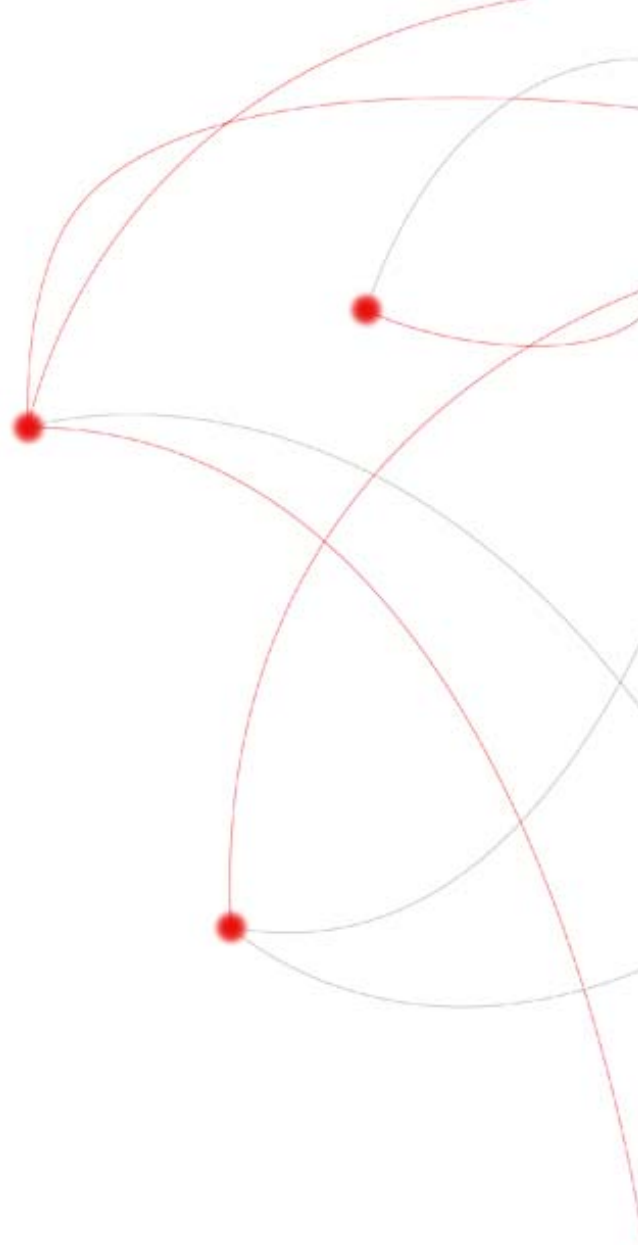

Network of Networks

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Telecom Italia Future Centre

Outline

- Why:
  - Context and Vision on Future Communications and Services
  - The operators' rationale
  - The project vision
- What:
  - Main goal: an open architecture for Network of Networks
  - Architectural vision and principles
- How:
  - Main Enabling Technologies
  - Technical Approach
  - Current results
  - Next
- Publications and internal documents

Incipit

- Positive Dilemmas: Network Operators should investigate disruptive scenarios for Future Communications and Services in order to be aware of how to transform their biz models and exploit network and service infrastructures;
- One of the most challenging scenario is characterized by:
  - high pervasiveness (computing systems distributed and connected everywhere);
  - connectivity as a commodity;
  - structure as Network of Networks (adaptive networks);
  - intelligence at the edges (terminals and end points);
- This scenario is highly disruptive as it implies moving intelligence at the edge of the network reinforcing the end-to-end argument and an open environment for services;
- There is a need of understanding:
  - the potential evolution of this scenario (in terms of architectures, technologies and services);
  - the role of the Network Operator (biz model, architectures, technologies, etc.);

Trends and limitations of the current evolution of Internet

- Internet is not “symmetric” any more because, in the prevalent client-server paradigm, servers are more capable and “important” than clients;
- Internet evolution is determined not only by technological progress but mainly from business contrapositions (tussles) that impede a smooth technical evolution and the realization of new business models;
- Operators tend to bring intelligence in the network centralizing functions and creating complex platforms (e.g., IMS, SDP) and contradicting the Internet principles;
- Current IT distributed architectures (e.g., SOA, GRID and cloud computing) are not able to scale and concentrate the intelligence within administrative domains;
- These approaches in the long run will:
  - challenge the “end to end argument”, which is the pillar of the Internet;
  - hamper the design of open architectures that permit different players to build solutions based on different communications and computing paradigms;
  - not properly support high pervasiveness of resources;

Context and Vision of Future Communication and Services (1/2)

- Pervasive computing environment in which the terminals will be Always Best Connected:
  - end points will be more and more capable and some of them will be miniaturized;
  - the connectivity will be a commodity (ubiquitous, seamless and granted);
- Autonomic systems and resources:
  - the system nodes and terminals will self-organize and self-manage in order to tackle the complexity of the environment and to reduce the human involvement;
  - self-management will enable robustness resilience and high availability of resources, services, applications, and functions;
  - the global system will be energy-savvy and environment conscious (using dynamically only the resources that are strictly needed);

Context and Vision of Future Communication and Services (2/2)

- **Personal services:**
  - **services will be tailored to the single user and its relationships with "communities";**
  - **the computing environment will be able to dynamically recreate the favorite and personalized portfolio of services and functions independently from terminals being used, location and time;**
  - **services will readily adapt in order to provide the better functions according to computing and communication environment;**
- **Service composition:**
  - **services will be composed from different providers, stakeholders, and even end-users' terminals;**
  - **different business models will coexist and compete;**
  - **users will not be tied to a Provider or environment:: services will cross different administrative domains and users will be able to compose and mash them up freely;**
  - **services will be self-provisioned and really plug&play;**

Rationale for Operators: the role of network

- **A better exploitation of network infrastructure:**
  - **usage of adaptive and peer-to-peer communication systems rebalance the asymmetry of the client-server architectures (currently it is all in favor of WebCos like Google, Amazon, IBM, while operators could just be followers);**
  - **adaptive network is more manageable:**
    - **Self organization and self management;**
    - **Less human intervention;**
- **Need to compensate for a commodity model**
  - **Connectivity follows a Subscription or Utility model;**
  - **However Value goes back to the network and its nodes. It can take advantages "twice" of Metcalfe's Law:**
    - **on its own network offering;**
    - **on the aggregation of Network of Networks;**

Rationale for Operators: the role in service ecosystems

- Different service paradigms (e.g., client-server, peer-to-peer, network intelligence) will be equally implementable on a service base:
  - operator can choose different paradigms based on economical and technical reasons;
  - the operator can put in place appropriate platforms in order to enter into new businesses;
  - the operator can be easily part of different Eco-Systems that can exploit the adaptive network;
  - users can be part of the deployment and provision chains, so infrastructural and service costs can be shared;
- It can take advantages of Reed's Law:
  - the operator can be a broker of connectivity, resources and services provided by other public and local networks (Network of Networks);
  - the operator can aggregate and provide services and contents to large communities;

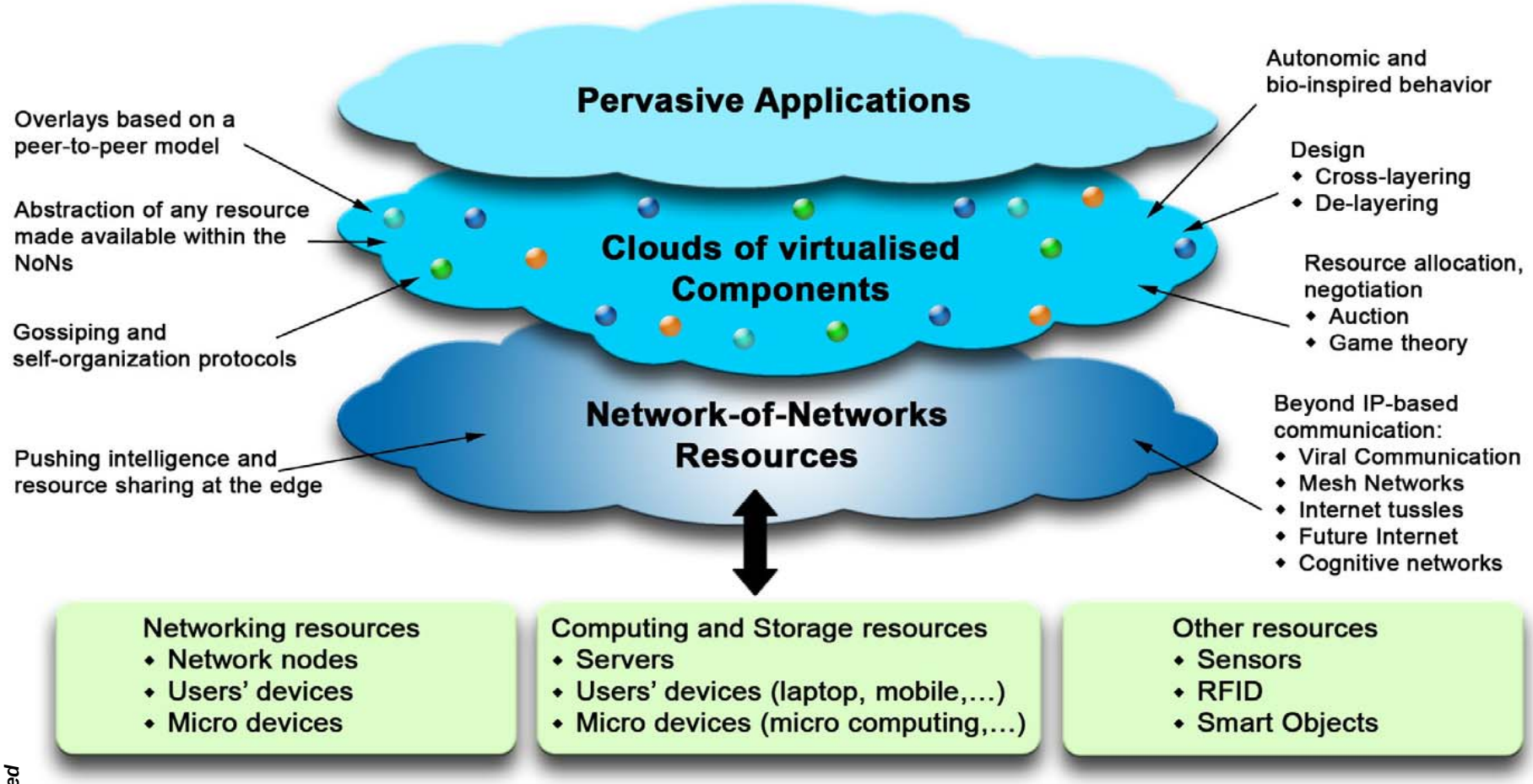
Vision of the Project

- An highly adaptive, open, and scalable architecture composed by a decentralized common pool of interacting resources abstracted and interconnected by dynamic (and even local) Network of Networks;
- This architecture should reinforce the end-to-end argument and should be characterized by Organic-P^3 (OP-CUBE) features:
  - Organic, i.e., it is resource aware and tries to optimize the consumption and the usage of resources (using adaptive and bio-inspired algorithms);
  - Personal, i.e., the personalized computing environment will follow the specific users, it will be able to adapt to the specific context and the set of devices being used, it will be private (secure and respectful of privacy) but open;
  - Pervasive, i.e., communications and computing capabilities will be available in a seamless way anytime, anywhere;
  - Peer-based, i.e. different users, and networks, will be able to cooperate and share on an equal and fair base knowledge, information and capabilities;

Towards an open architecture for Network of Networks

- The architecture will move the intelligence towards the edge, up to including Users' terminals (e.g. smart-phone) that will be capable of sharing storage, processing and communications capabilities (abstracted as autonomic components);
- The architecture will blur the distinction between network nodes/systems (servers, routers, switches, etc.) and the edge and Users' devices: the role of a resource is no more tied to specific layers of the protocol stack, but it is determined by its abstractions joining overlays aggregations;
- The architecture will have self-CHOP features (Configuration, Healing, Optimization, and Protection) to optimize the allocation of resource and self-manage their usage;

Architectural vision and principles (1/3)



Architectural vision and principles (2/3)

- **Architecture of Network of Networks relies on three functional separations:**

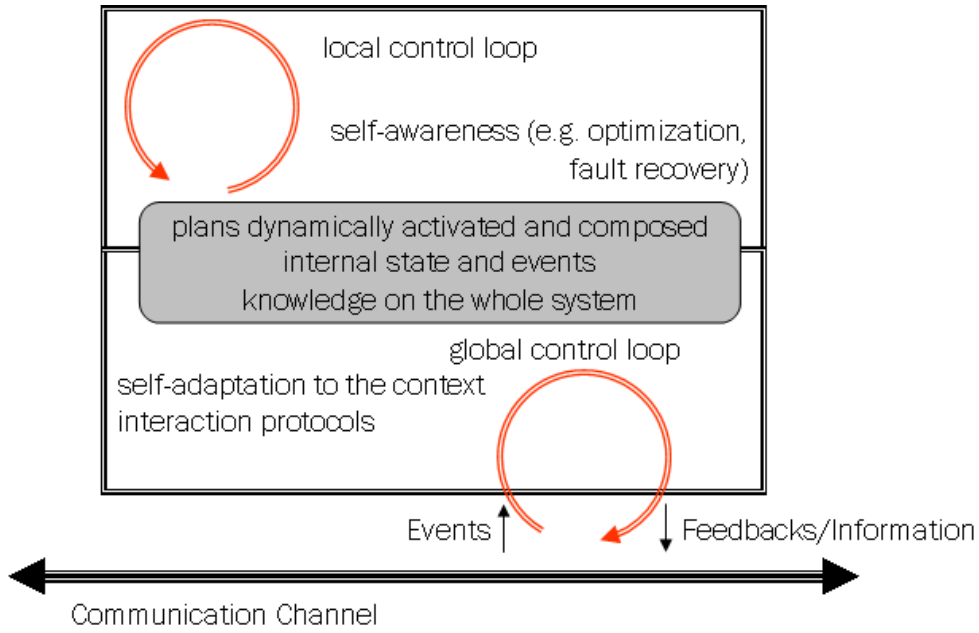
  1. **pervasive heterogeneous resources, provided both by network systems, Users' devices at the edge (grouped in forwarding/communication, computing, storage units) and "things" (e.g., sensors, sources of data, contents, specialized service functions, etc.);**
  2. **a cloud of Autonomic Components (ACs), virtualizing the networked services, enablers and resources; components follow autonomic rules (e.g. self-CHOP: self-Configuration, self-Healing, self-Optimization, self-Protection) to guarantee scalability, resilience and decentralization. ACs interact with each other (self-organized) overlay networks in which each component is providing and using features and resources in a peer-to-peer way;**
  3. **an ecosystem of composable applications/services, provided and used by several actors (e.g., service/network providers, LEs, SME's, Prosumers, users), which are deployed and executed by exploiting and aggregating the features provided by the underlying cloud of ACs;**

Architectural vision and principles (3/3)

- New architectural principles under consideration include:
  - autonomic capabilities and bio-inspired algorithms (e.g., gossiping protocols, self-organization algorithms), to deal with complexity;
  - P2P overlay network for organizing components, in order to guarantee scalability, reliability, and abstraction from underlying infrastructure;
  - cross/de-layer design principles, to deal with optimization of resources and to obtain a modular architecture able to adapt to dynamic changes in actors requirements and to evolution of the execution context;
  - flexible mechanisms and policies (based on auctions, game theory, etc.) for optimized resource allocation and usage (e.g., power saving);
  - viral communication principles to better integrate end-users terminals and exploit their device-to-device communication and networking characteristics (e.g., mesh networks);

Main enabling technologies: autonomic computing and networking

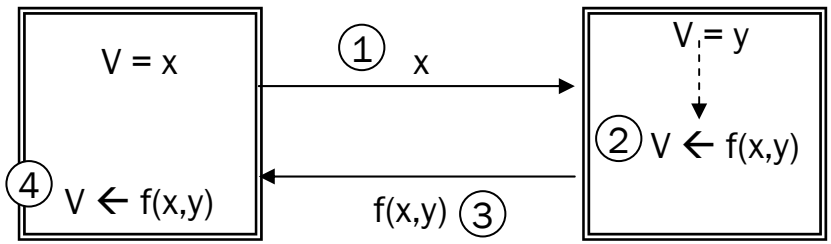
- Software systems are structured in distributed components, enriched with capabilities for self-adapting its behavior according to the changes of its local state, the changes of its environment and the information received through interaction with the other components;
- Self-* capabilities (e.g., self-CHOP) of Autonomic Components are achieved through the dynamic application and composition of execution plans, which defines how ACs have to react to internal or external events, e.g.:
  - modifying the value of internal state;
  - updating the current execution plan;
  - interacting with neighbors;
- The maximum "distance" over which two ACs can communicate is small compared with the size of the entire system: each AC interacts with a few nearby neighbors;
- Interactions are performed through an overlay, which are set-up through specific mechanisms (e.g., discovery or self-organization protocols);



Main enabling technologies: self-organisation algorithms

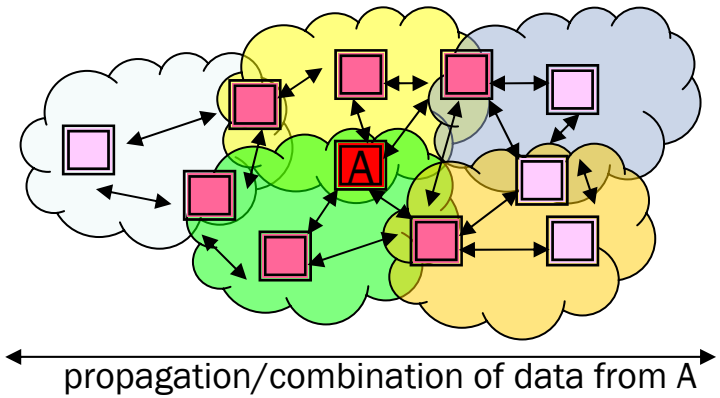
Gossiping and self-aggregation protocols

- Highly distributed systems require to introduce locality in communications, performed on overlay networks created and maintained through self-organized algorithms;
- Gossiping protocols enable a node to exchange, at each step, only a limited amount of information with some of their immediate neighbors of an overlay;
- Self-aggregation algorithms are based on the combination of information exchanged with its neighbors through a gossiping protocol;



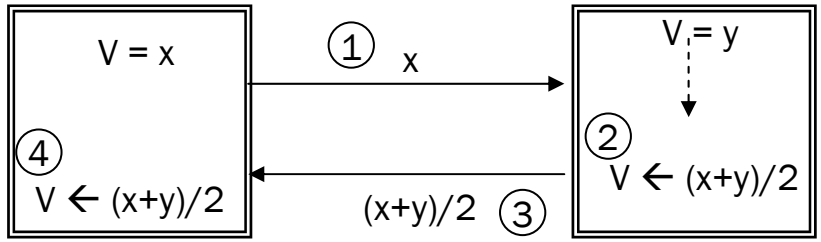
Emergence of quasi-optimal global solutions based on local decisions

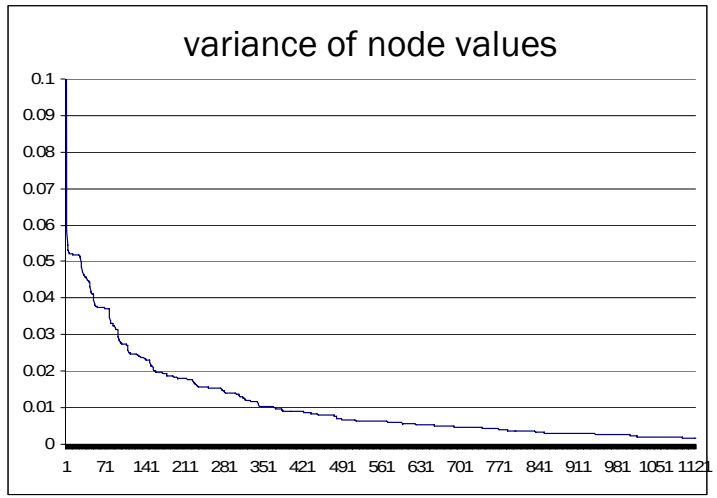
- Though gossiping and self-aggregation are based on local communications, their combination enable the spread of information across the whole system;
- The information are progressively combined and spread across the system (e.g., to compute the average of a value in a completely distributed way);

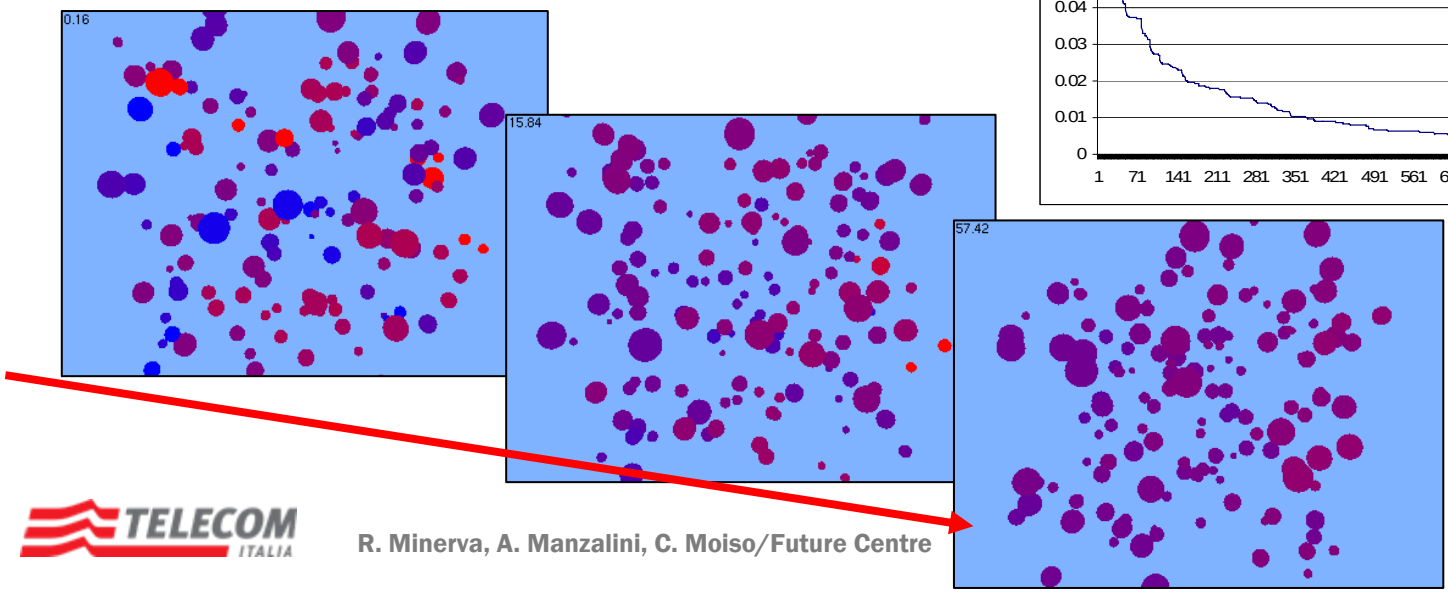


Main enabling technologies: an example of gossiping algorithm

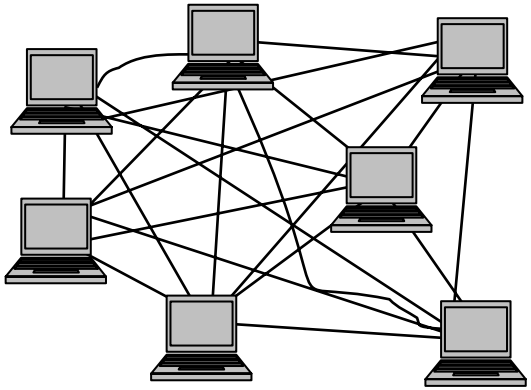
- **The problem:**
  - **calculate, without a central server, the average of the values stored in a set of mobile devices;**
- **The solution:**
  - **at each step, a mobile device interacts with its nearest neighbor;**
- **A snapshot:**
  - **the purple tone of a device is proportional to its value in [0:1] (0=blu; 1= red);**
  - **all the devices tend to assume a purple value, whose tone is proportional to the average of the nitial values of the devices;**







Main enabling technologies: P2P for balancing the asymmetry of the Internet



Capacity (HD System) = $\sum (b_i, s_i, p_i)$

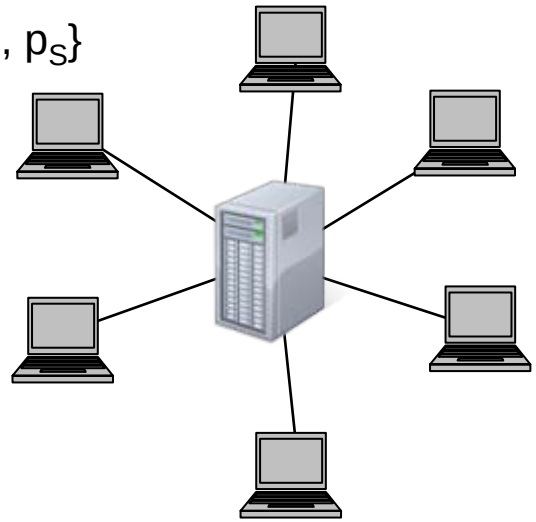
Where:
b_i = bandwidth of node i
s_i = storage of node i
p_i = processing of node i

Network Usage Optimization is a problem

Optimization is a function of a business model

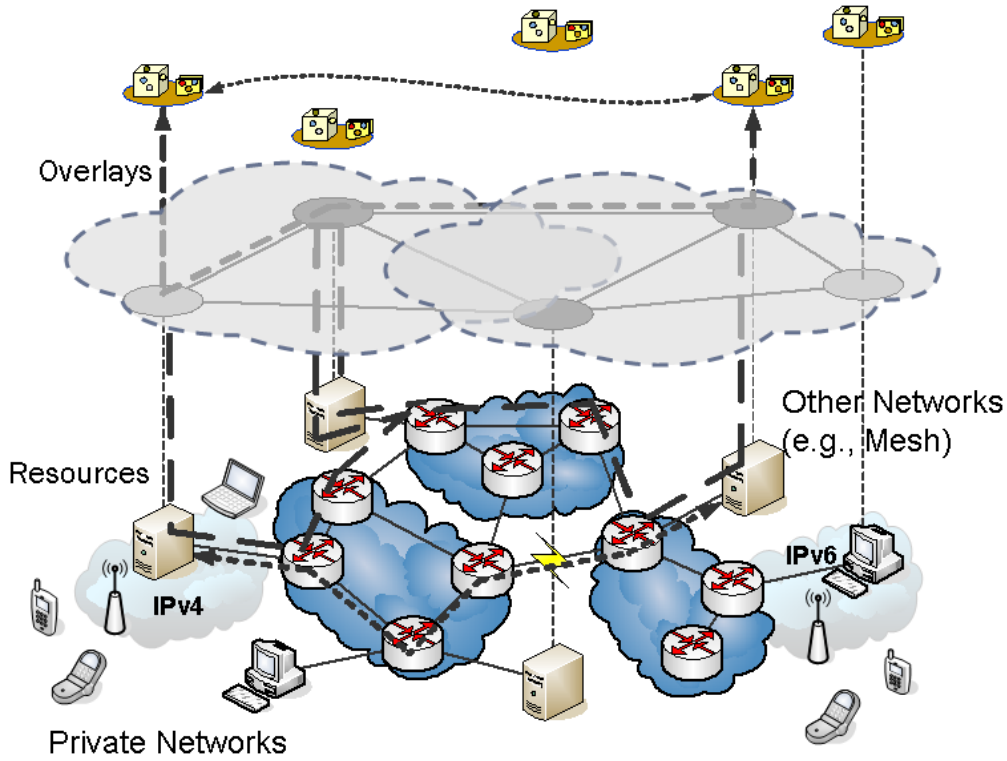
Capacity (Centralized System) = $\{b_S, s_S, p_S\}$

Where:
b_S = bandwidth of the Server System
s_S = storage of the Server System
p_S = processing in the Server System



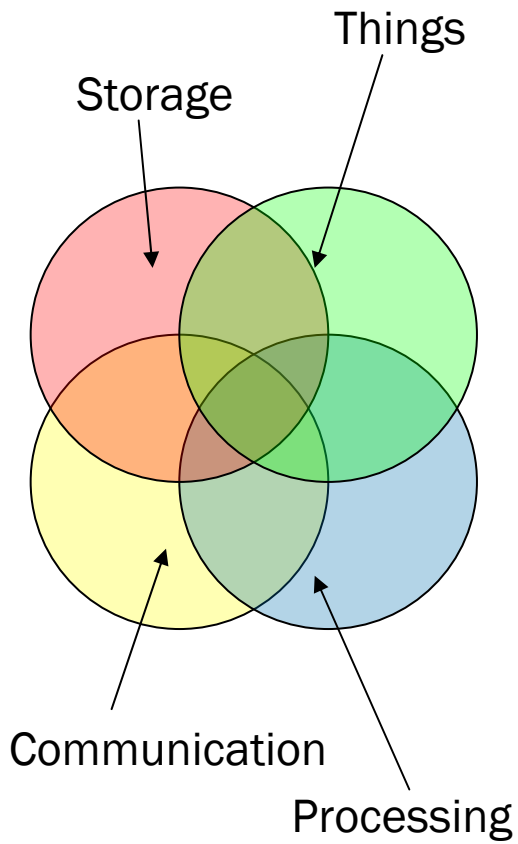
Main enabling technologies: Overlay networks

- **Overlay networks enable the creation, optimization, and maintenance of distributed virtual environments, for the deployment and execution of distributed applications:**
  - **handling of dynamic and unpredictable introduction and remove of nodes;**
  - **abstraction of underlying resource and network heterogeneity;**
  - **abstraction of network topology and networking protocols;**
  - **functions for unique addressing of virtual nodes, and for routing messages;**
  - **fully distributed peer-to-peer control and self-management of nodes and aggregations, according to several architectures (e.g., structured, unstructured, hybrid);**

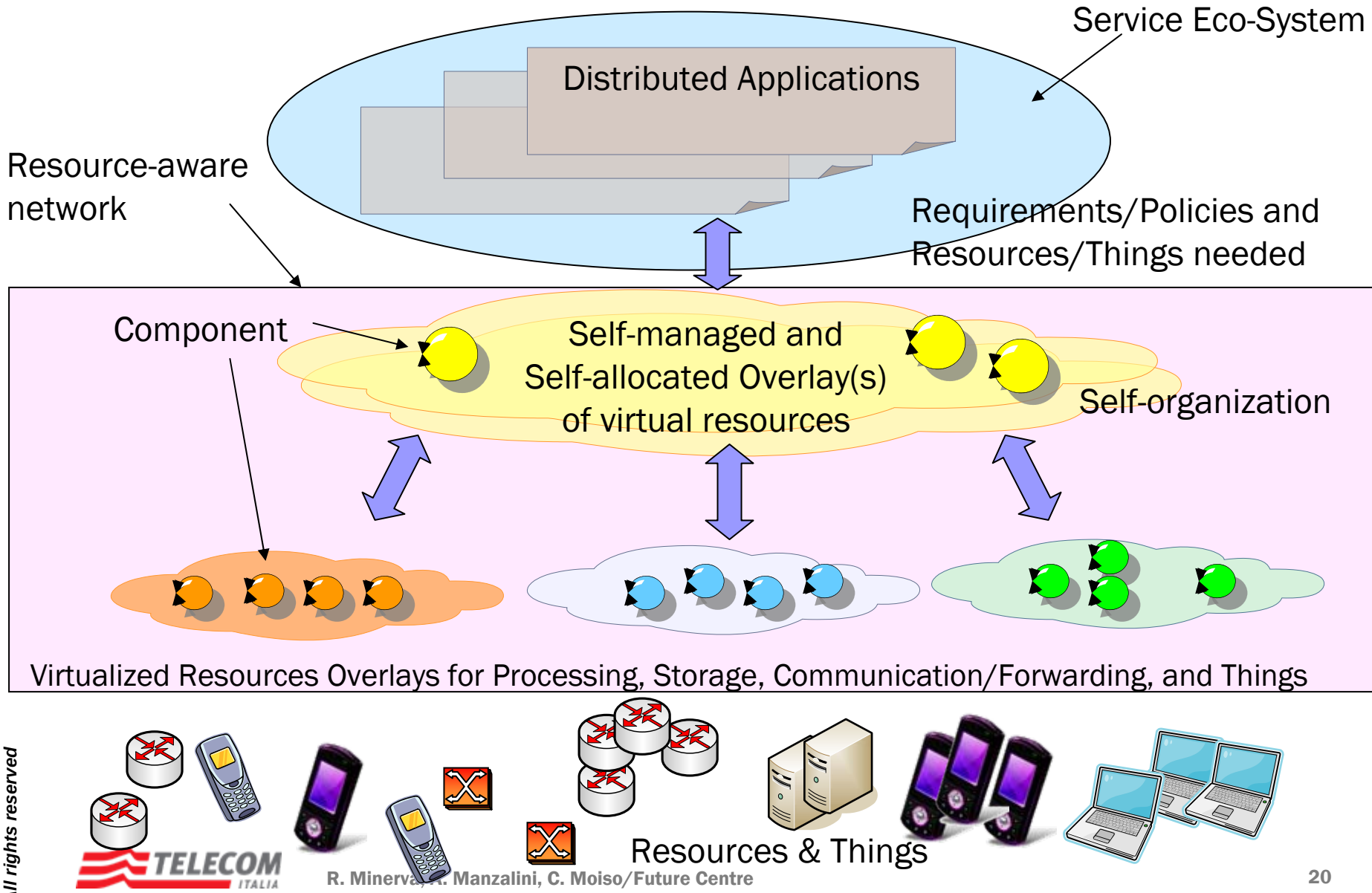


Technical Approach: Resource-awareness

- Distributed applications in a Service Eco-systems must be fed with Resources for their execution:
  - Processing, Communication, Storage, and
  - "Things" (e.g., sensors, contents, information/data);
- Resources should be allocated to applications to:
  - fulfill application needs (e.g., performance, robustness, required functions/contents);
  - optimize their usage (e.g., efficiency, reduction of bandwidth and energy);
- Allocation of shared resources must avoid "Tragedy of Commons":
  - service eco-system must find an equilibrium between allocation of resources to services and the sustainability of the entire environment;
- Resources are organized in (self-organized) overlays to implement distributed self-management policies:
  - overlays of resources of the same types;
  - overlays of resources allocated to the same application;



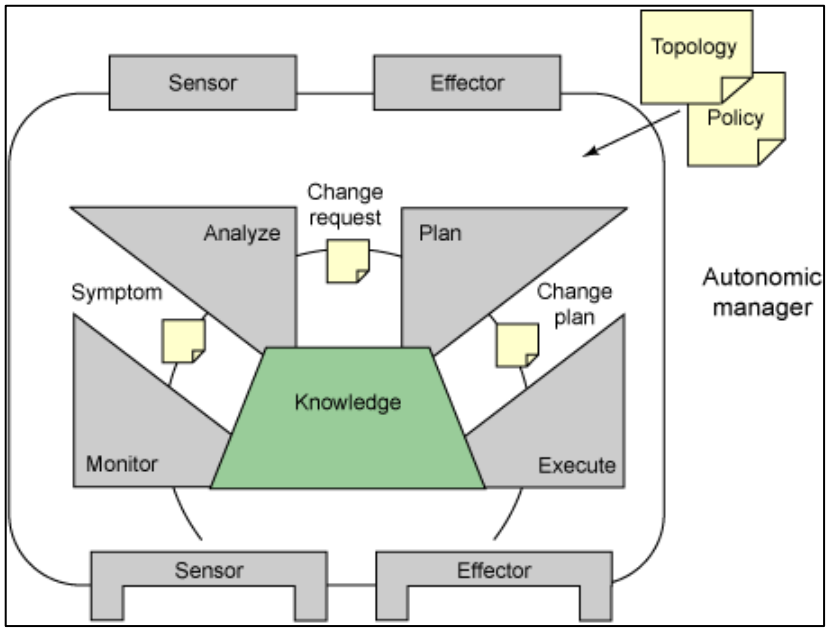
Technical Approach: Resource-awareness



Technical Approach: Cross-Layer and De-Layer approaches

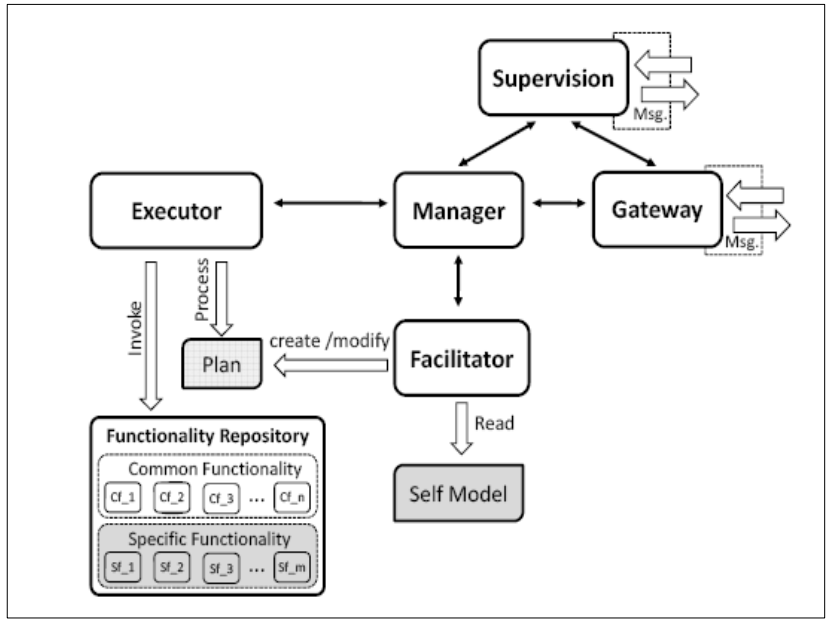
- Cross-Layer Design (CLD) has become an increasingly important methodology for enhancing the quality (in terms of throughput, delay, and efficiency etc.) of various communication systems. Cross-layer design refers to methodologies to integrate the layers of protocol and network stacks in order to improve the efficiency and quality. Recently more systematic CLD frameworks (e.g. game-theoretic and optimization based) for cross-layering have been studied but further research is still required;
- De-Layer Design (DLD) refers to the design of NoNs, that cannot be simply modeled with a traditional layered approach (i.e. based on a client-server interactions). The power of such innovative architectures stands in the dynamic and layer-less interactions of clouds of components (e.g. based on peer-to-peer organization) virtualizing the underneath resources. New DLD methodologies are required to design layer-less, highly dynamic NoNs;

Current results: Autonomic Communication Element (ACE)



AUTONOMIC COMPONENT

http://www.ibm.com/developerworks



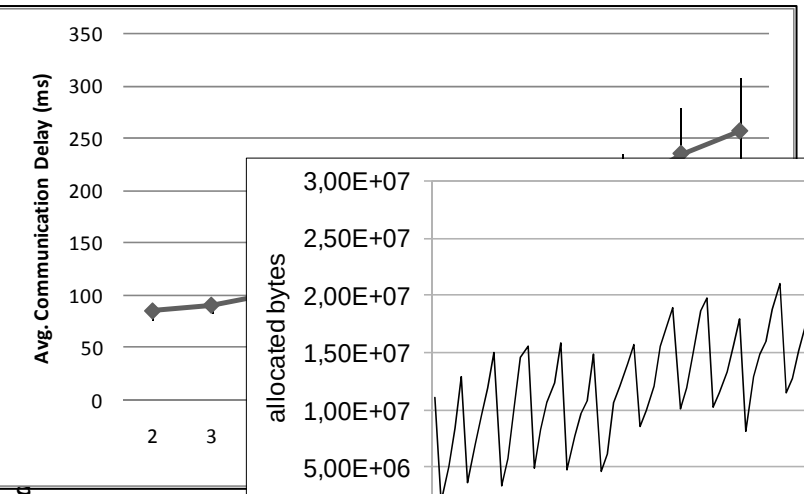
CASCADAS ACE

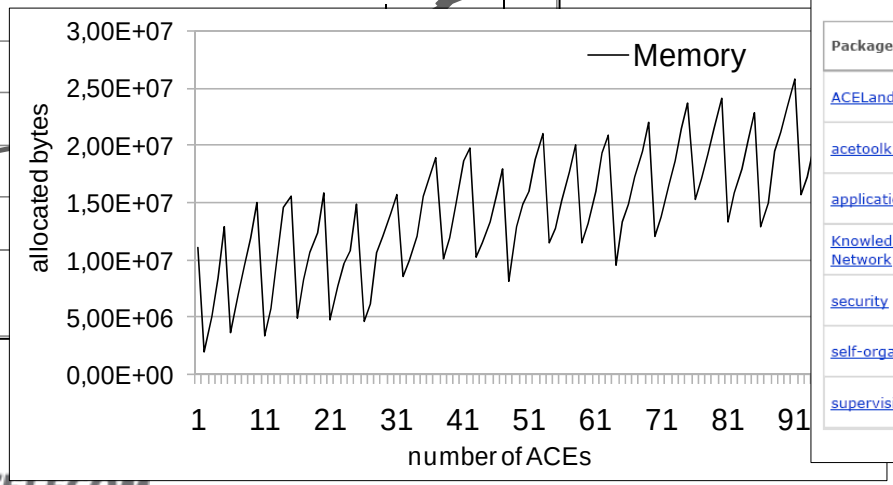
http://www.cascadas-project.org/

- **ACE is an autonomic component abstracting functions and/or resources; CASCADAS distributed service ecosystem is composed by interacting and self-organising ACEs;**
- **ACE consists of organs (Gateway, Manager, Facilitator, Executor, Functionality Repository and Supervision) performing certain autonomic capabilities and thus assuring the emergence of overall self-* behaviors in the distributed service ecosystem;**

Current results: A distributed Tool-Kit of ACEs

- ACE toolkit is running on servers, laptop and even mobile devices (e.g. it has been ported on Nokia 800 and Android);
- ACE tool-kit is highly stable and shows good scalability in terms memory, threads and communication delays;
- ACE toolkit is available in OpenSource at http://sourceforge.net/projects/acetoolkit/;



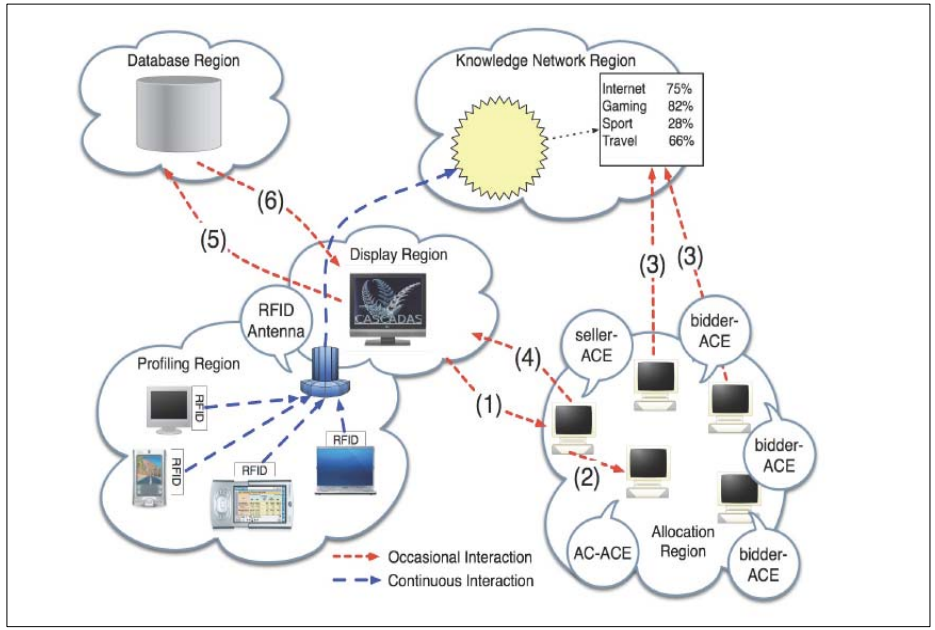


A platform for setting up autonomic services in a distributed environment. Provides service discovery, service provisioning / usage, autonomic adaptation to the context, mobility, support for supervision and service aggregation, and more.

Package	Release	Date	Notes / Monitor	Downloads
ACELandic	ACELandic v2.0	December 18, 2008		Download
acetoolkit	ACE Autonomic Toolkit v1.4	February 25, 2009		Download
applications	Pervasive Behavioral Advertisement Demo	January 13, 2009		Download
Knowledge Network	Knowledge Network Extension v1.1	December 20, 2008		Download
security	Security-1.0	December 9, 2008		Download
self-organization	Adaptive Aggregation	December 11, 2008		Download
supervision	Integrated Demo - Supervision Extension	January 12, 2009		Download

Current results: ACE Tool-kit tested in a real experimental use-case

- Scenario is a public place with a number of screens used to display contents and ads messages;
- CASCADAS tool-kit provides contents dynamically adapted to the profiles of the people in front of a screen;
- Service is provisioned by a pervasive infrastructure including also Users' devices (e.g. smart phones, RFID tags);
- Screens are equipped with a local network of "receptors" to detect (anonymous) profiles of people in front of a screen;
- Algorithms compute an average profile describing the population in front of the screen and selects (after an auction between Advertisers) the content on the basis of such a dominant profile;



Personal Behavioral Ad

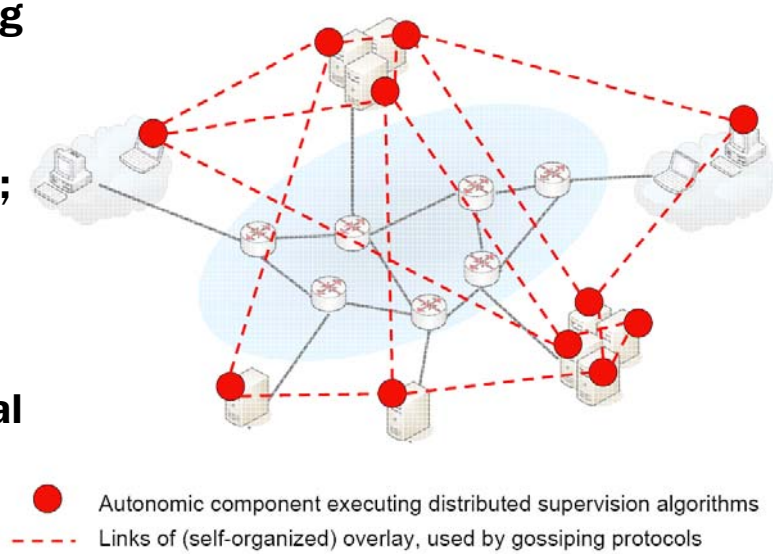
Current results: Self-* distributed supervision algorithms

The context:

- Supervision of a distributed cloud of pervasive computing elements (e.g., servers/clusters, users' devices) interconnected through Internet, where nodes can dynamically join/leave the cloud;
- Characteristics of the dynamic pervasive cloud prevent the adoption of centralized solutions:
  - computed solution could be obsolete, due to cloud dynamicity;
  - impossibility to have an effective picture of the system state, due to the geographical distribution, dynamic evolution of the cloud and the possible (temporary) disconnections;

The solution:

- The cloud is managed through a set of ACs interworking through an overlay network:
  - setup of overlay network through self-organization;
  - distributed supervision through ACs self-adaptation;
  - information exchange through gossiping;
- Supervision logic is fully distributed:
  - no centralized knowledge of system state;
  - local decisions perfomed by ACs based on local state and data exchanged with neighbors);
- Human involvement limited in configuration;

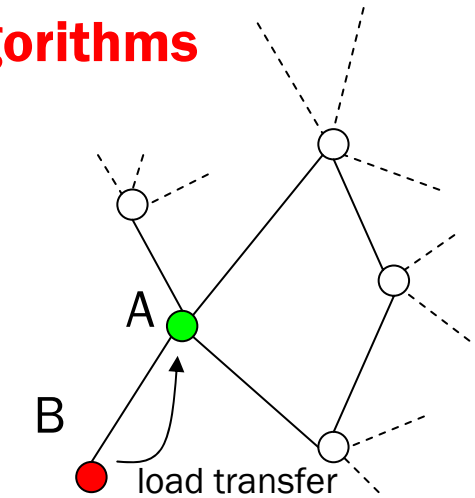


Current results: Self-* distributed supervision algorithms

Simple rules for load balancing and saving power

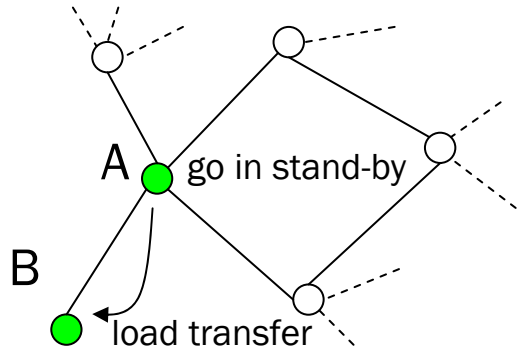
Pull-when-underloaded load balancing (LB):

- **when a node A is underloaded, A interacts with its neighbors in the overlay to get some load;**
- **if an overloaded node B receives a request to transfer some load, B provides the information on the load to transfer;**



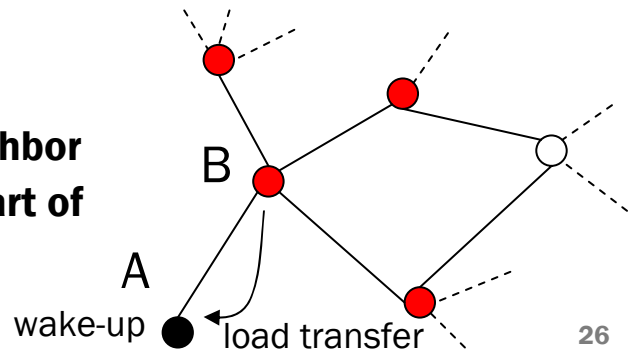
Stand-by logic (PS):

- **an underloaded node A starts it;**
- **A gets a random neighbor B in the overlay;**
- **if B is not overloaded and is able to take all the load of A, A transfers its load, and goes in stand-by;**



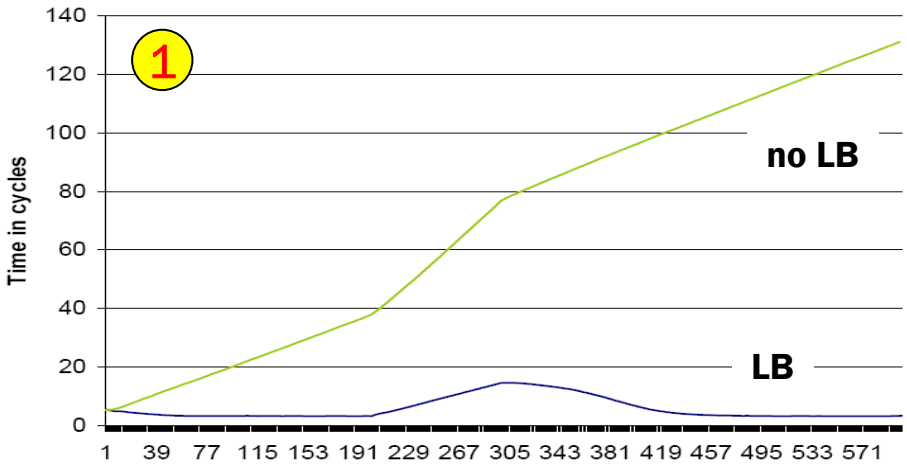
Wake-up logic (PS):

- **if an overloaded node B cannot find any underloaded neighbors to transfer some of its load, it selects a neighbor A in stand-by mode, if any, wakes up A and transfers part of its load to A;**

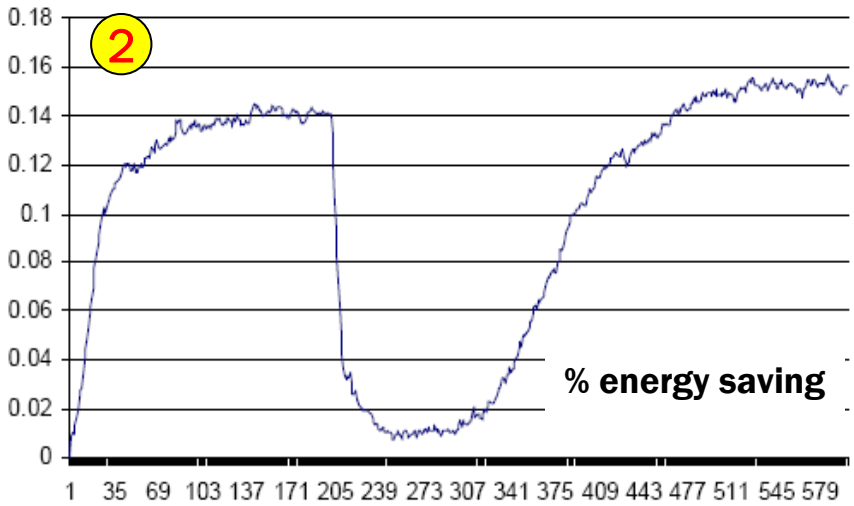


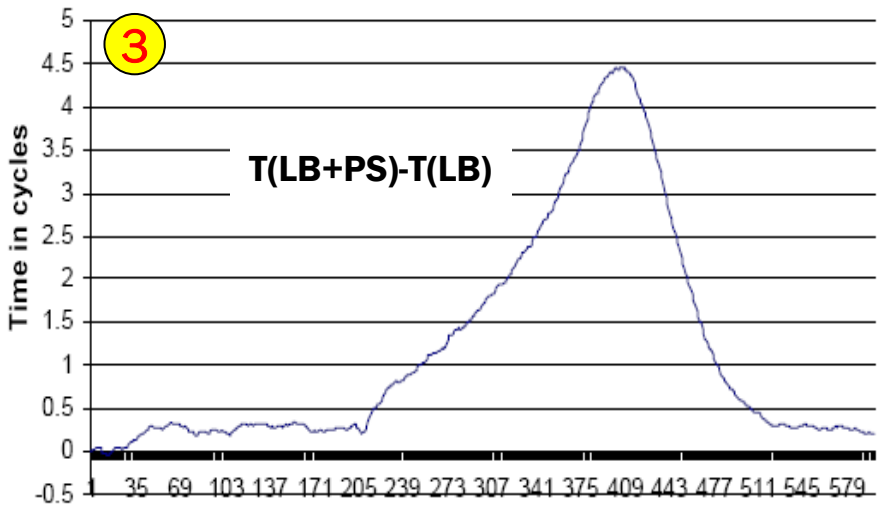
Current results: Self-* distributed supervision algorithms

Simularion results for load balancing and saving power



- Simulations with Breve tool (www.spiderland.org):
  - 6400 nodes;
  - pick of traffic (+50%): [200-300] cycles;
- Some results:
  1. the system with LB is stable;
  2. the system with LB+PS has a power saving of ~14%
  3. with limited incremement of execution time (~5%). during normal traffic periods:





Next: Open Questions

- Which mix of networking and computing paradigms and technologies will enable the scenario (characterized by high pervasivity, with connectivity as a commodity and Network of Networks) ?
- How to optimize allocation, sharing and management of pervasive resources, to guarantee the best Users' experience whilst reducing the systems and Operators' costs ?
- How to ensure the sustainability of the entire ecosystem, to avoid "Tragedy of Commons" due to unplanned usage of shared resources ?
- How to protect the ecosystem ?

Next: Future work

- Definition of components virtualising resources and functions;
- Definition of interfaces between autonomic components;
- Identification of distributed algorithms for:
  - self-management and self-organization of resources and services;
  - optimal allocation of resources (e.g., by means of game theory, auction);
- Definition of design paradigms:
  - Cross Layer vs. De-Layer design;
  - Design for Choice;
- Identification of algorithms and solutions for:
  - incentives and punishments of free riding nodes;
  - security issues (e.g., identity, detection of malicious nodes);

Publications and internal documents (1/2)

- R. Minerva, “On Some Myths about Network Intelligence”, in Proceedings of International Conference on Intelligence in Networks - ICIN2008 (October 2008)
- R. Minerva. “Crossing the Web 2.0 chasm: a winning strategy for Operators” in SDP 2.0 – Service Delivery Platforms in the Web 2.0 Era, edited by Kimbler, K., Taylor, M., for Moriana available in www.moriana.com
- A. Manzalini, R. Minerva, C. Moiso, “Exploiting P2P solutions in Telecommunication Service Delivery Platforms”, in N. Antonopoulos, G. Exarchakos, M. Li, A. Liotta Eds. "Handbook of Research on P2P and Grid Systems for Service-Oriented Computing: Models, Methodologies and Applications”, IGI (2009), also in “Verso le Piattaforme Adattative per Reti di Servizi”, Telecom Italia Technical Document TFC0900002 (January 2009)
- A. Manzalini, R. Minerva, C. Moiso, “Bio-inspired Autonomic Structures: a middleware for Telecommunications Ecosystems”, in A. Vasilakos, M. Parashar, S. Karnouskos, & W. Pedrycz (Eds.), “Autonomic Communication”, Springer (2009), also in “Distributed Autonomic Middleware for Telecommunications Ecosystems”, Telecom Italia Technical Document TFC0900005 (January 2009)
- R. Minerva, A. Manzalini, C. Moiso, “I dati di un Operatore: quali sono, come usarli e perché esporli”, Telecom Italia Technical Document TFC0900006 (February 2009), in Italian
- P. Deussen, L. Ferrari, A. Manzalini, C. Moiso, “Highly Distributed Supervision for Autonomic Networks and Services”, Proceedings of the Fifth Advanced International Conference on Telecommunications - AICT2009 (May 2009)
- S. Sahuquillo, L. Ferrari, A. Manzalini, C. Moiso, J. Solé Pareta, B. Otero, “Self-Organized Server Farms for Energy Savings”, in Proc. 6th International Conference on Autonomic Computing and Communications - ICAC09 (June 2009)

Publications and internal documents (2/2)

- R. Minerva, A. Manzalini, C. Moiso, Supervision of decentralized systems: the magic of self-organization", Telecom Italia Technical Document TFC0900009 (June 2009)
- A. Manzalini, C. Moiso, E. Morandin, Cloud Computing: stato dell'arte e opportunità, Telecom Italia Notiziario Tecnico (July 2009), in Italian
- A. Manzalini, R. Minerva, C. Moiso, "If the Web is the platform, then what is the SDP?", in Proc International Conference on Intelligence in Networks - ICIN2009 (October 2009)
- A. Manzalini, R. Minerva, C. Moiso, "Autonomics in the home", in Proc. International Conference on Intelligence in Networks - ICIN2009 (October 2009)
- M. Baumgarten, P. Deussen, A. Manzalini, C. Moiso, M. Mulvenna, "Autonomic Re-Configuration of Pervasive Supervision Service", Proceedings of Emerging 2009 (October 2009)
- Manzalini, F. Zambonelli, L. Baresi, A. Di Ferdinando, "The CASCADAS Framework for Autonomic Communications", in A. Vasilakos, M. Parashar, S. Karnouskos, & W. Pedrycz (Eds.), "Autonomic Communication", Springer (2009)
- A. Manzalini, C. Moiso, "Tecnologie autonomiche per ecosistemi di servizi", Mondo Digitale (2009), in Italian
- P. Deussen, A. Manzalini, C. Moiso, F. Zambonelli, "Autonomic Clouds of Components for future Service Ecosystem", Telecom Italia Technical Document TFC0900008 (May 2009)
- CASCADAS Project, Deliverable on CASCADAS results, www.cascadas-project.org

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