Services, Clouds and Robots

Mihhail Matskin

Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Royal Institute of Technology (KTH), Stockholm, Sweden.

Brifly about me

- Past:
  - PhD from Institute of Cybernetics, Tallinn, Estonia, 1984
  - Assoc. Professor 1995-2001 at NTNU
  - Full professor 2001-2002 at NTNU
- Present:
  - Professor in Software Engineering at KTH (from 2002)
  - Adjunct professor in Computer Science at NTNU (from 2002)
- Current interests:
  - service composition, robotic services, autonomous computing systems, semantic user profiling, service-oriented architectures, trust, privacy, semantic Web services.

Contents

- Service robots
- Web services and robots
  - Service environment for robots
  - Robots using Web services
  - Robots as Web service
  - Advance Web service issues
- Clouds and robots
  - Outsourcing resources
  - Robotic clouds
- Conclusions

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Service robots

"A service robot is a robot which operates semi- or fully-autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations. "

International Federation of Robotics (IFR)

Service robots

- **Service robots** can have different functionality but their main goal is to help humans perform tasks that are dangerous, difficult, dirty, distant or repetitive
- They are autonomous
- They are often mobile
- They might be connected to environment via WIFI

Some groups of service robots

(http://www.ifr.org/service-robots/products/)

Robots for domestic tasks
- Robot butler/companion/assistants
- Vacuuming, floor cleaning
- Lawn mowing
- Pool cleaning
- Window cleaning

Entertainment robots
- Toy/hobby robots
- Robot rides
- Education and training

Handicap assistance
- Robotized wheelchairs
- Personal rehabilitation

Personal transportation (AGV for persons)

Home security & surveillance

Professional Service Robots

Field robotics
- Agriculture
- Milking robots
- Forestry
- Mining systems
- Space robots

Medical robotics
- Diagnostic systems
- Robot assisted surgery or therapy
- Rehabilitation systems
- Other medical robots

Defense, rescue & security applications
- Demining robots
- Fire and bomb fighting robots
- Surveillance/security robots
- Unmanned aerial vehicles
- Unmanned ground based vehicles

Underwater systems

Mobile Platforms in general use

Robot arms in general use

Public relation robots
- Hotel and restaurant robots
- Mobile guidance, information robots
- Robots in marketing
- Others (i.e. library robots)

Special Purpose
- Refueling robots
- Others

Customized robots

Humanoids

Professional cleaning
- Floor cleaning
- Window and wall cleaning
- Tank, tube and pipe cleaning
- Hull cleaning (aircraft, vehicles…)

Inspection and maintenance systems
- Facilities, Plants
- Tank, tubes and pipes and sewer

Construction and demolition
- Nuclear demolition & dismantling
- Construction support and maintenance
- Construction

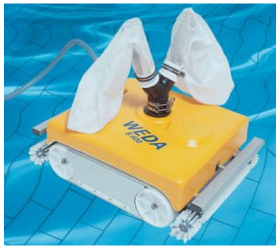
Logistic systems
- Courier/Mail systems
- Factory logistics (incl. Automated Guided Vehicles for factories)
- Cargo handling, outdoor logistics
- Other logistics

Some service robots

Milking robot - DeLaval

Lawn Mower - Friendly Robotics Israel

Underwater vehicle - Atlas Maridan



Pool Cleaner - Weda

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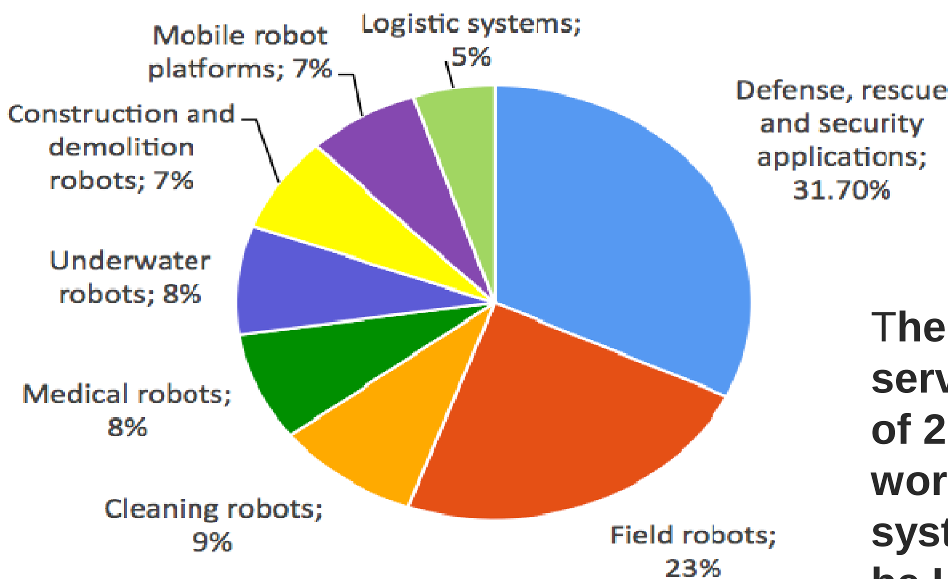
Diagnostic System - Siemens

Elecrtolux Trilobite Version 2.0

Serving robot at the *"Ubiquitous Dream"* exhibition in Seoul

Professional service robot market (2008)



The total value of professional service robots sold by the end of 2008 was USD 11.2 billion; the world market for industrial robot systems was then estimated to be USD 19 billion in 2008 alone

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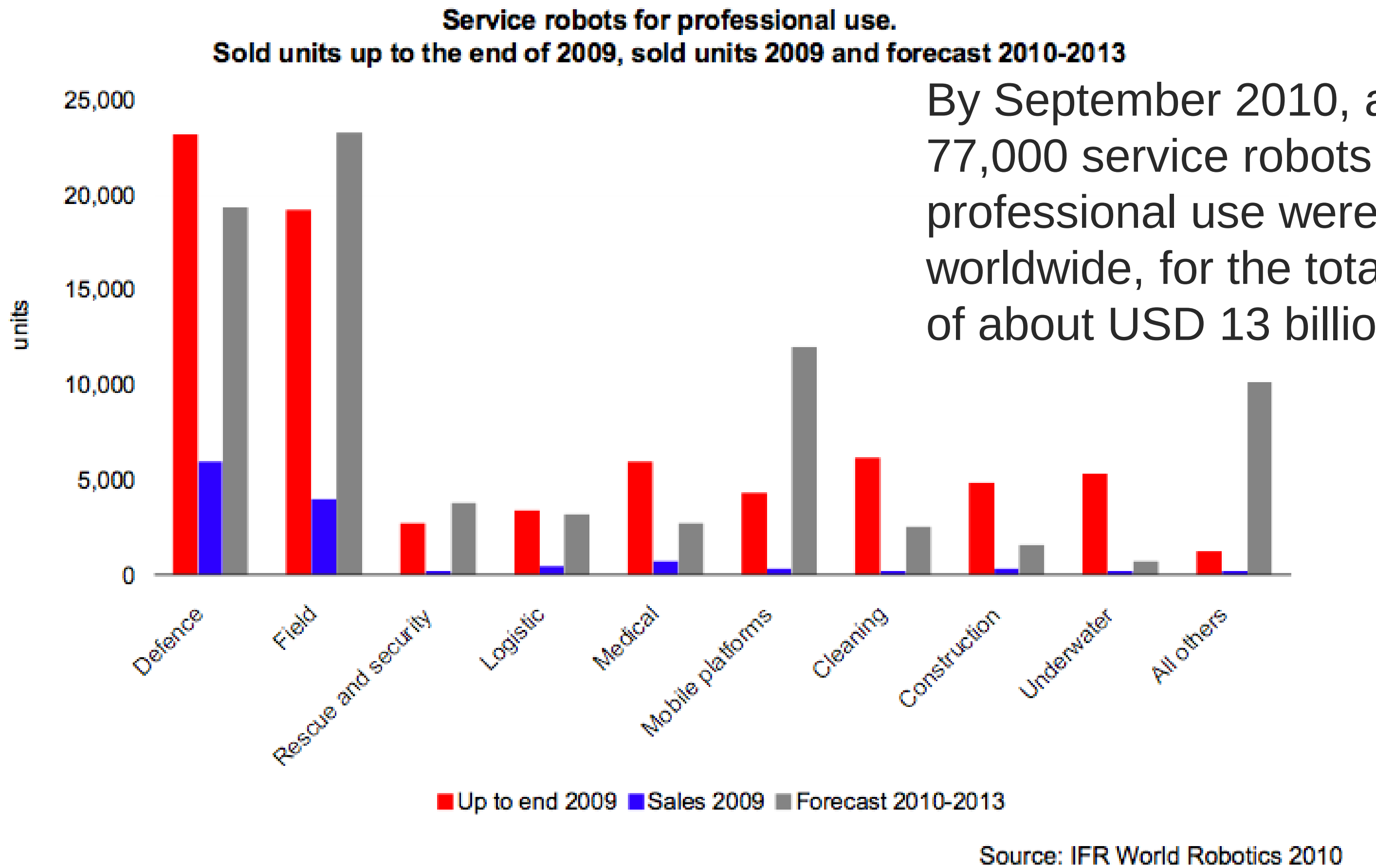
(Source: IFR Statistical Department)

Professional service robot market (2010)



By September 2010, about 77,000 service robots for professional use were sold worldwide, for the total value of about USD 13 billion

(Source: IFR Statistical Department)

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Availability of Robotic services

- Can we consider Robotic services as other software services and deliver them over the Web?
- Can Robotic services be treated as other (Web) services?
- Can robots consume other (Web) services?
- Can robots provide and consume services from other robots?

- **Why not?**

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Web services

- A way of software application delivery
- Web as a delivery channel for software services
- Text/XML based specifications

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What about Web service and robots?

Robots and Web Services (some previous work)

- Robot with Web Service interface (Germany)
  - J. Levine, L. Vickers, “Robots Controlled through Web Services”. Technogenesis Research Project, 2001.
- DERI – electric engine commected to Web services (Ireland and Korea)
  - L. Vasiliu, et. al., “A Semantic Web Services driven application on Humanoid Robots”. 4th Int. Workshop on Software Technologies for Future Embedded & Ubiquitous Systems, IEEE, 2006, pp. 236 – 244.
- Planner for robot as Web Service (Germany)
  - R. Hartanto, J. Hertzberg, “Offering Existing AIPlanners as Web Services”. GI Workshop Planen und Konfigurieren, Germany, 2005

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Our experience in ROBOSWARM

- The objective of the ROBOSWARM project is to develop an open knowledge environment for self-configurable, self-learning and robust robot swarms usable in domestic and public area applications - cleaning, patrolling, semantic mapping, escorting and other.
- The project focuses on creating on-site (near to the objects of interest) distributed data environment, developing a universal inter-robot communication format, database access language, and a global robot knowledge base accessible via web services.

ROBOSWARM partners

Estonia
Tallinn University of Technology

Sweden

France

NTNU
Norwegian University of Science and Technology

Finland
Helsinki Unversity of Technology

Finland

Estonia
ELIKO

Spain

Portugal

Italy
University of Genoa

Roomba robots **iRobot Corporation**

- Introduced in 2002
- By year 2008 over 2.5 millions units are sold, in 2010 about 6 millions sold
- Has serial interface and Roomba open interface APIs

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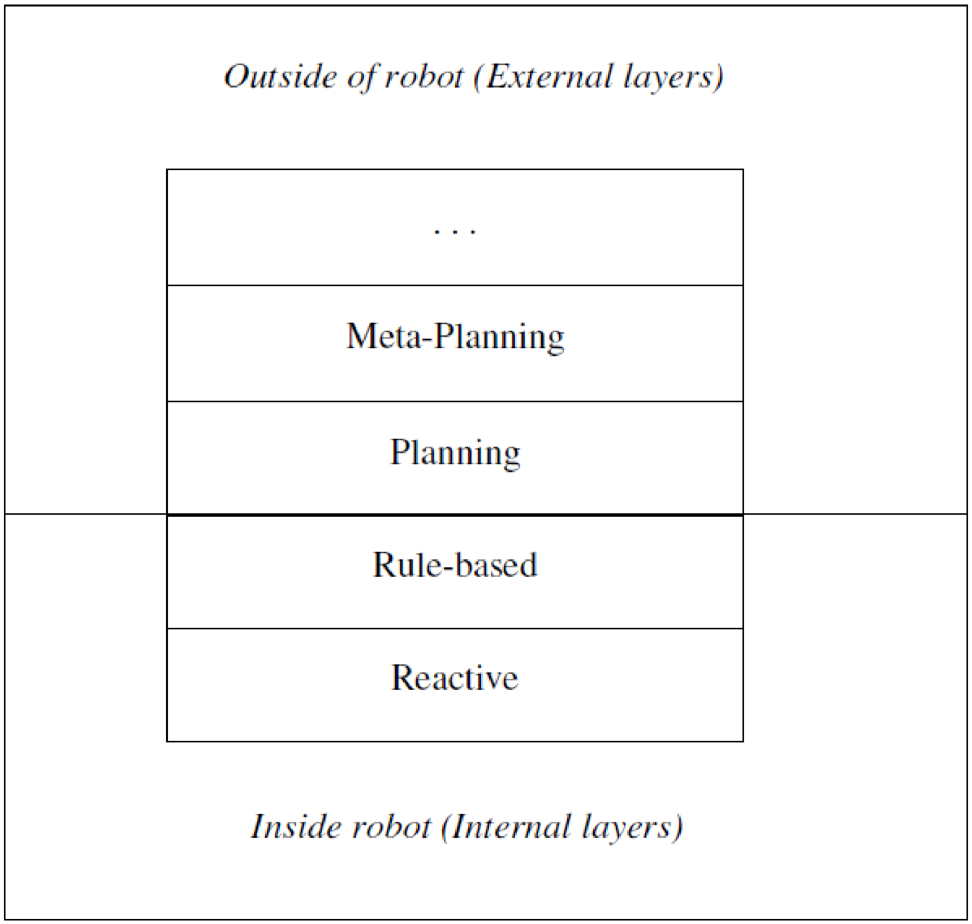
ROBOSWARM* Use -case

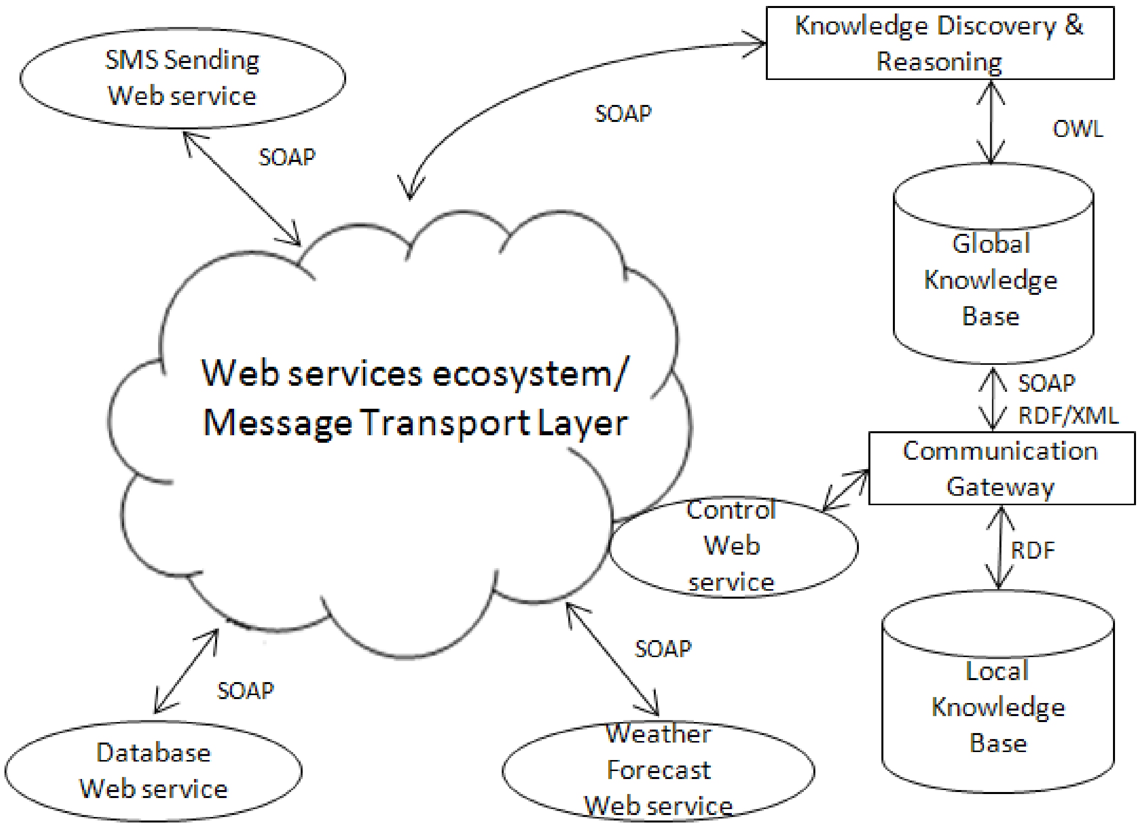
- A **swarm** of **heterogeneous** and mobile robots along with server side components cooperate together in order to achieve a high level common goals coming out from user requests.

ROBOSWARM

Architecture



Global/Local Knowledge base



How does it work with SOAP?

```
<env:Envelope xmlns:env=http://www.w3.org/2001/12/soap-envelope
          xmlns:def="http://roboswarm.eu/soap">
     <env:Body>
          <def:addRDFTriplet>
            <rdf:RDF xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns#
                              xmlns:rs="http://www.roboswarm.eu/">
               <rdf:Description rdf:about="R1" rs:prefix="15">
                  <rs:TroubleStatus rs:type="xsd:string“  rs:source="R1"
                                rs:context="general"
                                rs:datetime="07-June-2007-14:55:01" >
                                        “11”
                  </rs:TroubleStatus>
               </rdf:Description>
            </rdf:RDF>
          </def:addRDFTriplet>
     </env:Body>
</env:Envelope>
```

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How does it work with rules?

- From robot:
  - TroubleStatus(“R1”,”11”).
- Rules in GRKB:
  - TroubleStatus(X, Y):- NotifyTechnician(X, Y)
  - NotifyTechnician(X, Y):- MessageSent(“RobotName”, X, “ErrorCode”, Y)
- Inferred predicate:
  - MessageSend(“RobotName”,“R1”,“ErrorCode”,“11”).
- Service request:
  - “RobotName=R1”, “ErrorCode=11” → MessageSend

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How does it work with Web service composition?

- Service request:
  - “RobotName=R1”, “ErrorCode=11” → MessageSent
- Atomic services:
  - FindTechnician : Time → MobileNumb
  - GetTextError : ErrorCode→ErrorText
  - ComposeMessage : ErrorText, RobotName →MessageText
  - sendSMS : MobileNumber, MessageTex t→MessageSenD,
- Composite service:
  - FindTechnician;
  - GetTextError ;
  - ComposeMessage;
  - sendSMS

ROBOSWARM
Employing Global Knowledge Base

Multi-Robots systems

- Multiple robots can share tasks and help each other to accomplish a mission more efficiently than a single robot if the mission could be divided across a number of robots operating in parallel.

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Overall Multi-Robot Characteristics

- Overall control of robot action is not embedded into any of the robots.
- Local behavior of each robot is loosely dependent on the behavior of other robots
- Local interactions among robots may lead to emergent of a complex behavior.

Integration of Heterogeneous Robots

- Heterogenity is due to different robot operating systems, programming languages, software and hardware vendors, legacy technologies,...

- Heterogenity in Communication
- Heterogenity in Robot Capabilities
- Heterogenity in Robot Application System

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Multi Robot systems

- Most of the previous works are **specialized** architectures for each type of robot team and application domain.

- There is need to a **generic** architecture which supports integration of heterogenous robots .

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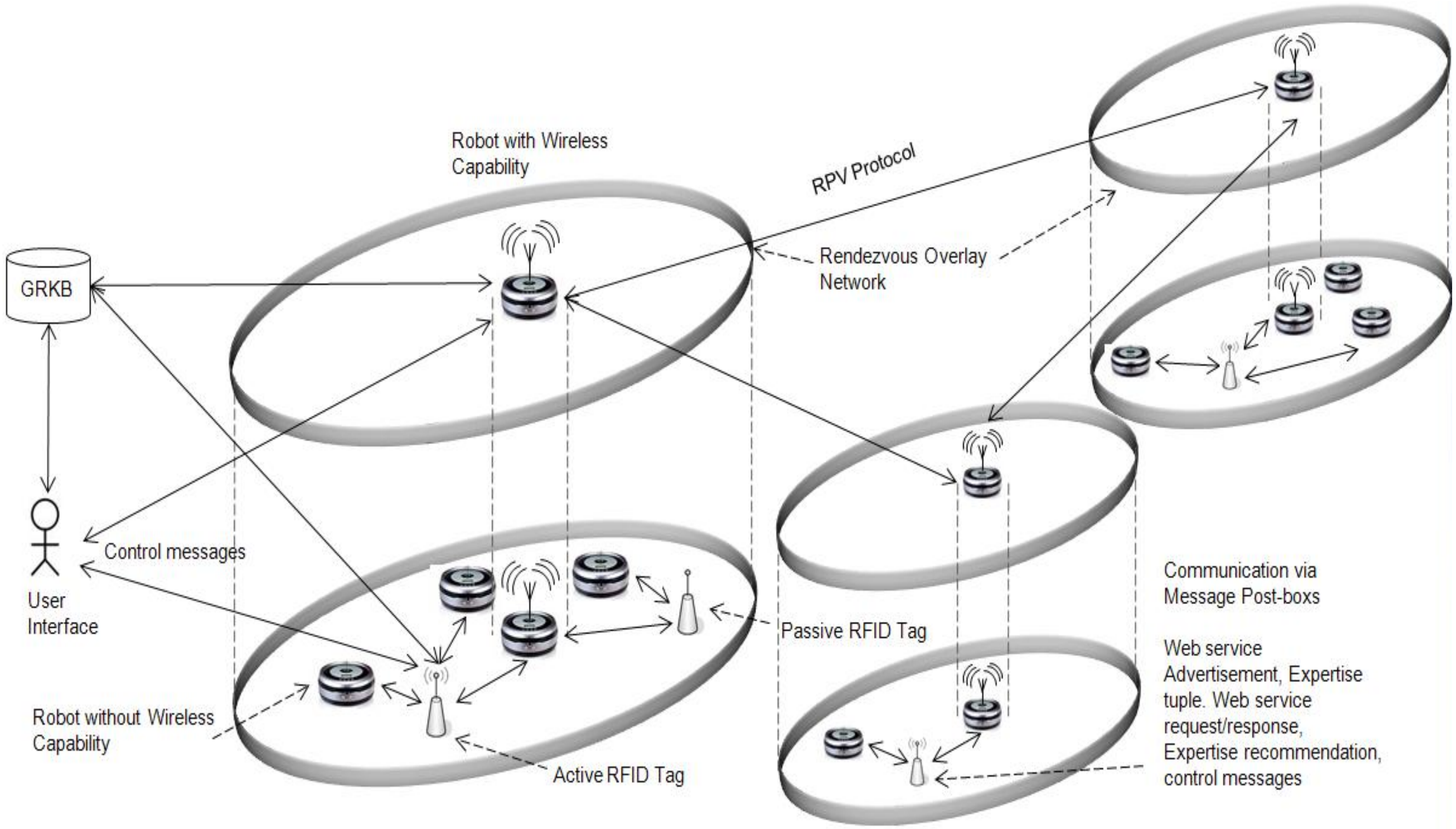
Communication infrastructure



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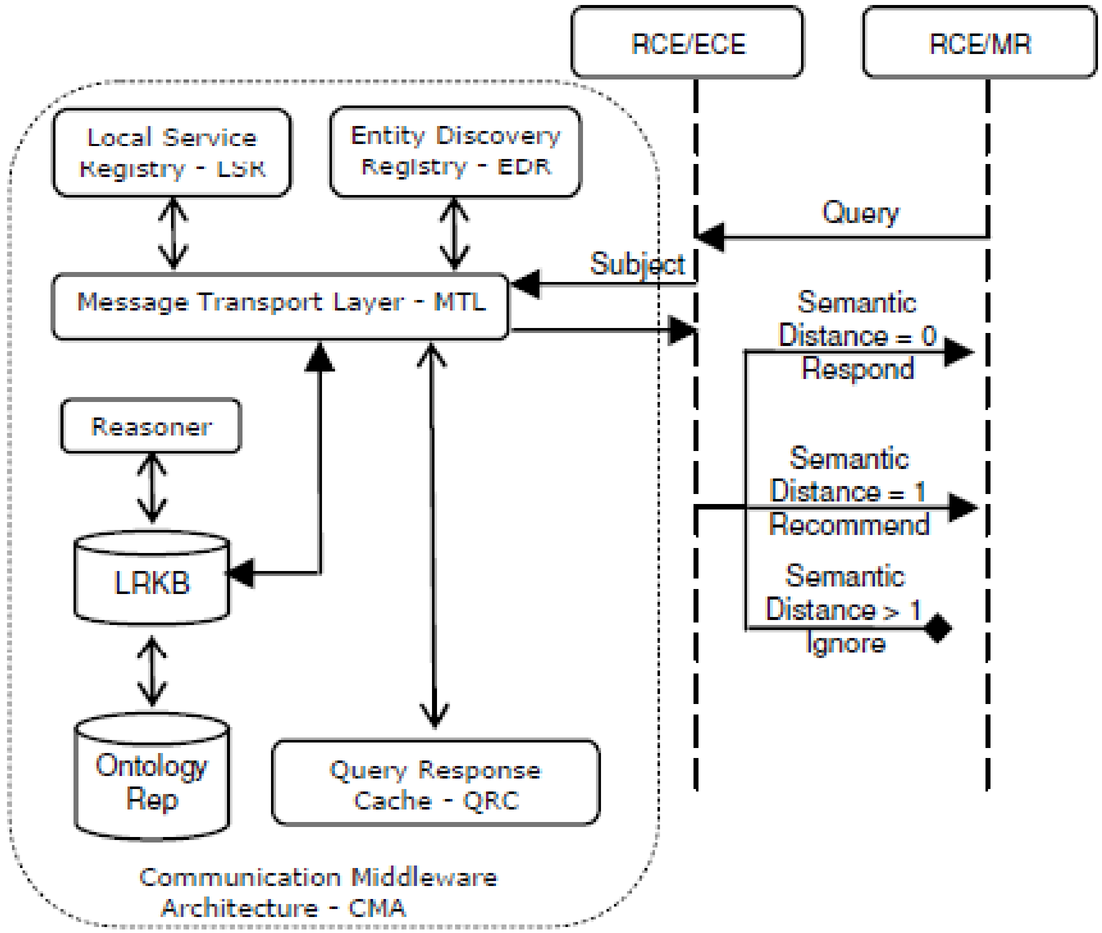
Distributed Service Discovery

- **Rendezvous computing entities (RCE)** are the computing entities with wireless connectivity or entities which can communicate outside a domain or with external world such as Internet
- **Edge computing entities (ECE)** are considered those entities that don’t have a capability to communicate in a point-to-point fashion with other computing entities and require some sort of information mediator/relay to communicate their messages.
- **Message Relays (MR)** or information mediators are effectively entities that serve ECE to communicate their messages.

Communication Middleware Architecture



Different modes of communication

(Licentiate work of Abdul Haseeb)

- **Active Communication Mode**
  - Web services descriptions are pushed to other entities/MR.
  - Active mode corresponds to a normal Web services publishing to UDDI.
  - Web services descriptions are first pushed inside a cluster/entity-group via MR and later RCE disseminates them to rest of network.
- **Passive Communication Mode**
  - In passive communication mode a Web services discovery occurs when an entity's (RCE or ECE) request is answered by some entity/MR. In other words entities don't publish their Web services descriptions unless requested.
  - Passive communication mode is less bandwidth intensive than active communication mode.
- **Conflicting mode** refers to a greedy mode in which entities don't wait for another entity to release MR.
- **Conflict-resolution mode** refers to a mode in which an active push or a passive Web services request locks the MR which is released upon either
  - Passing of Web services description or message request to another entity (i.e. at-least one entity has read the initiator's message) or
  - Time-out

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Advance Web service usage

- Service Composition technique to build ”Plan”
- Efficient task allocation based on Auctioning

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Web service composition with robots

- Composition engine in robot
- Composition engine on server

Multi –Robot Coordination System

1-Robot Control System (robot side) :

System to navigate, acquire, share and coordinate robots behavior within Swarm

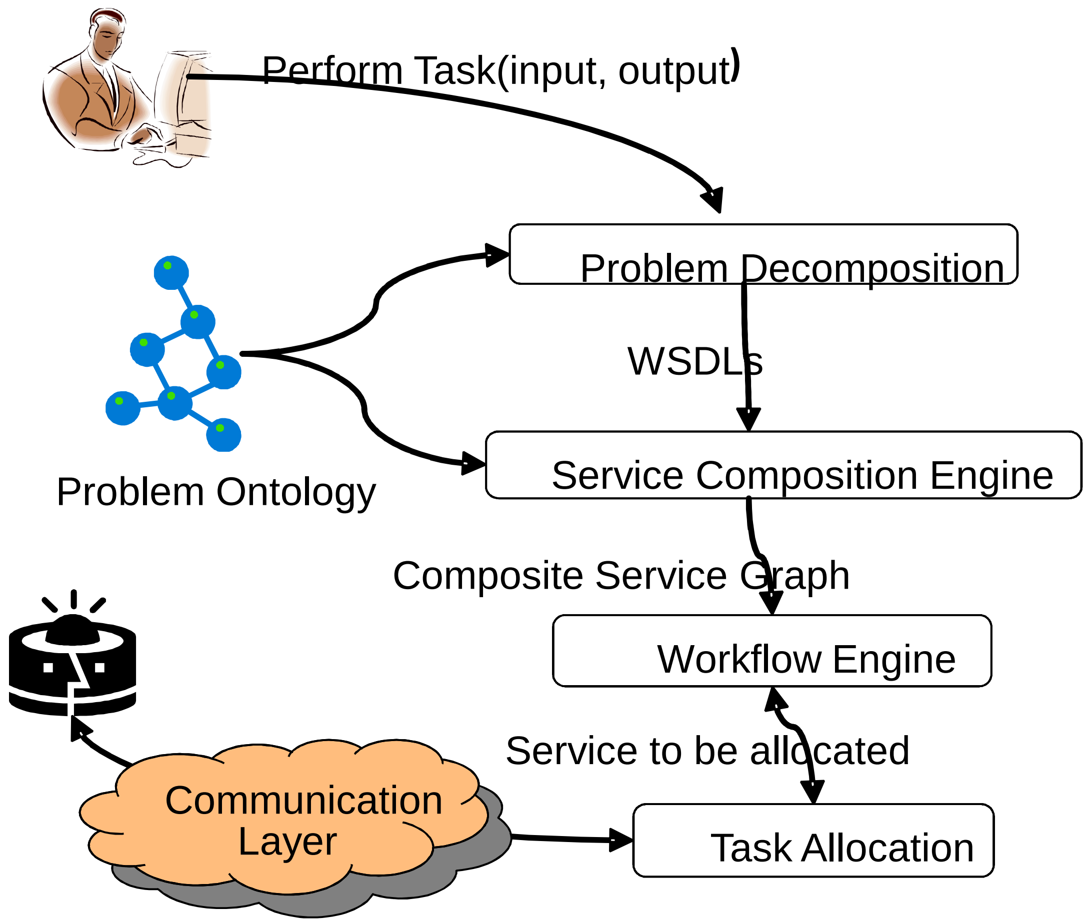
2-Service Coordination System (server side) :

implements the server-side coordination and decision-making methods. Its main tasks are :

a) Swarm Action Planning”

b) Allocation of tasks to robots.

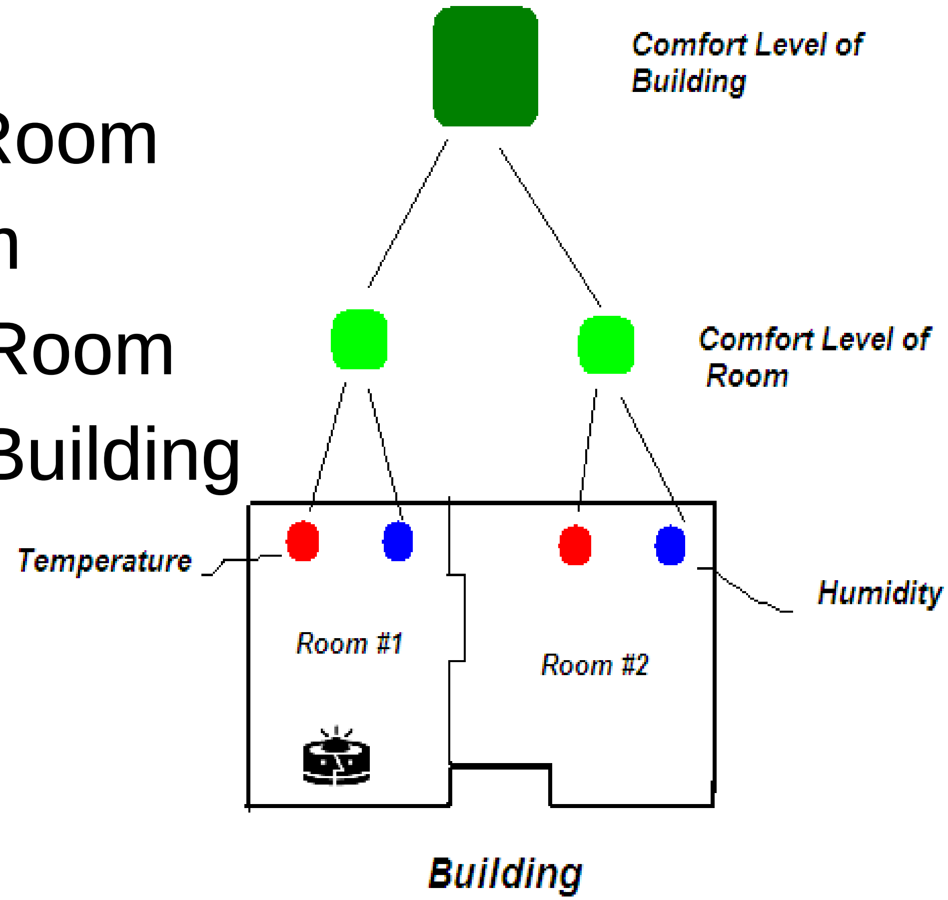
Action Planning Architecture



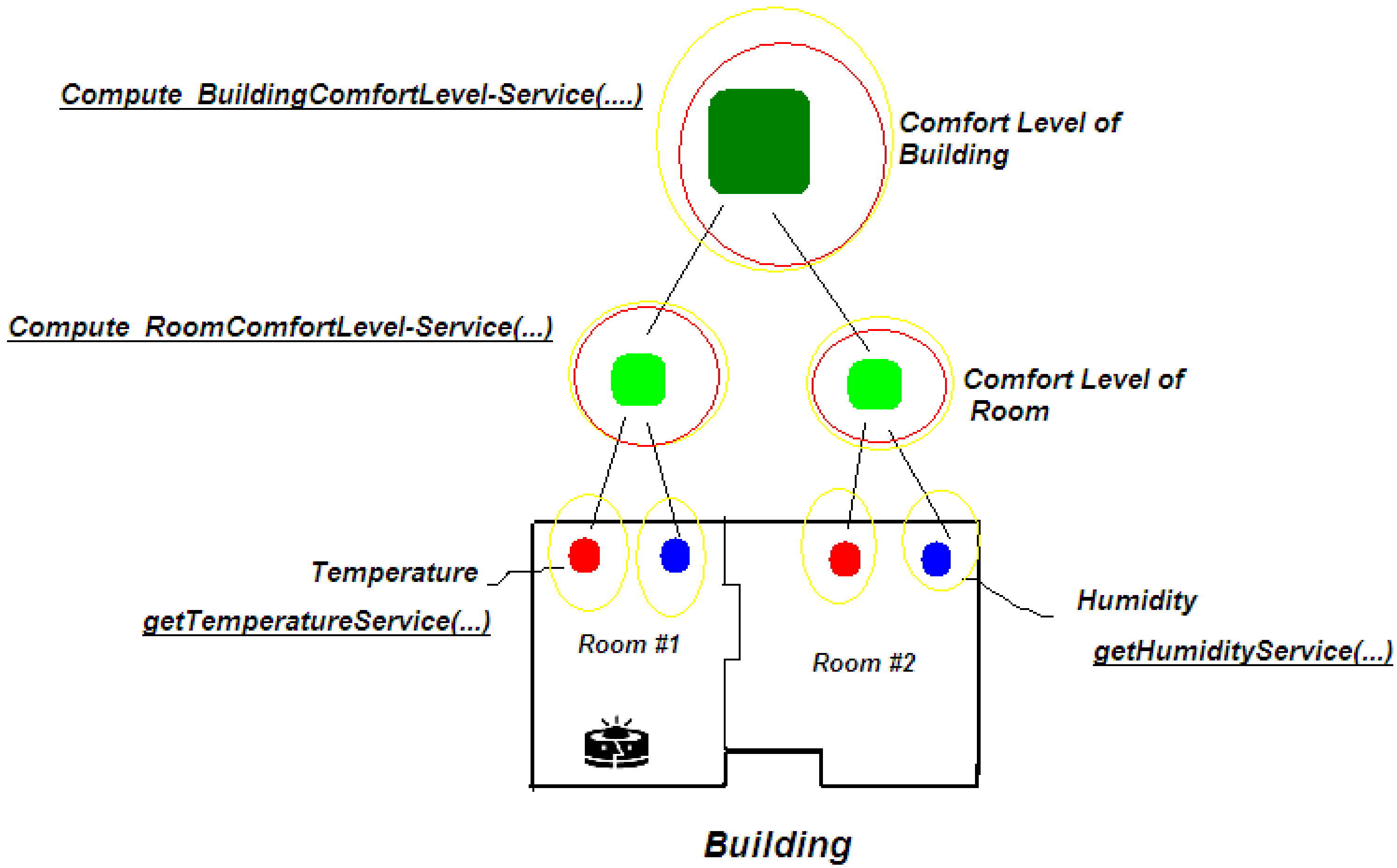
Concepts in Problem Ontology

Concepts:

- Temperature of Room
- Humidity of Room
- ComfortLevel of Room
- ComfortLevel of Building
- Building
- Room



Services bound to Concepts

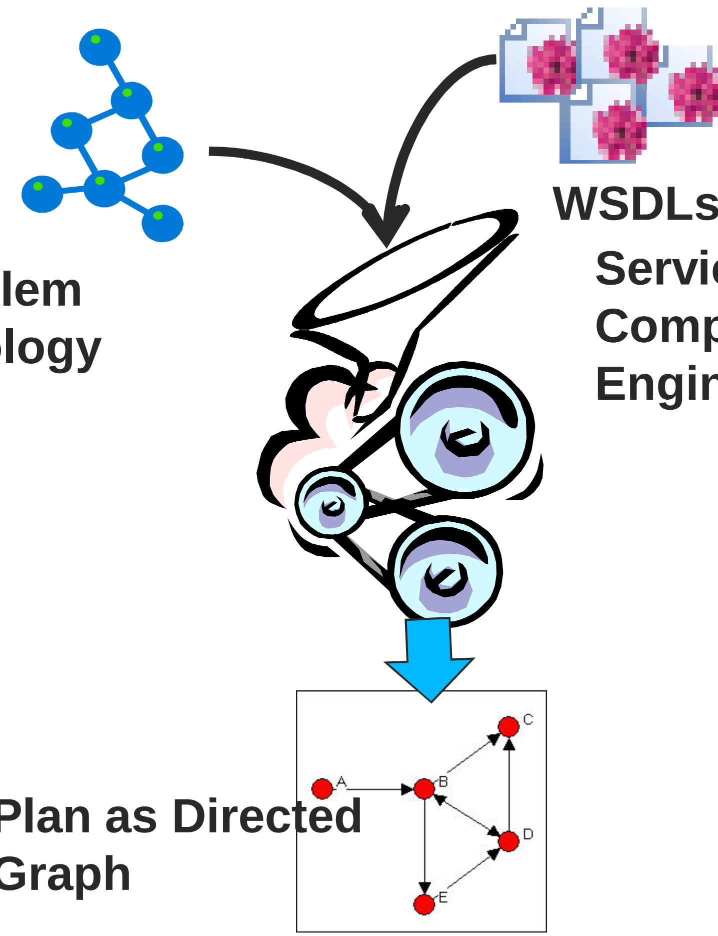


OWL Representation of Binding

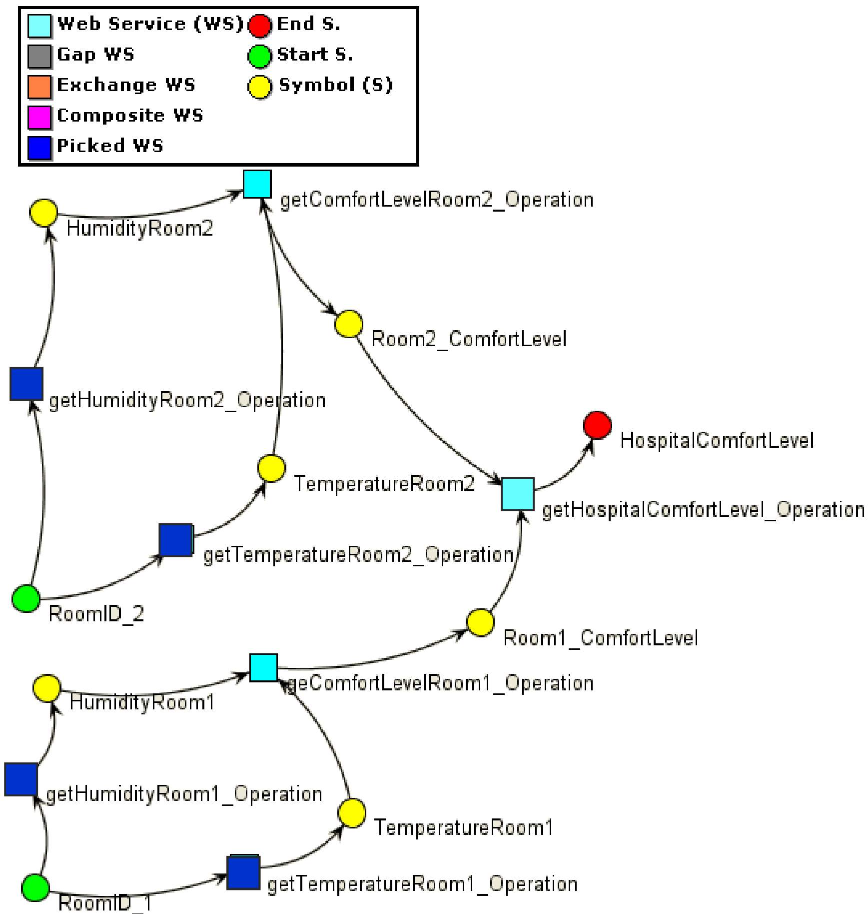
```
<Temperature rdf:ID="TemperatureRoom1">
 <hasService>
  <MeasureTemperatureOfRoom
                    rdf:ID="getTemperatureRoom1_Operation">
      <hasOutParam    rdf:resource="#TemperatureRoom1"/>
      <hasWSDL  xml:lang="en">
          getTemperatureRoom1_WSDL.wsdl
      </hasWSDL>
      <hasInParam  rdf:resource="#Room1"/>
  </ MeasureTemperatureOfRoom1>
 </hasService>
</Temperature>
```

Service Composition Layer

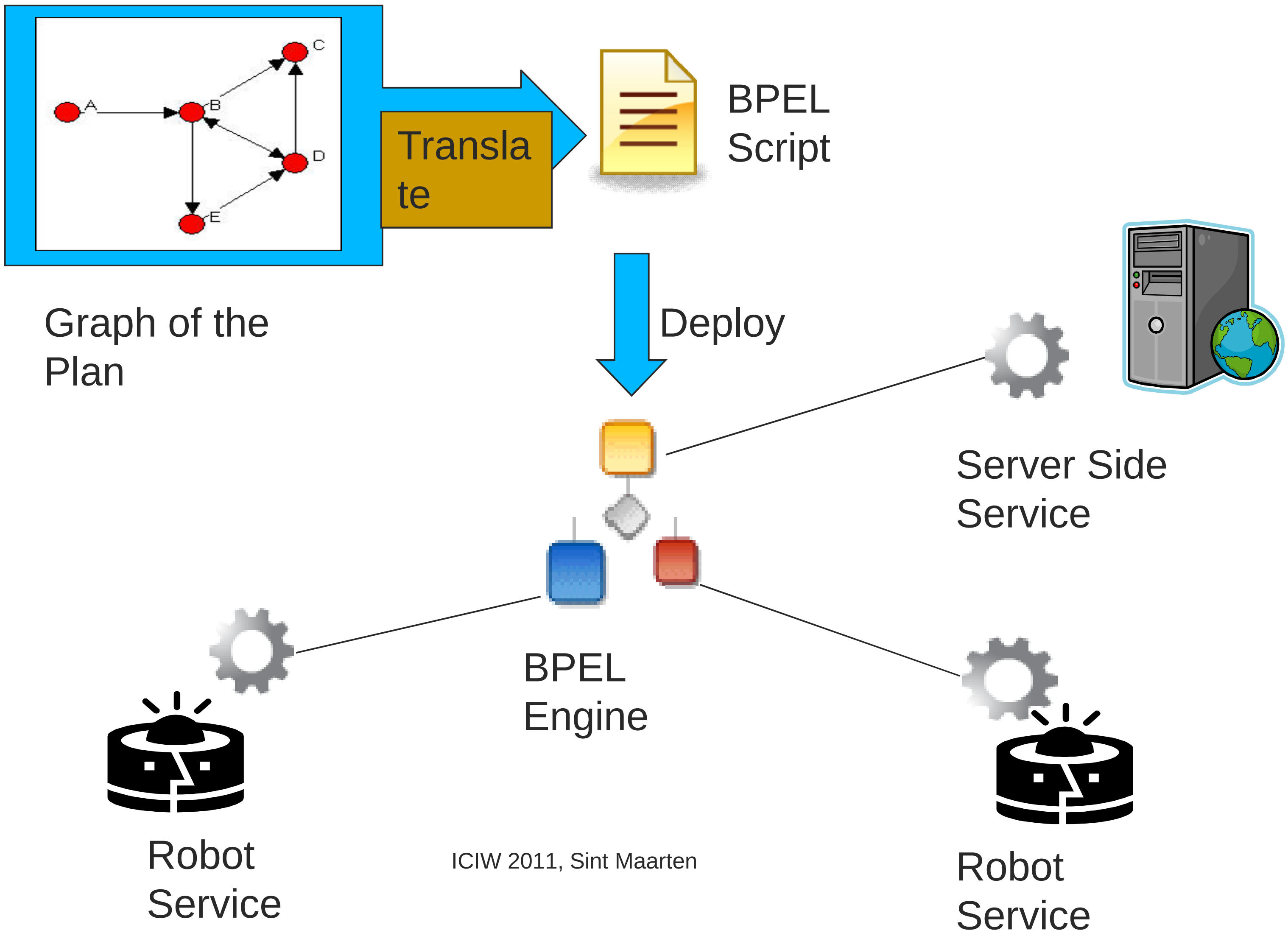
- **Goal:** To build a plan to fulfill the submitted goal out of given WSDLs.



Generated Composition Graph



Workflow Layer



Task Allocation Layer

- **Goal :** Assigning tasks (i.e. services) to robots in an effective way , to reflect to both environment changes (e. g. addition of new environment areas) and robots' team changes (e. g. robot failures).

  - **Input** : Service (task) definition (a robot service)
  - **Output:** the identification (end point) of a the robot of the swarm performing the service.

ROBOSWARM
Task Allocation and Composition

Clouds and robots

- Next step: Services via clouds
- Kuffner, Davinci and others
- Our proposal

Cloud computing

- Cloud computing assumes
  - flexible configuration;
  - virtualization of platform;
  - automation, interchange and management of resources and services to be delivered on-demand/need.
  - scalability/elastic-capability;
  - new resources can be added as per demand.
  - services for easy/on-the-fly integration of resources are located in the cloud (not on particular address)

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Kuffner

IEEE International Conference on Humanoid Robots, in Nashville, Tenn., this past December

- Shared knowledge
- Outsourcing heavy computations from clouds
- Shared skills – app stores

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Kuffner

IEEE International Conference on Humanoid Robots, in Nashville, Tenn., this past December

- Robots can improve their capabilities via clouds in:
  - 3D vision
  - Planning
  - Speech recognition
  - Language translation
  - ...

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DAvinCi project

The DAvinCi framework combines the distributed ROS architecture, the open source Hadoop Distributed File System (HDFS) and the Hadoop Map/Reduce Framework.

Data Storage Institute, A*STAR, Singapore.
Rajesh VA@dsi.a-star.edu.sg

Robots and Clouds (2 ways)

- Outsourcing resources
- Clouds of Robots

Main points

Autonomous robots are cloud eligible resources because of they can host and process data (they have storage and computational unit)

Autonomous robots are high level resources who provide sophisticated decision making capability

Robots in Clouds

- The main new features that robots as resources can bring into clouds are
  - autonomy,
  - mobility and
  - operation in physical world.
- From this point we need robotic knowledge about
  - monitoring robots (including positioning),
  - perception features (observing the physical world)
  - actuator features (mobility and all types of manipulators).

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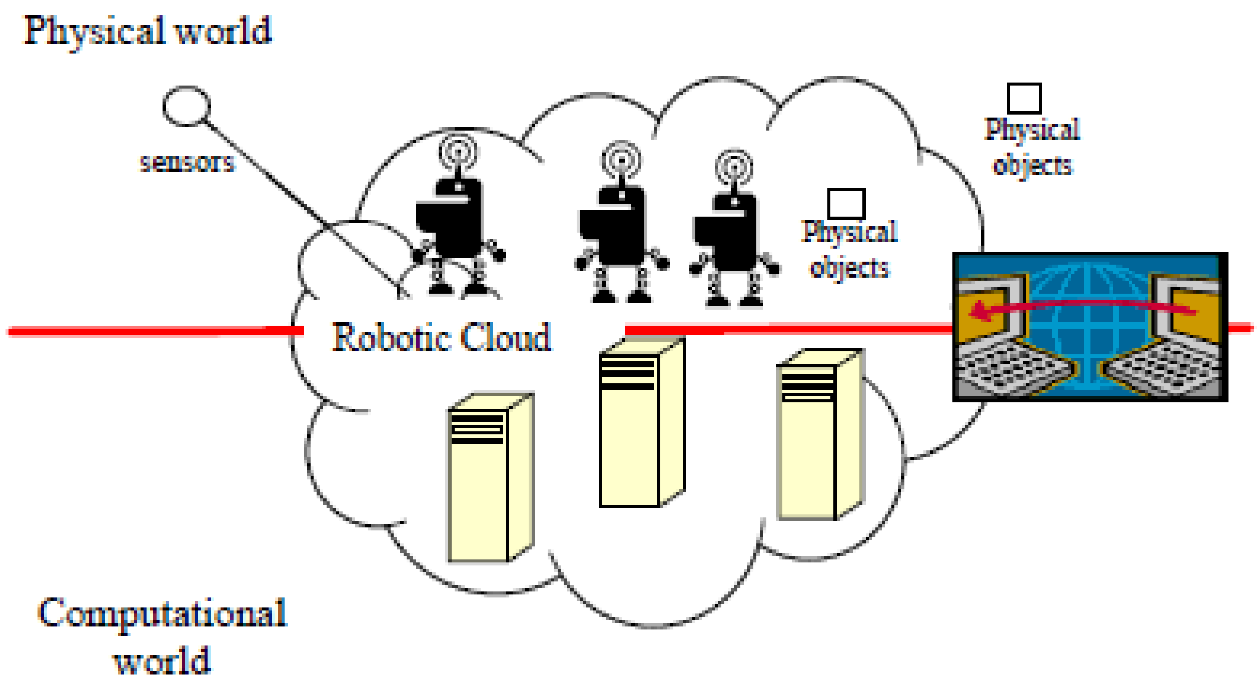
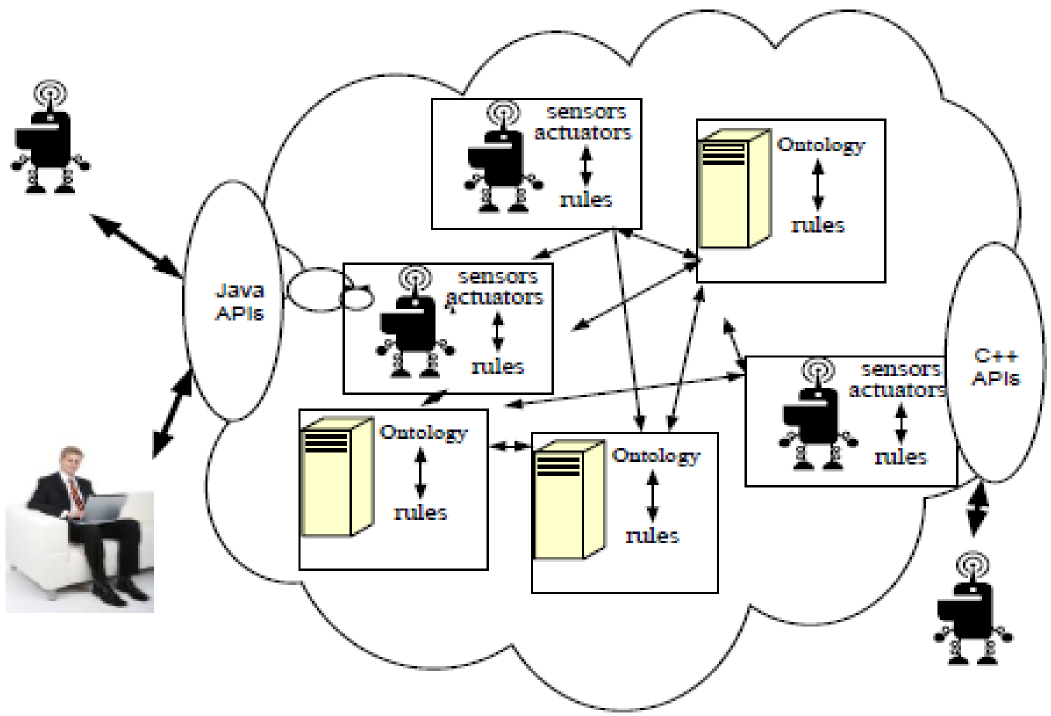
Robotic Cloud



RigourCLOUD project

Abstract communication architecture of a Robotic Cloud



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RigourCLOUD project

Some Challenges

- an ability of cloud to adapt to changing dynamic environments as well as reasoning with uncertainty and decision making capabilities are needed
- development intelligent negotiation methods as a new way of resource allocation in the cloud,
- development of new ways of manageability, adaptivity and self-* by providing learning, assessment and reasoning methods for self-evolving multi-robot systems,
- development of a knowledge infrastructure in the cloud (semantic and rule-based representation) which allows new programming model, resource configuration and resource control.
- dealing with issues ranging from low level communication and connectivity aspects of internal interoperability and distributed task allocation to provision of cloud middleware for loosely coupled dynamic resources.

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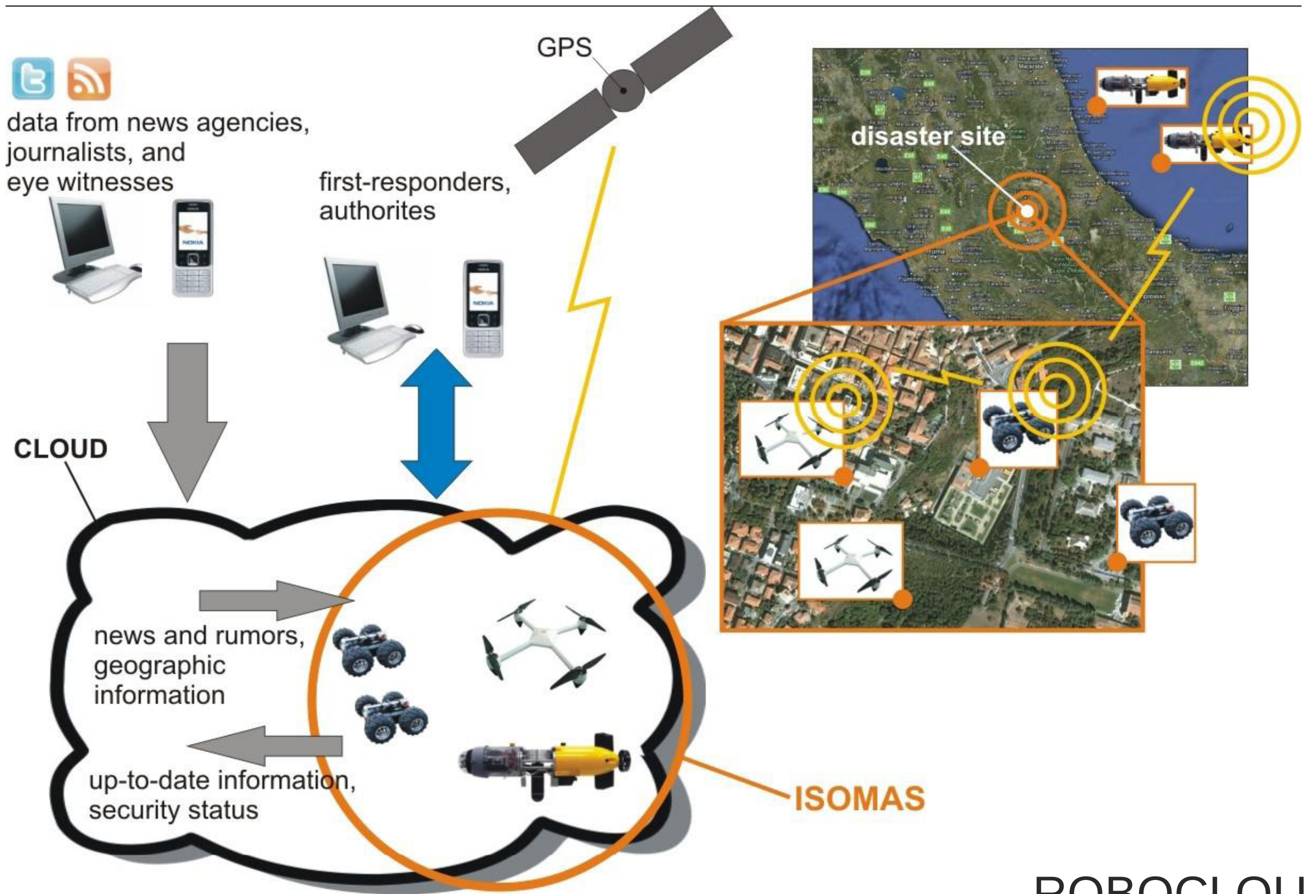
Possible operating scenarios (Disaster mitigation)



ROBOCLOUD project

Possible operating scenarios (Disaster mitigation)

- Supported informational streams:
  - **Robots → Cloud**: local georeferenced information (e.g. visual information)
  - **Cloud → Robots**: local rich situation with aggregation of all available information from other actors (first responders, UAV, UGV, UUV) and/or other informational sources available within the cloud (news, satellites, eye witnesses' reports/data, etc.).

- Expected improvements are:
  - Increase of time efficiency for victims search and rescue and for assessment of hazards area
  - Increase of dynamic replanning capabilities for UAV, UUV and UGV according to evolution of the situation
  - Optimal decision making level for robots
  - Augmented autonomy capability for robots

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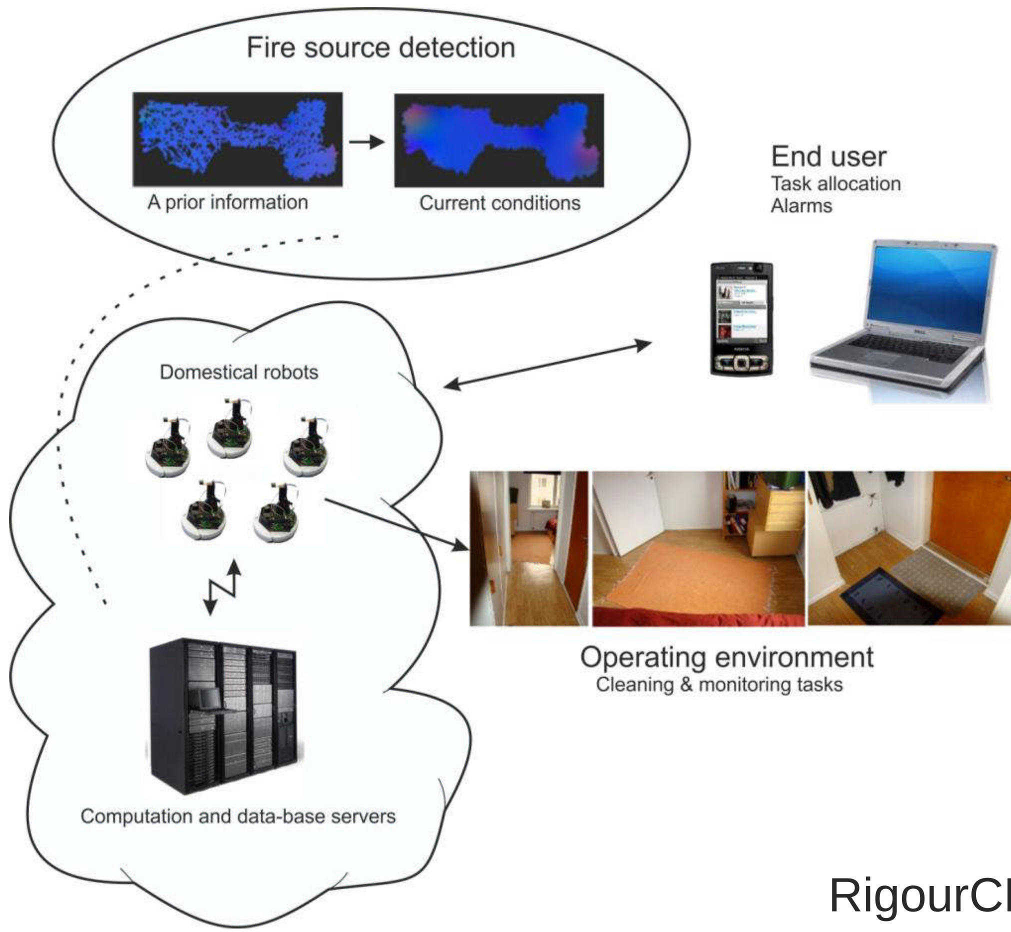
A general purpose ROBOCLOUD service platform

ROBOCLOUD project

Structural overview of indoor fire source detection



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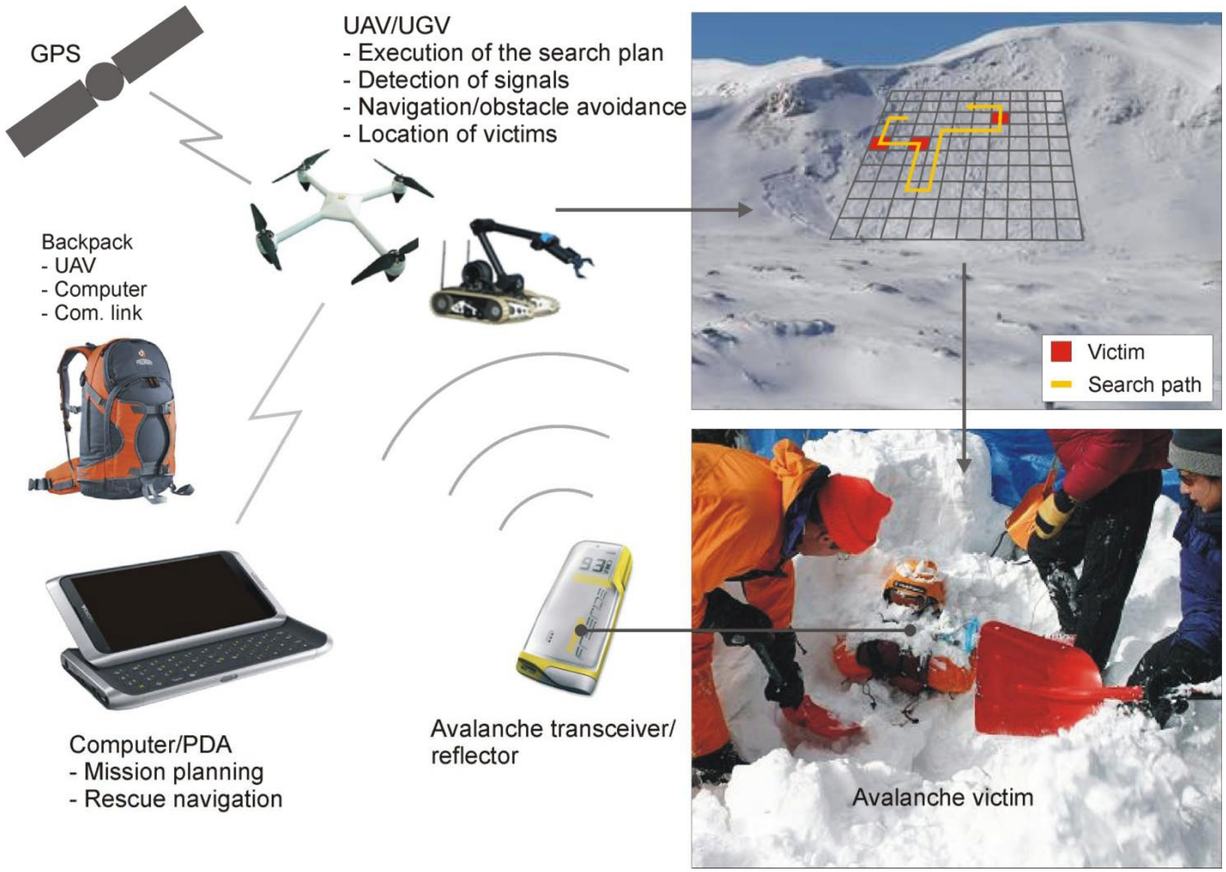
RigourCLOUD project

Structural overview of avalanche victim detection



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RigourCLOUD project

What are benefits of Robotic cloud computing?

- A new way of provision of robotic resources in a uniform way.
- Robots are able to provide computational resources in places where such resources were not available and because of ability to gather information about physical world that was not initially presented in cloud.

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Conclusion

- Service robots are available both to public and private/corporate use
- Robotic services can be provided as software service and we can create eco-systems where they can co-exists
- Cloud robotics is not only resource outsourcing but also a new way of robotic service delivery