Capturing the contributions of the semantic web to the IoT: a unifying vision (extended abstract)

Nicolas Seydoux[1,2,3], Khalil Drira[2,3], Nathalie Hernandez[1], Thierry Monteil[2,3]

[1] IRIT Maison de la Recherche, Univ. Toulouse Jean Jaurès,
5 allées Antonio Machado, F-31000 Toulouse
`{name.surname}@irit.fr`
[2] CNRS, LAAS, 7 avenue du Colonel Roche,
F-31400 Toulouse, France
`{name.surname}@laas.fr`
[3] Univ de Toulouse, INSA, LAAS, F-31400, Toulouse, France

Abstract. The Internet of Things (IoT) is a technological topic with a very important societal impact. IoT application domains are various, such as smart cities, precision farming, smart factories, smart buildings, etc, and the diversity of these application domains is the source of the very high technological heterogeneity in the IoT, leading to interoperability issues. The semantic web principles and technologies are more and more adopted as a solution to these interoperability issues, leading to the emergence of a new domain, the Semantic Web Of Things (SWoT). Scientific contributions to the SWoT are many, and the diversity of architectures in which they are expressed complicates comparison. To unify the presented state-of-the-art architectures, we propose an architectural pattern, Lower, Middle and Upper Node (LMU-N). LMU-N provides a reading grid used to classify processes to which the SWoT community contributes, and to describe how the semantic web impacts the IoT. A survey, based on this reading grid, capturing the integration of semantics into the IoT is the core of this paper. Then, the evolution of the semantic web to adapt to the IoT constraints is described as well, in order to give a twofold view of the convergence between the IoT and the semantic web toward the SWoT.

CEUR-WS.org/Vol-1930/paper-4.pdf

1 Introduction

The Internet of Things (IoT) is both a scientific, technological and societal challenge. The networks of connected devices are becoming an everyday reality for citizens across the world. The definition of the notion of IoT has evolved since it was first proposed in 1999 by Kevin Ashton[4]. An up-to-date definition is proposed by [1], embracing the diversity of nature and purpose of the so-called Things. The multiplicity of IoT application domains, as diverse as smartcity, agriculture, factory, home or e-health, learning, leads to a high heterogeneity in

---

[4] http://www.rfidjournal.com/articles/view?4986

term of applicative needs, and therefore a high heterogeneity on the hardware, the communication and the software layers.

This heterogeneity is a cause to the vertical integration of solutions: the same vendors distribute an application-dedicated hardware communicating with a potentially proprietary protocol with a dedicated application [2] . In this approach, data produced in a silo is not available to any other silo, even if it is of interest. Standardization bodies such as oneM2M[5] or the OCF[6] propose horizontal integration layers, easing access to data.

However, interoperability remains an issue at the semantic level. [3] defines semantic interoperability as a shared understanding of the meaning of data, based on common vocabularies and ontologies. Indeed, it is not guaranteed that applications will have the same understanding of a message they exchanged, provided they are technically[7] and syntactically[8] interoperable . Indeed, on the IoT, the communication is conceived Machine-to-Machine (M2M), with no intermediary to solve ambiguities if there are any. This requires a shared conceptualization between communicating systems, leading to the integration of the semantic web principles into the IoT, with the emergence of the so-called Semantic Web of Things (SWoT).

The contributions of the semantic web community toward the IoT are many: we counted 1426 publications at the end of 2016[9], which contributions are expressed in various architectures, and with complementary or competing visions. We focused on 71 scientific publications[10] for the survey this abstract advertises for, chosen for their quality, their innovative aspect, and for the balance in their content between semantic web and IoT. An extra attention was given to publications proposing semantic web contributions in explicitly and precisely defined IoT architectures.

The heterogeneity of the contributions presented makes their comparison harder. That is why we propose LMU-N, a unifying architectural pattern designed to describe the convergent contributions of the semantic web and the IoT communities. The LMU-N description is a preliminary to the survey at the core of the paper: LMU-N is used as a framework to contextualize semantic web contributions to the IoT. The use of a unified architectural pattern allows to study how the IoT architectures, and the characteristics of their nodes, influences the way semantic web approached can be integrated.

The remaining of the paper if organized as follows: first, an overview of the LMU-N pattern is provided. Then, we explain how LMU-N can be used as a reading grid for a survey of SWoT contributions. Especially, it allowed the identification of **data and system oriented processes instantiated in IoT**

---

[5] http://onem2m.org/

[6] https://openconnectivity.org/

[7] Hardware and software interoperability, e.g. shared communication protocols

[8] Data format interoperability (XML, JSON...)

[9] After a study on http://ieeexplore.ieee.org, http://www.sciencedirect.com and http://dl.acm.org, looking up the keywords "semantic web" and "internet of things"

[10] Which complete list is available in the full survey paper (link in the next page)

architectures enriched by semantic web principles. The papers of the survey are classified according to their contributions to these processes, situated in the LMU-N pattern. For further information, the survey described by this abstract is available in open access[11].

2 Unifying the heterogeneity of architectures with LMU-N

LMU-N is an architectural pattern issued from a **bottom-up analysis** conducted during the redaction of the survey this abstract introduces. LMU-N was derived from recurring patterns in already existing architectures presented in the surveyed papers. LMU-N is constituted of two main components, the **nodes** and the **flows**. The present section provides an overview of LMU-N, and references some of the architectures from which this pattern was extracted.

The node is a communicating entity on the network, an abstraction of both device and service, which play similar roles in the papers we surveyed. This abstraction aims at focusing on the common features of nodes, especially their intrinsic capabilities, and on how they process data. This design choice can be found in [4–8]. Based on their characteristics (memory, processing power, communication capabilities), the nodes can be clustered into three categories:

- **Upper Node (UN)** have high processing power, extended communication capabilities, and large storage capabilities (typically servers).
- **Middle Node (MN)** are very often referred to in the literature as **gateway**. They typically have medium processing power, extended communication capabilities, and restricted memory storage.
- **Lower Node (LN)** are typically connected devices, with very limited power source, processing and communication capabilities, and very limited to no storage capabilities.

The other important element of the LMU-N is the flow. In the representation of an IoT network as a graph, the edges are communications between nodes, instantiated by messages flows. As shown on fig. 1, flows can be directed in three general directions: **horizontal** for nodes of the same level, such as the work done in [9], **upstream** when the source node is of a lower level than its destination node (as in [10]), and **downstream** otherwise (as in [11]). The content exchanged in these flows can either be **application-dedicated**, specific to the function of the devices that collected it (temperature observations, user requests...), or **system-dedicated**, describing the nodes constituting the network. Content can be either raw data or semantically enriched information: the term ”content” is being used as a neutral reference to an element with any expressivity on the Data, Information, Knowledge and Wisdom (DIKW) pyramid [12].

---

[11] http://www.semantic-web-journal.net/content/capturing-contributions-semantic-web-iot-unifying-vision

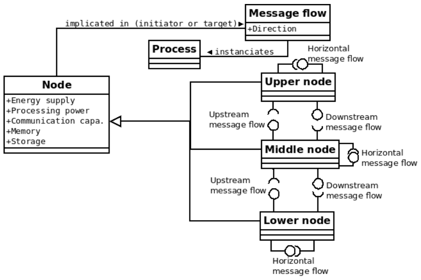

Fig. 1. The LMU-N pattern

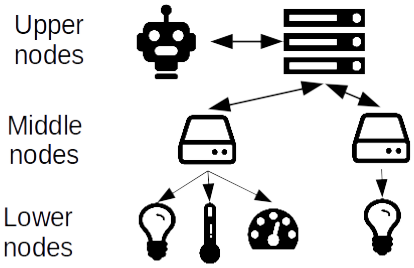

Fig. 2. An instantiation of LMU-N

Figure 2 represents an instantiation of the LMU-N pattern based on the work described in [13]. Two lamps, a temperature sensor, and a pressure sensors instantiate lower nodes. Their data is collected in a request-response fashion by two gateways. The communication is initiated by the gateway, therefore the arrows are directed from the gateways to the devices. The two upper nodes represent the server hosting the enrichment application, and the robot which processes the content generated by the sensors. The gateways themselves have push capabilities, and can also be queried directly by the server: the communication goes both ways.

3 Contributions of the semantic web to IoT processes

The core hypothesis in the present survey is that contributions from the semantic web to the IoT can be clustered into recurring patterns, called **processes**, and that **these processes are constrained by the nodes and the flows that support them**. This analysis aims at identifying how the semantic web principles can be weaved into IoT architectures. LMU-N is used as a reference frame where the contributions of surveyed papers are situated in terms of nodes and flows involved (e.g. upstream from lower to middle node), and in terms of processes (e.g. enrichment, node selection, abstraction...).

Processes can be separated in two categories, based on their topic of interest: the content-oriented processes, supporting application-dedicated processing, and the node-oriented processes, where the exchanged and processed data describes the graph of nodes itself. These two types of processes are both contributing to interoperability, at different applicative levels. We identified 11 content-oriented processes, covered by 38 publications and 6 node-oriented processes covered by 25 publications.

- Content-centric processes have been classified according to three aspects:
  - **Representation transformation**: Processes where the expressiveness of the content is modified, but not its core meaning. This category includes **Enrichment** and **Lowering**.

  - **Transport/provisioning**: Processes focused on content distribution across the IoT network, without modification of said content. This category includes **Notification/Dissemination**, **Control**, **Routing**, and **Querying**.
  - **Processing**: Processes using content for applicative purposes and value creation. This category includes **Abstraction**, **Consistency enforcement**, **Aggregation**, **Visualization** and **Decision support**.
- Node-centric processes have been classified according to two aspects:
  - **Awareness**: Processes dedicated to the representation for a node of other nodes of the network, and of their capabilities. This category includes **Discovery**, **Exposition** and **Selection**.
  - **Homogeneity**: Processes dedicated to solving issues related to nodes heterogeneity. This category includes **Abstraction**, **Composition** and **Specification/Configuration**.

This classification, with a **description of each process and of its instantiations** by surveyed papers, is the main contribution of the survey.

Moreover, the comparison of the contributions within a reference architecture allowed the identification of architectural trends in node communication patterns, and these trends are structuring the integration of the semantic web into the IoT. For instance, the hierarchical topology of IoT architectures, as well as the difference of processing capacities of nodes of different levels, are an incentive to push the resolutions of an issue for a given level to a node of an upper layer. This trend is one of the causes to the predominance of upstream processes observed in the survey. The identification of trends is supported by the analysis of the contributions studied in the complete survey.

This analysis of how the semantic web contributes to the IoT is completed by a survey of the evolution of the semantic web to adapt to the characteristics and constraints of the IoT. Transformations include the integration of semantic web technologies into dedicated protocol (such as CoAP [14]) and formats. The adaptation to IoT data is also driven by streaming approaches, and OBDA [15]. This twofold analysis emphasizes the convergence of both the IoT and the semantic web toward the SWoT.

4 Conclusion, perspectives and future work

To face the interoperability issues intrinsic to the expansion of the IoT, semantic web principles and technologies are more and more commonly weaved into IoT architectures, leading to the emergence of the SWoT. This paper proposes a survey of this convergence of IoT and semantic web. The use of a unifying architectural pattern allowed us to propose a state-of-the-art of the SWoT based on a reusable structure. This analysis supports our claim that processes in an IoT architecture are constrained by the nodes and flows they involve, entailing identifiable trends noticeable in the survey. The study of the reciprocal interactions between the IoT and the semantic web shows that not only does the semantic web provide solutions to the interoperability and complexity issues of the IoT, but the IoT also challenges the semantic web principles and technologies to evolve to be compliant with its constraints.

Some issues identified by the literature remain open challenges, such as consistency of data across the network or scalability to face the constant increase of the number of nodes, and therefore the constant increase of the volume of processed data. Future works include the study of a decentralized approach to face scalability without compromising consistency, and compliant with the different nodes and flows described by LMU-N.

A promising opportunity opened by the development of the SWoT as identified in this survey is the evolution of IoT traditional machine-centric data into richer, more expressive content, via its description with vocabularies connected to natural language resources. Machine-to-Machine (M2M) communication being by design unsuitable to human, natural language resources can be used to enable meaningful user interactions. Moreover, many ontology alignment techniques are based on natural language processing, and they represent a next step in semantic interoperability.

References

1. I. Szilagyi and P. Wira, "Ontologies and Semantic Web for the Internet of Things - a survey," in *IECON*, IEEE, 2016.
2. P. Desai, A. Sheth, and P. Anantharam, "Semantic Gateway as a Service architecture for IoT Interoperability," in *Kno.e.sis Publications*, 2015.
3. A. Gyrard, M. Serrano, and G. A. Atemezing, "Semantic web methodologies, best practices and ontology engineering applied to Internet of Things," in *2015 IEEE 2nd World Forum on Internet of Things (WF-IoT)*, pp. 412–417, IEEE, 2015.
4. M. Ben-Alaya, S. Medjiah, T. Monteil, and K. Drira, "Toward semantic interoperability in oneM2M architecture," *IEEE Communications Magazine*, vol. 53, no. 12, pp. 35–41, 2015.
5. C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos, "Context aware computing for the internet of things: A survey," *IEEE Communications Surveys and Tutorials*, vol. 16, pp. 414–454, jan 2014.
6. D. Pfisterer, K. Romer, D. Bimschas, O. Kleine, R. Mietz, C. Truong, H. Hasemann, A. Kröller, M. Pagel, M. Hauswirth, M. Karnstedt, M. Leggieri, A. Passant, and R. Richardson, "SPITFIRE: toward a semantic web of things," *IEEE Communications Magazine*, vol. 49, pp. 40–48, nov 2011.
7. V. Foteinos, D. Kelaidonis, G. Poulios, P. Vlacheas, V. Stavroulaki, and P. Demestichas, "Cognitive management for the internet of things: A framework for enabling autonomous applications," *IEEE Vehicular Technology Magazine*, vol. 8, no. 4, pp. 90–99, 2013.
8. M. G. Kibria, "Knowledge based open IoT service provisioning through cooperation between physical web and WoO," in *2015 Seventh International Conference on Ubiquitous and Future Networks*, pp. 395–400, IEEE, 2015.
9. M. Ma, P. Wang, and C.-H. H. Chu, "Ontology-Based Semantic Modeling and Evaluation for Internet of Things Applications," in *2014 IEEE International Conference on Internet of Things(iThings), and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom)*, no. iThings, pp. 24–30, IEEE, 2014.

10. A. Sheth, C. Henson, and S. S. Sahoo, “Semantic Sensor Web,” in *IEEE Internet Computing*, vol. 12, pp. 78–83, 2008.
11. S. Poslad, S. E. Middleton, F. Chaves, R. Tao, O. Necmioglu, and U. Bugel, “A Semantic IoT Early Warning System for Natural Environment Crisis Management,” *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 2, pp. 246–257, 2015.
12. J. Rowley, “The wisdom hierarchy: representations of the DIKW hierarchy,” *Journal of Information Science*, vol. 33, no. 2, pp. 163–180, 2007.
13. N. Seydoux, K. Drira, N. Hernandez, and T. Monteil, “Autonomy through knowledge: how IoT-O supports the management of a connected apartment,” in *Semantic Web Technologies for the Internet of Things*, pp. 67–78, 2016.
14. G. Loseto, S. Ieva, F. Gramegna, M. Ruta, F. Scioscia, E. D. Sciascio, and B. I, “Linked Data (in low-resource) Platforms : a mapping for Constrained Application Protocol,” in *ISWC*, (Kobe), 2016.
15. J.-p. J. Calbimonte, H. Jeung, O. Corcho, and K. Aberer, “Semantic Sensor Data Search in a Large-Scale Federated Sensor Network,” *Semantic Sensor Networks*, pp. 14–29, 2011.