

Engineering Software Systems for Ubiquitous Computing

Valérie Issarny
ARLES team
INRIA-Rocquencourt



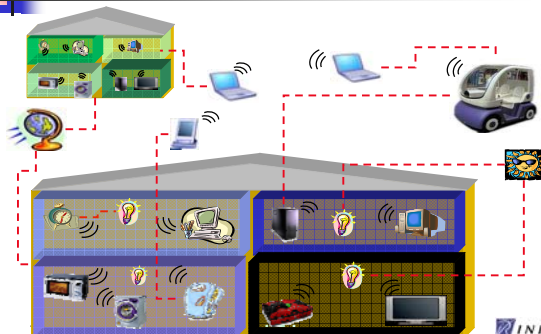
Outline

- An introduction to the ubiquitous computing vision
- Ubiquitous computing and challenges for the software systems
- Software systems for ubiquitous computing
- Conclusions

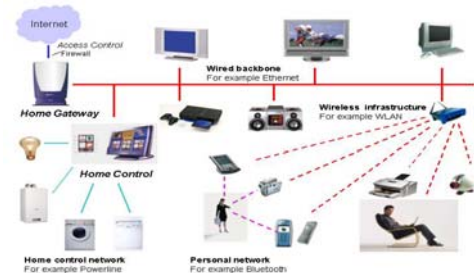
SmartUniversity – UC – 21/09/06 - 2



From ICT to Ubiquitous Computing



Technology already in today's home



SmartUniversity – UC – 21/09/06 - 4



But the vision is yet to be realized...

- Technology for people as opposed to
- People for technology
- Enabling seamless use of technology through adequate user interfaces and system transparency
- Bringing relevant applications to people

SmartUniversity – UC – 21/09/06 - 5



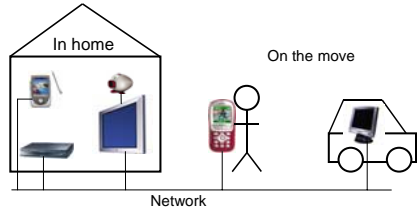
Various Challenging Applications

- **Feeling at home everywhere**
 - From basic integrated resource management to
 - Adaptive, context-aware, autonomic, ... , systems
- for
- Work-centric to entertainment applications

SmartUniversity – UC – 21/09/06 - 6

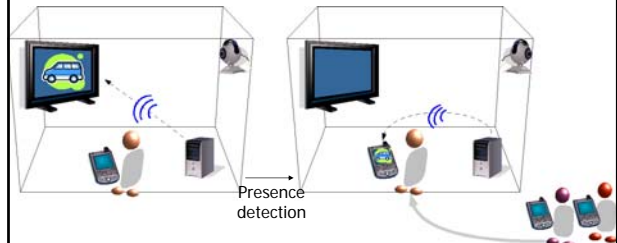


Feeling at home everywhere

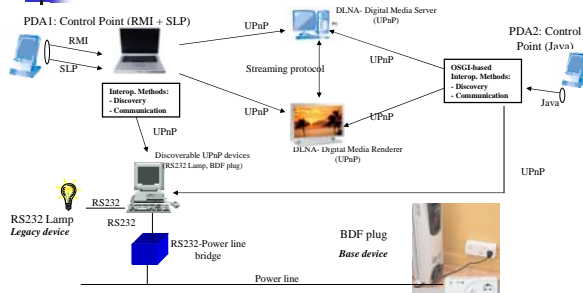


Using/accessing favorite/needed applications at will

Integrating resources in "user-centric smart spaces"



Major Challenges for the Software Systems



From integrating technologies to effectively composing them...

Outline

- An introduction to the ubiquitous computing vision
- Ubiquitous computing and challenges for the software systems
 - From ubiquitous computing to ambient intelligence
- Software systems for ubiquitous computing
- Conclusions

Ubiquitous Computing

- The starting point...

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"

Marc Weiser, Scientific American, 11/91

Numerous challenges remaining...

- Top challenges by Roy Want, Intel, ICSE'2005
 - Comprehensive power management
 - Usability issues for small mobile devices
 - Fast wireless discovery & connectivity
 - UI adaptation
 - Secure wireless interaction
- Using the local infrastructure to complement the capabilities of the user's mobile device

Impact on the software system

- **Power-awareness**
 - Power vs resource availability
 - Effectively exploiting hardware features (e.g., multiple processors, radios) at the software layer and still providing comprehensive high level interfaces
- **Effective resource discovery**
 - Scalability and increasing number of networked devices (from sensor networks to the Internet)
 - Networked devices and devices of interest/*belonging* to the user
 - P2P data & service sharing
- **Offering adaptive user interface**
 - Generic, context-aware multi-modal UIs based on their abstract definition
 - Evolving, context-aware smart space integrating surrounding resources (e.g., from cell phone to PC to large screen display)
- **Location-aware computing**
 - Location-based APIs using existing location management
- **Guaranteeing security**
 - Trust management in the open environment
 - Ensuring privacy in user-centric systems
 - Revising base security mechanisms for the open environment

SmartUniversity – UC – 21/09/06 - 13



Ambient Intelligence

- **Not just about ICT...**

"Ambient intelligence refers to the presence of a digital environment that is sensitive, adaptive, and responsive to the presence of people. [...] The new paradigm is aimed at improving the quality of life of people by creating the desired atmosphere and functionality via intelligent, personalized inter-connected systems and services."

An ambient intelligence environment exhibits the features of ubiquity, transparency and intelligence, (combining the disappearing computer with user-centered design)"

Emile Aarts, Rick Harwig & Martin Shuurmans, *Ambient Intelligence*, Chapter in *The invisible future*, McGraw Hill, 2002

SmartUniversity – UC – 21/09/06 - 14



Challenges revisited...

- **Key features of ambient intelligence systems**
 - **User-centrism** to place user in the foreground and ICT in the background
 - **Mobility** to meet the expectation of the mobile user
 - **Ubiquity** to ensure unobtrusive availability/presence of the system everywhere
 - **Heterogeneity** to integrate the various computing and networking facilities
 - **Ad hoc** nature to provide services to users opportunistically
 - **Dynamics** to encompass the evolution of the user's environment

SmartUniversity – UC – 21/09/06 - 15



Impact on the software system

- **Requirements for the software system architecture**
 - Evolvable/adaptive in structure and behavior to deal with the system's **dynamics**
 - Enables physical and logical **mobility**
 - Distributed & deployable on various infrastructures to deal with the system's **heterogeneity**
 - Highly scalable to enable **ubiquity**
 - Integrates sophisticated interaction and coordination modalities for **user-centrism**

SmartUniversity – UC – 21/09/06 - 16



Outline

- *An introduction to the ubiquitous computing vision*
- *Ubiquitous computing and challenges for the software systems*
- **Software systems for ubiquitous computing**
 - Background software systems
 - AURA for integrated user-centric resource management
 - Service-oriented systems for open pervasive computing environments
- **Conclusions**

SmartUniversity – UC – 21/09/06 - 17



Software systems for Ubiquitous Computing

- **From distributed systems to mobile computing to ubiquitous/pervasive computing**
 - By M. Satyanarayanan, IEEE Personal Communications, 2001

SmartUniversity – UC – 21/09/06 - 18



Distributed systems enable pervasive computing

- Remote communication
 - Protocol layering, RPC, ...
- Fault tolerance
 - Transactions, forward/backward error recovery, ...
- High availability/scalability
 - Replication, ...
- Remote information access
 - Distributed file systems, distributed DB, caching, ...
- Distributed security
 - Authentication, Encryption, ...

SmartUniversity – UC – 21/09/06 - 19



Mobile computing enhances distributed systems for pervasive computing

- Mobile networking
 - Mobile IP, ad hoc networks, ...
- Mobile information access
 - Disconnected operation, weak consistency, ...
- Adaptive applications
 - Proxies, transcoding, agility, ...
- Energy-aware systems
 - Goal-directed adaptation, ...
- Location sensitivity
 - GPS, WaveLAN triangulation, context-awareness, ...

SmartUniversity – UC – 21/09/06 - 20



But more is needed...

- **Smart spaces**
 - Exploiting the computing infrastructure embedded in the building infrastructure
 - Making software systems context-aware & ubiquitous
 - **Invisibility**
 - Minimal user distraction
 - Relates to user interface but also to the system's dependability
 - **Localized scalability**
 - Dynamic localized environment but globalized resources
 - Implementing integrated resource management *wrt* users
 - **Uneven conditioning**
 - Masking the diversity of smart environments
 - Reducing variability through adequate system functions (e.g., masking disconnection)
- Offering adequate middleware infrastructure integrating relevant solutions from the distributed system & mobile computing domain, and more

SmartUniversity – UC – 21/09/06 - 21



Middleware-based systems

- **What is middleware**
 - Middleware sits between the operating system and the application
 - Facilitates the development of distributed applications
 - Provides developers with abstractions, hiding details of the infrastructure (e.g., distribution)
 - Typical features include distributed systems functions (e.g., remote communication, remote information access, ...)
 - E.g., see <http://www.inf.unisi.ch/faculty/murphy/> for more detail

SmartUniversity – UC – 21/09/06 - 22



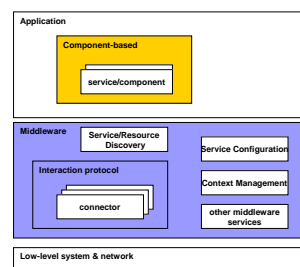
Middleware-based systems for pervasive computing

- **Why middleware for pervasive computing**
 - Demanding platforms regarding heterogeneity, resource management, ...
 - May provide reusable functions dealing with key features of pervasive computing systems (abstractions for smart spaces, context-awareness, localized scalability, globalized resource management, ...)
 - Enabler of dependability

SmartUniversity – UC – 21/09/06 - 23



Middleware-based system architecture



SmartUniversity – UC – 21/09/06 - 24



Key middleware functions for pervasive computing

- **Interaction protocol**
 - Providing the interaction protocols that best match the features of the environment and application requirements (P2P, data sharing, ...)
- **Resource discovery**
 - Basic functionality to deal with the dynamics and ad hoc nature of the system
 - Basis for localized scalability
- **Context management**
 - Context-awareness for user-centrism
 - Resource- vs user-centered context
 - Static vs dynamic context
 - Basis for realizing smart spaces
- **Service configuration**
 - Self-adaptive service according to context
- **Additional services for invisibility and uneven conditioning**

SmartUniversity – UC – 21/09/06 - 25



The AURA System

- **Towards distraction free pervasive computing**
 - <http://www.cs.cmu.edu/~aura/>
 - Integrated distributed resource management to create an environment that adapts to the user's context and need
 - Since 2000~

SmartUniversity – UC – 21/09/06 - 26



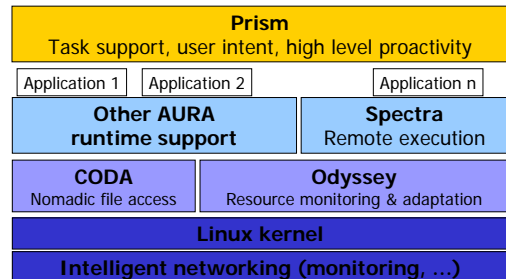
AURA features

- **Distraction-free pervasive computing**
 - Move computation & data as the user moves
 - Operations represented by tasks
 - Tasks can be accomplished by different services in different environments
 - Anticipate the movement of the user
 - Accomplished with the *Prism* monitor
 - AURA Middleware/System components include
 - Cyber-foraging enabling exploiting computation & storage of *nearby* devices
 - Bandwidth advisor to predict future bandwidth and advise user on best location
 - WaveLAN-based people locator, which uses signal strength

SmartUniversity – UC – 21/09/06 - 27



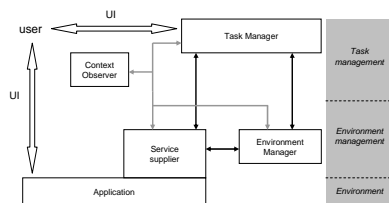
The AURA architecture



SmartUniversity – UC – 21/09/06 - 28



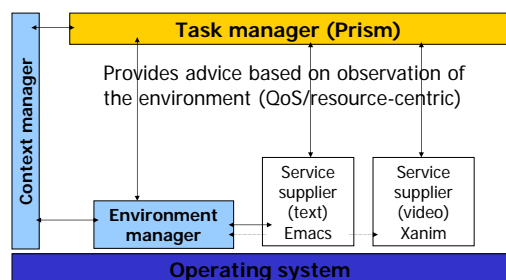
Task-based system



SmartUniversity – UC – 21/09/06 - 29



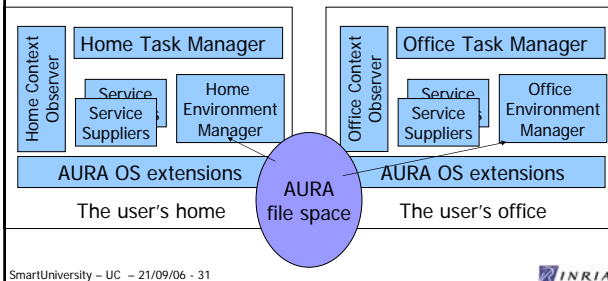
Prism to capture user intent



SmartUniversity – UC – 21/09/06 - 30



Task mobility in AURA



SmartUniversity – UC – 21/09/06 - 31



The Coda replication system

- **Network file system introduced in the early 90s for laptops**
 - Caching for performance and accessibility
 - Enables disconnected operations
- Supports nomadic computing
- Optimistic update policies
 - Conflict resolution performed by users on demand

SmartUniversity – UC – 21/09/06 - 32



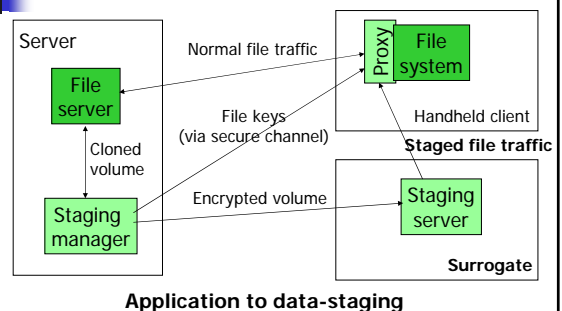
The Odyssey adaptation system

- **Complements Coda**
 - Introduced in the mid 90s for resource-constrained wireless devices
 - Supports application-aware adaptation
- Attempts to adjust the quality of data to match available resources
 - Application-dependent notion of fidelity
 - Data consistency, data resolution, ...
 - API for application-level adaptation
 - Environment features
 - QoS policy changes

SmartUniversity – UC – 21/09/06 - 33



Cyber foraging to augment the computing resources of users



SmartUniversity – UC – 21/09/06 - 34



Spectra for remote execution

- Adaptive remote execution mechanism that uses context to decide how best to execute a remote call
- E.g., where to do speech recognition

SmartUniversity – UC – 21/09/06 - 35



AURA assessment

- Integrated distributed resource management for enabling smart spaces
 - Builds on CMU work on distributed file systems for nomadic users
- Task-based applications for deployment in the changing smart spaces
 - Resource-centric context-awareness
 - Proprietary middleware that limits openness & ubiquity

SmartUniversity – UC – 21/09/06 - 36



Service-oriented systems for ubiquitous computing

- Enable pervasive networked services so that:
 - Services get available anytime anywhere
 - Complex services may be composed out of available networked services
 - Services may be easily deployed on various platforms and networks
- Challenges
 - Enable the networking of services, independent of the underlying technologies
 - Network with services according to **what they do** and not how they do it
 - Benefit from the pervasive networking environment

SmartUniversity – UC – 21/09/06 - 37



Towards pervasive services

- Pervasive service-oriented system architectures and supporting middleware developed within INRIA ARLES
 - <http://www-rocq.inria.fr/arles/>
- Interoperable service-oriented architecture for ambient intelligence in the networked home, as part of the Amigo solution (see presentations of 2nd day)
- Multi-protocol context-aware service discovery and access in heterogeneous wireless networks, as part of the UBISEC & PLASTIC projects

SmartUniversity – UC – 21/09/06 - 38



Pervasive environments

Interoperability

- Multi-networks & multi-radio devices
- Multi-platforms/protocols

Context-awareness

- Service-rich, heterogeneous environment

SmartUniversity – UC – 21/09/06 - 39



Related work

- **Interoperability**
 - **Transparent** with network level component translating messages between protocols (e.g., Amigo-INDISS)
 - **Explicit** with clients accessing an interop. layer on top of existing protocols (e.g., ReMMoC, Jini-UPnP, Broker....)
 - Efficiency vs. extensibility
- **Context-awareness**
 - Mostly new protocols with context-aware service descriptions
 - Semantic layer on top of service discovery
- Solutions targeted at “homogeneous” networking environments (same IP network)

SmartUniversity – UC – 21/09/06 - 40



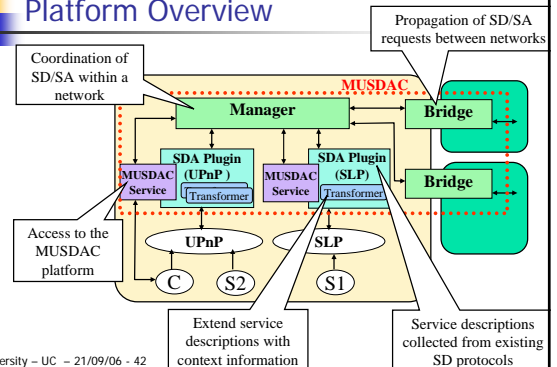
MUSDAC for service discovery in pervasive environments

- **Platform goals**
 - SDP interoperability
 - Context-awareness
 - Support service access (nomadic mobility)
- **Approach**
 - Explicit approach to enhance discovery requests
 - SD as a service (specific API for clients)
 - Client-side interoperability
 - Dynamic composition of independent networks
 - Heterogeneous networks, no global IP routing
 - Federation of independent networks

SmartUniversity – UC – 21/09/06 - 41

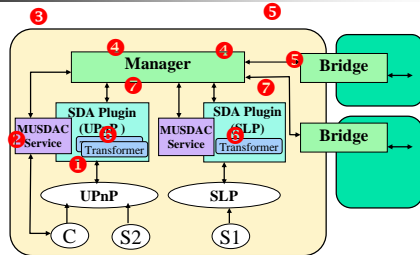


Platform Overview



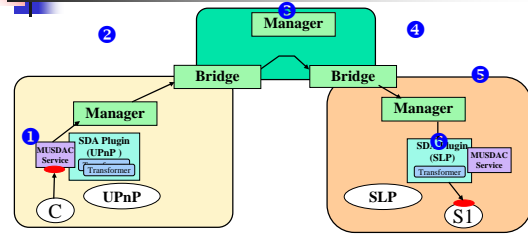
SmartUniversity – UC – 21/09/06 - 42

In a nutshell: Service discovery



- Clients discover the MUSDAC Service using their preferred SDP
- Client access this service using MUSDAC API and formats
- SDA Plugins: translation between SDP-specific and MUSDAC formats
- Bridges: propagation to remote networks and update of the propagation list

In a nutshell: Service access



- Local endpoint managed by the MUSDAC Service (returned in the MUSDAC service description)
- Clients initialize the service proxy with this local endpoint
- Access messages encapsulated in a MUSDAC message
(Client → MUSDAC Service → Manager → Bridge(s) → SDA Plugin → Service)

Context-awareness for the pervasive environment

- **Pervasive environments**
 - Plenty of consumer devices with similar services
 - Various network connectivity, restrictions,....
 - Multi-networks
 - Bridging devices with limited resources
 - Prevent network flooding
- **Approach**
 - Context management integrated in the SD layer
 - Focus on context information/management for SD
 - Use context information to
 - Provide more accurate results
 - Control the dissemination of service information
 - Support existing (context-less) SDPs

SmartUniversity – UC – 21/09/06 - 45



MUSDAC context model

- **Context information**
 - Parameters: tuples (type/value)
 - Rules: Boolean expressions used to control the selection of a service or the propagation of a discovery request.
- **Context types**
 - User context (device and client)
 - Service context
 - Network context

```
Service context
srvCharge = "free"
srvAuthentication = "secure"
(screenResolution eq "high")
```

```
User Context
audioOutput = "true"
screenResolution = "high"
((netBandwidth eq "medium")
or (netBandwidth eq "high"))
and (srvAuthentication eq "secure")
and (srvCharge eq "free")
```

SmartUniversity – UC – 21/09/06 - 46



Context generation

- **User context**
 - Provided by user when issuing a request to the MUSDAC service
- **Service context**
 - Available in original service description
 - Generated by Transformers
 - Third-party components implementing a specific interface
 - Dynamically loaded into the MUSDAC platform
 - Knowledge of context information for certain services, able to access a context server in the network or call the context interface of a service...
- **Network context**
 - Generated by MUSDAC Managers based on collected information
 - Broadcasted to the network's MUSDAC Bridges.

SmartUniversity – UC – 21/09/06 - 47



Context processing

- **Managers**
 - Use user context in the request and the service context in the service description for service selection
- **Bridges**
 - Use user context in the request as well as network context from the source and destination networks to control request propagation

SmartUniversity – UC – 21/09/06 - 48



MUSDAC prototype

- Java implementation of the MUSDAC Platform
 - Initial support for UPnP, SLP, Ariadne, and PDP SD protocols
 - MUSDAC Service: SOAP and XML/socket implementations
 - Service access: implementation for SOAP services (multi-networks)
 - Prototype available as OSS (<http://www-rocq.inria.fr/arles/>)
- Service discovery evaluation
 - Overhead: a few 100's ms (SOAP) or a few 10's ms (plain XML)
 - Propagation adds about 30 ms per Bridge
 - Access as a service is costly, SOAP processing is costly
 - SLP (<1ms) << UPnP (100's ms) << UDDI (>6s)
- Service access evaluation
 - Only one SOAP call (client to MUSDAC service)
 - Propagation adds about 20 ms per Bridge

SmartUniversity – UC – 21/09/06 - 49



Evaluation of context-awareness

- **Context processing**
 - Processing of context information grows linearly
 - Context-aware service discovery
 - Adds 8.5 ms for the processing of 5 rules/40 parameters (SOAP)

	0 CR	5 CR	10 CR	20 CR	40 CR
SD time (ms)*	47	55.5	63	75.5	88.5

⇒ Simple/Efficient context processing

* SD time for the local discovery of a UPnP service

- MUSDAC description already in the cache of the Manager
- XML/Socket implementation of the MUSDAC Service

SmartUniversity – UC – 21/09/06 - 50



MUSDAC Assessment

- SD/SA in multi-networks configurations
 - Explicit SDP interoperability to enhance legacy SDPs
- Context management integrated in the SD layer
 - Used to filter services and limit the propagation of service formation
- Further exploitation of heterogeneous networks
 - Accounts for B3G and related multi-radio devices
 - Integrate with semantic-aware services

SmartUniversity – UC – 21/09/06 - 51



Outline

- *An introduction to the pervasive computing vision*
- *Ubiquitous computing and challenges for the software systems*
- *Software systems for ubiquitous computing*
- **Conclusions**

SmartUniversity – UC – 21/09/06 - 52



Conclusions

- The vision of ubiquitous computing remains as challenging as when the vision was introduced in the early 90s
 - Enabling ICT has since emerged and keeps evolving
 - E.g., smartphone, interaction technologies, ...
 - But the enabling software systems are yet to come
 - Developing user-centric systems remain the key challenge ?
- For more information: <http://www-rocq.inria.fr/arles/>
- Thanks to colleagues and in particular N. Georgantas & P-G. Raverdy

SmartUniversity – UC – 21/09/06 - 53

