Aalto University
School of Science

Mobile Offloading

Matti Kemppainen
kemppi@cs.hut.fi

Lecture Slides

T-110.5121
Mobile Cloud Computing

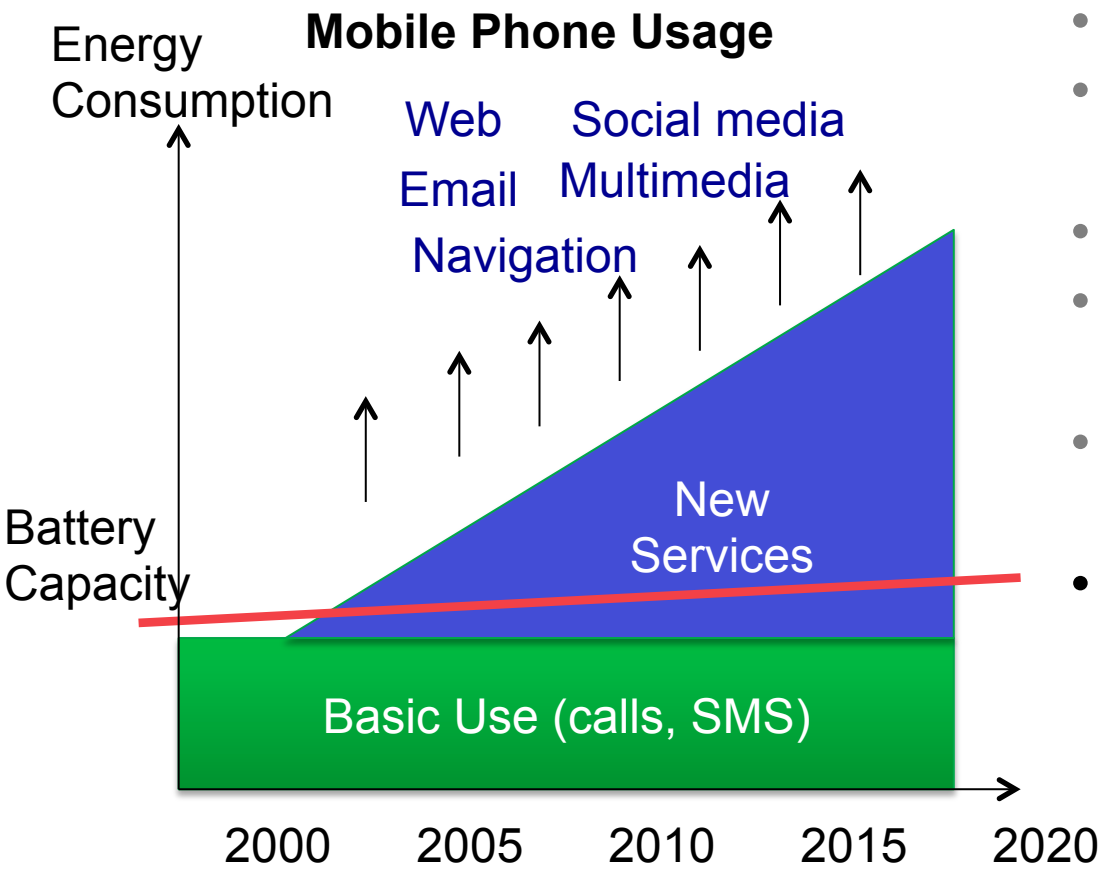
17.10.2012
Otaniemi, Espoo

Agenda

1. Problem scope
2. Overview of *mobile computation offloading*
3. Appearance in application development
4. Challenges
5. Some first-hand experiences
6. What next?
7. Summary

Problem Description

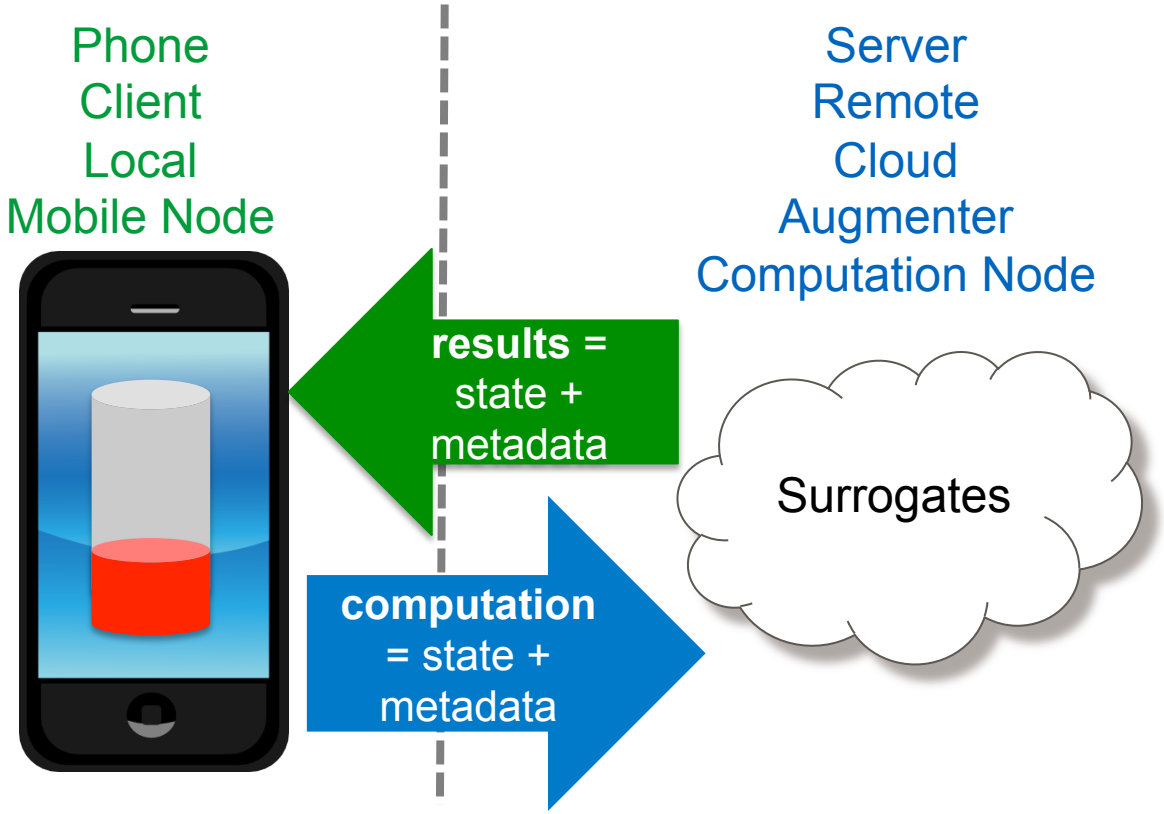
Slide by Prof. Jukka K. Nurminen



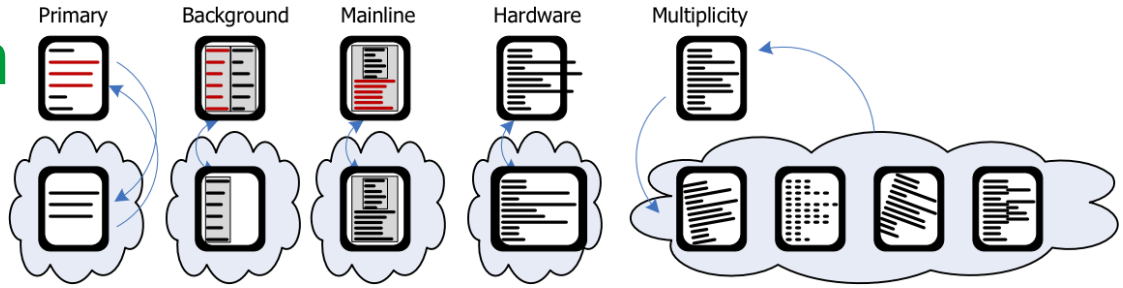
- less new services
- more frequent battery charging
- physically larger battery
- more energy-efficient components
- a breaktrough in battery cell technology
- **a more clever way to utilize the available power**

Mobile Computation Offloading

Transfer of Execution of Computation Outside The Mobile Device



Some Application Examples



Primary functionalities

- speech, video processing…

Background tasks

- web crawling, photo analysis…

Hardware augmentation

- speedup with more resources, specialized resources…

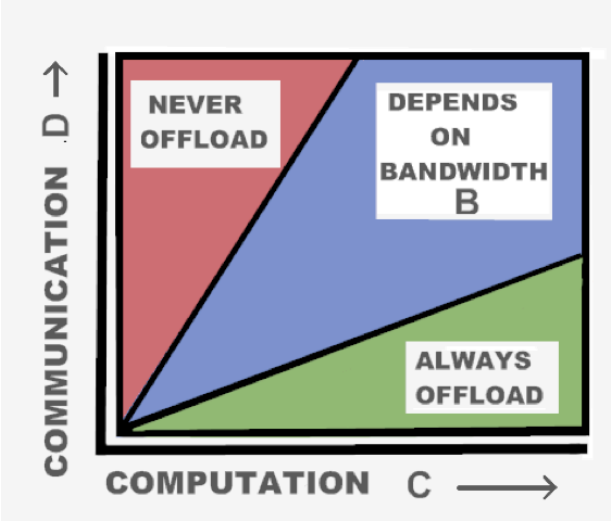
Multiple execution paths

- artificial intelligence, different analysis methods…

Chun & Maniatis, 2009
Augmented Smartphone Applications Through Clone Cloud Execution

Gaining Benefit

End User's Perspective



Offloading is beneficial, if

the related overhead costs
are less than
the cost of computation done locally.

Kumar & Lu, 2010
Cloud Computing for Mobile Users: Can Offloading Computation Save Energy?

Motivation…

Saving Energy

Enhancing Reliability

Enabling Performance

Exploiting Context

Easiness for Application Developers

…Constraints

Monetary Cost

Security and Trust

Code Migratability,
Limits of Automation

Key Features of Offloading Frameworks

Migration Support

- no need for application-specific networking protocols

Offloading as an Alternative

- Remote execution is an opportunistic alternative, not a must.
- Offloading is an optimization method, not a requirement.

Dynamic Decisionmaking

- Environmental conditions may have an effect on the execution location.

Offloading Framework Architectures

Levels of Offloading

Feature

- idea: implement features and use them through an interface
- example: a typical network-enabled mobile application

Method

- idea: execute resource-hungry methods remotely
- example: AI analysis of game logic

System

- idea: clone the runtime environment (or the relevant parts)
- example: everything that might run on a system

Feature Offloading

Architecture

```
1 interface RemoteService {
2     /* tasks required by
3        the framework */
4 }
```

offload sematically coherent parts of the application

Cuckoo (Android)

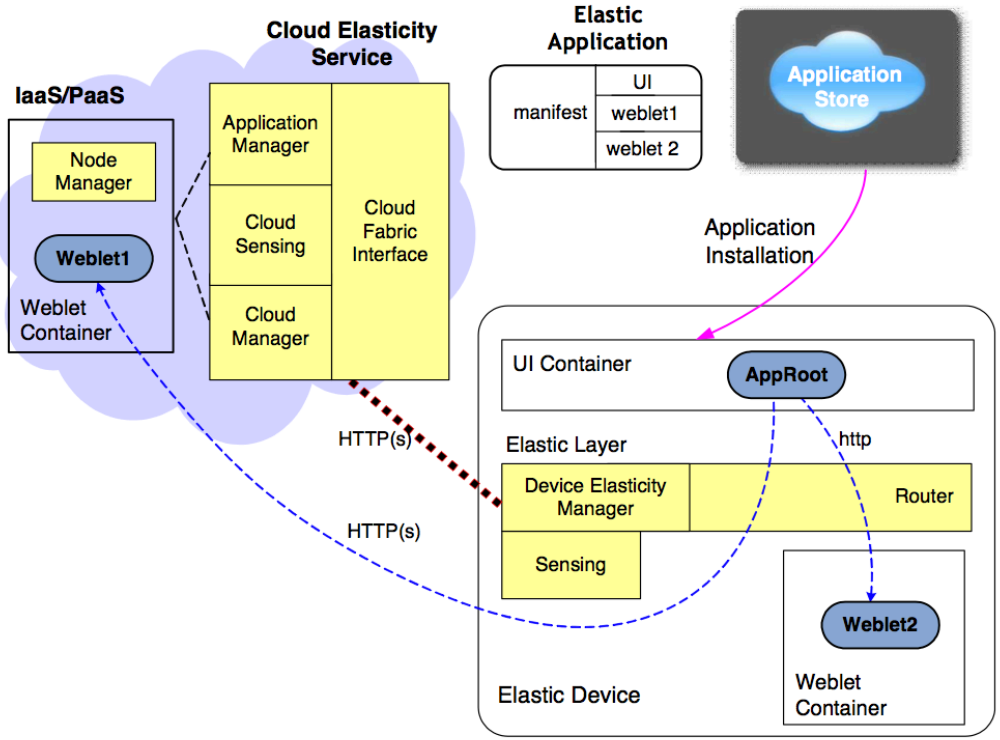
Vrije Universiteit, Amsterdam

Requirements: Standard Dalvik VM and Android software stack

1. Developer defines an interface (in AIDL) for the part of the application that is subject to offloading.
2. Building system generates the needed implementation stubs and proxies.
3. Developer implements the features. Local and remote implementations may differ.

Elastic Application Architecture

Feature Offloading



Zhang et al., 2011
Towards an Elastic Application Model
for Augmenting Computing Capabilities of Mobile Platforms

Method Offloading

Architecture

```
1 class MyClass {
2     @remoteable
3     void myMethod() {
4         // implementation
5     }
6 }
```

offload method calls including needed data

Example: MAUI (.NET)

Duke, U. Mass. Amherst, UCLA, Microsoft Research

Requirements: Standard .NET software stack

1. Developer annotates the desired methods as *remoteable*.
2. Framework *considers* offloading of the remoteable methods. It may also choose to invoke a method locally.

Image Offloading

Architecture

```
1 class MyClass {
2     void myMethod() {
3         // implementation
4     }
5 }
```

offload bytecode, program image or even volume image

CloneCloud (Android)

Intel Labs, Berkeley

Requirements: A custom version of Dalvik VM

1. Developer lets the underlying system make partitioning and offloading decisions.

Architecture Comparison

Abstraction Level	Developer Workload	Level of Automation	Need for Platform Support
Feature	**+++** high	+ medium	- not needed
Method	+ medium	++ medium	? depends
System	- low	**+++** high	**+++** necessary

Migration of Process State

```
struct DataSet {
    void *data;
    struct DataSet *nextItem;
};
struct ResultSet* do_the_trick(struct DataSet *data);
```

Data transfer costly

- Transfer as little as possible

Serializability

- Data needs to be transferrable (e.g. hardware driver cannot be offloaded)
- Class inheritance may pose considerable problems

Complexity of Automation

- What is the needed dataset?

Decisionmaking

Prior Analyses

Developer's Decisions

Application Profiling
- CPU usage, memory consumption
- network usage
- disk I/O

Use-case Profiling

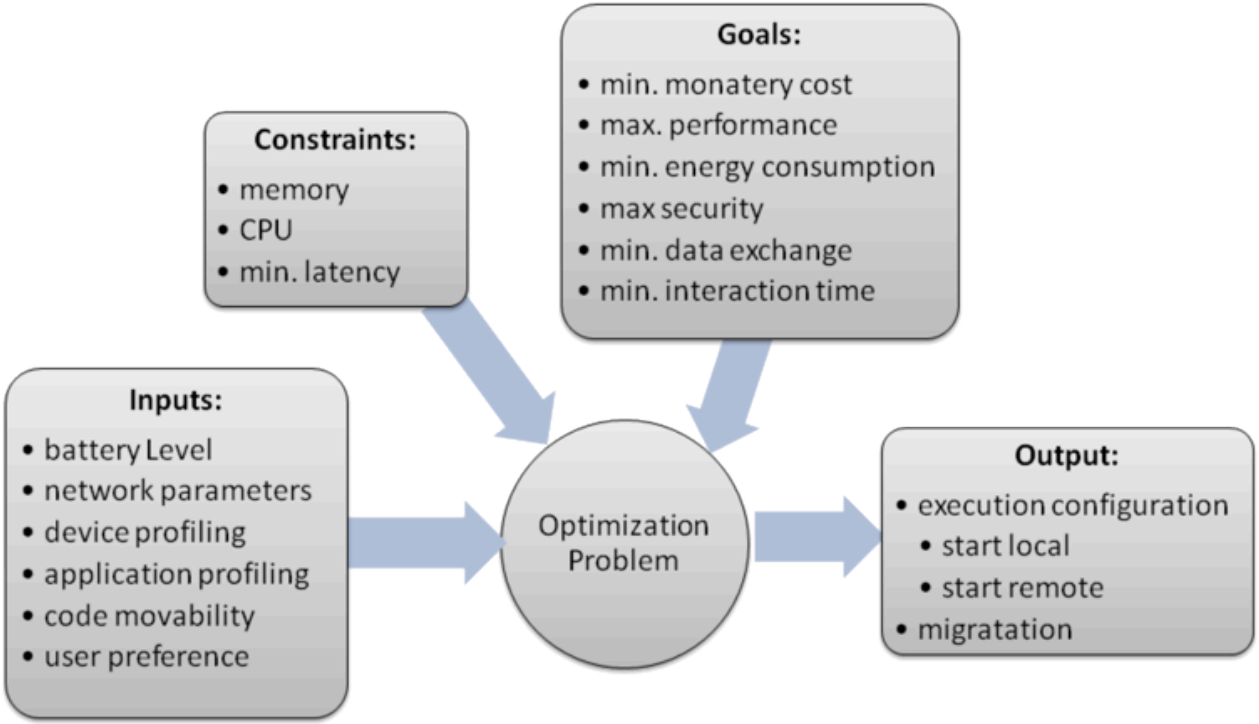
Runtime Analyses

User's decisions

Environment Profiling
- hardware resources, network availability…

Action Monitoring
- feedback-driven controlling of offloading process

Optimization Problem



Kovachev et al, 2011
Mobile Cloud Computing: A Comparison of Application Models

Infrastructure

Where to Offload?

Runtime environment for the migrated code

- different implementations or a common software stack?

Cloud services

- virtualization as a way to providing a suitable environment

Networking performance

- surrogates closer to the clients

Existing resources

- private clouds, PCs, specialized processors, other network devices in the local environment

Networking

Mobility means wirelessness

- Sparse connectivity
- Multitude and heterogeneity of network stacks
- Energy consumption of antenna amplifier
- Long RTTs, packet loss

Some Resolutions

- Network stack abstractions
- Traffic shaping
- Route selection (a.k.a. data offloading)

Other Considerations

Code Transfer

- application caching at surrogate
- application libraries

Data Transfer Optimizations

- transfer deltas
- delay tolerance of data

Service Discovery

- mainstream users don’t want to configure IP addresses

Trust And Security

- how to make offloading trustable?

ThinkAir Offloading Framework

Deutsche Telekom (modifications in Aalto)

Method-level offloading framework

- runs on default Dalvik VM, no modifications needed
- modifications necessary to application code

Client-server networking paradigm

- target application acts as an offloading client
- surrogate is a server application, runs inside an unmodified Dalvik VM
- automatic application code transfer

Kosta et al., 2011
Unleashing the Power of Mobile Cloud Computing using ThinkAir

What about mainstream applications?

Existing promises

- MAUI: 45% energy savings for **Chess AI**
- CloneCloud: 20x speedup and energy savings for **a large image search**
- MACS (2012): more than 20x speedup in **face recognition from a video**

Biased measurements?

- Tailored application sets in previous literature

Effect of communication energy consumption

- Could offloading be utilized for traffic shaping?

Experiences And Results

Communication Offloading with ThinkAir

We offloaded successfully!

- ThinkAir handled the necessary procedures for execution migration
- some advantage with WLAN

…but…

- We did modify the application for custom serialization
- 3G RTT nullified the advantages
- Debugging is hard: Errors may even be unnoticed

Saarinen at al., 2012
Can offloading save energy for popular apps?

Method Migratability

Definition of migratability (simplified)

- Method does not access physical resources of the mobile device.

Real-life migratability

- 15% of all methods in 16 different open-source applications

Application Developer must be an active part of offloading process.

Saarinen at al., 2012
Can offloading save energy for popular apps?

Some Cool Ideas

Popular services brought nearby

- e.g. many subscribers for a newspaper on an airplane → a clever proxy that retrieves personalized content

Collaborative services

- Many users with a common goal in vicinity → ad-hoc collaboration for reaching the goal

Universal application execution

- one application with two different interfaces for supporting many terminals (e.g. desktop computer, mobile phone)
- “transfer” of live process with help of offloading

Ongoing Research (late 2011)

Cuckoo: dynamic decision-making

- MACS at RWTH Aachen (2012)

MAUI: state transfer optimization

CloneCloud

- Hardware accesses
- Advanced concurrency
- Trust

A few days ago: TransOS

- an operating system in the cloud?

Summary

Theoretical Aspects

Mobile Computation Offloading:
transfer of computation outside the mobile device

- related terminology is emerging while research continues

MCO differs from traditional distributed computing

- opportunistic operation
- low-quality networking environments

Offloading brings many potential benefits

- energy saving, performance, reliability, ease for the software developers, better exploitation of contextual information...

Offloading has also many other opportunities

- business opportunities, collaborative local services, universal application execution…

Summary

Current State of Art

- Today's frameworks deal with the essentials.
- There is no publically available offloading framework.
- Current frameworks seem to be more or less for academic purposes.

The big question:

What kind of mainstream application would benefit from offloading?

Aalto University
School of Science

Thank you!
Any questions or comments?

Matti Kemppainen
kemppi@cs.hut.fi