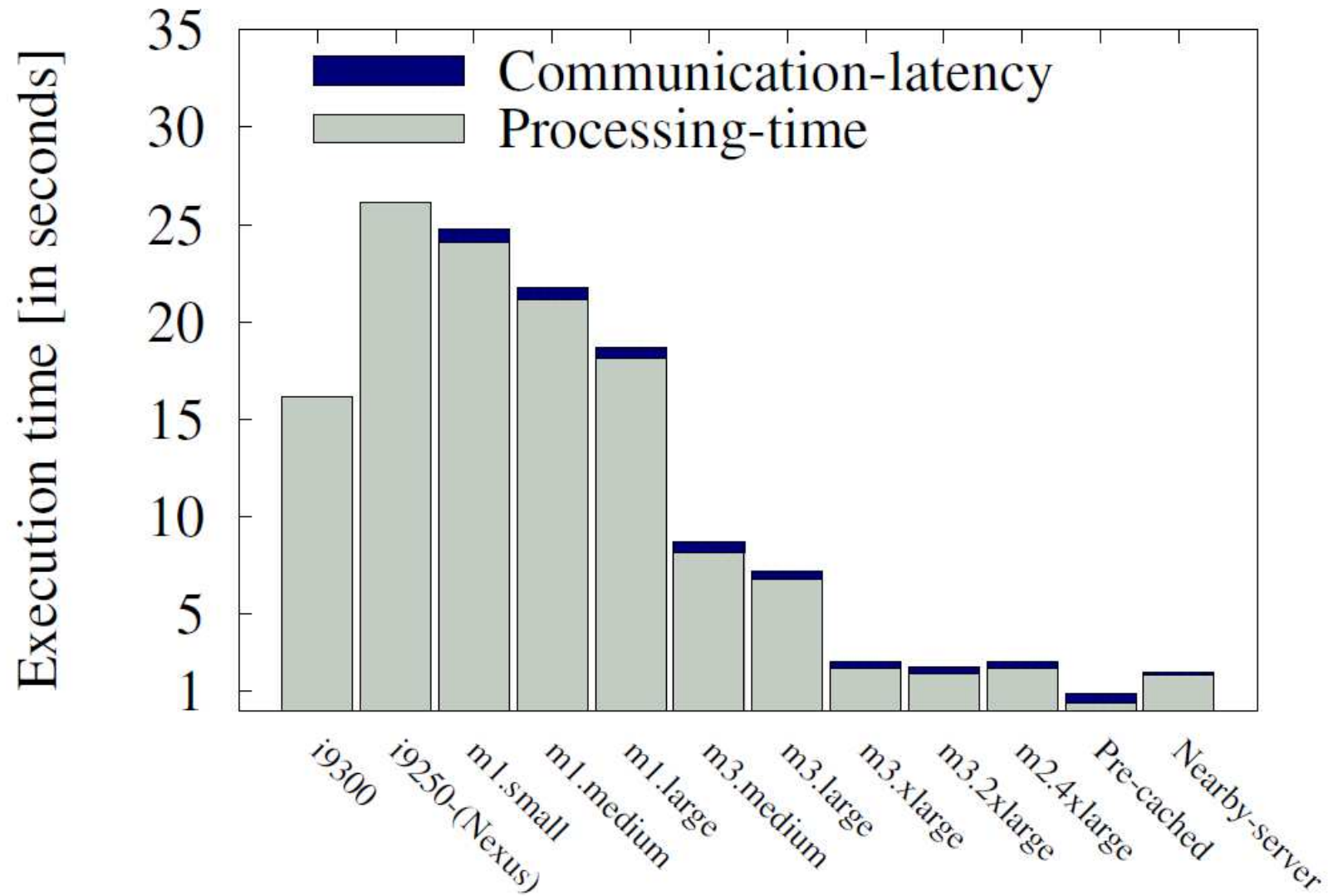
Applications that can benefit became limited with increase in device capacities

Multi-tenancy for code offloading

Surrogate

Surrogate (clone)

Auto-scaling becomes a challenge

Code offloading

(1)

(2)   (4)

Push notification

(3)

Dynamic configuration

Cloud ecosystem

Surrogate *m1.micro*

Surrogate *m1.small*

Surrogate *m1.large*

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

Different devices

Acceleration via pre-cached results

Pre-cached responses

Surrogate

Speed up responses

Common requests
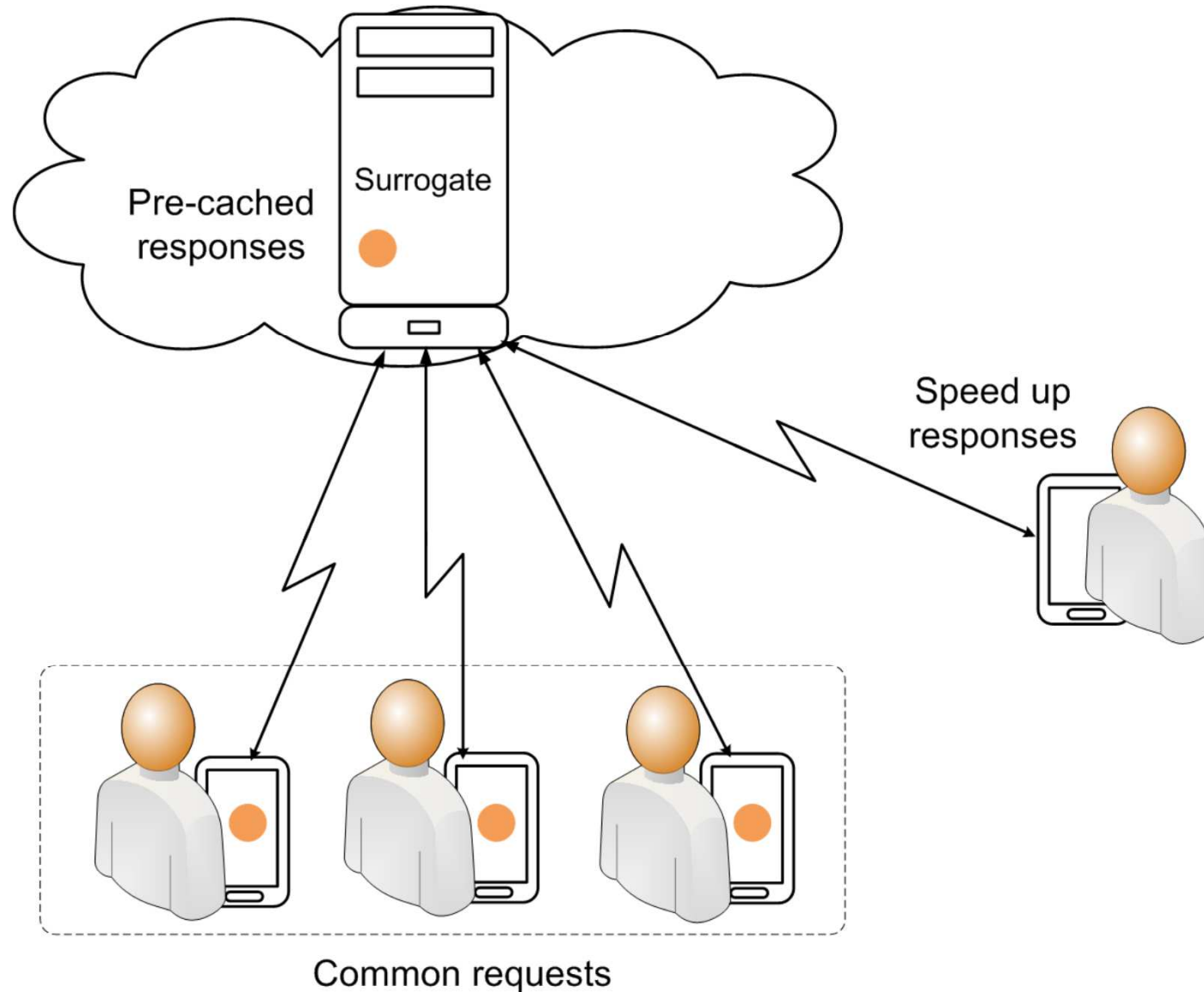
Conclusions

- Mobile has significant advantage by going cloud-aware

- Mobile Cloud based system should take advantage of some of the key intrinsic characteristics of cloud efficiently

- Task delegation is a reality!!!

- Code offloading still has significant distance to cover and has enough future research directions
  - However, applications that can benefit from code offloading are becoming limited

Current work – Fog Computing
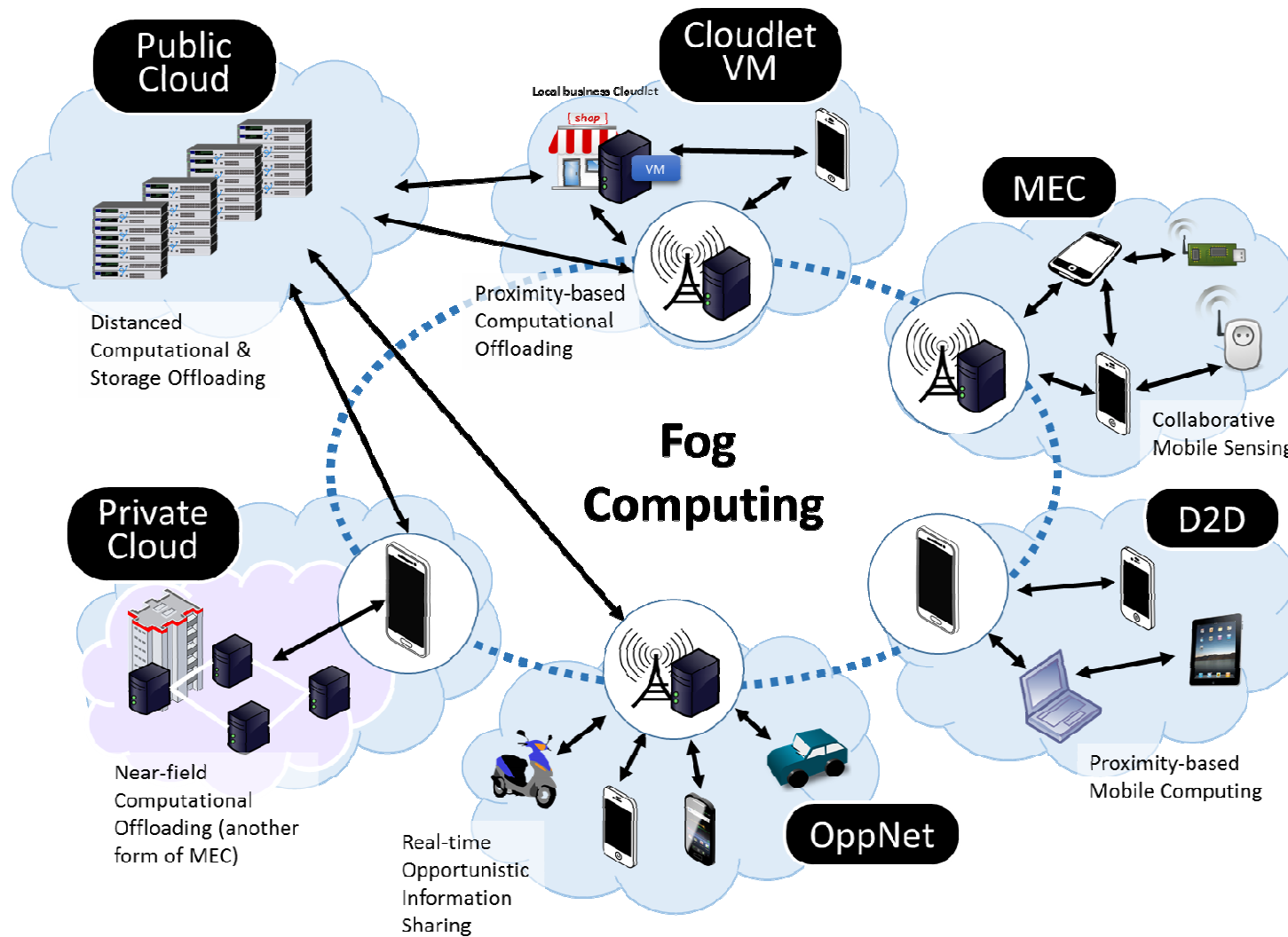
Other research interests

- Dynamic deployment and Auto-Scaling applications on the Cloud [Srirama et al, Cloud 2016]
  - Optimal Resource Provisioning for Auto-Scaling Enterprise Applications [Srirama and Ostovar, CloudCom 2014]
- Scientific Computing on the Cloud [Srirama et al, SPJ 2011]
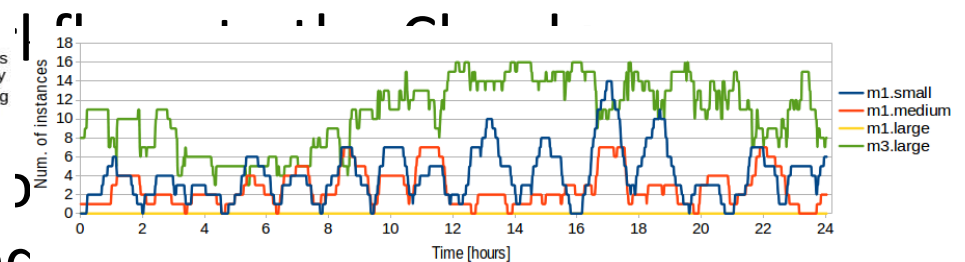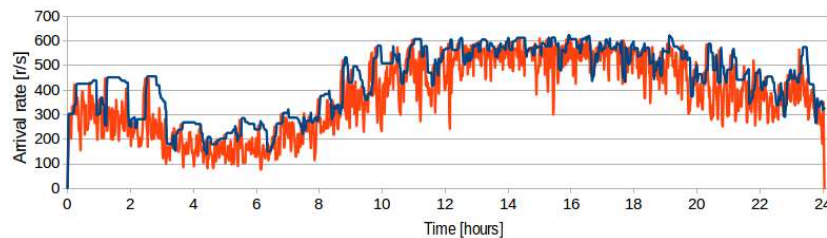
frameworks like MapReduce and BSP [Srirama et al, FGCS 2012] [Kromonov et al & Jakovits and Srirama, HPCS 2014]

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THANK YOU FOR YOUR ATTENTION