Mobile Cloud Computing

Concepts, practice and beyond

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Mobile Cloud Lab

iktp

European Union
Regional Development Fund

Investing in your future

Who am I

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

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Mobile Cloud Lab

Estonia pop: 1,300,000

TARTU

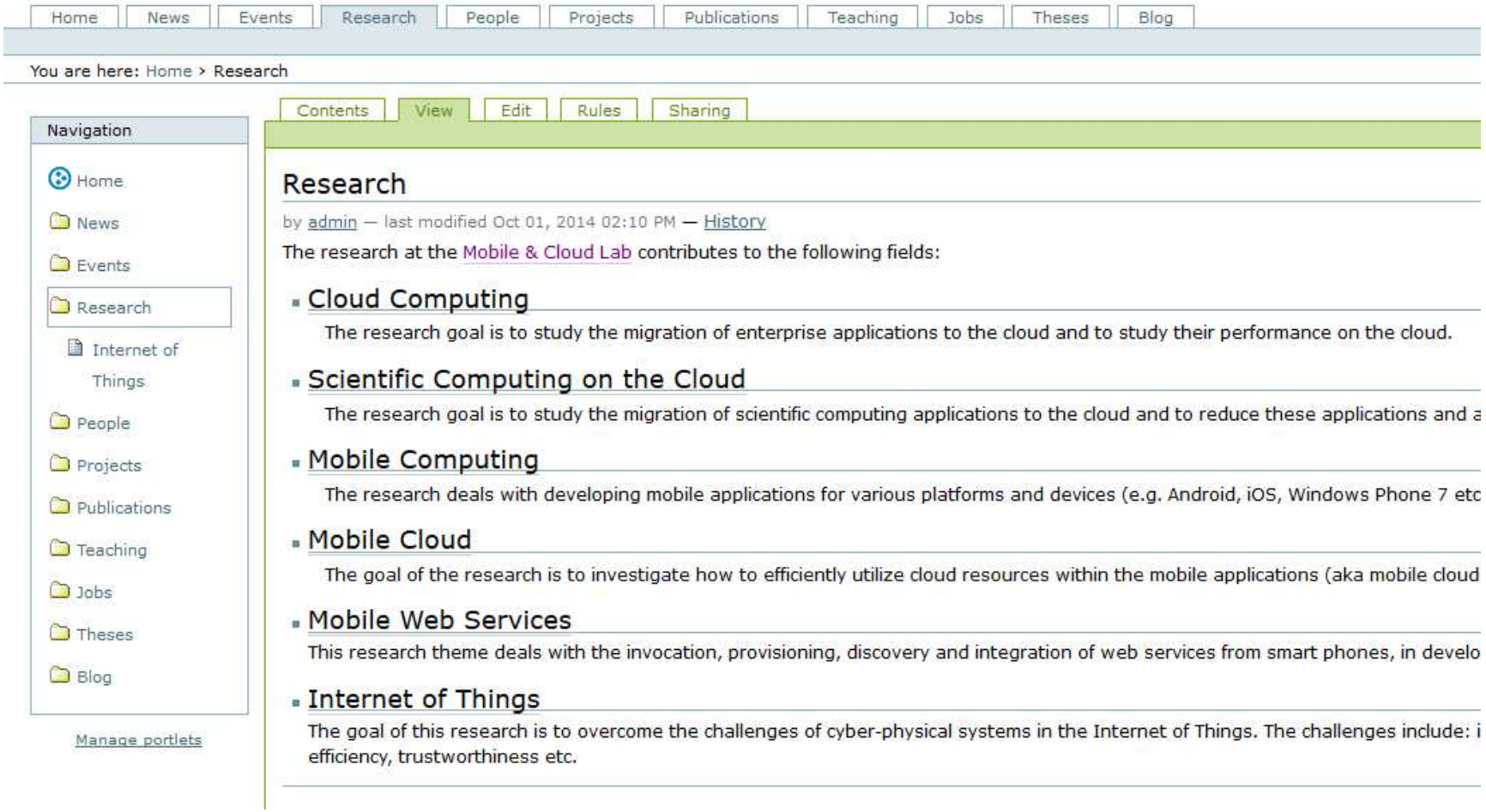
Pop: 100,000

Academic excellence since 1632

Main Research Activities

Mobile Cloud Lab

UNIVERSITY OF TARTU
Institute of Computer Science
1632



Outline

- Mobile computing
- Cloud computing
- Mobile Cloud Binding Models
  - Task delegation
  - Code offloading
- Conclusions

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]

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, 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]
  - 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

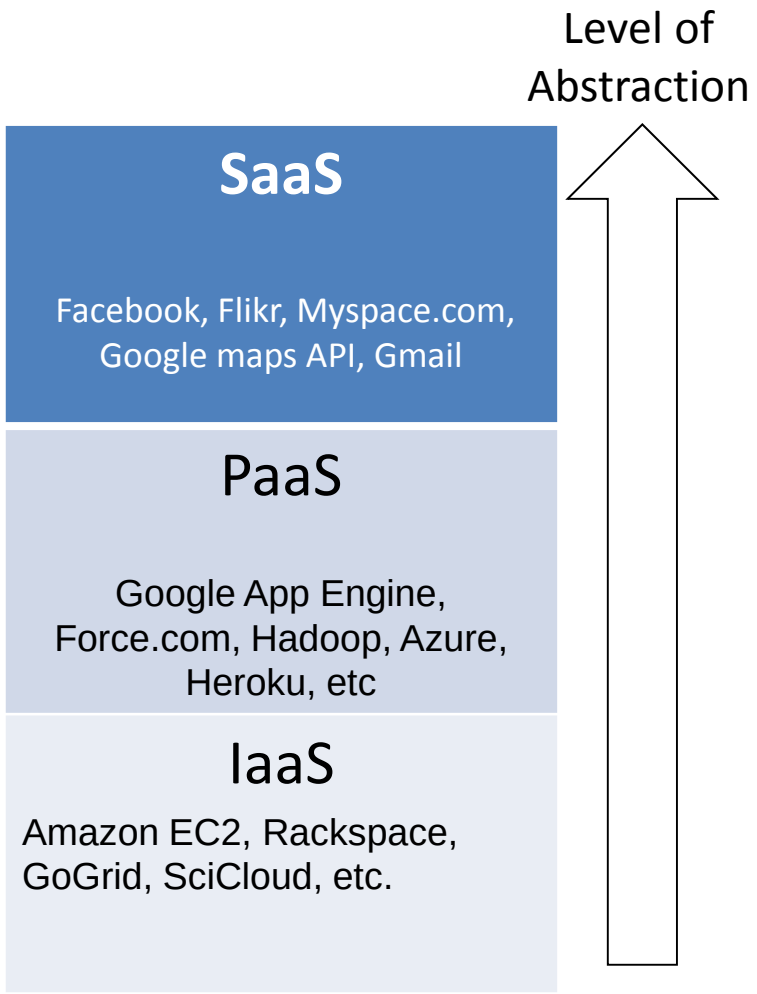
1969 – Leonard Kleinrock, ARPANET project

- "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



Cloud Computing - Themes

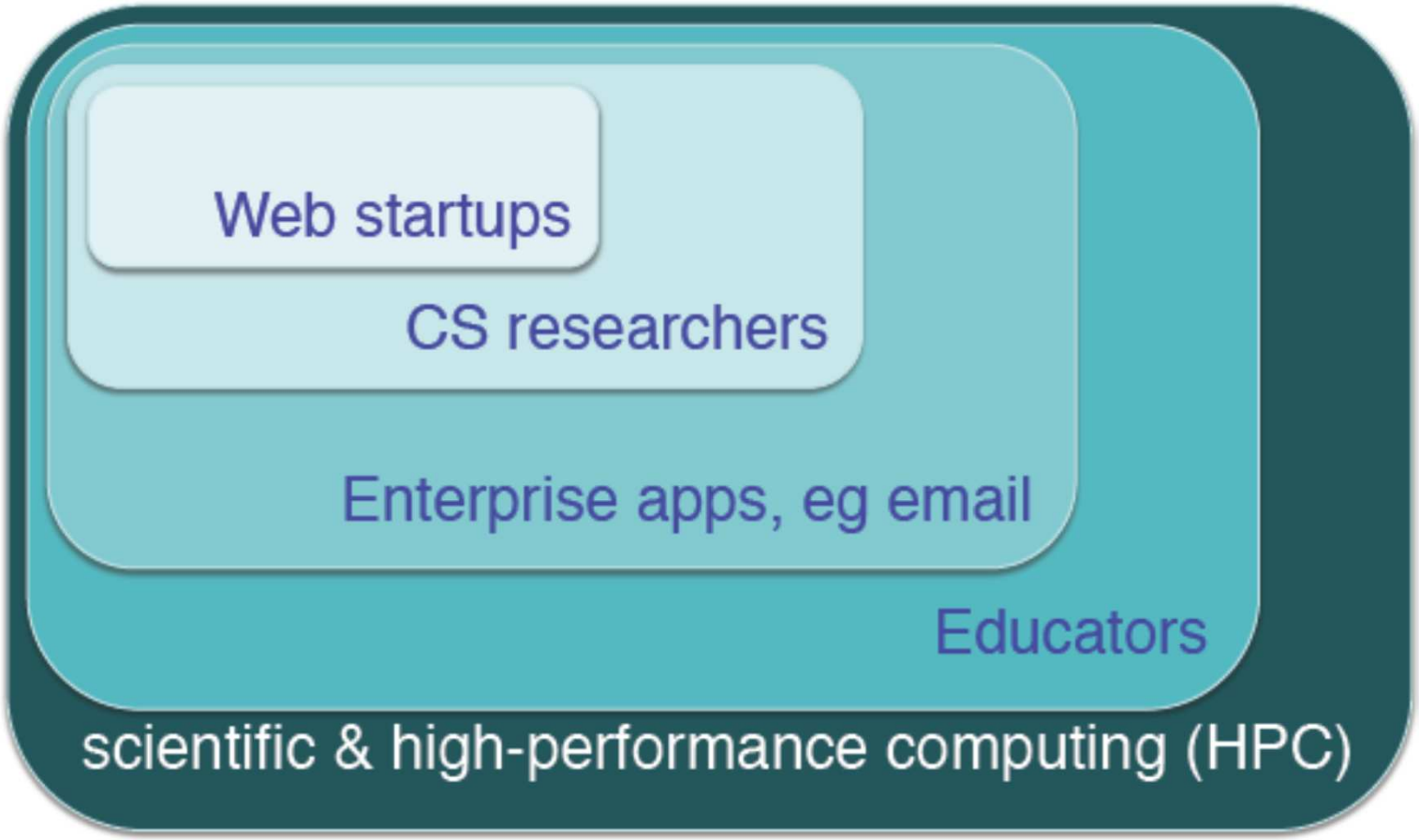
- Massively scalable
- On-demand & dynamic
- Only use what you need - Elastic
  - No upfront commitments, use on short term basis
- Accessible via Internet, location independent
- Transparent
  - Complexity concealed from users, virtualized, abstracted
- Service oriented
  - Easy to use SLAs

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



[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

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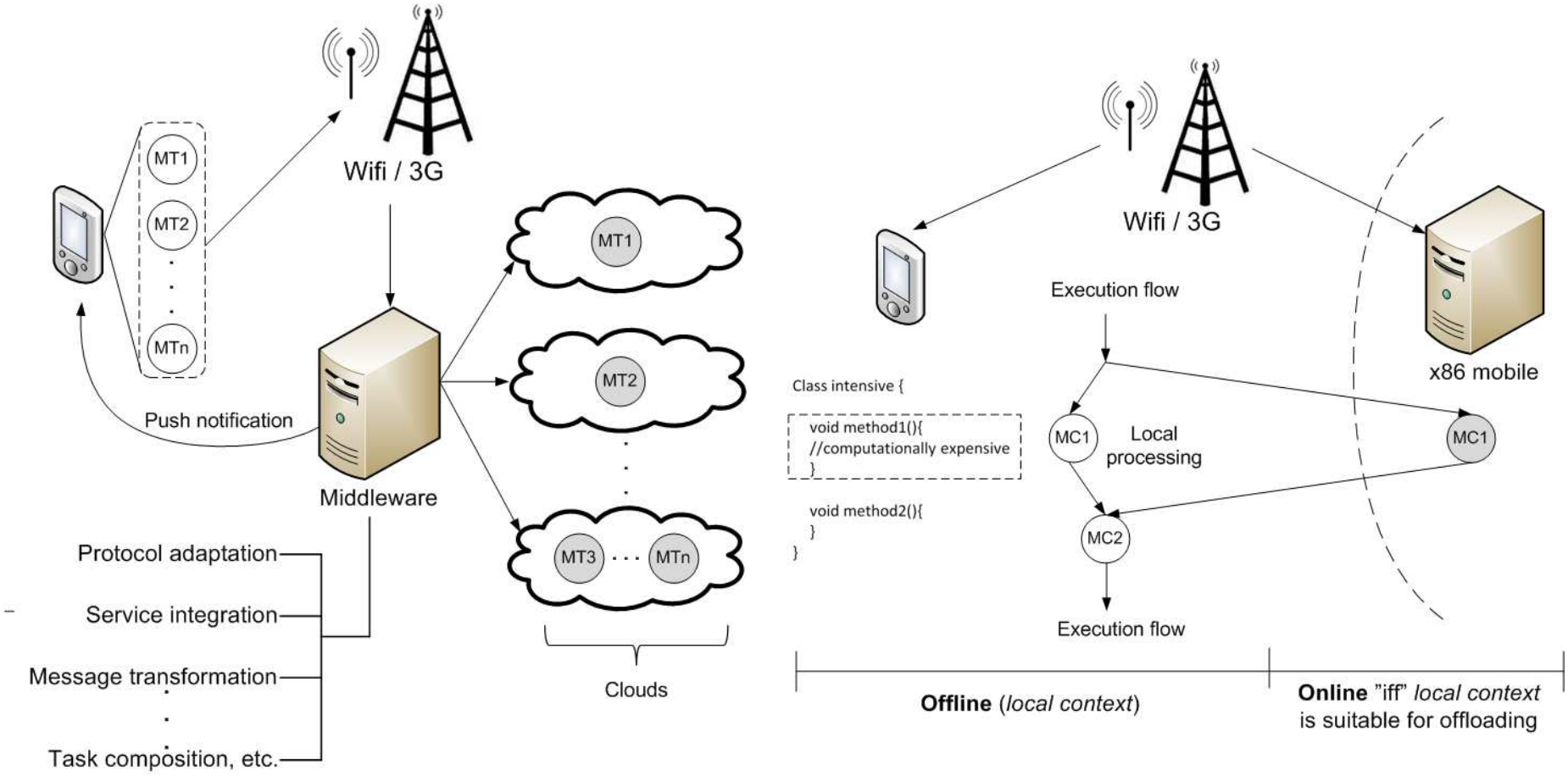
Mobile Cloud Binding Models



Task Delegation **Code Offloading**

[Flores & Srirama, JSS 2014]

Mobile Cloud – Our interpretation

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

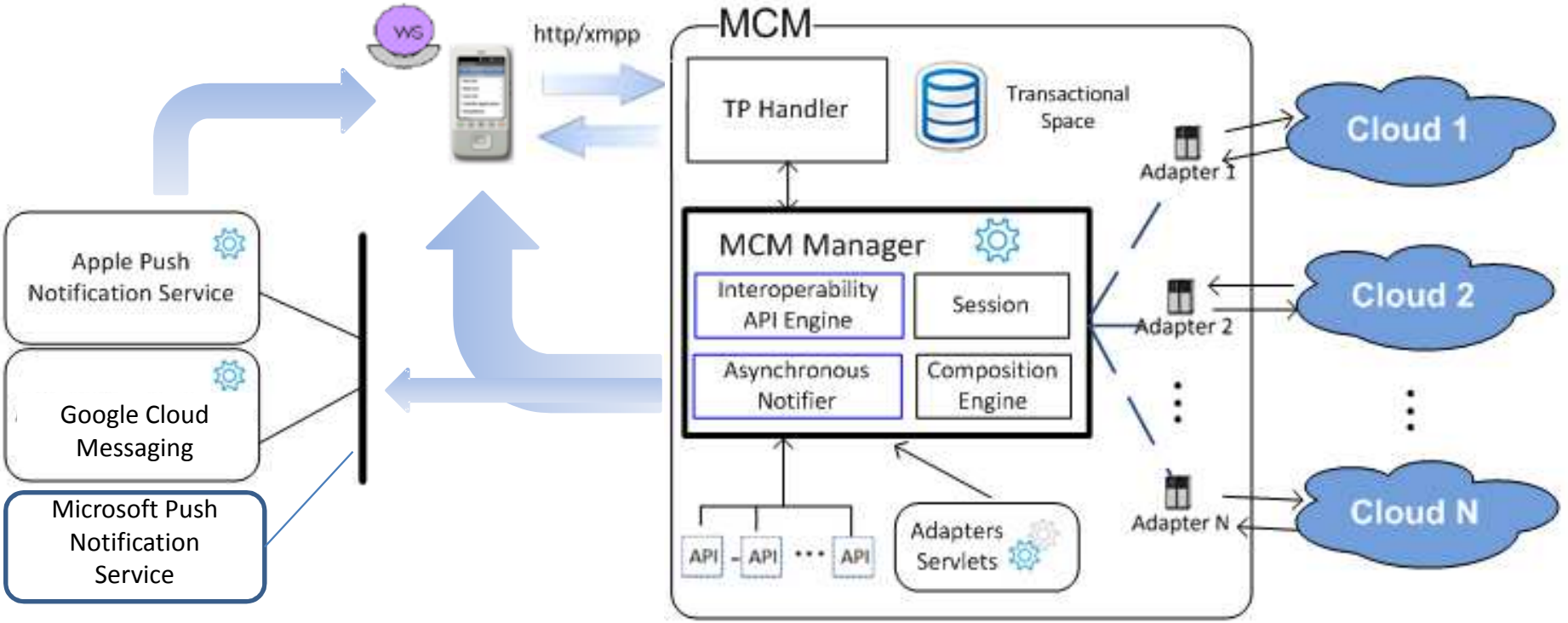
- Mobile Cloud based system should take advantage of some of the key intrinsic characteristics of cloud efficiently
  - Elasticity & AutoScaling
  - Utility computing models
  - Parallelization (e.g., using MapReduce)

Task Delegation

- Follows traditional SOA model to invoke services
- 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]



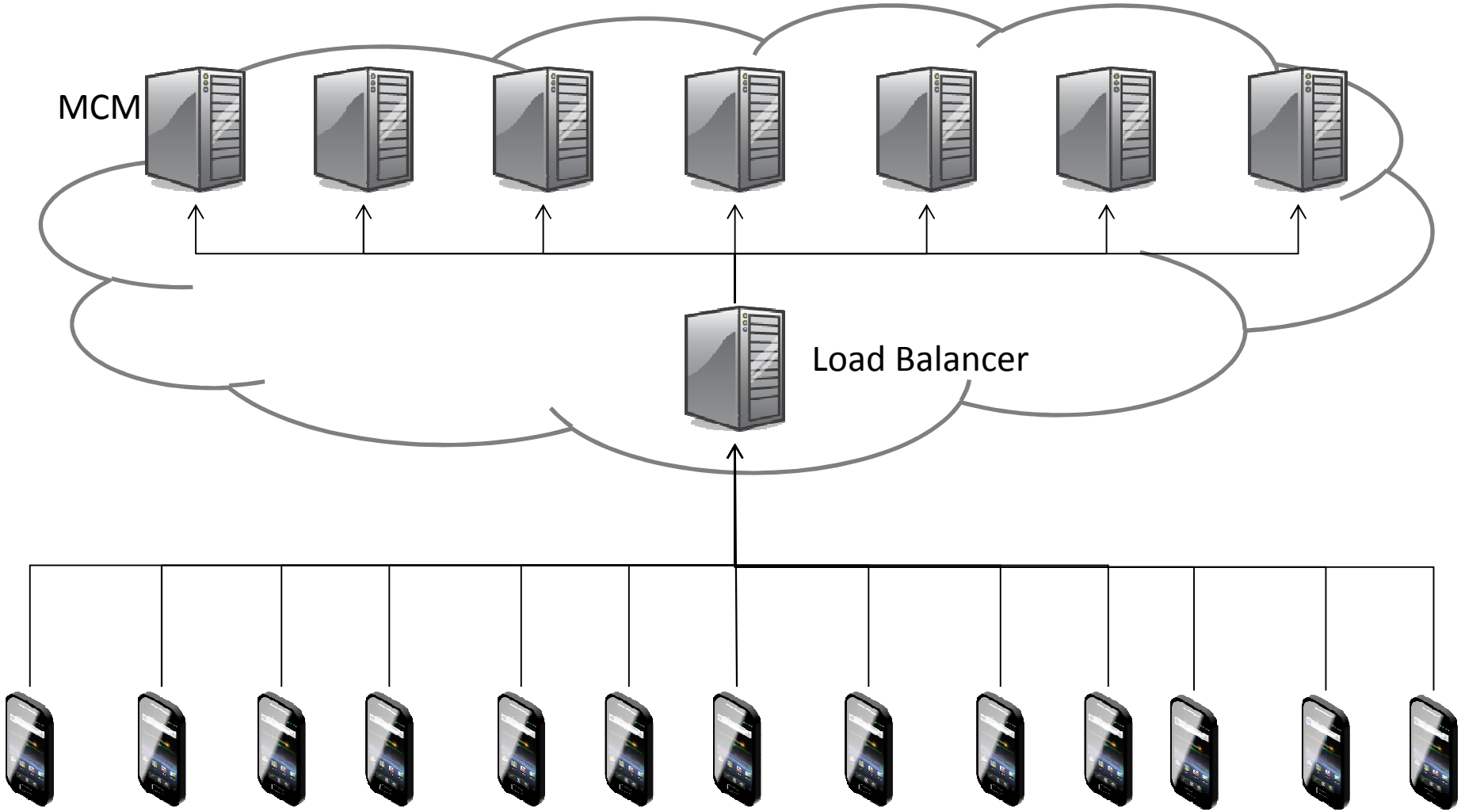
[Warren et al, IEEE PC 2014]

[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



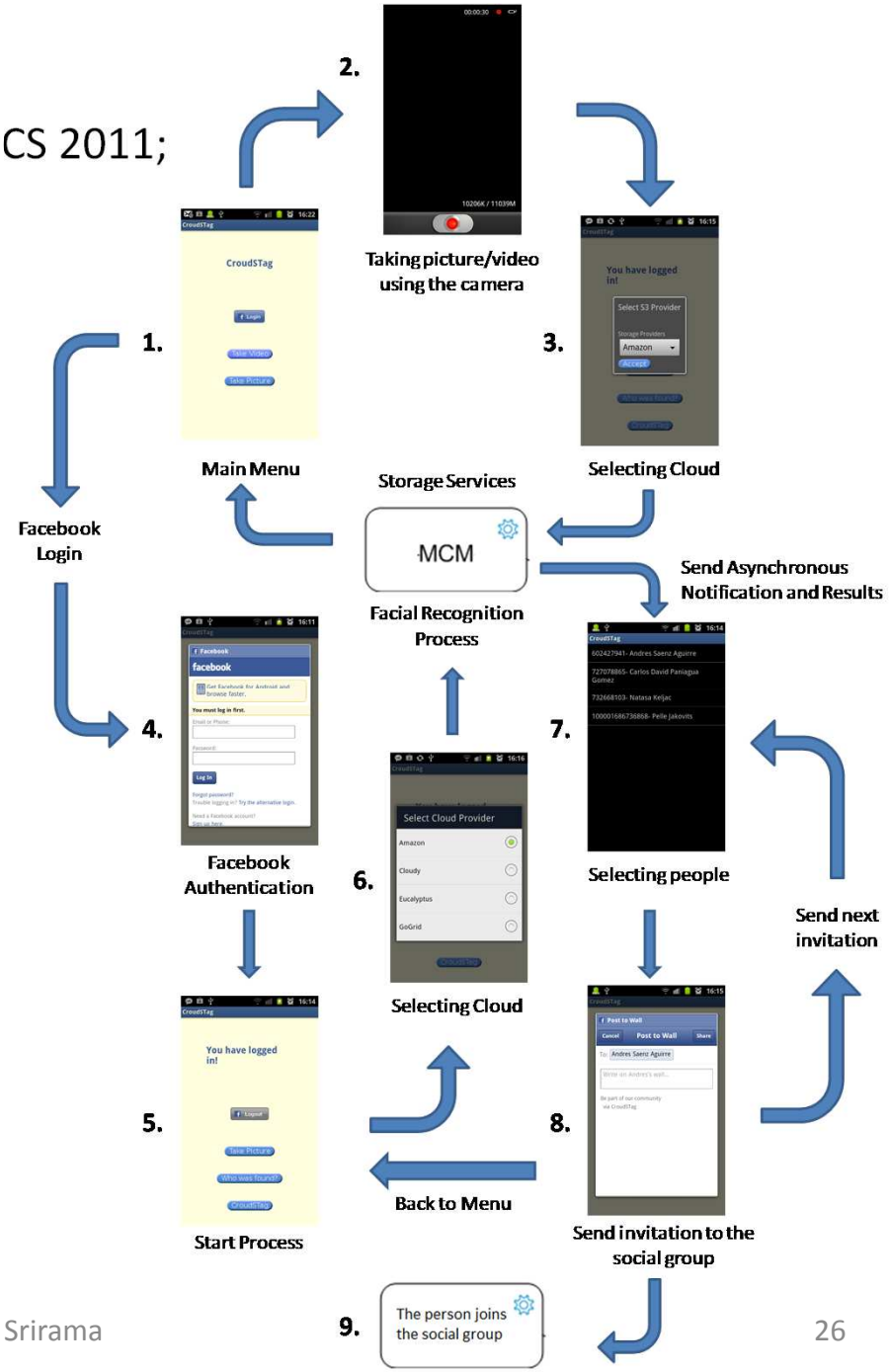
[Flores & Srirama, JSS 2014]

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

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]

Current research focus

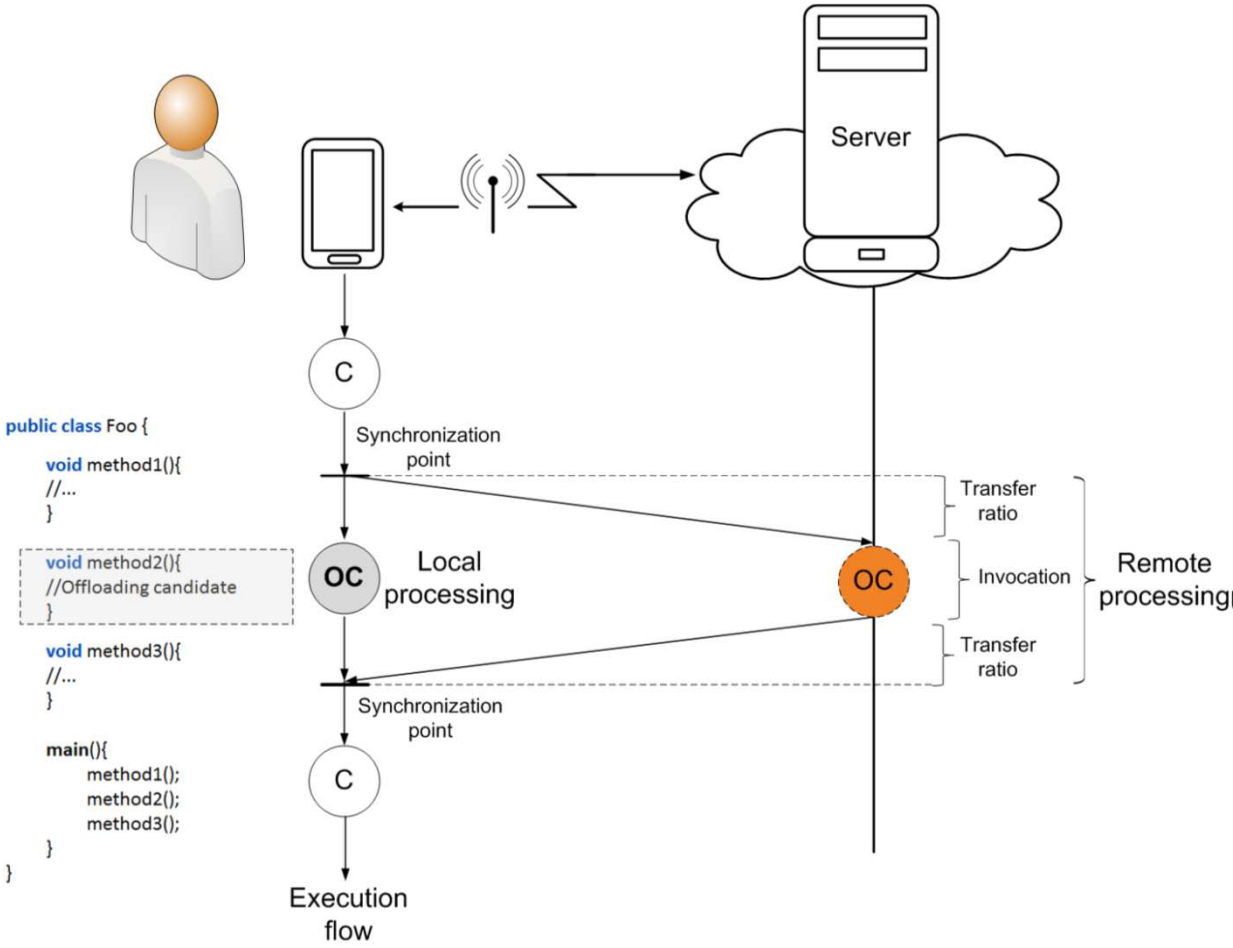
- Task delegation is a reality!!!
  - Cloud providers also support different platforms
- Dynamic deployment of application configurations
  - Using standards such as CloudML [Ferry et al, Cloud 2013]
    - Developed to tame cloud heterogeneity
- Auto-Scaling applications on the Cloud [Srirama and Ostovar, CloudCom 2014]
  - Optimal Resource Provisioning for Auto-Scaling Enterprise Applications

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

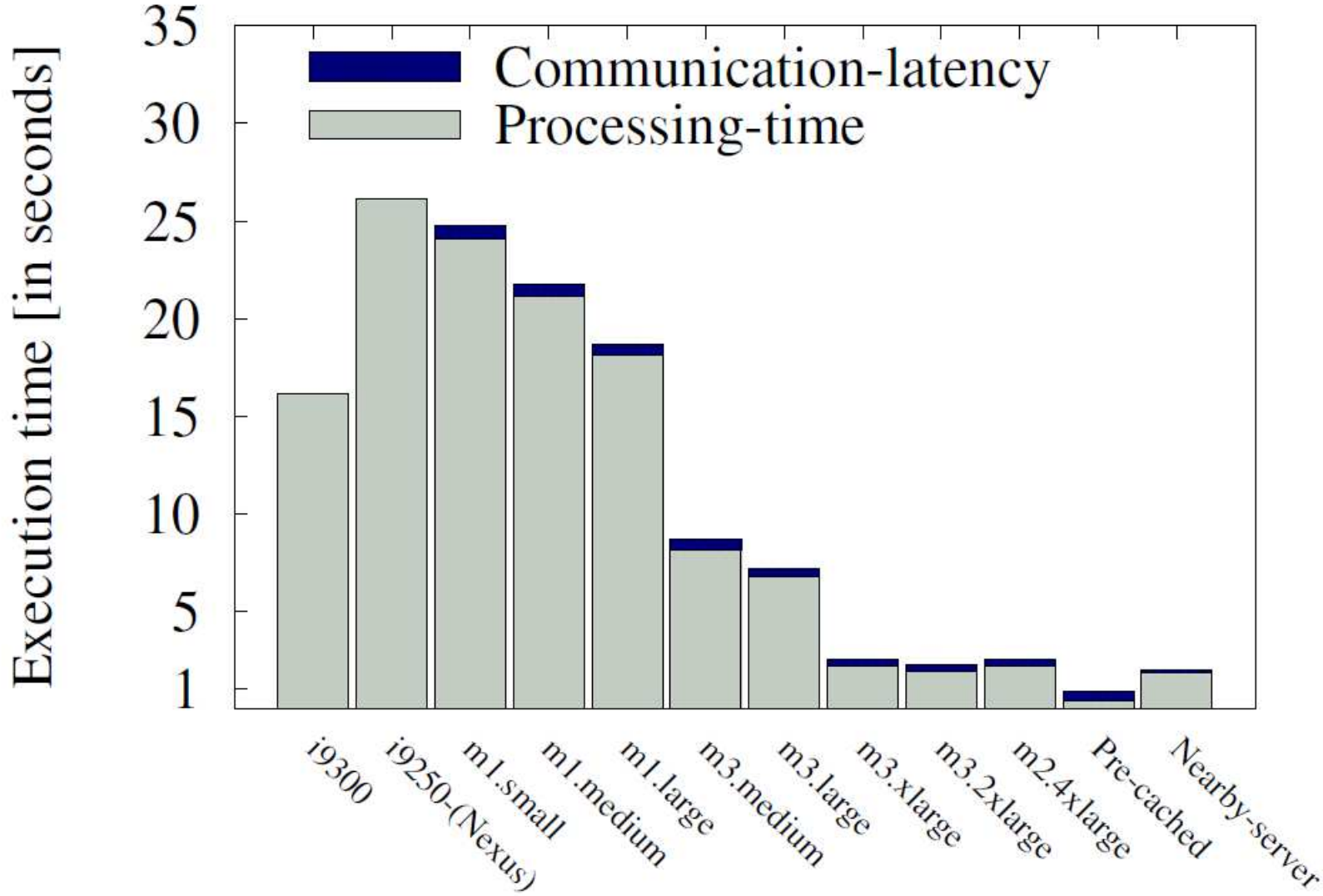
- MAUI
  - Manual annotations [Cuervo et al., 2010]
- CloneCloud
  - Code profilers & Automated process [Chun et al., 2011]
- ThinkAir
  - Manual annotations and scalability [Kosta et al, 2012]
- EMCO [Flores and Srirama, MCS 2013] & etc.
- Work in controlled environments like nearby servers
  - However, none can be adapted for real life applications
    - Provide only a partial answer to what, when, where and how to offload
  - Decision engines do not consider load on cloud

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
  - Dynamic behaviour vs Static annotations
    - E.g. Static annotations cause unnecessary offloading
- Dynamic configuration of the system
- Offloading scalability and offloading as a service
  - Surrogate should have similar execution environment
  - Should also consider about resource availability of Cloud

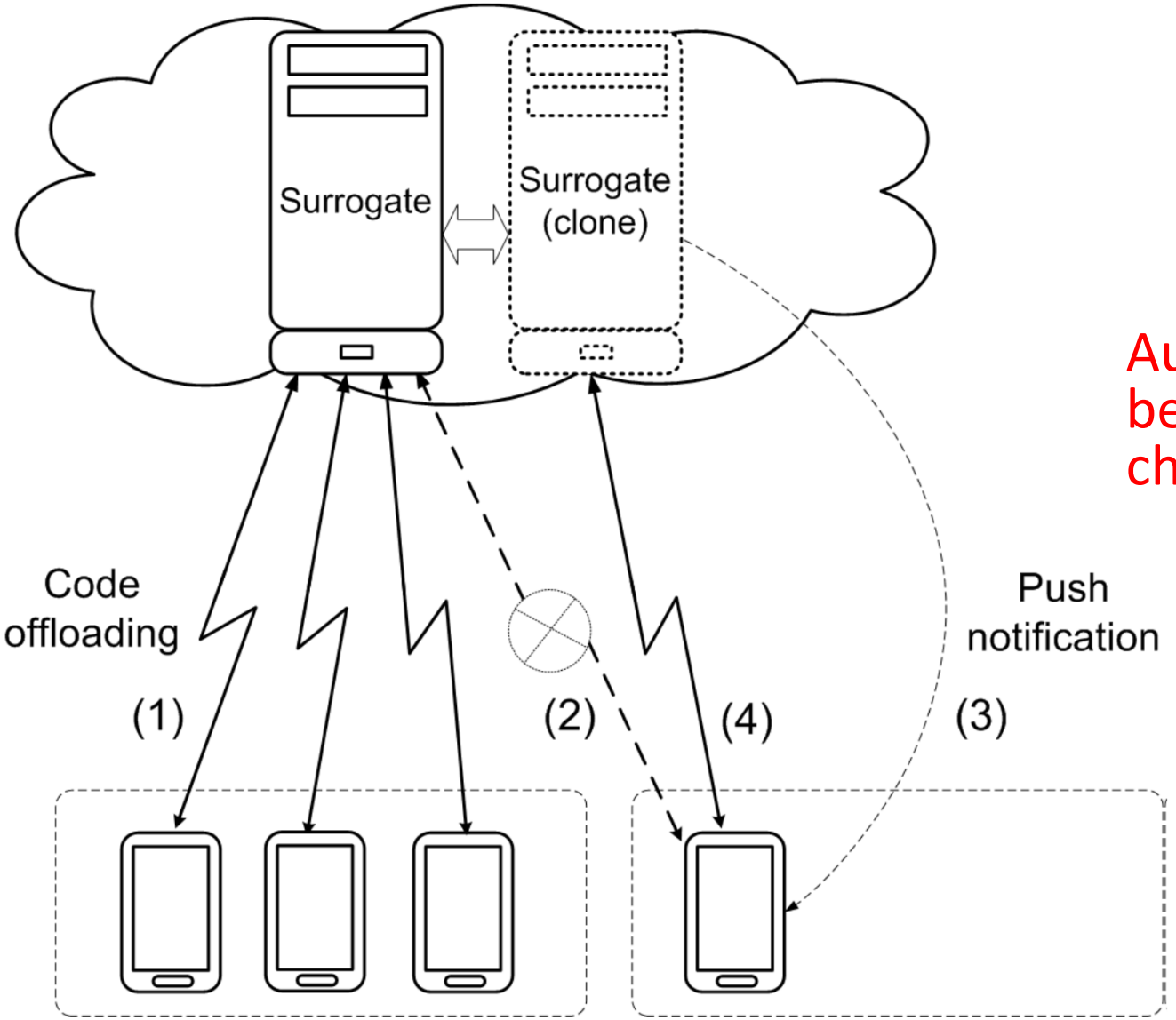
[Flores et al, IEEE Communications Mag 2015]

Practical adaptability of offloading



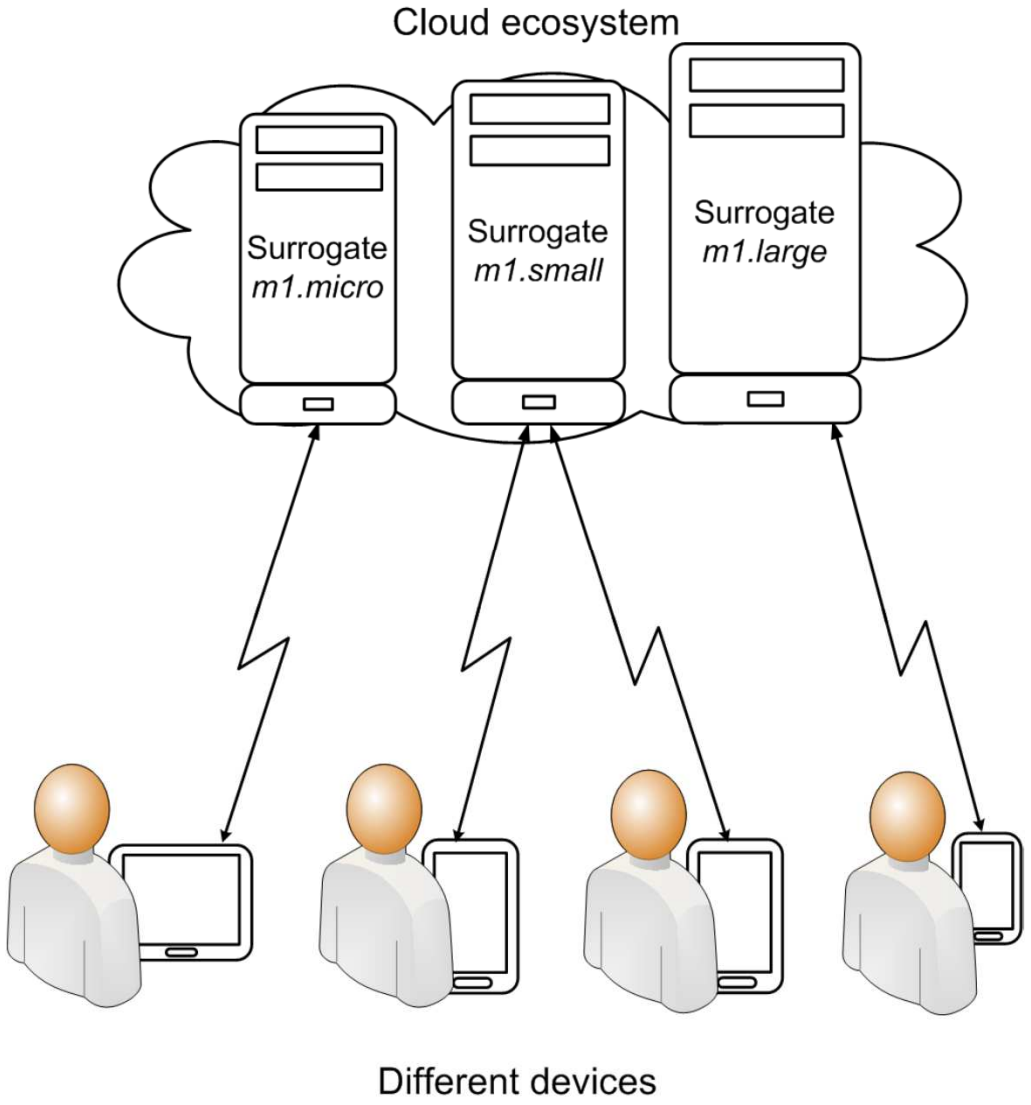
Applications that can benefit became limited with increase in device capacities

Multi-tenancy for code offloading



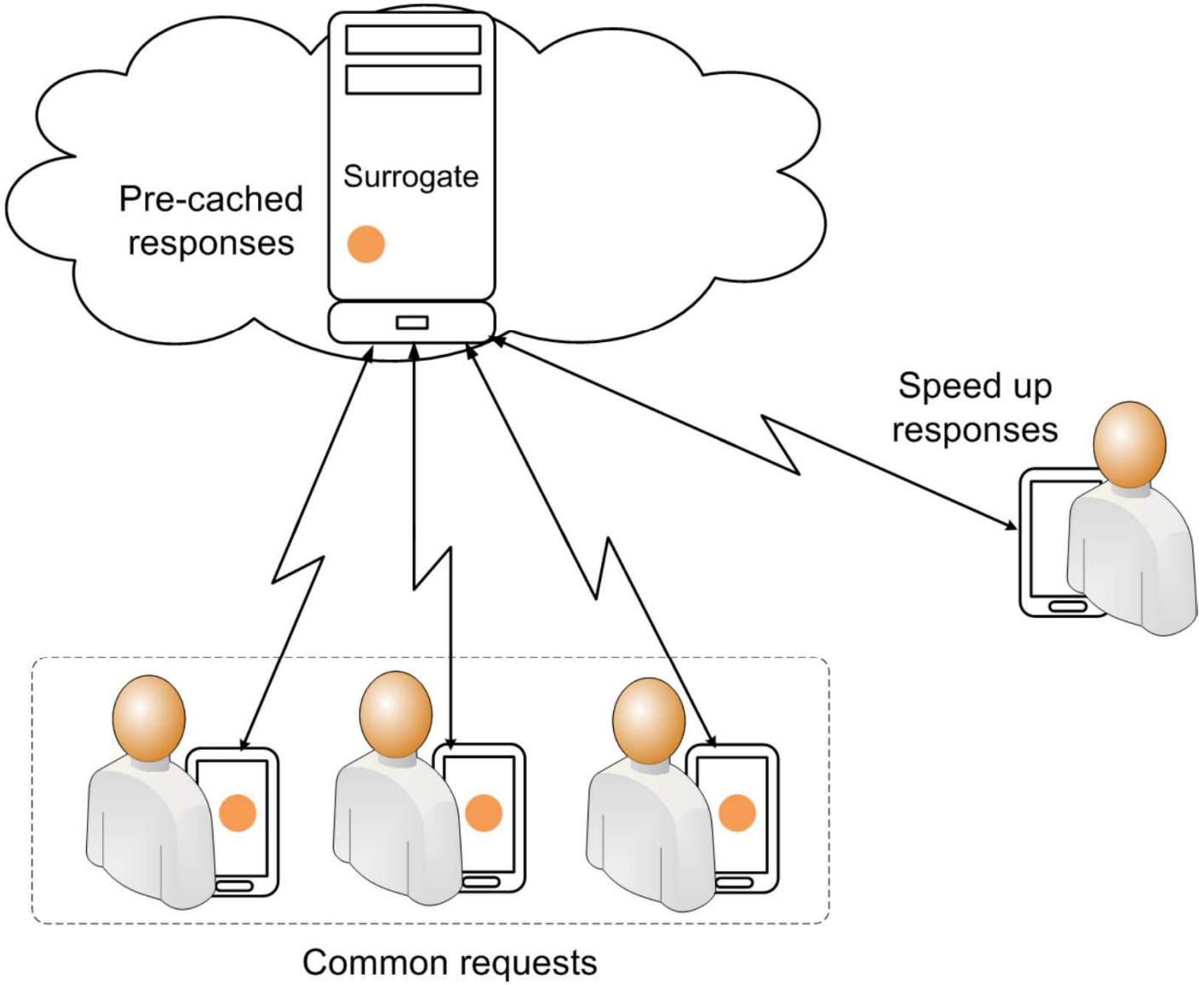
Auto-scaling becomes a challenge

Dynamic configuration



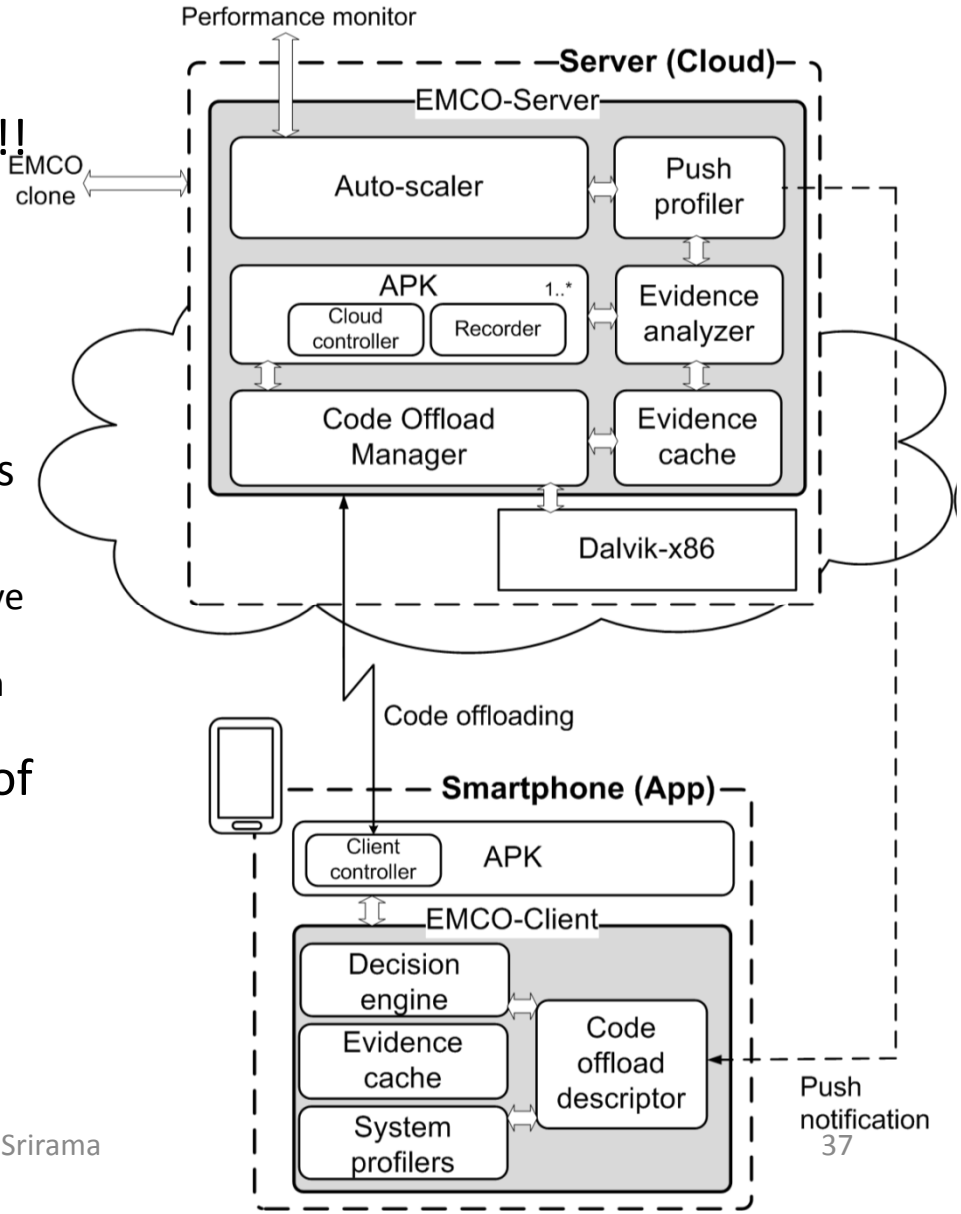
Vast resource allocation choices in the cloud ecosystem and the large diversity of smartphones make the context very variable

Acceleration via pre-cached results

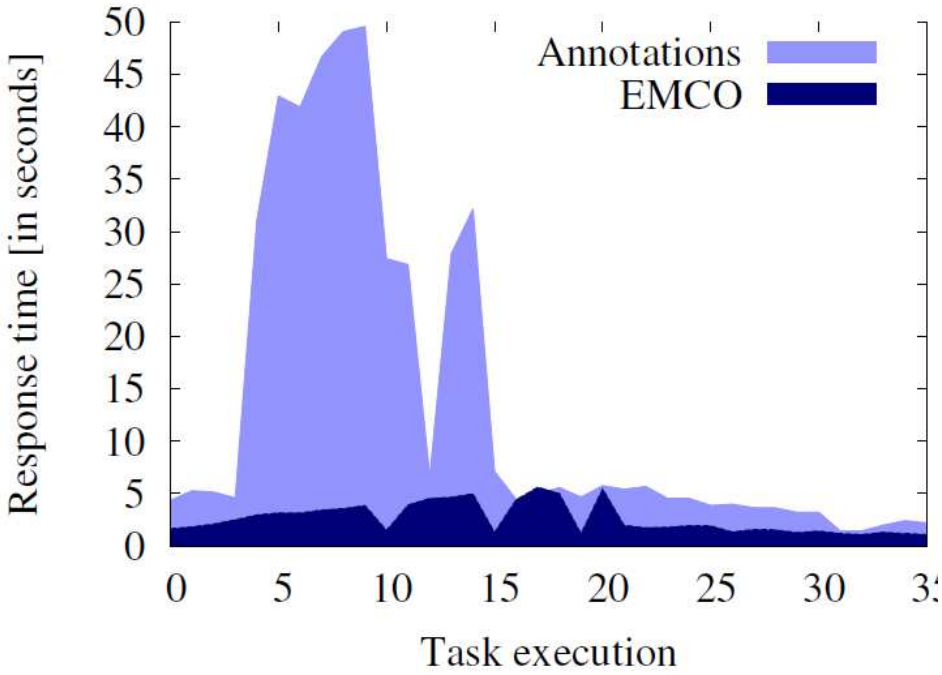


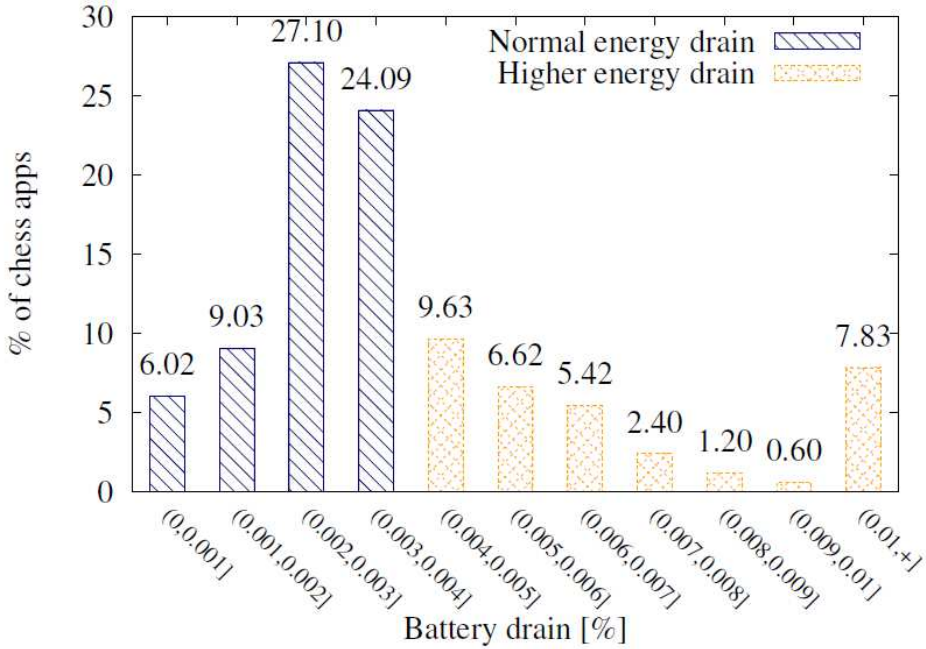
Way to proceed?

- Code offloading is not yet a reality!!!
- Take advantage of crowdsourcing
  - Computational offloading customized by data analytics
  - By analysing how a particular app behaves in a community of devices
  - E.g. Carat detects energy anomalies [Oliner et al, 2013]
    - By studying over ~328,000 apps gets an idea on what is resource –intensive app
    - Determines energy drain distribution of an app
- Rely on low-level compiler instead of virtualization
  - Android Open Source Project
  - X86 server architecture



Performance of EMCO





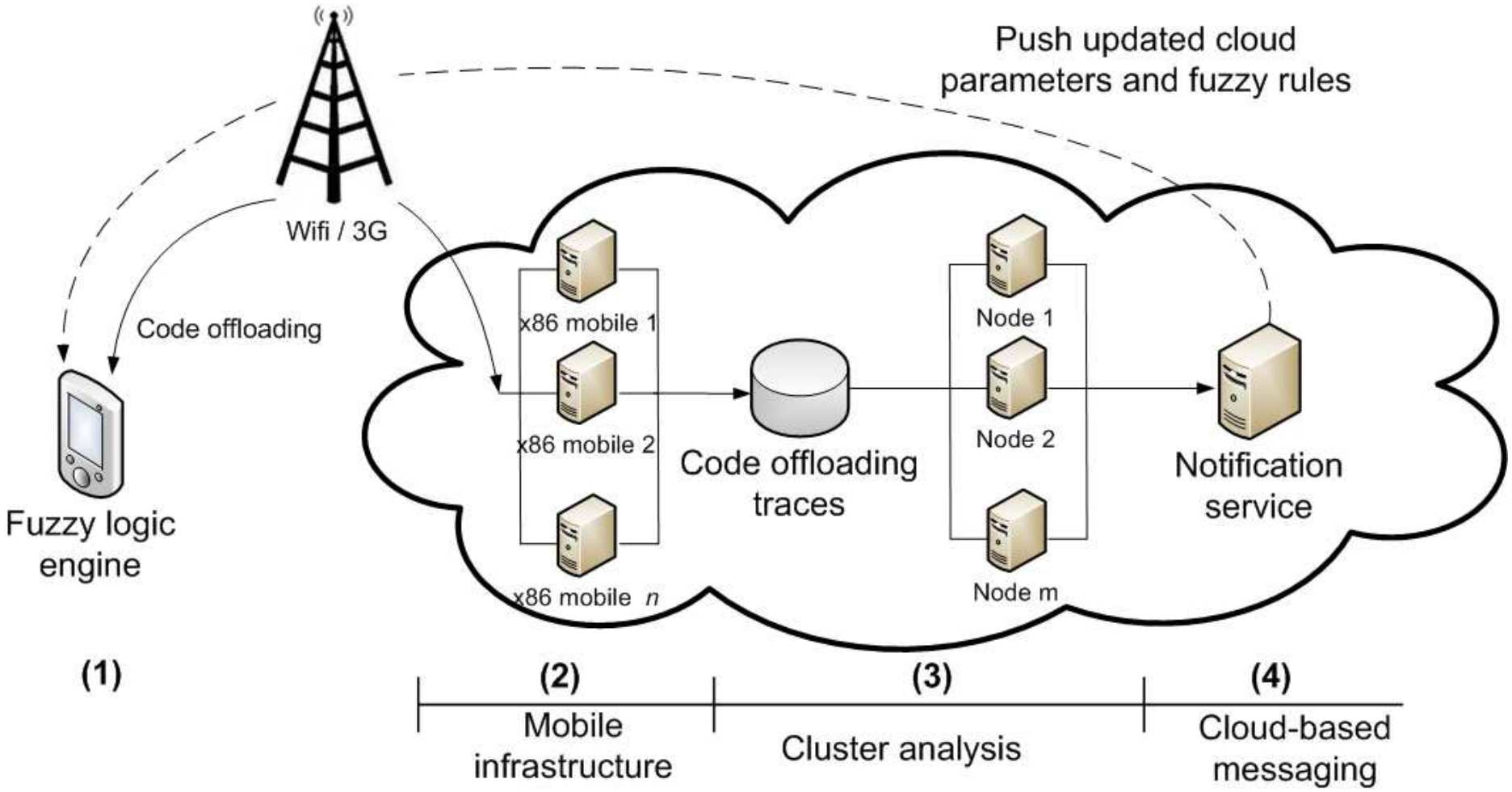
[Flores et al, IEEE Communications Mag 2015]

Extensions to decision engine

- Offloading from a different perspective
  - *"Offloading is a global learning process rather than local decision process"* [Flores and Srirama, MCS 2013]
- How it can learn?
  - Analysis of code offloading traces which are generated by the massive amount of devices that connect to cloud

"EMCO: Evidence-based mobile code offloading"

Evidence-based Mobile Code Offloading



[Flores and Srirama, MCS 2013]

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

Other research interests

- Migrating enterprise/legacy applications to the Cloud [REMICS]
  - Control and supervision of enterprise applications [Srirama and Ostovar, CloudCom 2014]
  - Remodelling enterprise applications for the cloud migration
- Scientific Computing on the Cloud [Srirama et al, SPJ 2011]
  - Migrating Scientific Workflows to the Cloud [Srirama and Viil, HPCC 2014]
  - Adapting Computing Problems to Cloud computing frameworks like MapReduce and BSP [Srirama et al, FGCS 2012] [Kromonov et al & Jakovits and Srirama, HPCS 2014]
- Mobile web services and adaptive mediation frameworks and workflows [Chang et al, PMC 2014; ICSOC 2012; MUM 2014]
- Internet of Things

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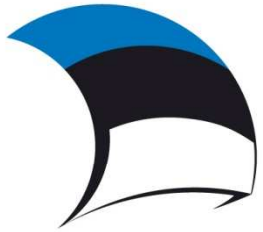

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