Metropolitan Ecosystems among Heterogeneous Cognitive Networks: Issues, Solutions and Challenges

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Abstract. Cognitive Networks working on large scale are experimenting an increasing popularity. The interest, by both a scientific and commercial perspective, in the context of different environments, applications and domains is a fact. The natural convergence point for these heterogeneous disciplines is the need of a strong advanced technologic support that enables the generation of distributed observations on large scale as well as the intelligent process of obtained information. Focusing mostly on cognitive networks that generate information directly through sensor networks, existent solutions at level of metropolitan area are mainly limited by the use of obsolete/static coverage models as well as by a fundamental lack of flexibility respect to the dynamic features of the virtual organizations. Furthermore, the centralized view at the systems is a strong limitation for dynamic data processing and knowledge building.

Keywords: Cognitive networks, Semantic technologies, Distributed computing, Sensor networks.

1 Introduction

Cognitive Networks [1] working on large scale are object of an increasing interest by both the scientific and the commercial point of view in the context of several environments and domains.

In fact, during the last years, research activities about local phenomena and their correspondent impact on global phenomena have been object of great interest inside the scientific community as well as in the context of public and private research institutions. Concrete environments (Figure 1) could depend by the research scope/goal and they can significantly vary for size, amount and kind of information, involved actors, etc. An ideal scenario in this sense is a metropolitan area that provides a complex heterogeneous ecosystem in which humans, machines and the environment are constantly interacting.

Common research activities at metropolitan area level are mainly focused on the study of climatic or environmental (e.g. chemical or natural element presence or concentration) phenomena and of human behavior (behavioral patterns, traffic, noise, etc.).

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The study of these phenomena, first of all, interests the citizens (or concrete collectives) because it can be a complex and exhaustive feedback in order to improve the quality of life or to provide specific services for the interested collectives (allergic people for example). The evolution of these phenomena in the medium and large period, as well as its social impact, is object of great interest in the context of different domains and disciplines.

The natural convergence point for these heterogeneous disciplines is the need of a strong advanced technologic support that enables the generation of distributed observations on large scale as well as the intelligent process of the obtained information (Figure 1).

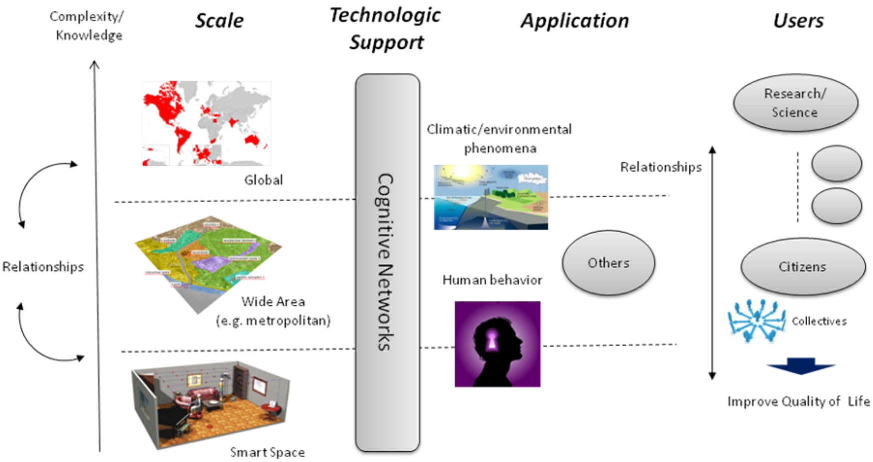

Fig. 1. Cognitive Networks as technologic support

Existent solutions at level of metropolitan area are mainly limited by the use of obsolete/static coverage models as well as by a fundamental lack of flexibility respect to the dynamic features of the most modern virtual organizations. Furthermore, the centralized view at the systems is a strong limitation for dynamic data processing and knowledge building. Finally, the heterogeneous nature of data and sources implies complex model for data representation and the related knowledge has to be analyzed according to several perspectives (e.g. local knowledge, domain, cross-domain).

This paper would exhaustively discuss the impact of the application of semantic technologies to high scale cognitive network, enabling semantic ecosystems among heterogeneous structures and information.

The paper is logically structured in two main parts. The first part has mainly the goal to define and characterize semantic ecosystems in relation with real environments. It also deals the main limitations currently existing for the massive dissemination of cognitive networks working on metropolitan scale. A short overview about the most innovative solutions for each one of the key technologic aspects featuring cognitive networks will be provided as well as a short analysis about related business models. Finally, in the last section, the impact of the semantic technologies application is analyzed, as key factor for the improving of the interoperability level among heterogeneous networks, sub-networks and data. Furthermore, the capabilities of knowledge building and intelligent analysis of data can be strongly improved.

2 Cognitive Networks: From Science to Reality

A classification of Cognitive Networks could be hard to be proposed because there is an intrinsic relation between the application and these complex systems. According to a simplified view at cognitive networks, in the context of this paper we will consider a cognitive system composed of four independent but interrelated functional/logic layers:

- *Data Sources.* Cognitive Networks implicitly work on large scale. A first and simple way to classify and categorize them is the conceptualization of the data sources. The modern society implicitly or explicitly provides great amounts of information. This information has to be "captured". We could basically distinguish between generated data (normally observations by sensors) and available data (data already existing in some electronic system). This second class of information is experimenting a constantly increasing of popularity mainly due to the social focus [2] that is becoming always more popular in large scale systems and applications. In the context of this work, generated data will be mostly referred, even if the most of approaches and solutions discussed are source-independent topics.
- *Data Representation.* Considering the heterogeneity of the available data from multiple data sources, the representation of data has a strong importance for the capabilities of systems. Semantic annotations and, more in general, ontologies could play a key role in this context as well as any other model/technology that allow advanced model for data interoperability.
- *Knowledge Building.* The main feature of the data representation is the need to provide a basic knowledge. This is not a limitation but, on the contrary, an added level of flexibility. In fact, the knowledge (understood as high-level information) building is provided by a further layer that directly works on the top of basic data. This model can assure the convergence of local knowledge to a unique virtual knowledge environment.
- *Application.* This is the only layer visible for the final user. Knowledge is represented, filtered and elaborated according to the application purposes.

Figure 2 proposes the formalization of the model using a Semantic Network [3]: semantic relations among concepts are built through a directed or undirected graph consisting of vertices, which represent concepts, and edges.

Evidently, this model is knowledge-oriented and it implicitly assumes the existence of a distributed communication infrastructure that implements the functional core of the system.

In this section, first the semantic ecosystems will be defined and characterized both with their relationships with real environments. Later, the current approaches to concrete solutions and related limitations are analyzed. Therefore, the main section scope is the definition of a generic reference scenario for semantic ecosystems in relation with their technologic and economic sustainability. As it will be discussed, there is, at the moment, a significant gap between theoretical models and their concrete application.

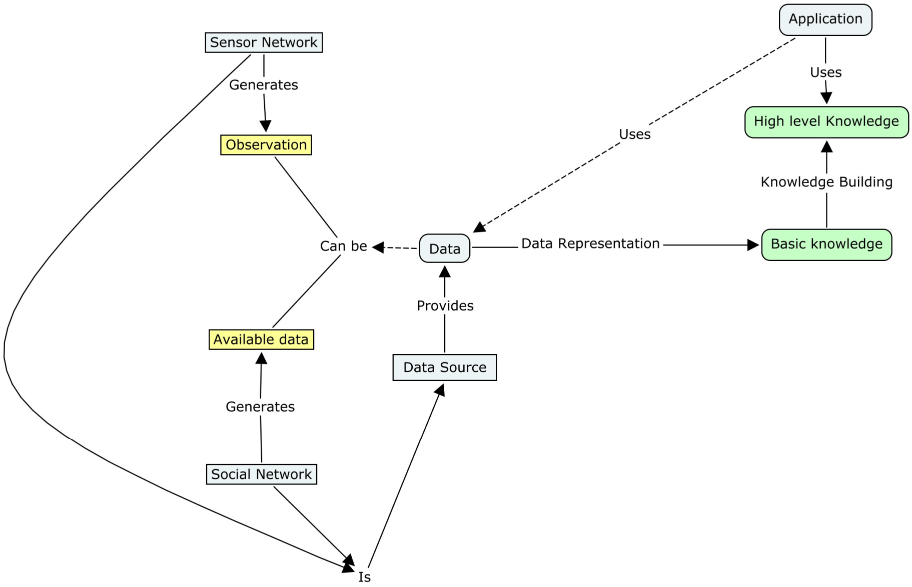

Fig. 2. Formalization of the model using Semantic Networks

2.1 Semantic Ecosystems among Heterogeneous Cognitive Networks

In the context of this work, a metropolitan or urban [4] ecosystem (Figure 3) is defined as a large scale ecosystem composed of the environment, humans and other living organisms, and any structure/infrastructure or object physically located in the reference area.

An exhaustive analysis of environmental and social phenomena is out of paper scope. Just considering that we are living in an increasingly urbanized world. From recent studies, it appears that this tendency will be probably followed also in the next future. It is a commonly accepted assumption that further increases in size and rates of growth of cities will no doubt stress already impacted environments as well as the social aspect of the problem.

Considering this tendency is hard to be controlled or modified, there are a great number of interdisciplinary initiatives, studies and researches aimed to understand the current impact of the phenomena as well as to foresee the evolution of it.

These studies have, evidently, a scientific focus, but they also could be of interest in the context of the everyday life. In fact, modern cities change their structure and physiology in function of human activities that constantly act as inputs for the feedback system. It is easy to imagine the great number of services that could improve the quality of life of citizens (or collectives) with a deep knowledge of the environment.

As mentioned, the study of the human activities, of the environmental and climatic phenomena is object of interest in the context of several disciplines and applications. All these studies are normally independent initiatives, logically separated researches and, in the majority of the cases, results are hard to be directly related. This could appear a paradox: interest phenomena happen in the same physical ecosystem, involving the same actors but the definition of the dependencies/relationships among atomic results are omitted even if they are probably the most relevant results.

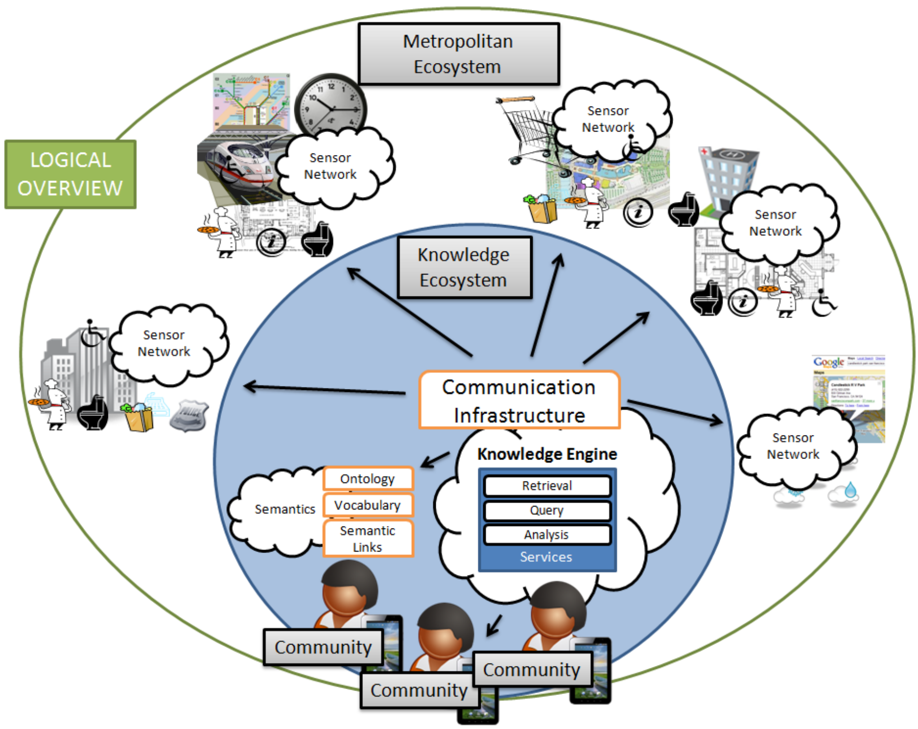

Fig. 3. Logical overview at Semantic Ecosystems

The common point is the need of great amounts of heterogeneous data, normally generated on large scale [5]. They can be "simple" measurements or complex phenomena, sometimes hard to be detected. This overall approach according heterogeneous model has a strong impact especially in the representation and processing of the information.

Summarizing, at now urban ecosystems have a directly equivalent logic concept by a knowledge perspective but its realizations are mainly knowledge environments than effective knowledge ecosystems.

2.2 Current Approaches and Limitations

The normal technologic support for enabling knowledge environment is the cognitive network [1] that assumes a physical infrastructure (sensors) able to detect interest information or phenomena and a logic infrastructure able to process the sensor data (knowledge building) eventually performing actions, responses or complex analysis.

The parameters that can potentially affect the "quality" of the applications or studies are mainly the sensor technology (constantly increasing in terms of reliability, precision and capabilities), the coverage area, the amount of data and, finally, the process capabilities.

Current solutions are hard to be proposed on large scale due to the current limitations of the massive sensors deployment on large scale [6]. Furthermore, the following limitations can be clearly identified:

- *Lack of Social View at the Information* [7]. Applications and studies have a fundamental lack of interaction and cooperation, even if they are part the same logic and physical context. A social approach could increase the possibilities of data sharing and collaboration.
- *Static Coverage Models*. High coverage areas imply the need of sustainable infrastructures. The common models that assume static nodes can be a high expensive solution in a context of high density of sensors. Mobile sensor networks [8] could be a suitable solution for environments, as metropolitan areas, characterized by the presence of a great number of mobile actors (e.g. humans, vehicles, bikes, etc.).
- *Obsolete View at Resources*. Physical and logic networks are undistinguished with the consequent lack of flexibility in distributed environments. This is a strong limitation for a great number of business scenarios as well as a technologic restriction to the resource (physical in this case) sharing among structured virtual organizations [6]; [9]; [10]; [11].
- *Not Always Effective Business Models*. Due to the static view at resources and applications, innovative scenarios are hard to be realized and common business actors are hard to be identified in real contexts.

The impact of the proposed points can be limited if a distributed perspective for infrastructures and information is assumed. Due to the heterogeneous features of the data source and information, the interoperability plays a key role for the effective realization of the model.

In the next section, a distributed approach for the main infrastructure is described both with the most advanced solutions based on semantic interoperability that allow a social perspective for the knowledge. Also the analysis for the knowledge building process based on the application of the last generation contextual semantic is proposed.

3 The Impact of Semantic Technologies: Distributed Approach

The previous section propose an abstract model for semantic ecosystems as a possible evolution of cognitive networks to a distributed approach that should allow the enablement of complex logic ecosystems in a context of flexibility and economic sustainability. This conclusion is mainly motivated by the objective difficulty of modeling virtual organizations using centralized models as well as by the low level of interoperability that currently characterizes heterogeneous systems.

Distributed solutions (Figure 4) objectively improve the flexibility of architecture but they require a high level of interoperability among systems especially if they are not part of the same social and economic context.

This section would discuss the benefits introduced by semantic technologies as general solution for improving the interoperability and as key support for the processing of heterogeneous data (knowledge building).

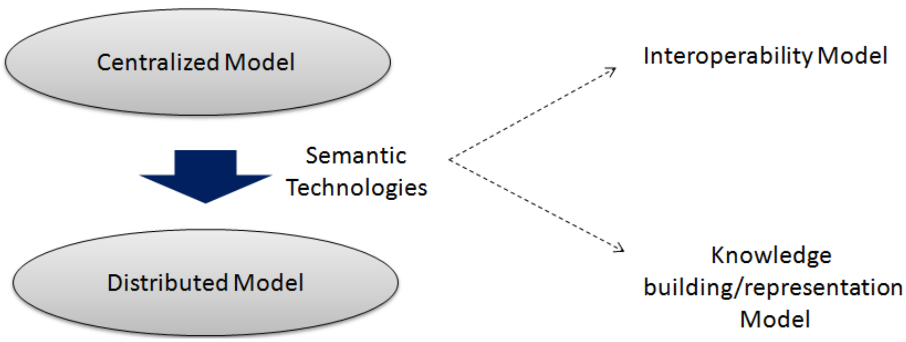

Fig. 4. Towards distributed approaches

3.1 Semantic Interoperability

Considering a distributed sensor domain, the key issue is the evolution of the Sensor Web model to the Semantic Sensor Web that, in practice, assumes systems interchanging semantic information on the top of the common functional interoperable layer [12].

The current semantic model for the web is affected by several problems. These open issues, such as ambiguities and performances, are object of an intense research activity that is proposing several solutions as simplification or particularization of the main model.

In order to enable effective working systems on large scale, a simplified model of the semantic web is considered [13]. It assumes semantic reasoners operating over three interrelated semantic structures (Figure 5):

- *Ontology* as in common semantic environment, it has to represent data and knowledge at different levels.

- *Shared Vocabulary*. It could be a contextual structure that represents an "agreement" in order to avoid possible ambiguities and semantic inconsistencies inside semantic ecosystems.
- *Semantic Link*. Additional structures that should link concepts from different ontologies and concepts from vocabularies. These structures can directly relate concepts from different ontologies and they can indirectly build contextual semantic environments.

As showed in Figure 5, the Ontology is a semantic structure normally associated to a local knowledge environment. Concepts from different ontologies can be related at domain level through semantic links to vocabularies concepts.

In the example represented in Figure 5, the concepts c1 and c6 are equivalent to the concept c3 at domain level and so, at this level, they are also equivalent to each other.

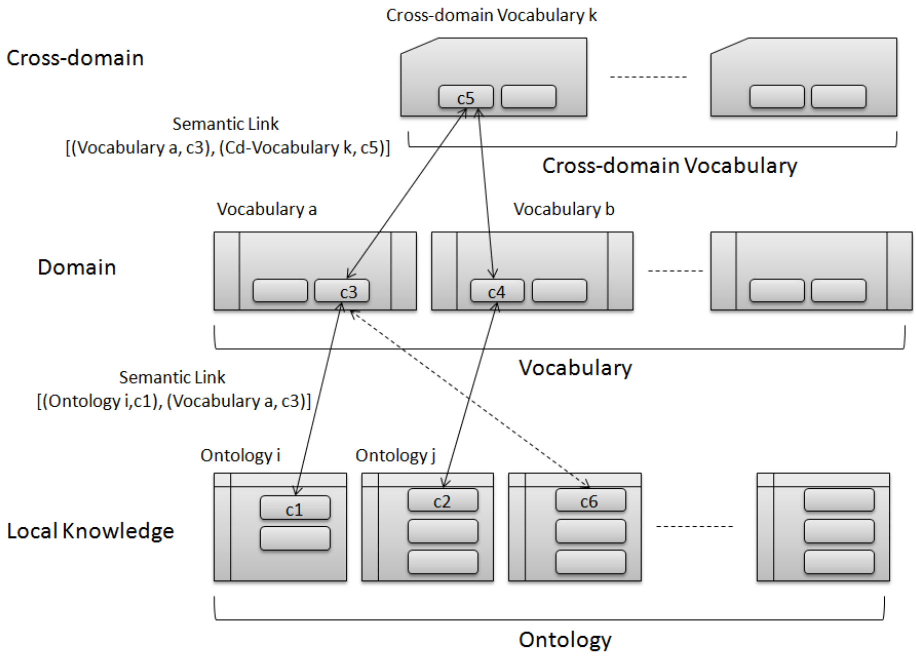

Fig. 5. Interoperability model schema

This schema could be an exhaustive model for the great part of logic environment associated to a concrete domain. But the heterogeneous features of semantic ecosystems force the knowledge environment to work in a multi-domain context. This last aspect need a further semantic layer (Figure 5): *Cross-domain Vocabularies* are defined in order to relate concepts from different domains through semantic links.

In the example of Figure 5, the concepts c3 and c4 are equivalent to c5 at global level. This also implies that c1 (linked to c3) and c2 (linked to c4) are equivalent to c5 and that they are equivalent to each other at global level.

A short analysis of the model proposed in Figure 5 first of all puts in evidence the hierarchical structure of the semantic knowledge building according to an increasing level of abstraction.

On the other hand, the semantic model is completely open and assures, through semantic links to higher concepts, a high level of expressivity and interoperability without forcing standard data models.

This last aspect has a critical importance at application level where models, rules and relationships need integrations, particularizations and extensions in function of concrete applications and domains.

3.2 Knowledge Building

This second support is the natural complement to the first one in order to provide systems with the capability of building abstracted knowledge on the base of basic sensor data on the model of [14].

The main challenge is the generalization of this approach on large scale and considering heterogeneous environment. As showed in Figure 6, a local knowledge schema (Ontology) is composed of two kinds of concepts:

- *Low-level Concepts*: They have a mean only in the context of their local knowledge environment. The main consequence is the lack of any class of semantic link. In practice, they are low-abstracted information that normally is “visible” only in the local system.
- *High-level Concepts*: They are a set of concepts that naturally complete the previous one. In fact, they are high-abstracted concepts that have evidently a local mean but also a domain and/or global mean.

A deeper analysis of the structure (Figure 6 on the right) allows the definition of semantic layers inside the main structure:

- *Data Source*. Set of low-level concepts that represent the data-sources (sensors or any other kind of physic/human data source).
- *Data.* As the previous one but representing data.
- *Core*. Abstracted layer composed of semantic rules that relate low-level and high-level concepts. Due to its critical role, this is the key layer in the semantic structure.
- *Domain-specific Layers*. Any set of high-level concept required in the context of concrete domains and applications.

The main advantage introduced by the schema is the possibility to have a common ground for data source and data representation, as well as a clearly defined set of standardized high level abstracted concepts.

Also the core part of the ontology, that has the goal of building the knowledge of basic data, is an ad-hoc component of specific applications. In the context of an ideal semantic ecosystem, any class of information (basic data or abstracted knowledge) can be correctly interpretated in the context of the owner system as well as inside other systems socially connected.

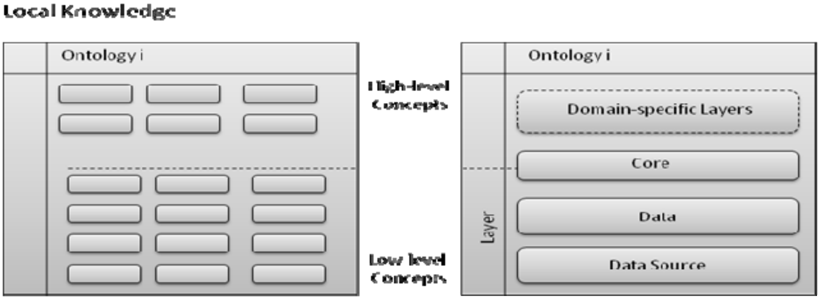

Fig. 6. Local knowledge model

4 Conclusions

The power of collecting and relating heterogeneous data from distributed source is the real engine of high-scale cognitive networks.

The economic sustainability, as well as the social focus on the great part of the applications, determines the need of an innovative view at networks and architectures on the model of most modern virtual organizations.

These solutions require a high level of interoperability, at both functional and semantic level. The current "Semantic Sensor Web" approach assures a rich and dynamic technologic environment in which heterogeneous data from distributed source can be related, merged and analyzed as part of a unique knowledge ecosystem.

References

1. Thomas, R.W., DaSilva, L.A., MacKenzie, A.B.: Cognitive networks. In: 2005 First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, DySPAN 2005, November 8-11 (2005)
2. Wang, F.-Y., Carley, K.M., Zeng, D., Mao, W.: Social Computing: From Social Informatics to Social Intelligence. IEEE Intelligent Systems 22(2), 79–83 (2007)
3. Borgida, A., Sowa, J.F.: Principles of semantic networks: explorations in the representation of knowledge. Morgan Kaufmann Pub. (January 1991)
4. Urban ecosystem, Wikipedia, `http://en.wikipedia.org/wiki/Urban_ecosystem`
5. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: A survey on Sensor Network. IEEE Communication Magazine 40(8), 102–114 (2002)
6. Pileggi, S.F., Palau, C.E., Esteve, M.: Enabling Wireless Sensor Network within Virtual Organizations. In: Prasad, A., Buford, J., Gurbani, V. (eds.) Future Internet Services and Service Architectures. River Publishers (2011)
7. Rahman, M.A., El Saddik, A., Gueaieb, W.: Building Dynamic Social Network From Sensory Data Feed. IEEE Transactions on Instrumentation and Measurement 59(5), 1327–1341 (2010)
8. Pileggi, S.F.: A multi-domain framework for Wireless Vehicular Sensor Network. In: Proceedings of International Conference on Ultra Modern Telecommunications and Workshops (ICUMT 2009), St. Petersburg, Russia, October 12-14 (2009)

9. Foster, I., Zhao, Y., Raicu, I., Lu, S.: Cloud Computing and Grid Computing 360-Degree Compared. In: Grid Computing Environments Workshop, GCE 2008 (2008)
10. Mell, P., Grance, T.: Draft NIST Working Definition of Cloud Computing v14, Nat. Inst. Standards Technol. (2009), http://csrc.nist.gov/groups/SNS/cloud-computing/index.html
11. Foster, I., Kesselman, C., Tuecke, S.: The Anatomy of the Grid: Enabling Scalable Virtual Organizations. International J. Supercomputer Applications 15(3) (2001)
12. Pileggi, S.F., Palau, C.E., Esteve, M.: Building Semantic Sensor Web: Knowledge and Interoperability. In: Proceedings of the International Workshop on Semsntic Sensor Web (SSW 2010), Valencia, Spain (October 2010)
13. Pileggi, S.F., Fernandez-Llatas, C., Traver, V.: A Semantic Layer for Embedded Sensor Networks. ARPN Journal of Systems and Software 1(3), 101–107 (2011b)
14. Pileggi, S.F.: A Semantic Environment for Data Processing in Embedded Sensor Networks. In: Proceedings of the International Workshop on Semantic Interoperability (IWSI 2011), Rome, Italy (January 2011)