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# Towards a Ubiquitous Cloud Computing Infrastructure

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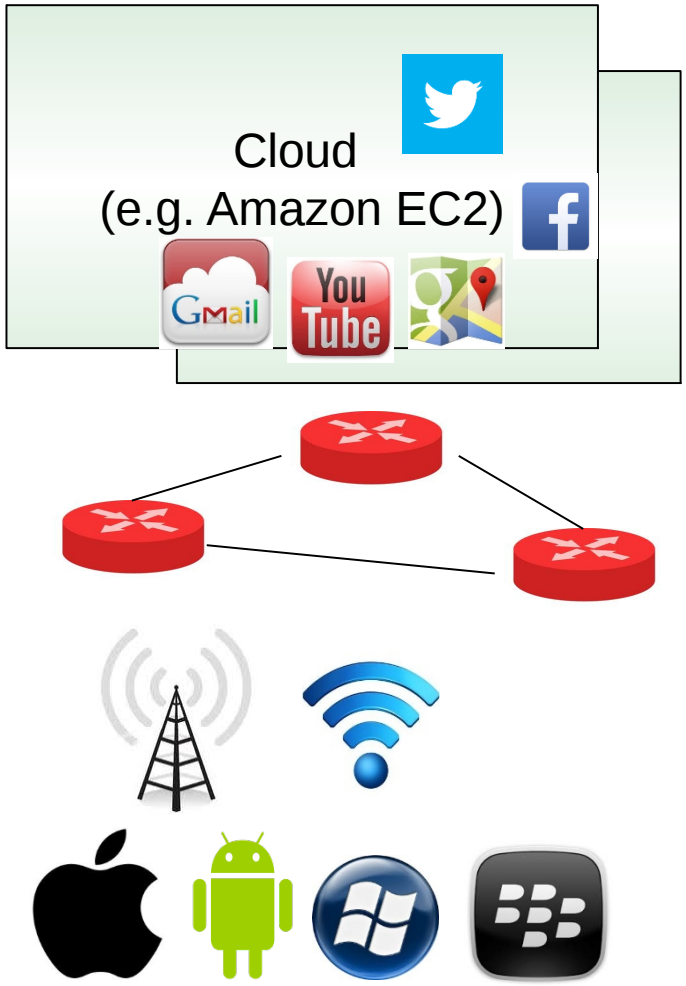
# Outlines

Forseen challenges to today’s mobile cloud infrastructure

Overview of ubiquitous cloud infrastructure

Related research at Aalto University

# Today's Mobile Cloud Infrastucture




**Centralized cloud infrastructure**

- ✓ lower the marginal cost of system administration and operations

**High asymmetry in traffic**

- ✓ Downlink to uplink ratio: about 6:1 [1]

**High latency over cellular network**

- ✓ Median: 125ms[1]



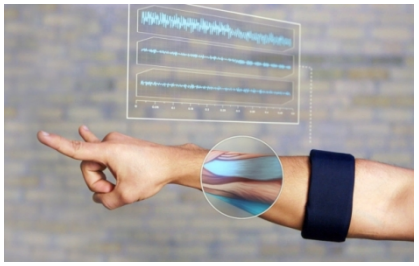
[1] Hossein F., Dimitrios L., Ratul M., Srikanth K., and Deborah E. 2010. A first look at traffic on smartphones. In IMC'10.

# Emerging Mobile Devices & Applications

- ✓Mobile augmented reality
- ✓3D gaming
- ✓Crowdsensed traffic control in urban areas
- ✓Gesture control
- ✓……

*There is more to come!*






# Challenges

**Compute-intensive**

- ✓ e.g. object recognition, 3D rendering, activity recognition

**Latency-sensitive**

- ✓ 100ms is the way too long for interactive applications like 3D gaming and augmented reality

**Bandwidth-intensive**

- ✓ Video to dominate the mobile data traffic in few years
- ✓ Rapid growth of user-generated content such as first-vision videos

**Privacy-sensitive**

- ✓ In the scenarios of crowdsensing, the value of the sensing data heavily depends on the granularity of the data
- ✓ There is a tradeoff between privacy and the value of the data

# Potential Solutions

**Compute-intensive?**

- **Computation Offloading**

**Latency-sensitive?**

- **Low latency access network + Computing at the Edge**

**Bandwidth-intensive?**

- **Caching at the Edge vs.  Increase Core Network Capacity**

**Privacy-sensitive?**

- **Crowdsourcing: 1+1 > 2**

# Cloudlet Vision

The design of cloud infrastructure will move from centralization to ***ubiqutious***

# Example Implementation of Ubiquitous Cloud Infrastructure

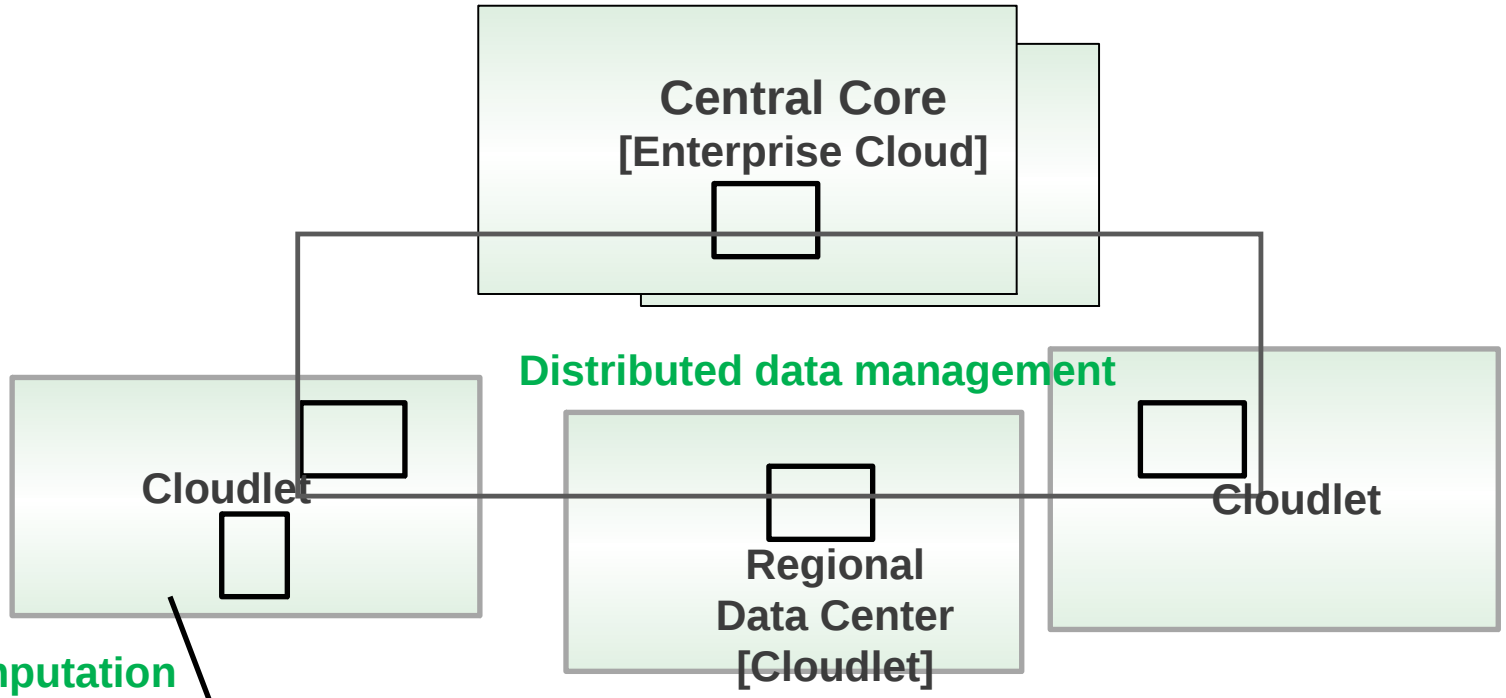
* The 3-tier cloud infrastructure, mobile-cloudlet-cloud, was first proposed in 2009

***A cloudlet can be viewed as a "data center in a box" whose goal is to "bring the cloud closer"***

[2] Mahadev Satyanarayanan, Paramvir Bahl, Ramón Caceres, and Nigel Davies. 2009. The Case for VM-Based Cloudlets in Mobile Computing. *IEEE Pervasive Computing* 8, 4 (October 2009), 14-23.

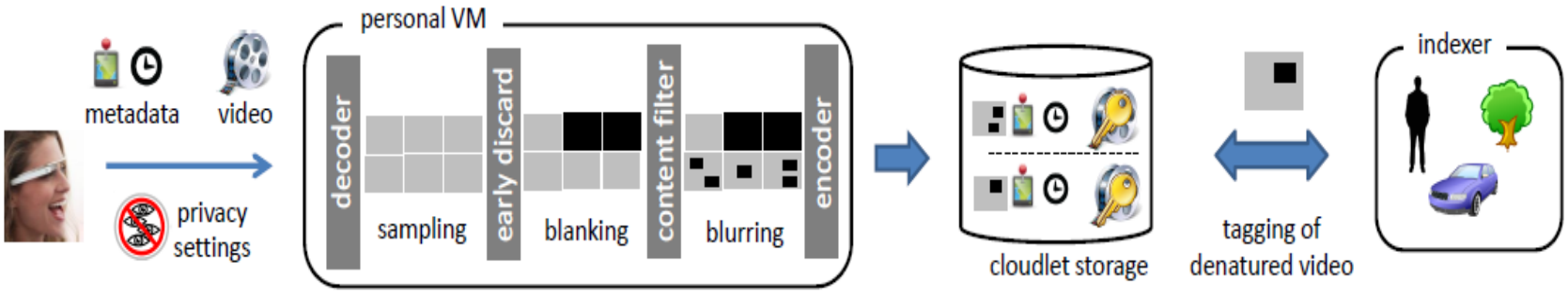
* An opensourced cloudlet framework is being developed by Carnegie Mellon University
  * The framework is built on standard cloud technology
  * Application servers can be installed on the virtual machines that run on distributed cloudlets

# Ubiquitous Cloud Infrastructure




**Cloudlets[2] are deployed close to the mobile devices, typically in the access or aggregation network of Wi-Fi or cellular network providers e.g. NSN Radio Application Cloud Server(RACS) can be considered as a cloudlet collocated with LTE base station**

# Example Application: Crowdsourcing of Video from Mobile Devices[3]




## * Computing at the edge

* First-person videos captured from mobile devices were processed on the cloudlets close to the mobile devices
* In this case, the video processing includes face detection and blurring

## * CDN in reverse

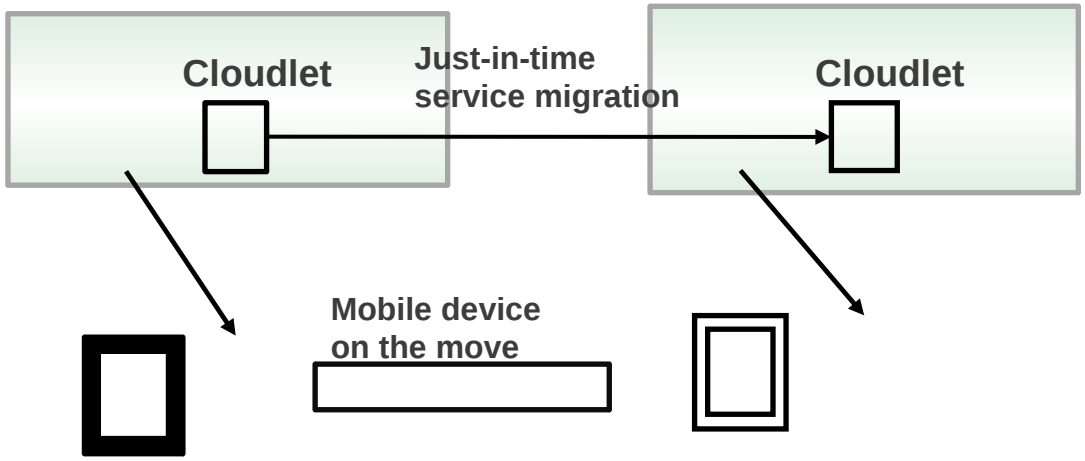
* The processed video files are stored on ditributed file system
* On each cloudlet a daemon tags the local video files with the information of the recognized objects
* Tags of the local video files are gathered into the database located in central core



[3] Simoens, P., Xiao, Y., Pillai, P., Chen, Z., Ha, K., Satyanarayanan, M. Scalable Crowd-sourcing of Video from Mobile Devices. in ACM Mobisys 2013

# Technical Challenges

* Just-in-time service migration in mobility scenarios




* Distributed data management and collaborative computing over cloudlets
* Energy-efficient task partitioning between mobile, cloudlet and the central cloud
* End-to-end network performance analysis and optimization

# Related Research at Aalto CSE

* Collaborating with Carnegie Mellon University from 2012 on the development of mobility support for the cloudlet framework

* Researching on
  * End-to-end networking performance analysis and optimization (funded by Academy of Finland)
  * VM-based Network emulation platform that can be used for cloudlet deployment planning
  * Cloudlet-based home entertainment solution

* Planning to combine the cloudlet research with the crowdsensing research in University of Helsinki
* Interested in deploying and testing cloudlet software on NSN RACS

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# Further reading


- Mahadev Satyanarayanan, Paramvir Bahl, Ramón Caceres, and Nigel Davies. 2009. The Case for VM-Based Cloudlets in Mobile Computing. IEEE Pervasive Computing 8, 4 (October 2009), 14-23. DOI=10.1109/MPRV.2009.82 http://dx.doi.org/10.1109/MPRV.2009.82

- Simanta, S.; Lewis, G.A.; Morris, E.; Kiryong Ha; Mahadev Satyanarayanan, "A Reference Architecture for Mobile Code Offload in Hostile Environments," Software Architecture (WICSA) and European Conference on Software Architecture (ECSA), 2012 Joint Working IEEE/IFIP Conference on , vol., no., pp.282,286, 20-24 Aug. 2012

- Tim Verbelen, Pieter Simoens, Filip De Turck, and Bart Dhoedt. 2012. Cloudlets: bringing the cloud to the mobile user. In Proceedings of the third ACM workshop on Mobile cloud computing and services (MCS '12). ACM, New York, NY, USA, 29-36. DOI=10.1145/2307849.2307858 http://doi.acm.org/10.1145/2307849.2307858