A Study on Middleware for IoT

A comparison between relevant articles

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Abstract – *In this paper, we present initial concepts of Internet of Things, whose technology combines Internet, sensors and smart objects; and Middleware, that is software that interconnects hardware and software in different layers. We analyzed several scientific publications covering many visions of Internet of Things using Middleware to integrate objects into different applications and networks. Using this knowledge base, we made summaries of the main articles, aiming to bring the main points addressed in each one, and performed a comparative analysis between them, highlighting their similarities and points of greatest relevance. In the end, we bring conclusions about the current state of the use of Middleware for IoT and the main challenges for combining IoT and marketing applications.*

Keywords: Middleware; Internet of Things; Comparative Analysis

1 Introduction

The Internet of Things (IoT) has become an increasingly constant topic in everyday conversations. It is a concept that not only has the potential to affect the way we live, but also the way we work.

The term "Internet of Things (IoT)" was created by Kevin Ashton at the end of the 90s, more precisely in 1998, in a presentation to executives of a major international brand that had the objective to gather the use of RFID's (Radio - Frequency IDentification) with the product supply network in retail markets and wholesale [1]. Then the Massachusetts Institute of Technology (MIT) presented their IoT vision in 2001 [2] and later, the Internet of Things was formally established by the International Telecommunication Union (ITU) by the ITU Internet Report in 2005 [3].

The concept of IoT it is defined as the connection of any electronic device to the Internet. This includes cell phones, coffee makers, washing machines, lamps, portable devices, refrigerators, and many others a multitude of devices built with sensors and connection capabilities. This also applies to machine components, e.g., a jet aircraft engine, an automobile press mill or an oil platform drill. The connection between these devices generate a significant amount of data, which in turn must be stored, processed and presented efficiently and easily interpretable way. [4]

When a large number of sensors are implemented, and the generation of data is initiated, the approach based on the traditional application (i.e., the connection of sensors directly to the applications individually and manually) becomes unfeasible. In order to address this inefficiency, significant amounts of Middleware solutions are reported by researchers. Each Middleware solution focuses on different aspects of the Internet of Things, such as device management, interoperability, platform portability, security and privacy, among others. Even so, some solutions address several aspects, and an ideal Middleware solution that addresses all aspects required by the IoT is yet to be developed [5].

This paper presents an analysis of a few researches that addresses Middleware applied to IoT, together with the understanding of the work done by different authors and draws a comparative analysis of the selected studies. Specifically in Section II, it presents an overview of the concepts of the Internet of Things (IoT) and in section III, about a review of the concepts of Middleware. Section IV provides a summary of selected articles and their comparative analysis of the articles are presented in Section V. Finally, Section VI presents the conclusion and final considerations.

2 Internet of Things (IoT)

Internet of Things (IoT) is the convergence between Internet and RFID, sensors and smart objects. Internet of Things can be defined as "things that belong to the Internet" for the supply and access to all real-world information. According to Gullemin and Friess [6], IoT allows people and things to be connected anytime, anywhere, with anything or anyone, preferably using any path and any service. Figure 1 illustrates this connection between the "things" related by Gullemin and Friess more easily.

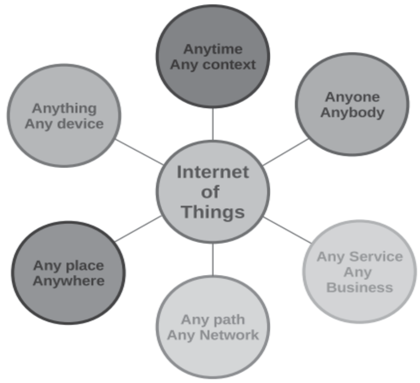

Fig. 1. Connection between the "things" according to the definition of IoT for Gullemin and Friess [6].

According to Atzori [7], Internet of Things can be accomplished in three paradigms: Middleware, sensors and Knowledge Base, which interact with each other and fulfill oriented visions of the Internet for Things. One paradigm will not meet all the connectivity vision. The intersection of these visions will be the main focus to make and connect objects on the network. For any network, the things will be active participants in business, information, and social processes.

The wireless sensor has brought technological advances in hardware domain for circuits and communications bringing effective and robust devices for sensing applications. This has led to diverse environments using wireless communication devices as described in Atzori [7]. Sensor data is collected and sent to a processing data centralized, distributed or hybrid processing module. Therefore, there are several challenges that a wireless sensor network has to face to develop a successful communication network of Internet of Things.

The Internet of Things, the interconnection and communication between everyday objects, allow many applications in several fields. Many of the attributes that can and should be considered when developing an application relate to network availability, bandwidth, coverage area, redundancy, user involvement and impact analysis. Some studies separate these areas in different applications, which are divided into two broad categories: first, Information and Analysis and in the second, Automation and Control [8]. In the following Tables 1 and 2, the six different applications are presented:

Table I. IoT Application Categories

Information and analysis		
Track behavior	*Enhanced situational awareness*	*Decision analysis guided by sensors*
- To monitor the behavior of people, things and data through space and time.	- Using the data infrastructure or environmental conditions to make real-time decisions.	- Help in making decisions about the use and analysis of data and visualization.

Table I. Information and Analysis Categories.

Table II. IoT Application Categories

Information and analysis		
Processes improvement	*Optimize resource consumption*	*Complex autonomous systems*
- Automatic control of industrial systems. - Continuos adjustment of factory lines.	- Consumption control to optimize the use of resources throughout the chain of generation of products, services, and natural resources.	- Automated in open environments. - Cleaning of hazardous materials through the use of robots

Table II. Information and Control Categories.

3 Middleware

The Middleware is a layer or set of software sub-layers interposed between the levels of application, operational and communication [9]. Its characteristic is to hide the details of different technologies, protocols, network environment, data replication, parallelisms, among others, it is essential to exempt the programmer about issues that are not directly relevant to its purpose, which is the development of the specific application. Furthermore, the Middleware masks the heterogeneity of computer architectures, operating systems, programming languages and network technologies to facilitate programming and application management.

The main features of a Middleware are:

- Hide the information distribution, which means hiding the fact that an application is usually composed of many interconnected parts running in distributed locations;

- Hide the heterogeneity of various hardware components, operating systems and communication protocols;

- Provide uniformly high level of standard interfaces for developers and application integrators, so that applications can be easily built, reused, ported and made to interact;

- Provide a set of common services to perform various functions general used in order to avoid efforts duplicated and facilitate the collaboration between applications [10].

There are different types of Middleware and the best knows are:

- Object Oriented: focuses on the receiver of the information and the introduction of reference tools to remote objects or proxies, to preserve the "look and feel". An advantage of this approach is that the coding can be used by anyone because the code will be done in the same way whether the system is distributed or not. An example of Middleware: CORBA.

- Services Oriented: similar to the object-oriented Middleware, except that there is less focus on the target object invoked and more emphasis on the operation to be performed. It's simpler to develop because the identity and life of remote objects do not need to be completely resolved. An example of Middleware: Thrift.

- Focused on data: this Middleware does not focus on the receiver, but in information propagated, i.e., the purpose and the meaning of what is transmitted. More effort is spent in ensuring the effective encapsulation of information and its transmission quality, controlling the physical aspects, time and bandwidth. Examples of Middleware are DDS and JMS implementations.

- Oriented message: this Middleware differs in its focus from all the previous ones, because either the receiver, the operation or the data are the communication paradigm, but the communication, with its physical aspects, such as size and time. The main idea of this Middleware is that the communication is not hidden or encapsulated, but exposed at least to the extent that allows it to be managed. When sending a message the receiver receives an identifier that allows you to track the progress of the delivery of the message. This is the identifier that is the focus on the delivery process. An example of Middleware: YAMI4 [11].

Middleware has gained more importance in recent years because of its role in simplifying the development of new services and integration of old and new technologies [12]. Businesses and organizations are increasingly integrating applications and systems, which they were independent, with new technology and development, building information systems for the entire company. This integration process involves legacy applications and outdated data bank. Many of these applications can only be used for its old interface and modifications are expensive or even prohibitive. The use of Middleware can connect this information within the entire company, various departments, and systems by placing them in a centralized environment with easier operation and maintenance. But with all this ease, there are many technical challenges for scale use of Middleware, such as interoperability, scalability, abstraction, spontaneous interaction between the "things", distributed infrastructure, security and privacy and a variety of types of Middleware [13].

4 Analysis of Relevant Articles

In this section, we summarize the most relevant articles from the point of view of citation numbers, year of publication and relevance for this research.

In the article "*Flexible IoT Middleware for Integration of Things and Applications*" [14], Bowman argues that while the Internet of Things is certainly a long way from becoming ubiquitous, it becomes increasingly closer to every day. And the future of the Internet of Things will consist of a variety of sensors connected to a network that will send the data to some types of cloud storage service, which will be available for all users, or authorized users. The authors also indicate that data should be shared between applications.

In this sense, the article summarizes that Internet of Things (IoT) must be supported by a Middleware that enables consumers and IoT developers to interact in a friendly manner, regardless of the different perspectives of use of IoT systems. The authors propose software that is bridge the gap between consumers and developers. The authors propose what they called the first step toward a ubiquitous Middleware for Internet of Things.

Charith Perera – 2014 in his article "*Context-Aware Computing for The Internet of Things: A Survey*" [5], it emphasizes that in our walk towards the Internet of Things (IoT), the number of sensors in operation around the world is growing at an accelerated rate. Market surveys have shown significant growth of new sensors in the last decade and predict an incremental growth rate in the future. These sensors have generated continuously, a huge amount of data. However, the use of such data is not trivial - it is necessary to understand them better. For Charith the use of context-aware computing is extremely important to the challenge of collecting, modeling and distribution of data generated.

The authors studied a subset of projects, representing research and commercial solutions proposed in the Context-Aware Computing area conducted over the last decade (2001-2011), based on a taxonomy presented by the researchers. The survey covers a wide range of techniques, methods, models, features, systems, applications, solutions and Middleware related to awareness of context and IoT. One of the article's focuses was to discuss the applicability of Computer Context-Aware applied to Internet of Things. The results obtained by researchers presented positive conclusions regarding the use of the Context-Aware Computing.

Zhen Peng – 2012 in his article titled "*Message Oriented Middleware Data Processing Model In Internet of Things*" [15] argues that with the development of Internet of Things, more and more devices are connected to the network. Devices have generated many different types of applications, however, they also bring new challenges for the maintenance and management of the network. One of the significant differences between the Internet and the Internet of Things pointed out by the authors, is that embedded devices represent an important category of devices on the Internet of Things, single function, poor performance and in large quantities. When divided by their functions, all devices are distributed in a monitored network and in data collection all the time.

The authors point out that even with the new challenges, the efficient data transmission and how to meet the needs of new applications that will arise. At work, the researchers detailed the data transmission characteristics of these applications. Moreover, the authors presented a new data processing model using a Message Oriented Middleware. With the new model Peng points out that transmission and data processing will be more convenient, efficient, easy to share and secure.

Hiro Gabriel Cerqueira Ferreira – 2014 in his article "*Proposal of a Secure, Deployable and Transparent Middleware for Internet of Things*" [16] proposes a security architecture for Middleware for IoT, focused on bringing real-life objects into the virtual world, the architecture proposed by the author is implementable and includes protective measures based on existing technologies for security such as AES, TLS and OAuth . He further says that privacy, authenticity, integrity and confidentiality of the data exchange services are integrated to provide security to smart objects generated for users and services involved, reliably and implementable.

In a previous [17] work, Hiro proposed a Middleware for IoT and detailed usage scenarios, while in the above article he specifies the security architecture based on existing technologies. The Middleware resulting of Hiro's article allows the implementation of the Internet of Things environments. In relation to the specific security aspects, the article details how communication and commitment must be to provide privacy, authenticity, integrity and confidentiality of users, applications, and devices. The model proposed by the author analyzes and resolves questions about scalability, a variety of devices and applications, simplicity, robustness and it keeps the possible interactions with low computational resources and energy entities. In his conclusion, the author draws attention to future works, including the creation of wrapper of existing devices that already communicate using other technologies. These devices should be placed under the master domain controller in order to become available under Middleware API. It addresses the issue to be resolved is the mobility for end devices and identification and how to automatically carry your settings and permissions to other controllers.

Jayavardhana Gubbi - 2013 in his article "*Internet of Things (IoT): A vision, architectural elements, and future directions*" [18] addresses that ubiquitous sensing enabled by Wireless Sensor Network (WSN) technologies are presented in many areas of modern life. He claims that it offers the ability to measure, infer and understand environmental indicators, ecologies and natural resources in urban environments. The proliferation of these devices in this communication network sets the creation of the Internet of Things, in which sensors and actuators combine perfectly with the environment around us, and the information is shared across platforms, in order to develop a common operational picture (COP).

Fueled by recent adaptation of a variety of enabling wireless technologies such as RFID, sensors and actuators embedded, IoT has gone reality and it is the next revolutionary technology to transform the Internet into a fully integrated Internet. He also states that as we move from the Web page (static web pages) to web2 (web social networking) to web3 (web ubiquitous computing), the need for data on demand using sophisticated intuitive queries increases significantly. The article also presents a vision-centered in cloud computing for the implementation of the Internet of Things.

Gubbi's article resulted in the proposal of a cloud-based model, centered on the user, allowing the flexibility to meet the diverse needs and conflicts from different sectors. The authors proposed a framework capable of using the Internet of Things. The structure allows that network themes, computing, storage and visualization allow separated independent growth in all sectors, but complementing each other in a shared environment.

In the article "*Middleware for IoT-Cloud Integration Across Application Domains*" [19], Chengjia Huo presents a Middleware capable of connecting to the Internet of Things to the Clouds to provide a more robust security. The implementation shown in the article is a proof of concept of this approach. It is an example that shows how to integrate embedded systems and cloud computing. In the article, the author proposed IoT architecture with the inclusion of what he called "Rimware", a Middleware that is integrated with the cloud and the gateway. The authors assumed that the data service for a particular application would already be available in the cloud as well as configuration and command devices belonging to authenticated users via the gateway. In the study, the gateway consisted of an application running on a smartphone that performs user authentication and connects to Bluetooth devices. They identified some problems with this approach, as limits iteration of users and applications. With this in mind, they proposed a plugin allowing multiple gateways can be used at the same time.

In their work the authors had as a result, the concept of rimware for IoT integration to the clouds to form a powerful cyber-physical system. This Middleware, called BlueRim is scalable globally. They assert that the effectiveness of the characteristics contained in the Middleware proposed has been validated in real applications with different types of access.

5 Comparative Analysis Between Articles

In this section, we will raise aspects that were considered relevant to the thematic context and applicability in the real context.

The result of comparative analysis these articles reveal that the integration between objects is still the great challenge since the IoT conception. In near future people and objects relate autonomously and directly. To achieve this, researches are directed to the integration of objects through brokers or Middlewares, where the location and integration of objects must be automatic. Because the scale is not feasible there is human intervention, this has to be a process, at least semi-automated or automated, to connect them. Another important challenge for this theme will be the creation of a pattern of communication between objects where in this pattern will be possible an automatic analysis of objects and their integration [5].

Overall, the articles that address this study attack the problem at different bias. The majority of studies propose a Middleware architecture [12] [17] [20] [22] [23] [24] [25] [26] [27] [34] to integrate the "things" with networks and systems, other devices, applications and social networks, and other articles, try to address the security issue [21] [30] [31] [32], which is one aspects of most concern because it involves issues of privacy, confidentiality and data integrity throughout the IoT architecture; and in this aspect, the solution usually is pointed out in the cloud computing [19] [21] - Middleware integrated to cloud computing, where it is possible to increase the demand for network, hardware, storage and systems to meet growing number of IoT applications. The results show that softwares and applications will be essential in developing solutions for IoT, in the coming years. As the developers plan to interconnect objects with multiple systems, including mobile applications, desktop, database, cloud services, enterprise applications, Middleware and other devices to the Internet of Things.

6 Conclusion and Future Works

The current state of the art of Middleware for the Internet of Things explores different approaches to supporting for some of the features provided in IoT. In our study, we found enough research evidence related to information security in this area. It is a major concern of researchers to develop a usable architecture, integrated into the clouds to provide certain abstractions like security and scalability. In most of the researches, it has a marketing nature, and the authors of the studies analyzed are indicating future works in one-way: the handling and processing of the data generated are and will remain a major challenge for the IoT to establish fully.

Although some of the articles we have covered in this study did not deal directly of Middlewares, we feel favorable the analysis since the topics discussed other solutions to answer the challenges to adoption of the Internet of Things.

For future researches, there is a great deficiency to find out a stable architectural solution that they are able to meet the demand for data, keeping them private, fair and accessible. Based on our analysis, perhaps the most appropriate way to go, it is to an architecture that integrates Middleware and cloud computing in order to use existing services, facilitating the devices integration in the worldwide network of things.

7 Acknowledgments

Authors would like to acknowledge the support from CESAR in the development of this research.

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