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# If Objects Could Talk: Novel Resource Discovery Approaches in Pervasive Environments

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# Outline

- Building a Semantic Web of Things
  - The Internet of Things
  - Issues in pervasive resource discovery
  - Semantic-enhanced approach
- Ubiquitous Knowledge Base (u-KB) framework
  - General architecture
  - Semantic-enhanced EPCglobal RFID
  - Knowledge dissemination and discovery protocol
  - Annotation compression
- Reasoning in mobile and pervasive environments
  - Mobile matchmakers
  - Inference algorithms with ODBMS
- Applications areas
  - Wireless Semantic Sensor and Actor Networks
  - Automotive
  - Smart homes

# The Internet of Things

- Pervasive computing:
  - bridging the gap between physical and digital world
  - increasing availability and decreasing visibility of HCI
- Embedding in the environment many micro devices (RFID tags, sensors) with:
  - small storage space
  - little or no processing
  - short-range, low-throughput wireless links
- Each micro device provides a small amount of information
- Mobile computing devices (phones, PDAs, etc.) provide and/or use services/resources in wireless ad-hoc networks

# Pervasive resource/service discovery

- Mobile ad-hoc networks are unpredictable environments
  - Location of devices could change continuously
  - Information about services is often unavailable

**SERVICE DISCOVERY is an essential feature**

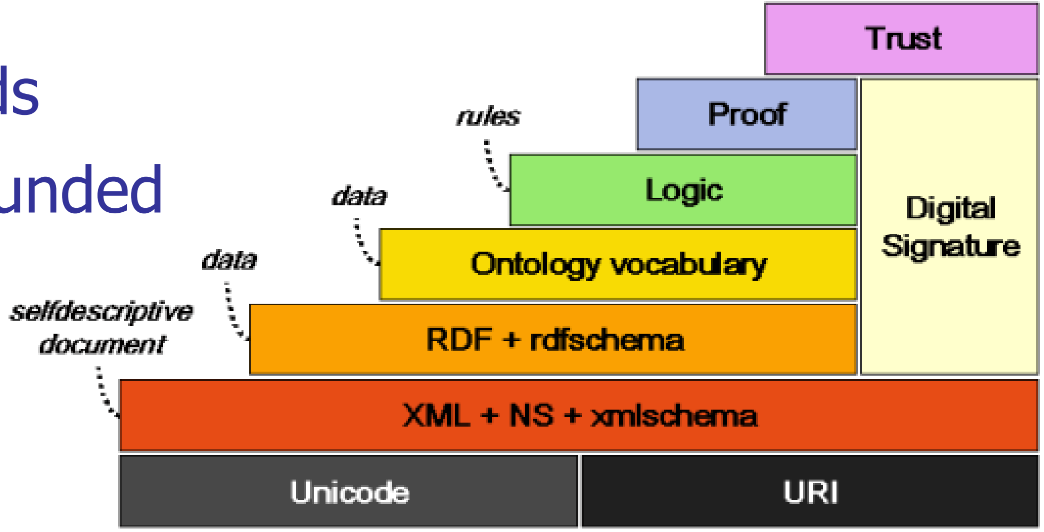
- Existing mobile service discovery protocols have been obtained by adapting protocols designed for wired networks
  - Centralized and registration-oriented mechanism
  - Trivial syntactic match of resource attributes

# Main issues

- More flexible resource discovery is needed
- A decentralized approach is required
  - A node should not be depending on some other node to advertise/register services
  - Each resource should be autonomously exposed
  - Applications on the other nodes should be able to autonomously perform a discovery
- String-matching is inadequate in advanced scenarios
  - Need to submit articulate requests, to obtain adequate answers
  - Need to cope also with non-exact matches to grant satisfaction of user request as much as possible
- What technologies could help?

# The Semantic Web

- **Vision:** build flexible discovery mechanisms using languages and technologies borrowed from the Semantic Web
- The Semantic Web
  - **Goal:** to seamlessly share, reuse and combine (by software agents) available information in the WWW
  - **Means:** each resource annotated with machine-understandable metadata
- A stack of W3C standards
- Ontology languages grounded on formal semantics of Description Logics



# Description Logics

- A family of logic languages for knowledge representation. Elements:
  - concept names: sets of objects
  - role names: relations between objects
  - constructors: combine basic elements to form concept and role expressions
- Definition and inclusion axioms model the domain knowledge into an ontology
- Each DL allows a different set of constructors:
  - $\mathcal{AL}[\mathcal{C}][\mathcal{N}][\mathcal{H}][\mathcal{I}][\mathcal{Q}]\ldots$
- Computational complexity increases with expressiveness

# Semantic-based matchmaking

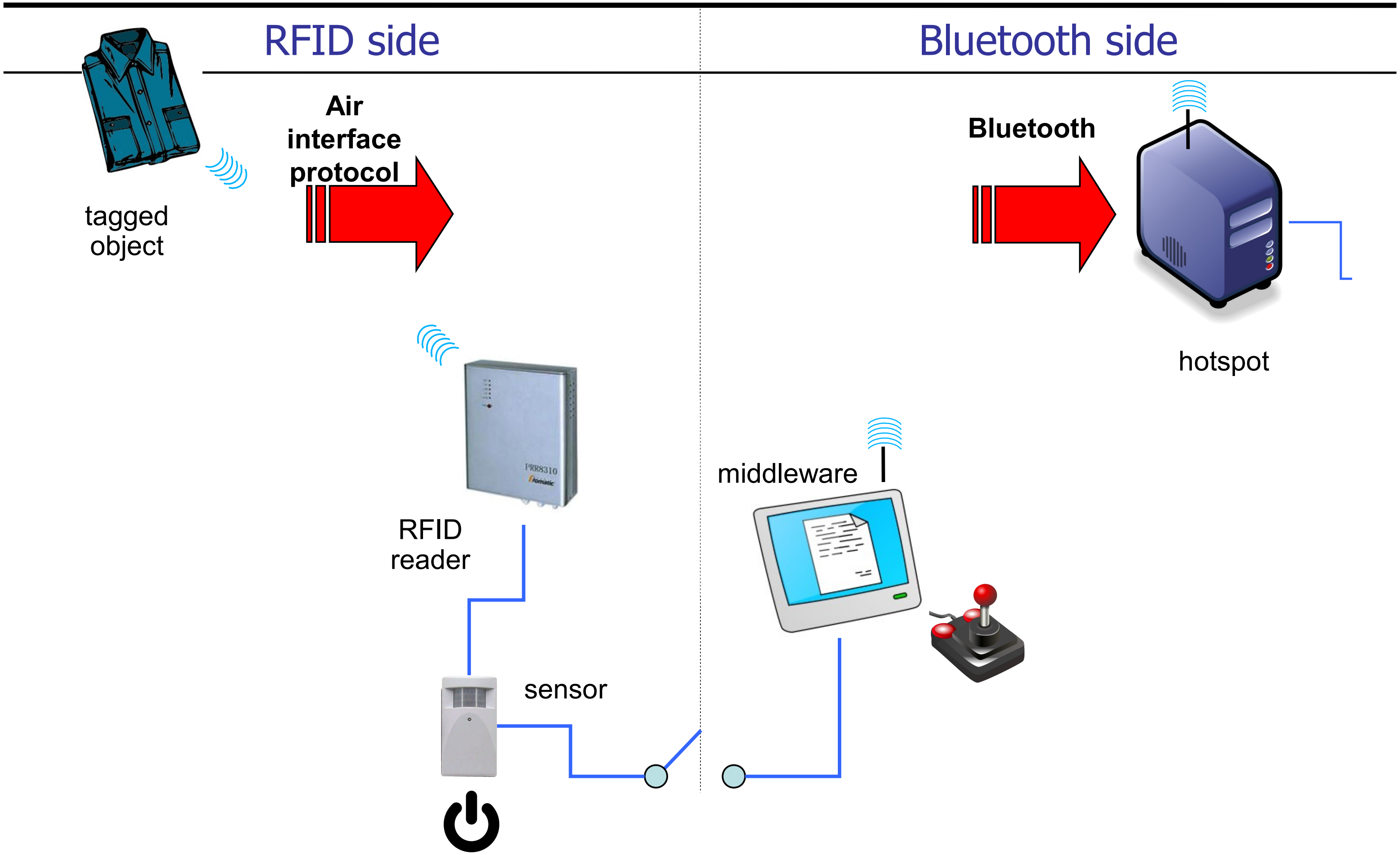
- To find the best supplies w.r.t. a request, when both request R and each available supply S are described in logic-based language according to a common ontology
- Principles:
  - Open world assumption
  - Non-symmetric evaluation
- DL-based systems usually provide two basic reasoning services:
  - Satisfiability: are S and R compatible?
  - Subsumption: does S fully match R?
- Although subsumption and satisfiability are very useful, full matches are infrequent

# Non-standard inference services
## [Colucci *et al.*, IJEC, 12(2), 2007]

- Other non-standard inference services are needed to perform a more fine-grained matchmaking and resource ranking
- Concept contraction: if S and R are incompatible, *what part* G of R must be given up, and what part K can be kept?
  - Provides explanation for (in)satisfiability
- Concept abduction: if S does not match R fully, *what hypothesis* H should be made about S in order to reach a full match?
  - Provides explanation for missed subsumption

# Basic approach - architecture

- Ruta *et al.*, IJWGS, 2(4), 2006; Ruta *et al.*, IJSWIS, 4(1), 2008



# Basic approach – u-commerce apps

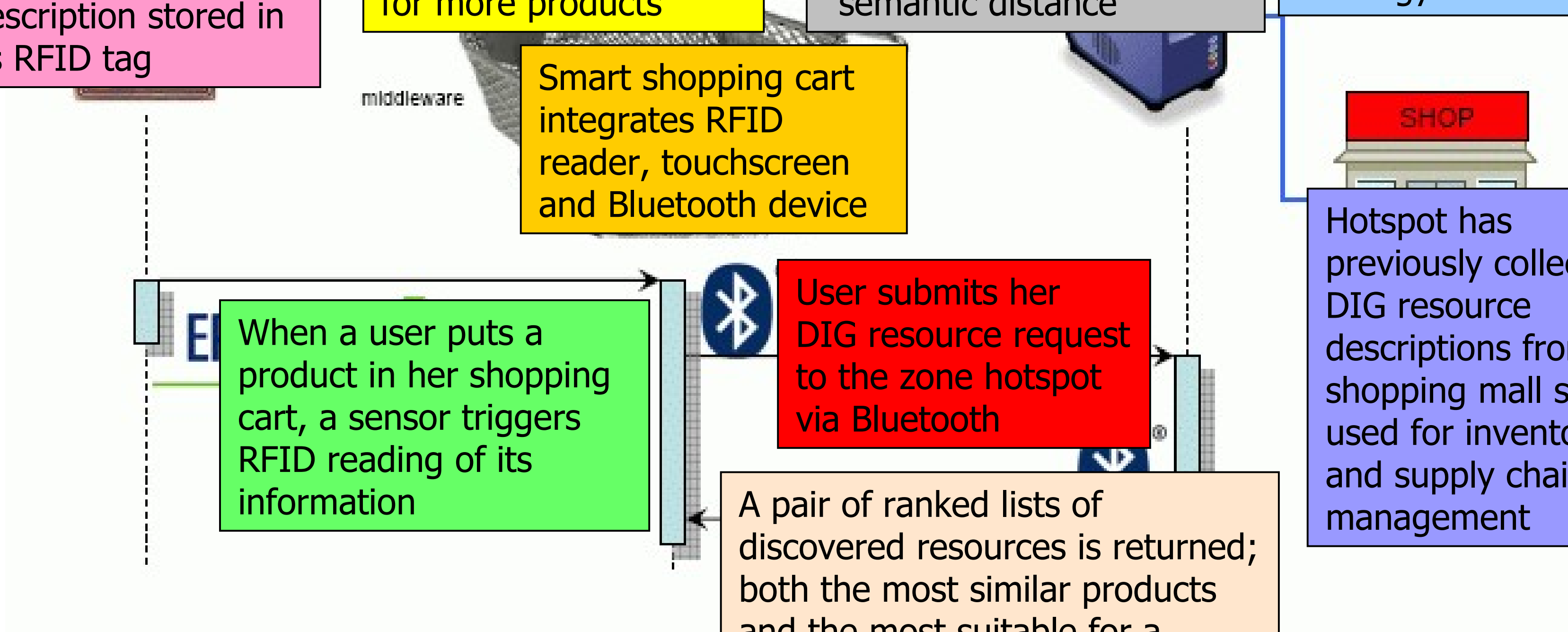
Each resource in the m-marketplace has an EPC and is annotated by a DIG description stored in its RFID tag

Product description is shown on the touchscreen as a hint to the user for composing her request for more products

Hotspot is endowed with a MatchMaker to compute matchmaking between request and available offers measuring a "semantic distance"

Hotspot classifies resource contents by means of an OWL-DL ontology

Smart shopping cart integrates RFID reader, touchscreen and Bluetooth device




When a user puts a product in her shopping cart, a sensor triggers RFID reading of its information

User submits her DIG resource request to the zone hotspot via Bluetooth

Hotspot has previously collected DIG resource descriptions from shopping mall server, used for inventory and supply chain management

A pair of ranked lists of discovered resources is returned; both the most similar products and the most suitable for a combination with the user request are provided.

# Developed case studies

- Product lifecycle management [Ruta *et al.*, IJIPT, 2(3/4), 2007]
- Ubiquitous commerce [Ruta *et al.*, IJSWIS, 4(1), 2008]
- Ubiquitous tourism [Ruta *et al.*, ICCSA-UWSI 2008]
- Dynamic RFID-based logistics support [Ruta *et al.*, ICEC 2008]
- Decision support in healthcare [Ruta *et al.*, ICEIS-IWRT 2009]
- Ubiquitous learning in heterogeneous environments [Ruta *et al.*, book chapter in *Multiplatform E-Learning Systems and Technologies*, 2009]

# Basic approach - discussion

## Accomplished goals

- Exploit theory and technologies of Semantic Web vision
- Integrate semantic-enhanced Bluetooth SDP and EPCglobal RFID in a unified resource discovery framework
- Adapt XML-based ontological languages to resource-constrained environments through compression
- Explore and show benefits/issues in several application areas

## Limits

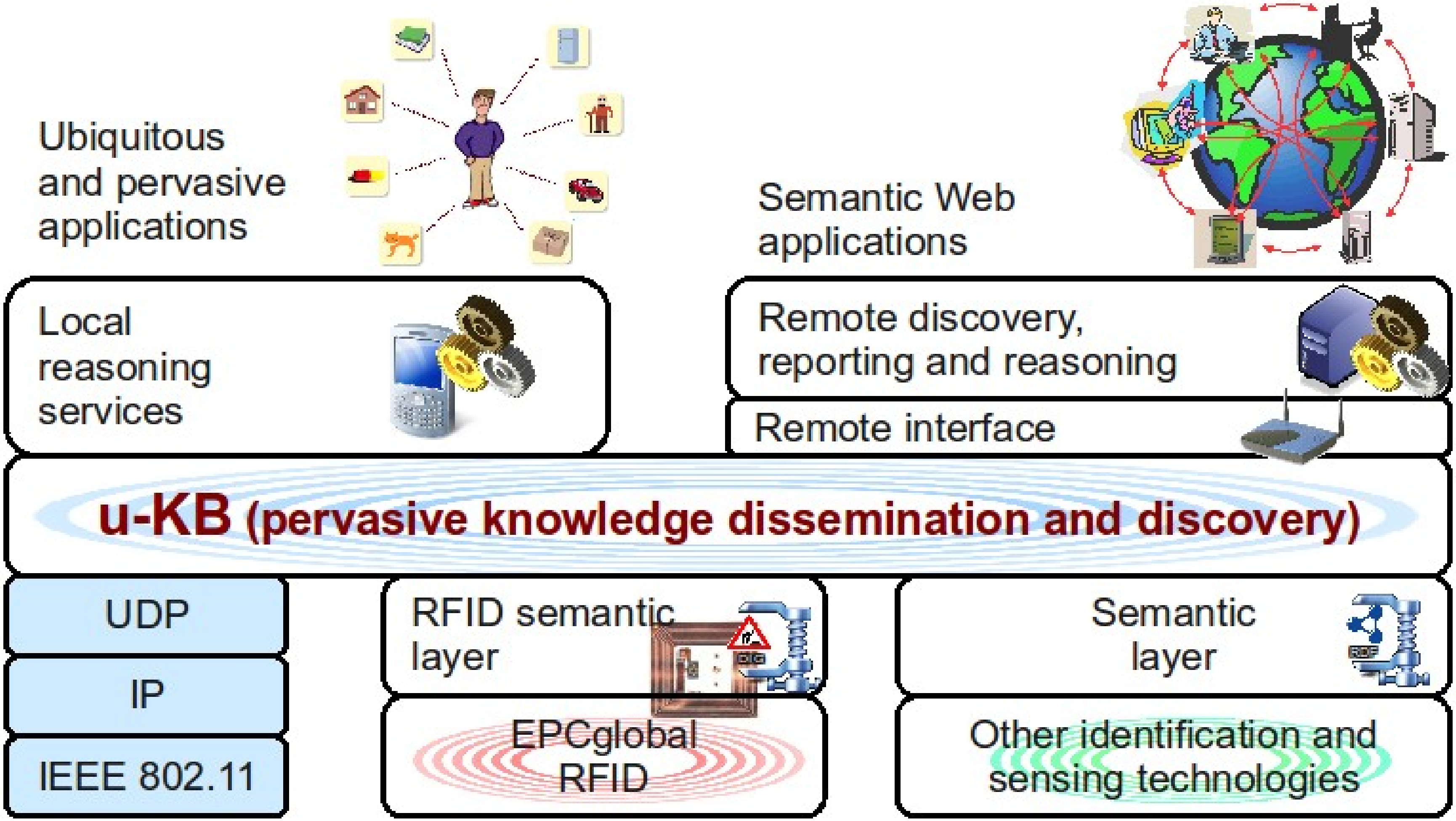
- A traditional KRS (MaMaS-tng) is needed as a reasoning engine
  - Information duplication
- Reasoning provided by single centralized wireless hotspot
  - Single point of failure
  - Limited flexibility and scalability for applications

# Proposed evolution

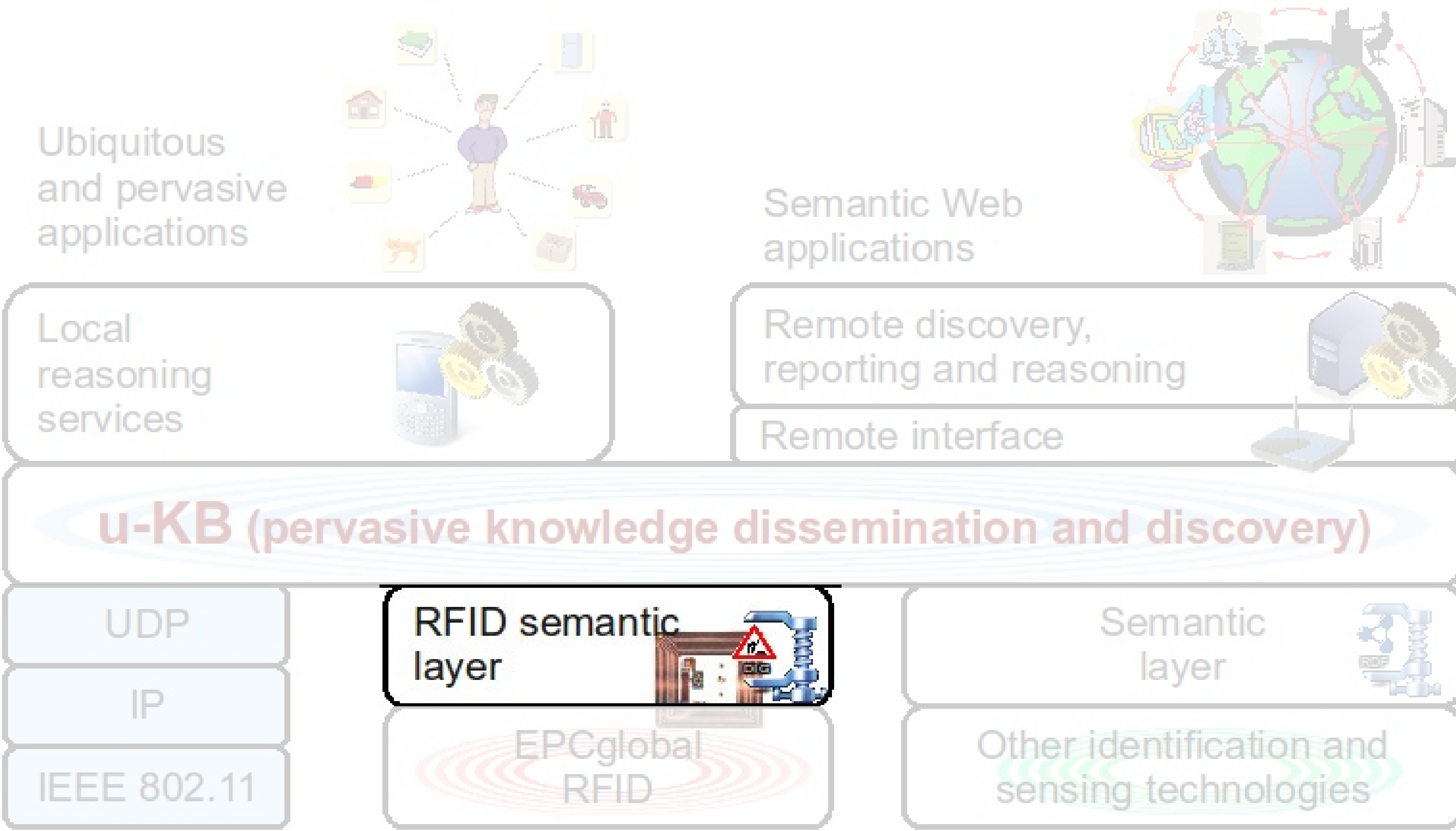
- A more distributed and dynamic approach
- **u-KB (ubiquitous Knowledge Base)** layer
  - Resource metadata distributed across multiple hosts in an ad-hoc network)
  - Each host advertises resources (RFID-tagged objects, sensor data, etc.) lying in its proximity
  - Data dissemination protocol to keep the u-KB up to date, aiming at communication efficiency
  - On-demand discovery protocol to build a local KB subset only when reasoning is needed

# Overall architecture





# Overall architecture



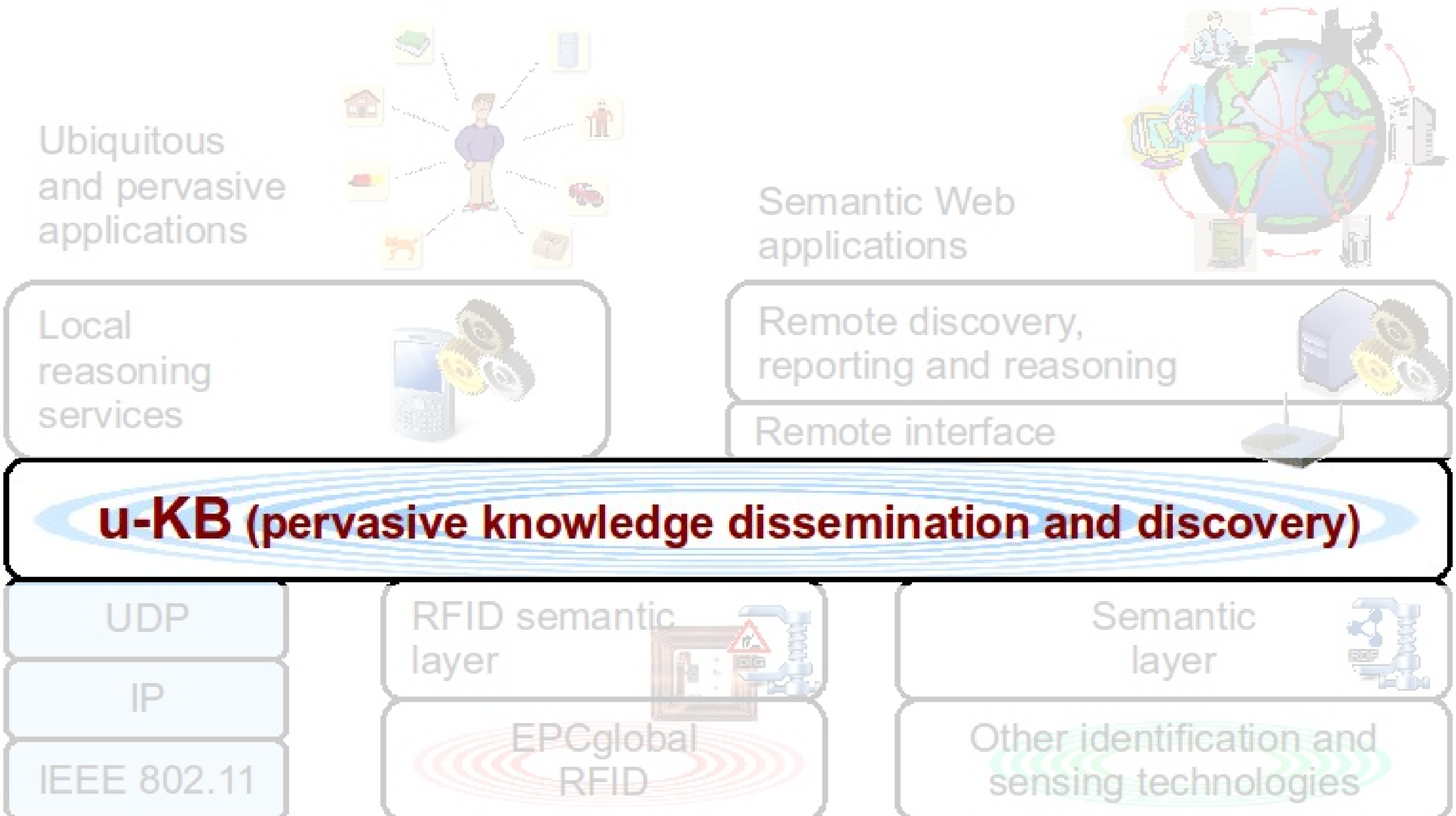
# Semantic-enhanced EPCglobal RFID

- Key technological features [Ruta *et al.*, IJIPT, 2(3/4) 2007; Ruta *et al.*, PAJAIS, 2010, to appear]
  - Slight tag memory extension to store
    - a semantic annotation
    - a set of data-oriented contextual attributes
  - Backward-compatible use of EPCglobal UHF Gen-2 Protocol to read/write tag contents
  - Ontology identifier (OUUID) code to mark each ontology (hence, each resource category)
  - EPCglobal ONS (Object Naming Service) for ontology support

# Annotation compression

- Semantic XML-based languages (RDF, OWL, DIG) are too verbose for storage on RFID tag memory
- Two annotation compression algorithms have been designed
- DIGCompressor [Ruta *et al.*, IJSWIS, 4(1), 2008]
  - Very high compression rates even for small annotations
- COX [Scioscia and Ruta, ICSC-SWIM 2009]
  - Uses Reverse Arithmetic Encoding to encode XML document structure
  - Due to homomorphism, allows queries directly on encoded documents
  - Lower compression rates

# Overall architecture



# u-KB components
## [Ruta *et al.*, PAJAIS, 2010, to appear]

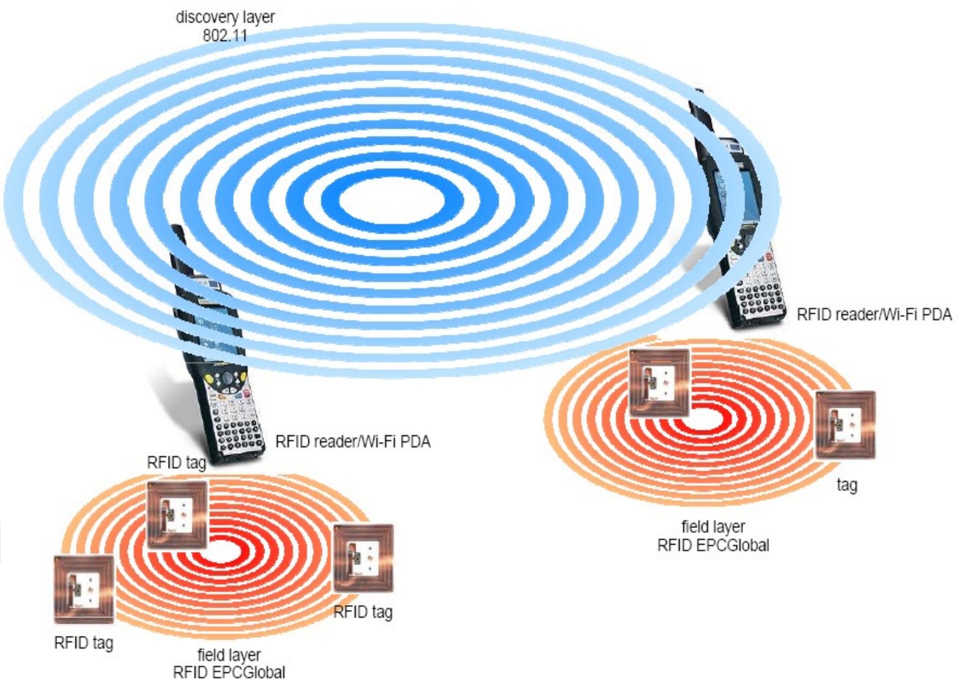
- **TBox** (a.k.a. *ontology*: conceptual knowledge)
  - An ontology file (currently fixed during normal application activity)
  - Managed by one or more MANET hosts
  - An ontology identifier (OUUID) marks each ontology
- **ABox** (factual knowledge)
  - Scattered throughout a smart environment
  - Each individual is physically tied to a tag deployed in the field
  - Individuals characterized by:
    1. unique ID (e.g. EPC code, MAC address)
    2. OUUID of reference ontology
    3. semantic annotation
    4. data-oriented attributes
- Multiple u-KBs can coexist in the same smart environment

# u-KB operations
## [Ruta *et al.*, PAJAIS, 2010, to appear]

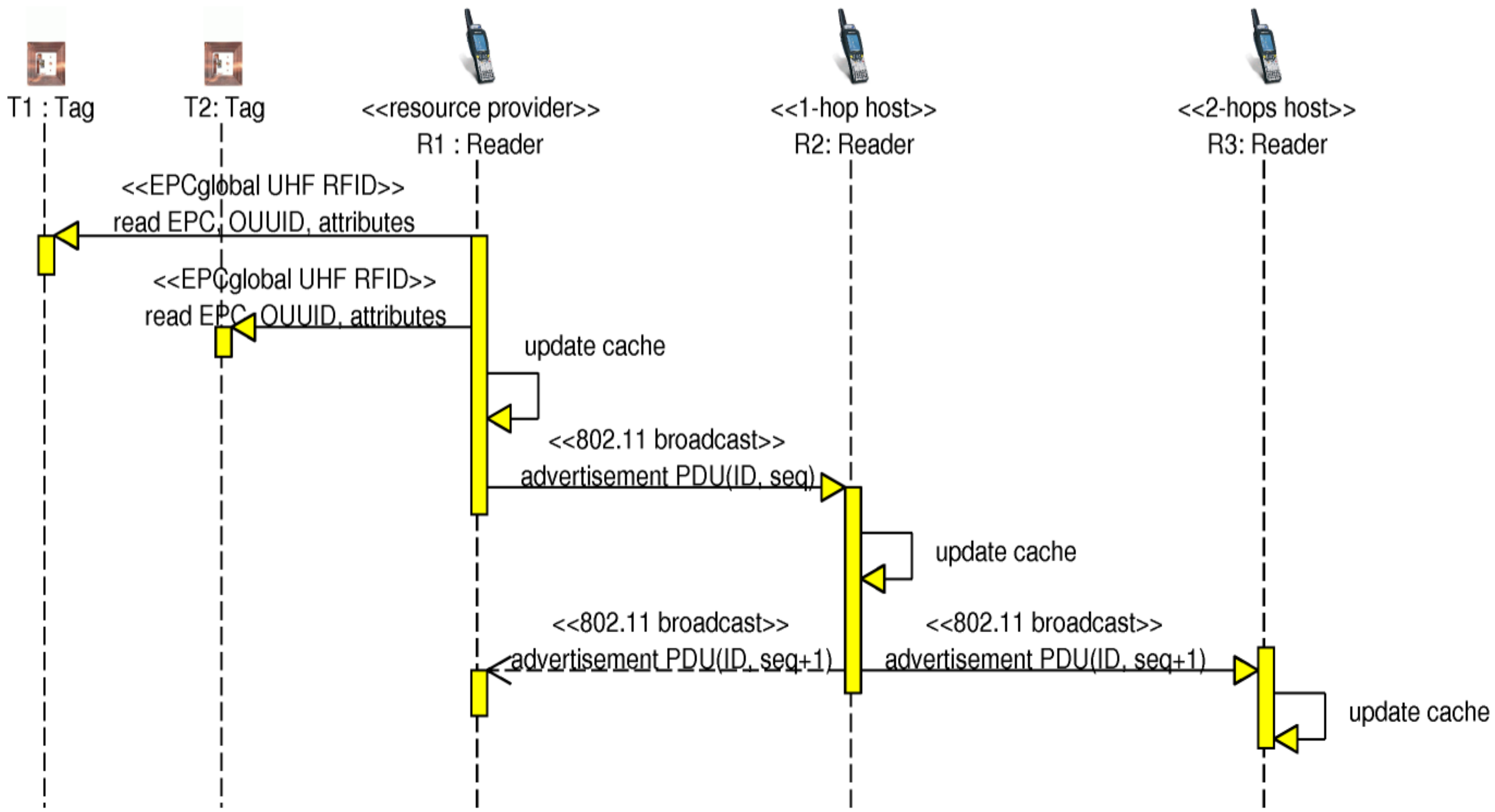
- Classical paradigm [Levesque, AI, 23(2), 1984] implemented in a novel way
  - **Tell/Un-tell** (explicit knowledge acquisition/retraction)
    - Autonomic creation and update of a virtual KB
    - Each host contributes with individuals detected in its proximity
    - Data alignment protocol makes each host aware of all network content
    - Only individual ID, OUUID and data attributes (no semantic annotations) are exchanged to minimize network load
  - **Ask** (extraction of – implied – knowledge)
    - Preliminary discovery step, based on OUUID and data attributes range
    - Addresses of hosts "owning" resources are retrieved
    - Semantic annotations are then requested in unicast
    - Subset of KB materialized just when needed for reasoning

# u-KB wireless architecture
# [Ruta *et al.*, PAJAIS, 2010, to appear]

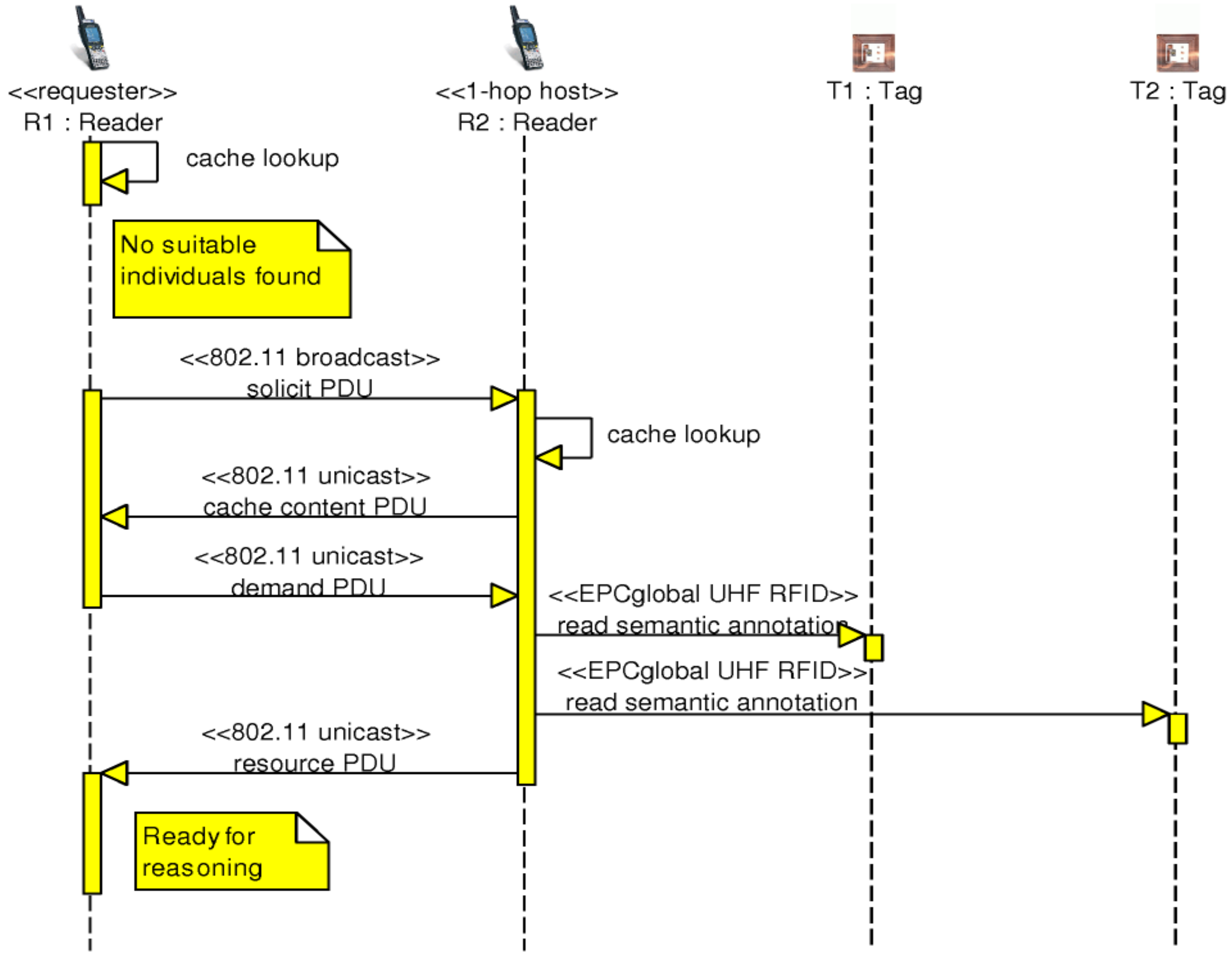
- Field layer: RFID, ZigBee, etc.
  - Extraction of resource parameters
  - Extraction of semantic annotation
- Discovery layer: IEEE 802.11 ad-hoc network
  - Resource advertisement and data dissemination
  - Request/response object discovery



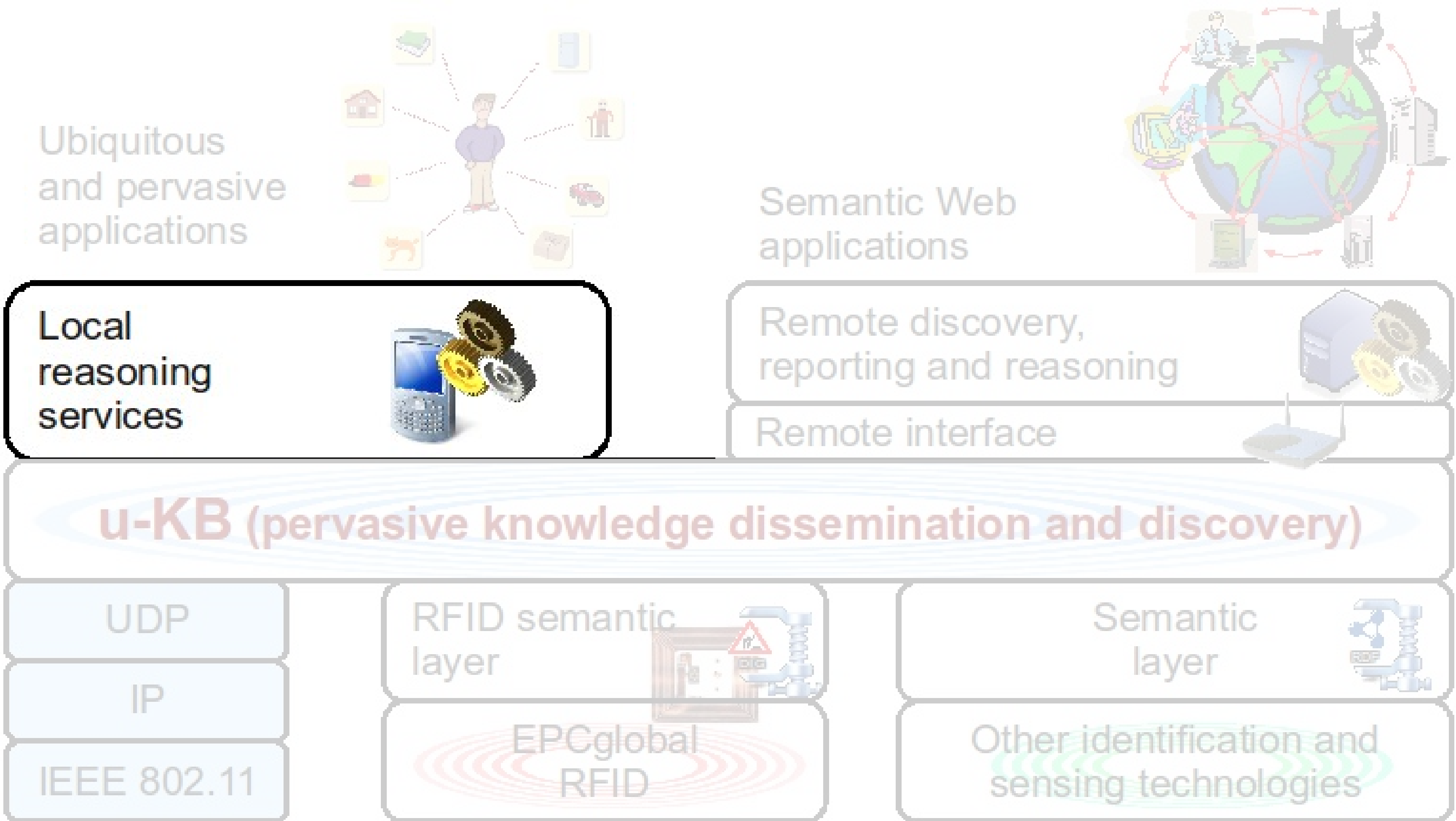
# Data dissemination



# Object discovery



# Overall architecture



# Reasoning in pervasive environments

- Mobile computing devices (e.g. smartphones) are natural candidates for running reasoning engines in pervasive contexts
  - Carried by users always and everywhere
  - Cluster-heads of field devices for knowledge extraction
  - Knowledge exchange with other mobile hosts in wireless ad-hoc networks
- Fast technological progress of computational capabilities...
- ...but still limited to support advanced semantic-based discovery
  - Processing power
  - Main memory
  - Energy efficiency

# Current approaches and issues

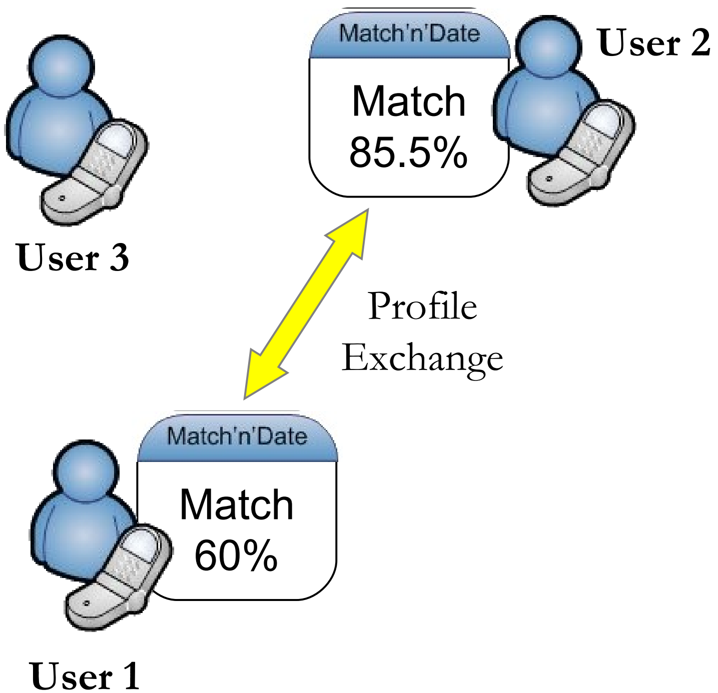
- Porting tools designed for the Semantic Web
  - Software platform requirements are hard to meet
  - Main memory limitations
  - Most known optimizations cannot be exploited
  - Inadequate performance
- Mobile reasoning engines
  - Support only for basic inference services
  - Inadequate for advanced service/resource discovery

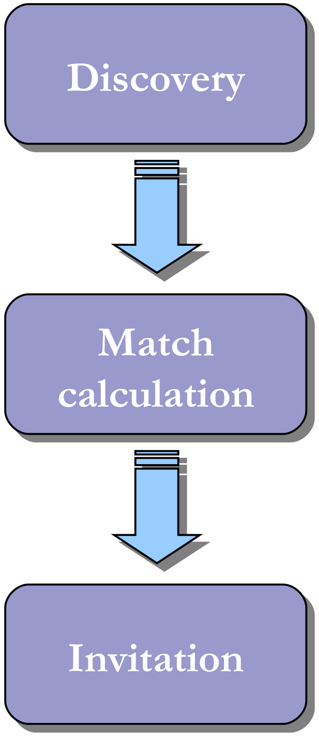
# Mobile structural semantic matchmaker

- Mobile system for semantic matchmaking with direct implementation of structural algorithms for fuzzy $\mathcal{ALN}$(D) simple TBoxes [Di Noia *et al.*, JAIR, 29, 2007]
  - Java Micro Edition mobile application for Bluetooth-enabled mobile devices [Ruta *et al.*, WI 2008]
  - Standard Semantic Web languages and technologies
  - Concrete domains to better handle data from the physical world [Ruta *et al.*, WIAS, 2010, to appear]
  - Fuzzy logic to express "vague" information through *membership functions* [Ruta *et al.*, ESWC 2010]
  - Non-standard inference services for fine-grained matchmaking and resource ranking

# Case study: Match'n'Negotiate
## [Ruta *et al.*, WIAS, 2010, to appear]

- Semantic matchmaking between descriptions of preferences and resource profiles referring to the same OWL ontology
- Overall match penalty computed using Concept Abduction and Concept Contraction

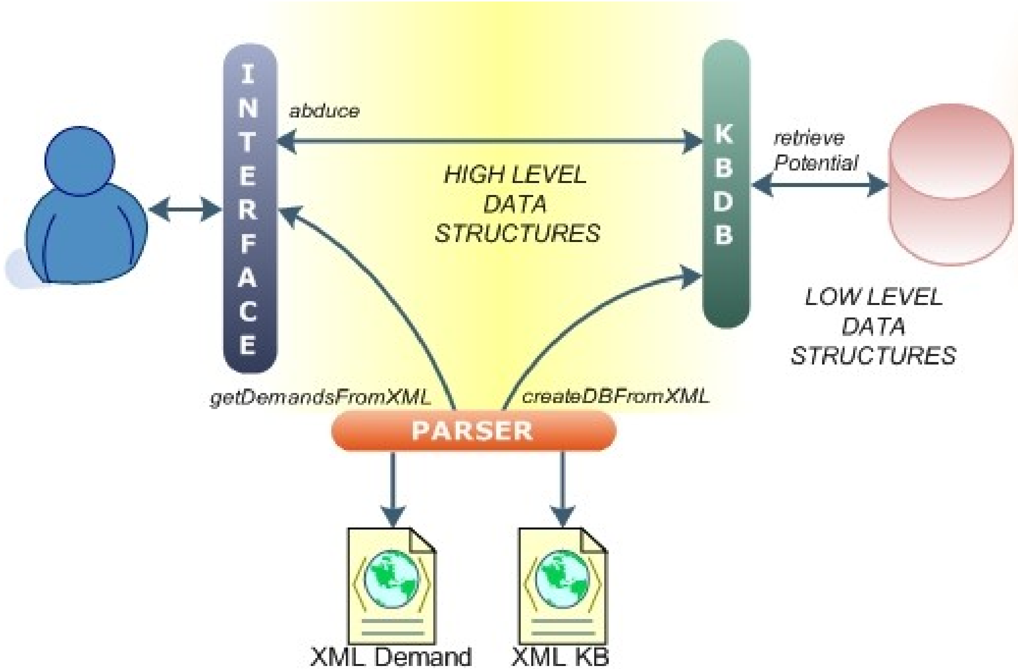


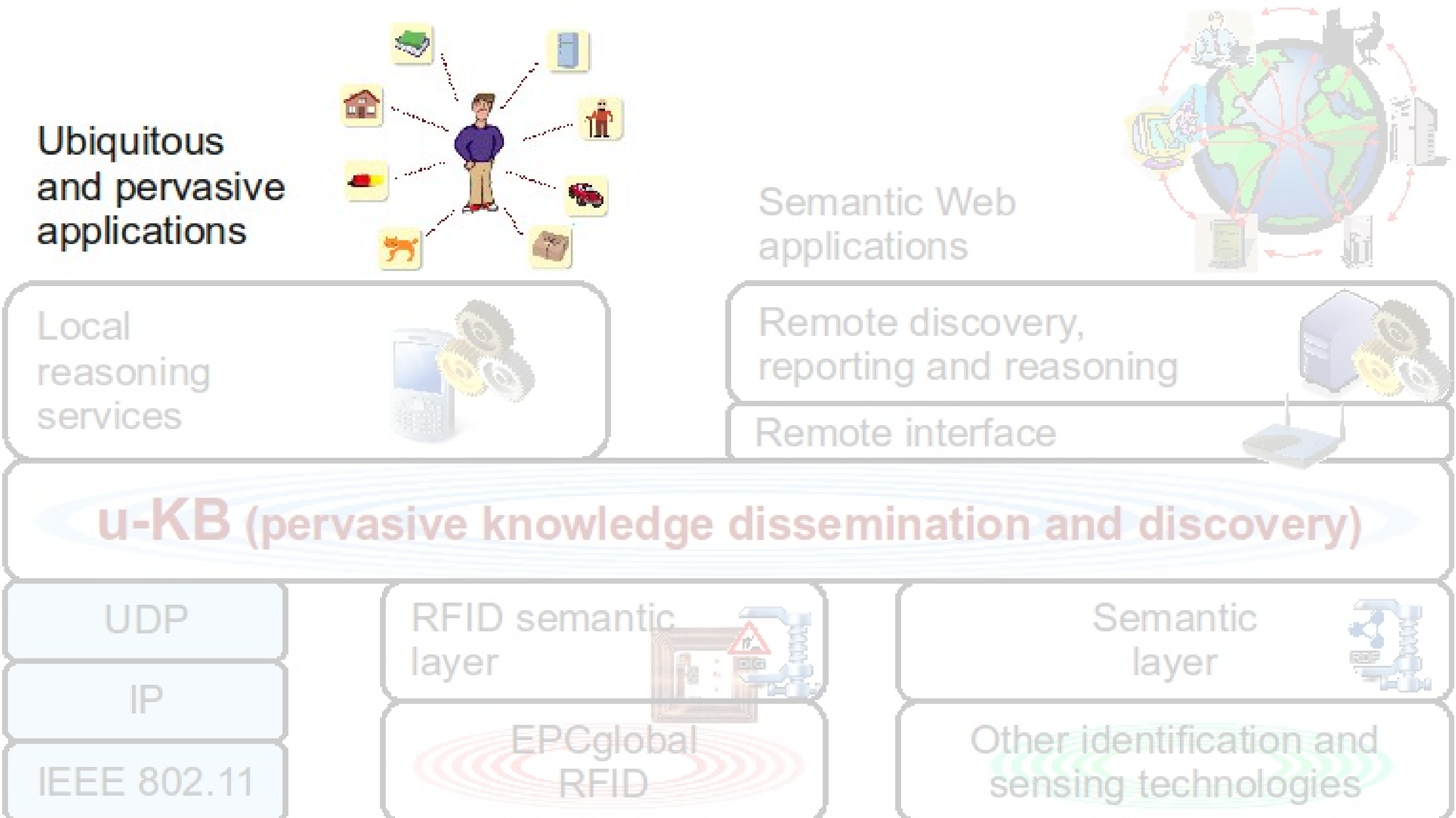
# Structural algorithms via m-ODBMS
## [Ruta *et al.*, WI 2009]

- Structural algorithms for consistency check, abduction and contraction in $\mathcal{ALN}$ simple TBoxes
- Implemented in mobile devices using object-oriented m-DBMS: **DB4O**
  - OSS embedded DB engine for Java and .NET
  - Low resource usage
  - Simplifies development by avoiding object-relational mappings
    - Direct object storage (also for composite objects)
    - Query by example (template objects)
    - Native queries (conditions evaluated by a custom Java or C# method)

# Matchmaker prototype architecture
## [Ruta et al., WI 2009]

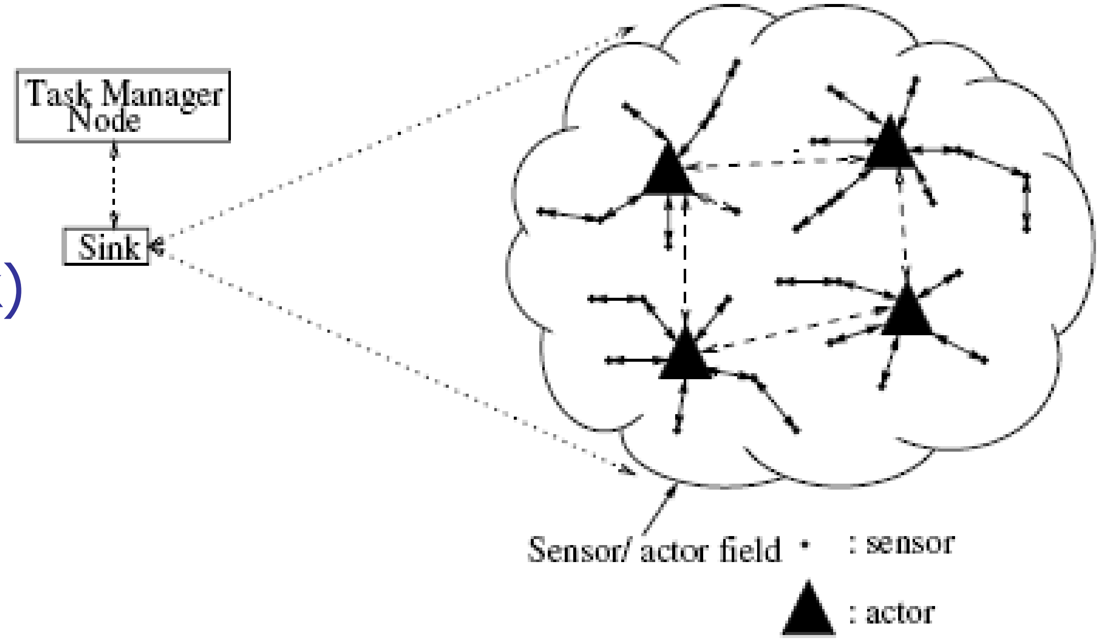



- Reasoning services
  - Retrieval of consistent resources
  - Concept Abduction
  - Concept Contraction
  - Composition via Concept Covering


Ubiquitous and pervasive applications
Semantic Web applications
Local reasoning services
Remote discovery, reporting and reasoning
Remote interface
u-KB (pervasive knowledge dissemination and discovery)
UDP
IP
IEEE 802.11
RFID semantic layer
EPCglobal RFID
Semantic layer
Other identification and sensing technologies

# Wireless Sensor and Actor Networks

- "A WSN is a self-organizing network composed of a large number of sensor nodes, tightly interacting with the physical world". [Ni et al., LNCS 3619, 2005]
- Three node types [Akyildiz, Kasimoglu, AHN 2,4, 2004]:
  - Sensor Node
  - Actor Node
  - Base Station (Sink)

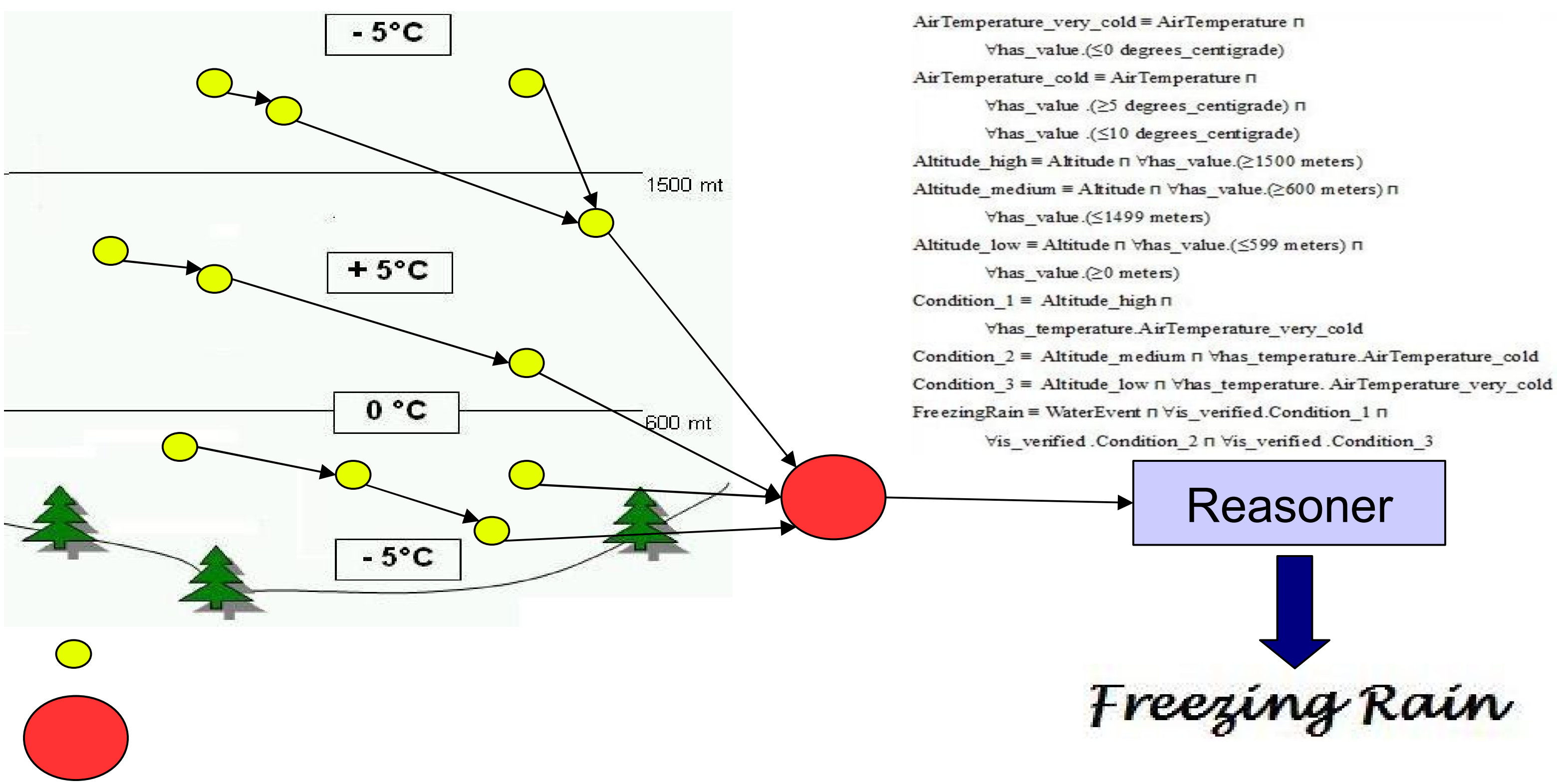


- Limits of current WSANs:
  - Each network is designed for a single application
  - Homogeneous sensor types only
- Wireless Semantic Sensor and Actor Networks (WSSANs)
  - Knowledge Representation techniques are used to annotate and describe:
    - sensor and actor capabilities, technical characteristics and state
    - collected data
  - Aims at increasing flexibility, interoperability

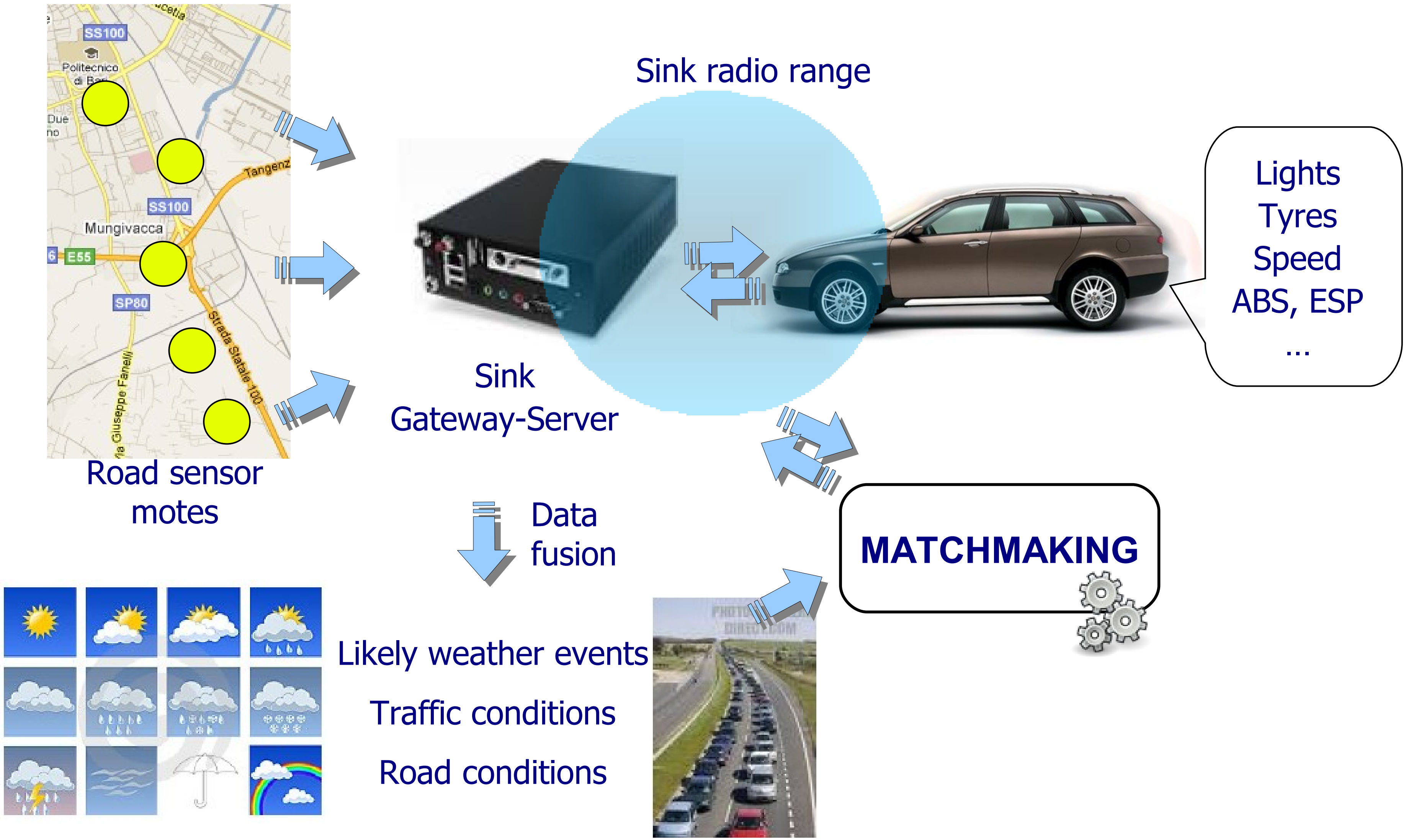
# WSSANs: data fusion and event annotation



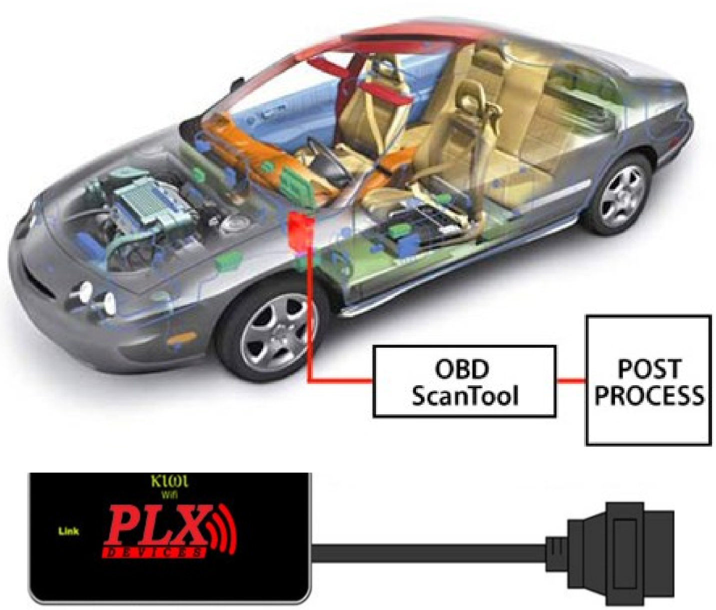
- Data fusion algorithms aggregate environmental sensory data and identify likely events
- Ontology-based event descriptions are timestamped and stored into an embedded database



# WSSANs: monitoring car risk level



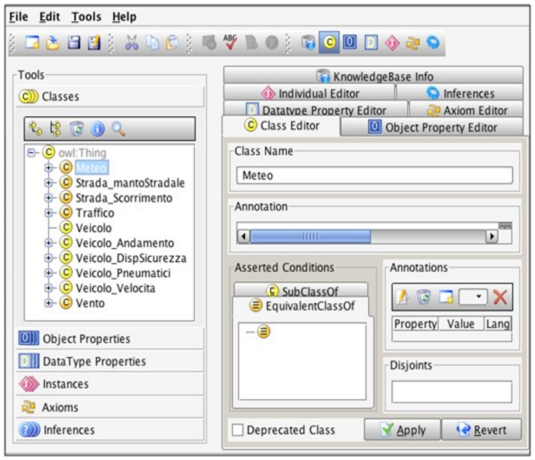
# Automotive: car behavior monitoring
## [Ruta et al., UBICOMM 2010]




**OBD-II + Wi-Fi**

**Apple iPhone**

**Knowledge Representation and Reasoning Techniques**




A system for car diagnosis and user assistance when driving

**Internal sensors:**

- Accelerometer
- Magnetometer
- GPS

**OBD-II parameters:**

- RPM
- speed

**Internet**

Goolge Maps
CloudMade
TWC Weather

DATA GATHERING

**Semantic characterization of:**

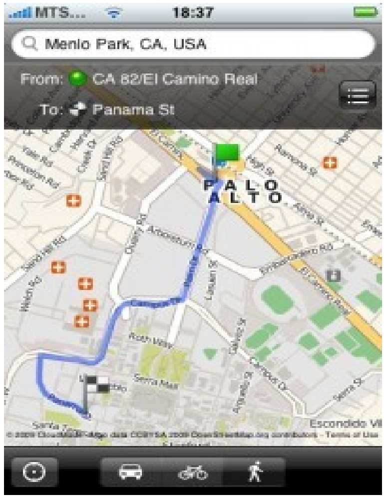
- User driving style
- Road conditions
- Traffic and weather conditions

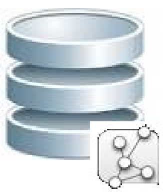
POST PROCESS

SEMANTIC MATCHMAKING

**User profile:** cultural interest, hobbies, travel info, ...


SEMANTIC MATCHMAKING integrated in Navit navigation OSS



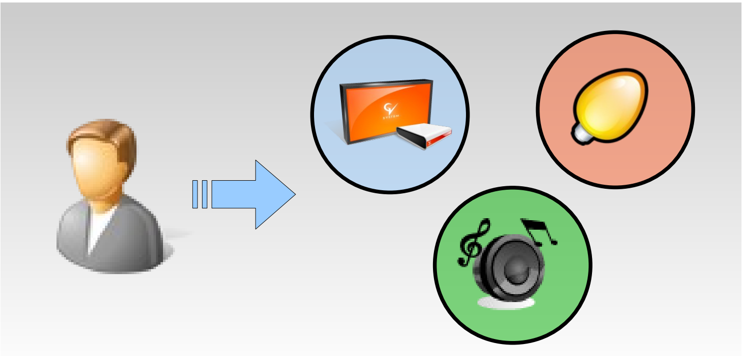




**OpenStreetMap POIs enriched with ontology-based annotations:** monuments, hotels, travelling, ...

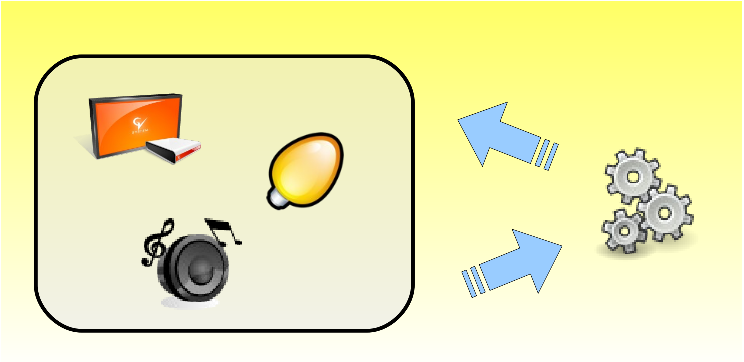
# Smart homes: basics

- **Aims**
  - Increase comfort and building efficiency
  - Decrease waste and maintenance costs
  - Integration of different home systems
  - Load management

- **Classic Domotics**
  - Static and not flexible architecture
  - Limited interoperability
  - Limited functionality and scenarios
  - Strongly required user-driven interaction

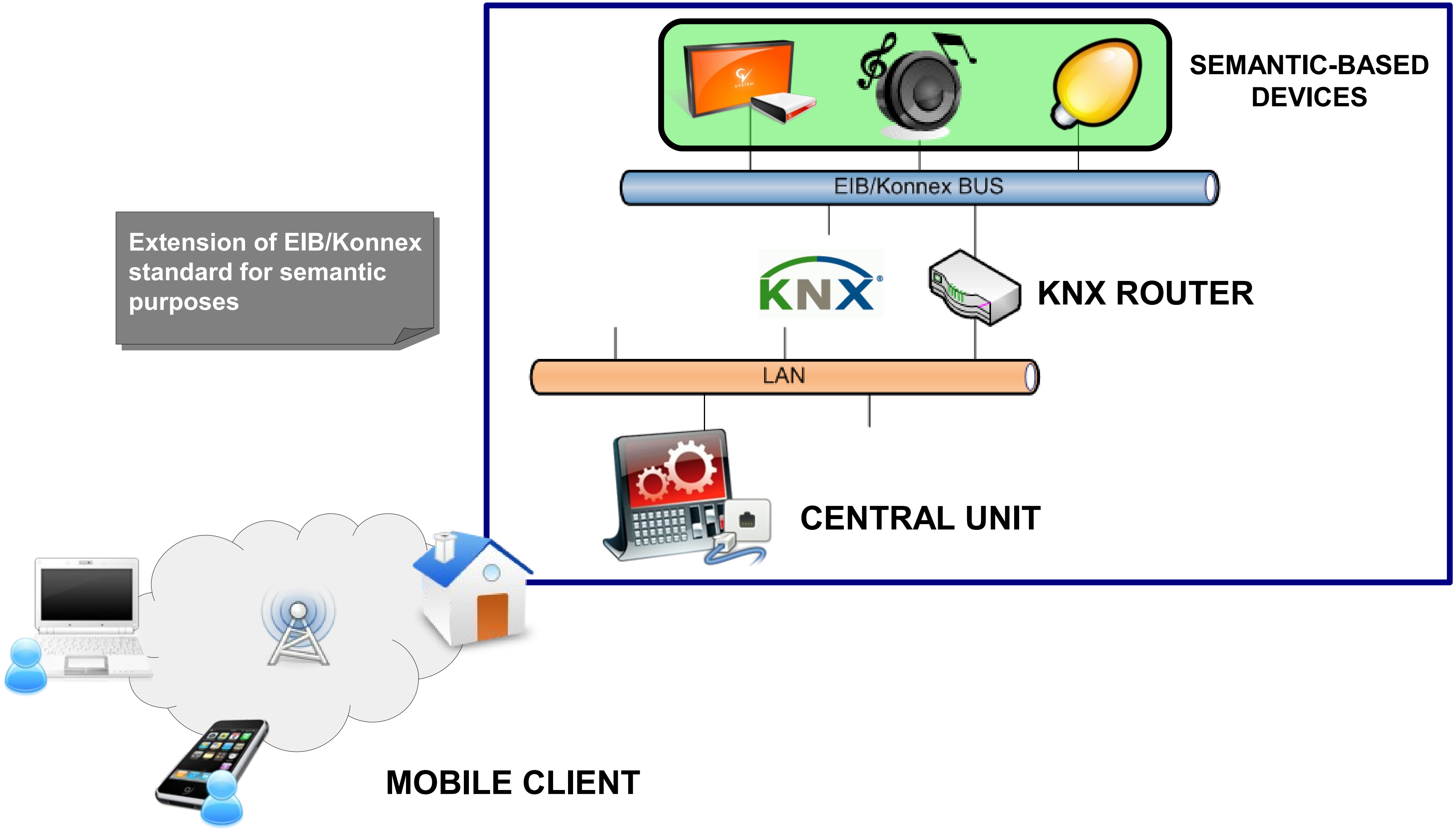


- **Semantic Domotics**
  - High flexibility
  - Complex user profiles
  - Device-driven interaction using matchmaking process



# Smart homes: framework architecture

Extension of EIB/Konnex standard for semantic purposes



# Smart homes: semantic-based building automation

Knowledge integration in classic home automation systems


Mobile semantic matchmaking to satisfy user and environment requirements


User Semantic Request

MOBILE MATCHMAKER

MOBILE CLIENT MANAGER

DEVICE MANAGER

New semantic services

Device Semantic Request

User profiles and device descriptions exploiting XML-based languages

# Conclusion

- Building a Semantic Web of Things
  - Peculiarities of the “object networks” make them not trivially assimilable to wired environments
  - Semantic-enhanced approaches allow to overcome limits in resource discovery due to unpredictability
- Ubiquitous Knowledge Bases provide the needed logic infrastructure to build a SWoT
  - Decentralized architecture
  - Exploitation of most common wireless technologies (RFID, 802.11, BT, ...)
  - Knowledge dissemination and discovery protocol
  - Annotation compression
- Reasoning in mobile and pervasive environments
  - Lightweight version of most common inference algorithms implemented in mobile matchmakers for PDAs and smartphones
- Several Applications areas
  - Healthcare, Sensor and Actor Networks, Automotive, Smart homes, ...

# Q&A

## Thank you

- Publications list at

  http://sisinflab.poliba.it/ruta/index.php?page=publications&author=Ruta&pg=-1
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