# A Multi-layered Agent Ontology System for Resource Inventory

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***Abstract*— Nowadays, worldwide public utility services providers feel the necessity of new flexible and scalable solutions aimed at managing their distribution networks and services. This is fundamentally due to the continuously technological evolution of distribution network infrastructures that impacts deeply on the software in charge of handling the services supply chain management. The purpose of this paper is to present an innovative system aimed at defining a new approach to resource inventory. This approach is designed both to reduce the influence of infrastructure evolution and to enable value-added services performed by autonomous intelligent agents. Based on the integration of semantic web technologies and agents paradigm, the system's mission is to define a new ontology-based model for resource inventory. Moreover, the system defines a new behavioral model enabling software agents to effectively react to the network environment in which they are embedded.**

**Keywords: resource inventory, intelligent agents, ontological modeling, behavioral modeling, semantic web.**

## I. Introduction

According with[11] the field of telecommunication industry nowadays needs more than ever to be considered as a public utility. Worldwide telecommunications industry went through two basic periods of transition: the liberalization of the business sector and the migration from a circuit-based network infrastructure to a packet-based one. In the same way the software in charge of managing telecommunications systems shared this transition that has influenced all the operators, starting from hardwired to mobile networks providers, up to internet service providers. All these companies took advantages of software applications aimed at automate manual processes influencing the whole telecommunications services supply chain, thus enhancing return on investment (ROI) while reducing costs. Due to the markdown of phone services pricing, service providers are more and more improving management software in order to remain competitive while keeping corporate profits and enhancing the earning power of provided solutions.

Recently telecommunications industry strategical focus has moved from large investments to a more careful exploitation of the market. Indeed massive investments days have been replaced by a lower budget intended to a more accurate search for a greater profitability. In such a scenario, more or less all telecommunications operators are trying to do more with the as lower as possible investment while, at the same time, trying to reduce the risks.

In the aforementioned big picture Operation Support Systems (OSS) find their role as software making the difference in services provisioning in that it assists service providers to attract and keep clients.

The OSS definition generally refers to software systems aimed at the realization of many functions related to telecommunications networks and services. These functions comprehend order management, service provisioning, service activation, fault management, performance management, inventory control, workforce management and network planning and engineering. Fundamentally, OSS software controls (both directly or indirectly) a set of processes designed to the usage, the development and the spreading of applications that interface clients to the network.

Most currently available OSS products are developed to solve specific organization problems and thus they are often customized depending on a given service provider or well defined business process. New Generation OSS (NG OSS) are appearing that improve the previous ones in order to supply service providers with more robust products suites. These include the development of solutions based on integrated platforms able to face with a wider needs spectrum. The importance of NG OSS is plain when looking at the whole life cycle of the telephone service as a set of OSS applications interconnected each other in order to face up to the effectiveness of a service provider. It stands likewise to reason how best-of-breed solutions are needed in order for a service provider to be competitive in terms of quality of the supplied services.

Out of the aforementioned functions a key role in network handling OSSs is played by inventory control. Independently from the networks dimension and complexity, it allows the automation of a great part of the foreseen business processes,

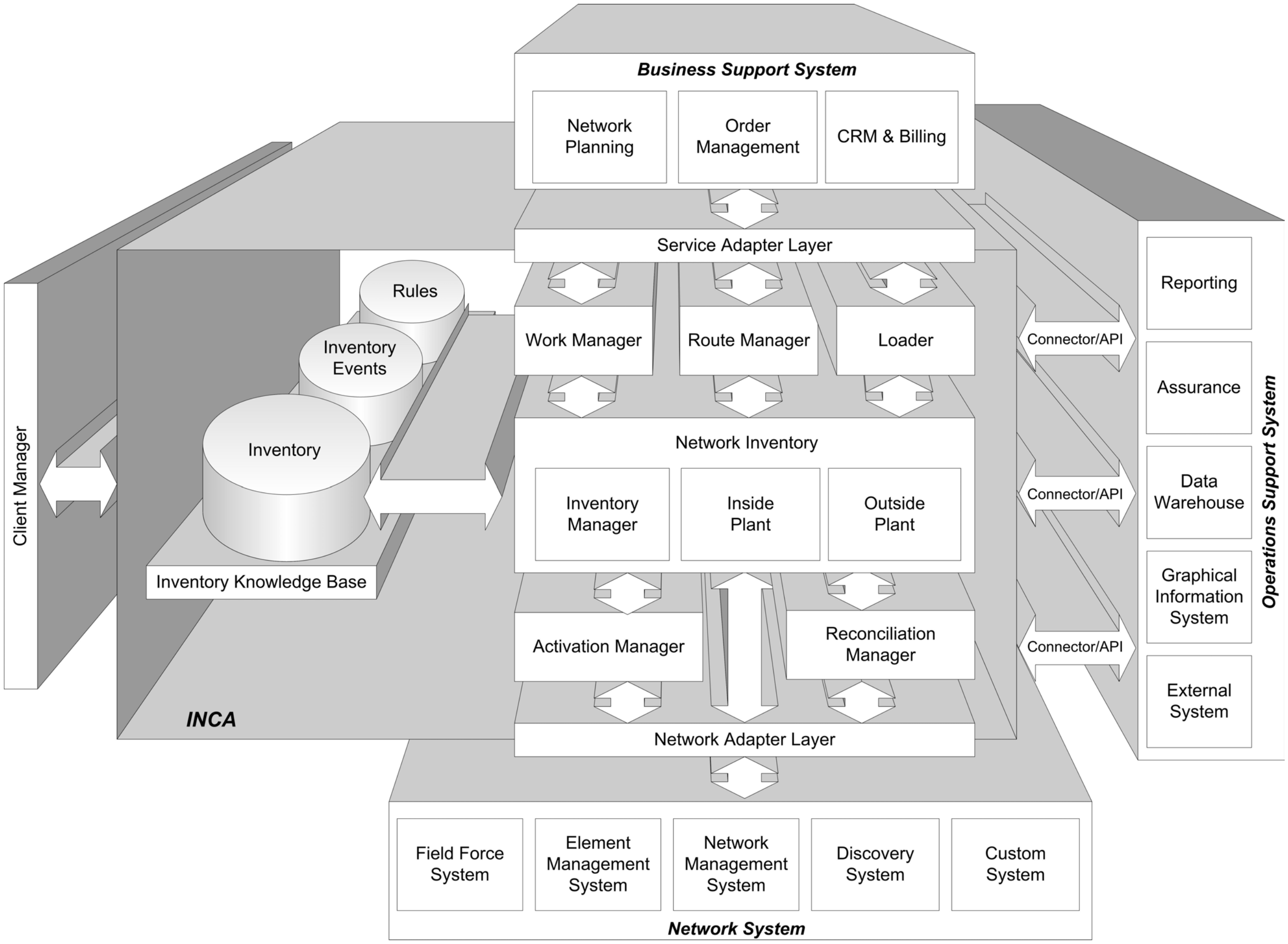


Fig. 1. Functional architecture of INCA

such as planning, implementation, configuration, and automatic provisioning of telecommunications services. Indeed, precise and detailed maintenance of network resources data is an essential prerequisite to enhance telecommunications networks handling.

This paper presents an innovative system designed to add a semantic dimension to network inventory while making it feasible to be exploited by autonomous agents in charge of performing some of the chief processes identified by the Enhanced Telecoms Operations Map (eTOM[36]) from the Telemanagement Forum. Some of these are:

- Service Creation, comprehending network designing and planning;
- Service Provisioning, the process allowing to satisfy services requests depending on the telecommunications network capacity and configuration;
- Service Activation, that allows to execute all modifications to the network configuration;
- Service Assurance, along with the support for ready problems solution and for a better planning of network maintenance;
- Network Provisioning, dealing with network adjustments in order to allow the activation of new services.

The project has been partially financed by the Italian Ministry of Economic Development and is based on the tight integration of semantic web technologies with agents paradigm. It defines a high scalable inventory system able to exploit the semantic knowledge about the network in order to provide value-added services to network operators. The system has been conceived by researchers from the University of Salerno in the context of INCA project conducted by I.T. Staff and expects the implementation of a prototype able to handle a mobile network inventory and services.

The paper is organized as follows: in Section II is described a INCA short abstract along with the general architecture of its core elements. Here is illustrated the general mechanism of an ontological events based behavioral model upon which depends the multi-layered agents system in charge of supporting the advanced network inventory model and activities. Some brief conclusions will follow in Section IV.

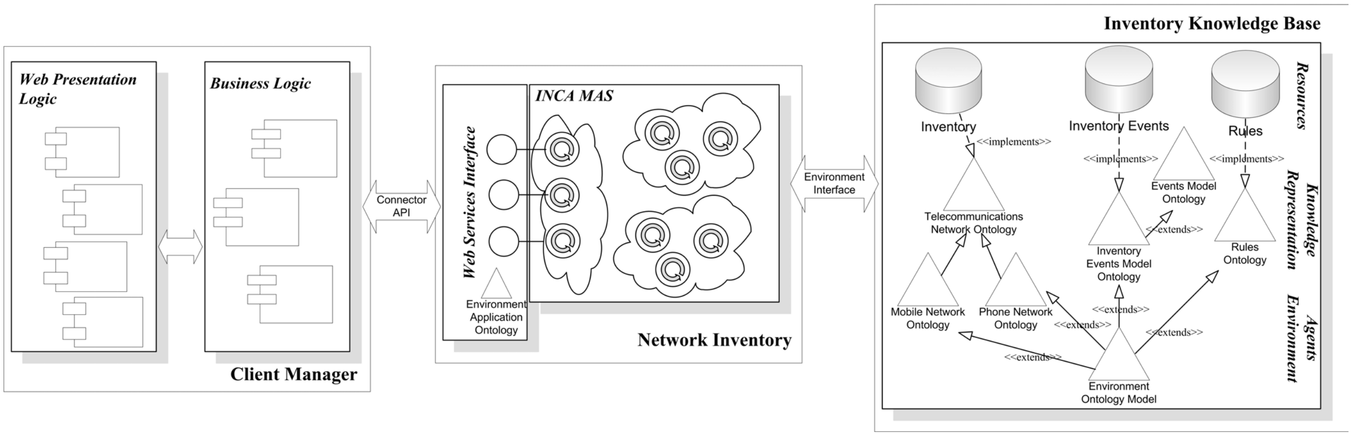


Fig. 2. Structural architecture of INCA

## II. Preliminaries

### A. General characteristics

INCA is an integrated software solution designed for telecommunications managers. It has been thought as a suite made up by several applications integrated in order to allow the automation of the chief business processes. The architectural design (depicted in Fig.1 from a functional point of view) has been conceived to be modular and highly scalable in order to meet specific needs of several network managers operating nowadays in the market, in terms of both dimensions (local, national and international) and technologies (mobile networks, etc.).

Complying to the international standard ITU G805, INCA is designed to support existing and emerging access and transport network technologies, such as PSTN, ISDN, IP, ATM, xDSL, SDH/SONET, PDH, DWDM, Frame Relay (FR) and 2G/3G mobile networks.

As shown in Fig.1 the system is made up by the following main components:

- *Work Manager*, coordinating and controlling the correct execution of service orders;
- *Route Manager*, finding and building network paths;
- *Loader*, allowing to upload data coming from legacy system;
- *Network Inventory*, the engine in charge of handling the inventory of network resources;
- *Activation Manager*, interfacing Network Management services to actuate work-orders;
- *Reconciliation Manager*, in charge of reconciliate inventory data;
- *Client Manager*, allowing INCA users to access the system;
- *Connector/API, Service and Network Adapter Layer*, providing integration with external systems;

All these functional modules provide everything is needed to exploit fully the resources made available by the inventory. The final result is a system completely integrated with other OSS and BSS systems.

Looking at the diagram it sounds to reason how the *Network Inventory* subsystem represents the core component of NG OSSs. In the form of a flexible and intelligent data model, it has been developed adopting semantic web technologies with particular reference to the ontology and ontological languages level. This has allowed to formalize network related knowledge preparing the basis to enable autonomous agents support activities.

### B. Architecture

The approach adopted in INCA follows from the definition of a semantic-driven Domain Object Model (DOM) integrating validation rules in the DOM itself and allowing both simple extensions and different views of the same objects at the same time. Fig.2 depicts the structural architecture of the INCA system showing its main components:

- *Inventory Knowledge Base*, maintaining all inventory data in the form of a semantic storage ;
- *Network Inventory*, made up by many different set of agents, is in charge of handling inventory related activities;
- *Client Manager*, allowing users to access the network inventory through a web-centric application;

Inventory Knowledge Base (IKB) and Network Inventory (NI) subsystems are the key components on which is based INCA. The IKB subsystem defines a new efficient and flexible resources inventory model able to be immediately applied to new or emerging technological contexts (such as UMTS, etc.). It is designed as a layered set of ontologies interconnected by means of extension and inclusion relationships. Each ontology models components from a specific technological context and can be added to the IKB without any service interruption. The ontologies hosted by IKB are of different types, according to the their intended purpose:

- *Domain Concepts Ontologies*, defining INCA's general and shared ontological representation of infrastructure components.;

- *Applicative Ontologies*, maintaining the conceptualization that a specific vendor has defined for a (possibly, set of) given physical component(s);
- *Semantic Bridging Ontologies*, allowing to specify how to convert applicative ontologies' concepts into/from domain concept ones;
- *Service Ontologies*, enabling the definition of roles and behaviours for agents in charge of executing tasks related to inventory resources;

Fig.3 shows the layering of IKB managed ontologies set. Specifically, the Domain Concept Ontologies is a set of ontologies semantically characterizing inventory resources. Each ontology can be defined by means of extending one or more preexisiting ones in order to model a new technological context. For each concept in these ontology a physical components provided by a specific vendor should exist. This latter is conceptually modelled by means of an applicative ontology. The binding and conversion from/to homologous instances into the two model is performed by a mapping module (called Semantic Bridge - SE) driven by an instance of the semantic bridge ontology. This instance defines what attributes from the thwo instances should be mapped each other and the conversion rules to be applied.

Indeed, the greatest obstacle to the execution of an efficient and accurate resources provisioning process is the existence of several different inventory representations. Each of these, generally, is designed to support a particular OSS or business department of service provider. All these different representations lead to unavoidable mistakes in translation processes designed to adapt the underlying data from a given representation to another.

The solution based on semantic bridging allows to directly support the integration of knowledge handled by preexisting inventory systems. This is expecially useful when thinking at real industrial contexts (where the migration to new systems is always looked with suspicion) in order to reduce the overhead and costs required by migration processes. The Services Ontologies tier lies at the top of the ontologies stack allowing to model business processes depending on inventory resources, such as provisioning automation, data reconciliation, etc.

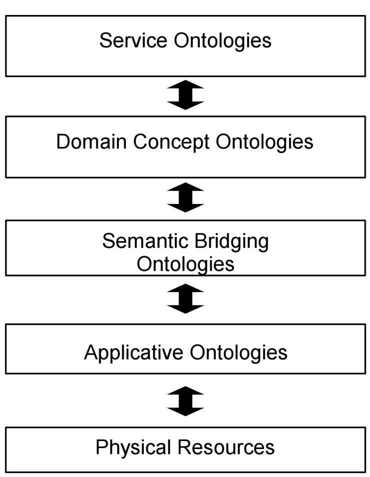


Fig. 3. IKB ontologies stack

The Inventory Knowledge Base defines the environment into which autonomous agents from the NI subsystem are embedded and work. Indeed, the NI subsystem is designed and organized in the form of a multi-agent system (INCA MAS) where each agent has a well defined set of assigned roles. Each agent interacts with other ones in order to reach (realize) shared business goals and tasks. Here, a goal is defined globally as a workflow where each activity generally depends on the occurrence of well defined events influencing the environment (see Fig.4).

An event is defined as a semantic rule involving inventory resources that must hold in the environemnt in order to activate the appropriate behaviour in charge of its handling. The key idea underpinning our approach is that the evaluation of the occurrence of a given event is considered equivalent to verify a given description logic formula against the ontological model (and its population) that defines the agent environment. In the same way, the generation of an event corresponds to a modification occurred in the environment by means of acting on an ontology instance both directly or due to a change in the state of the corresponding physical device.

In this vision the activities conducted by each INCA MAS role are defined through a set of tasks aimed at reacting to an event (or a set of them) occurred in the embedding environment. Each performed activity represents a step in a more general workflow and this let us see INCA MAS agents as pure reactive stereotyped autonomous agents where the behavior to actuate is defined by the occurred events.

Each agent in the NI is equipped with an interface making it able to access the ontological environment (see Fig.4) in order to sense or act on it. The diagram shows details about how a roles service is defined by a set of tasks instances whose ontological domain is defined by the environment.

An agent playing the defined role is bridged to the environment through the Environment Interface (EI) module enabling it to access its ontological model and population while offering query facilities, such as a SPARQL engine. The EI allows to translate each precondition to the activation of a specific action into a suitable query against the environment and each effect on the environment into an owl assertion to be added to the environmental knowledge base.

The EI is implemented by means of a service agent, the Ontological Environment Handler (OEH). The OEH agent is in charge of collecting and monitoring each change in the environment (and its ontological population). Each INCA MAS agent interested into sensing specific environmental event registers its interest with the OEH. This, in its turn, translates the request into a SPARQL query and stores it. Owing to a variation in the environment state, the OEH evaluates each stored query and, depending on the truth of the given condition, alerts the interested agent.

The adopted model allows to easily define, implement and maintain complex business processes driven and related by

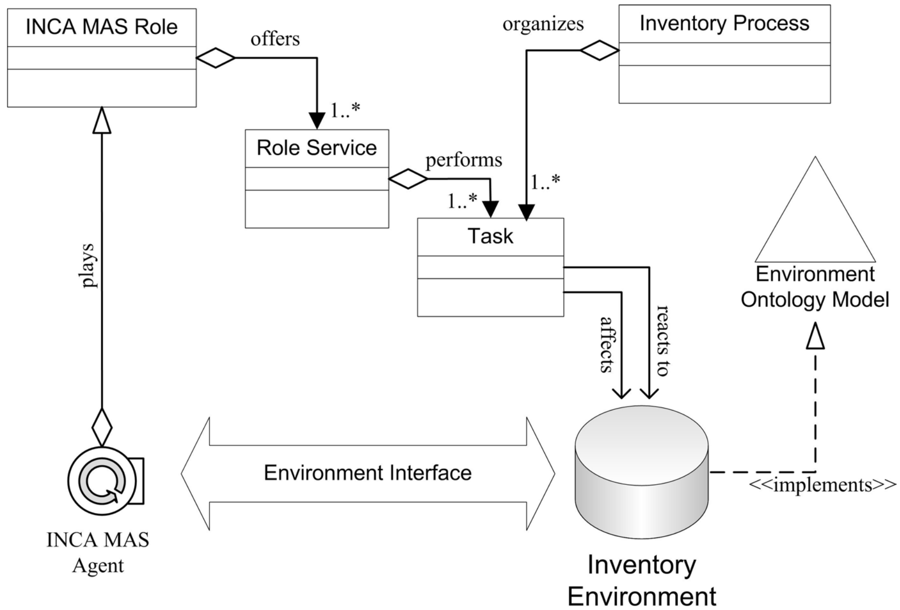


Fig. 4. Inventory processes decomposition in the INCA MAS

the underlying Inventory DOM.
The NI has been designed and implemented as a fully FIPA-compliant (Foundation for Intelligent, Physical Agents [16], [17], [18]) multi-agent system by means of the JADE (Java Agent DEvelopment Framework[24]). The multi-agent system has been designed according to the GAIA[37], [32] Agent Oriented Software Engineering methodology.
Network Inventory knowledge management services are offered on a SOA based approach. In particular, NI has been provided with a Web Service Interface (WSI) exposed by a specific set of agents in charge of translating service requests into inventory action events triggering INCA MAS agents activities. The WSI accepts both SPAR-QL querys and OWL-DL statements through ad-hoc exposed services thus providing NI an RDF-Storage nature.
The global INCA architectural model is an hybridized structure combining the typical Three Tier model for enterprise applications with the central index based peer-to-peer distribution model peculiar to multi-agent paradigm. From the application domain perspective the integrated solution comes as the logical consequence of the introduction of autonomous software processes in the enterprise development world. Binding the wide range of reliable and easily accessible services provided by nowadays application servers with the scalability and robustness of agent framework enables us to get an highly profitable solution for a system involving automatic processes.

## III. RELATED WORKS

In the current scenario of the OSS market resource inventory can be seen as the main component.
Indeed, any operator feels the need to fully master a complete and centralized view of its own infrastructure, with respect to both a physical and logical perspective. To fulfil this need operators are more and more reling upon “off-the-shelf” applications provided by leading role third parties. In the telecommunications field, among the others, leading products are:

- Telcordia Granite Inventory[35];
- GE’s Smallworld Network Inventory[20].

Being commercial products ruling the market long since and with regard to the purposes of this paper, the comparative analysis has been based on the inventory DOMs handling capabilities.
All currently available products are characterized by a DOM allowing them to provide a flexible inventory management system. In particular, DOMs provided by the aformentioned products allow the definition of new inventory types and elements, and the extension of the preexisting ones. This is achieved by means of logical views of physical devices.
INCA’s approach follows the same guildelines, providing a logical view of inventory resources. Nevertheless, the approach based on semantic bridging enables a further level of flexibility and scalability. In fact, simply redefining the involved semantic mappings, it allows to replace or modify definitions from the applicative ontology without any impact on domain ontology, services ontology and after all on the multi-agent system’s environment. This prevents the system to be affected by the performed operation while enhancing its global robustness.
Furthermore, using semantic web ontologies to model inventory resources allows us to use metadata in the definintion of complex resource handling tasks and semantic-driven business processes.
We believe that the inventory DOM of INCA can serve as a general framework for the construction of task-specific semantic driven resources handling tools that can be easily

adaptable for different domains, but we have not yet explored this aspect.

## IV. CONCLUSION

The worldwide OSS market, worthing $21.5 billion in 2006 is highly diversified, with many players competing for market share. OSS vendors are trying to expand and complement their core offerings in order to produce integrated solutions able to meet wider market segments. Vendors differentiate themselves mainly by the scope of their products, the features they support and the modularity, scalability and interoperability of their offerings. Among the key differentiating factors are innovation and integration capabilities. Gartner RAS Core Research in [26] states that "[...] OSS will remain a major focus area for carriers moving toward next-generation service delivery environments[...]".

In this scenario the approach to OSS will be more and more oriented to highly integrated multi-service environments. It sounds to reason that more flexible architectures and technologies are needed in order to allow the creation of new value-added services able to interface with adjunct systems, such as business support systems.

In response to this trend this paper illustrated a new model to Network Inventory management defining a new Network DOM suitable to address the continuous fast evolution of requirements, technologies and standards. At the same time the model enables autonomous agents activities as a way to model and implement value added services and workflows.

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