Bringing Dynamics to IoT Services with Cloud and Semantic Technologies

An Innovative Approach for Enhancing IoT based Services

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Abstract: In this paper, we present an innovative software architecture that brings dynamics to the world of interconnected small devices and sensors by mixing cloud services, semantics and border router technologies. Dynamic aspects can be enabled both in the way that the devices are deployed or managed as well as in the manner in which the data can be combined or interpreted to form additional services. We got inspired from the architecture of mediators and wrappers in databases and services systems and adapt them to the IoT world. We illustrate our purposes with a use case scenario that involves different actors from the energy and smart cities domains.

1 INTRODUCTION

Smart interconnected devices and sensors – commonly described by the term "Internet of Things" (IoT) - are increasingly becoming part of our everyday lives. Environmental sensors, domestic appliances, cars, wearables and infrastructure control devices are more and more interconnected, autonomous and able to communicate with other peers or services over the Internet. The automatic deployment, uniform access and availability of services and information from these IoT devices introduces significant applications that help people to achieve their goals, factories to improve their processes and products, and provide new ways for a society to improve its quality of life. In this paper we present a novel architecture that provides i) flexible and dynamic services, ii) open and easily available resources, iii) dynamic behaviour of IoT devices and iv) semantically rich data and services.

The distributed dynamic services, which this architecture proposes, take into account data from the observed environment, open public data and processed data offered by available services. All this information is composed to produce results relevant to the use case, for example offer guidance to users in a smart cities scenario, optimise manufacturing processes at chemical plants, assist and improve the quality of the production of an agricultural farm. In order to consider a cross domain application scenario that includes domain interoperability issues we will examine the use case of the smart energy management of a city. In this use case the actors that are involved are the energy providers, the energy producers, and the smart city citizens - the energy consumers. The data sources in this scenario include the energy plant sensor data, the power distribution facilities sensors with data on the power consumption at local level and the user appliance devices that provide usage and scheduled consumption data. Finally environmental data sensors such as weather stations together with socio-economic data analysis from social media and news feeds bring together all the environmental variables that can influence and improve the power distribution routing in the grid.

The architecture that we present in this paper a) uses IoT Border routers, which provide seamless connectivity to IoT devices; b) includes cloud services that provide IoT management and data services; c) adds semantics to the data produced by the devices or to the metadata of the devices themselves.

The border router was designed to act as a gateway that connects the wireless sensors network to the internet. This interconnexion allows a seamless exchange of data. On one hand, sensors send data when it is available and, on the other hand,

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they can be managed remotely, by receiving updates and commands.

Connected devices produce lots of data that needs to be stored and analysed, cloud technologies enable scalability of both storage and computing power. The devices and services are monitored and managed in a centralized way, and benefit from automatic deployment and continuous integration.

It is interesting to explore what can be achieved if we provide the meaning of the data together with the data itself from an IoT device via the Border Routers and through the cloud services. The receiver of this information can interpret its format and meaning and utilize the data in a straightforward and general fashion. Going back to our use case, this data can be environmental information produced by meteorological stations or power usage data coming from home appliances. By being accompanied by semantic descriptions, sensor data can be published or made available in many ways that would allow discoverability, inference of relationships with other data and allow predicting spikes and other events by applying feedback rules. Additionally, this semantically enriched sensor data can be analysed for discoverying trends in power usage. This could fullfil the specific needs of citizens of smart cities, especially when combined with data analytic techniques from various socio-economic feeds.

The benefit of combining the dynamic behaviour of border routers with the storage and computation flexibility of cloud services and providing knowledge about the data is that the receiver of the data does not need to have knowledge of the node capabilities or type of data collected, but can query and discover this information and dynamically use computation, inference and composition of data services to receive new information and services.

The rest of this article is organized as follows: Section 2 presents related technologies in the areas of IoT, Cloud Services and Semantic technologies. In Section 3 we present our suggested solution of a platform architecture that consists of 4 implementation layers based on the aforementioned technologies and finally we provide a conclusion and our implementation plans in Section 4.

2 RELATED WORK

We have identified three areas of scientific research that are relevant to our architecture. These are the Border router devices at the hardware and communication protocols level, the cloud services at infrastructure level and the semantic interoperability services at the application level.

2.1 IoT Border Routers

A wireless sensor network (WSN) is a network of spatially distributed autonomous sensor devices to monitor physical or environmental conditions (Madhav, B., et al., 2012). These devices have wireless communication capabilities and autonomously form networks through which sensor data is transported. The sensors are constrained devices with restricted capabilities, for this reason, algorithms and protocols need to address the following issues: increased lifespan, robustness and self-configuration. Such operating systems for wireless sensor network nodes increasingly resemble embedded systems. The reason behind this trend is the need for low cost and low power. This implies that most wireless sensor nodes use low-power microcontrollers, and mechanisms such as virtual memory are either unnecessary or too expensive to implement (Navjot Kaur, J., et al., 2015).

Contiki (Dunkels, A., et al, 2004) is a wireless sensor network operating system that consists of the kernel, libraries, the program loader and a set of processes. It is designed to deal with the sensors limitations mentioned before. Contiki provide mechanisms that assist in programming smart objects (or sensors) applications. It provides libraries for memory allocation, linked list manipulation and communication abstractions. Contrary to existing systems such as TinyOS (Hill, J., et al, 2000), Contiki provides a dynamic structure allowing the replacement of programs and drivers during run-time and without relinking.

The biggest advantage of IP based Wireless Sensor Networks is their ability to be seamlessly connected to the Internet. A device, which passes data from the lowpan to ordinary network is called a "Border Router". Such a device must support at least two network interfaces: 802.15.4 for the lowpan, and Ethernet (IEEE 802.3) or WiFi (IEEE 802.11) for the uplink. Systems based on proprietary or non standards stacks (e.g. the ZigBee - see http://www.zigbee.org - and the zWave - see http://www.z-wave.com) require to have a Gateway at the edge between the lowpan network and the Internet network. The gateway can also have a Data storage mechanism if necessary. Any modification in the format of the data requires an update of the Gateway, thus hindering the modification or the development of the lowpan network with new external elements. Currently, the trend is to replace these stacks with IP compliant stacks and open data format, for example ZigBee IP is a complete switch from the proprietary ZigBee stack towards a IPv6/RPL stack.

CETIC has developed an open-source IPv6 based Border Router (Deru, L., et al, 2013), build on top of Contiki, that allow the seamless integration of an IPv6/RPL based lowpan to an Internet infrastructure.

2.2 IoT and Cloud Services

Cloud platforms provide fine-grained control on the resources available in the target cloud via the Infrastructure as a Service (IaaS) layer. The Openstack (see http://www.openstack.org/) project implements most of the backend requirements for the proposed architecture: object storage and processing scalability through its Swift and Nova modules, time series database with Gnocchi, data processing in Sahara, and others.

The Platform as a Service (PaaS) layer enables management of the services and devices. Continuous delivery practices ensure the systems are always up to date, and the various components are automatically deployed using deployment (e.g. Openstack Heat, HashiCorp Terraform, Amazon CloudFormation) and provisioning (e.g. Ansible, Chef, Puppet) tools.

The Open Mobile Alliance proposes a standardized set of machine-to-machine (M2M) tools (see http://openmobilealliance.org/about-oma/work-program/m2m-enablers/) to manage IoT devices (e.g. border routers), notably the LWM2M protocol.

The OpenIoT project (see http://www.openiot.eu) implements an open source middleware framework for self-managed environments of IoT applications, and uses a cloud utility-based model. The outcomes of this project are being considered in our solution.

2.3 IoT and Semantic Technologies

With their machine-interpretable representation of information and unambiguous reasoning principles, Semantic technologies have a great role to play in the world of IoT. Many semantic-related projects and languages have recently emerged in order to cope with the biggest IoT challenges like service discovery in a large and dynamic environment, scalability, security or privacy.

Developed by the W3C Semantic Sensor Networks Incubator Group (Kolozali S., et al., 2014), the SSN ontology (see https://www.w3.org/2005/Incubator/ssn/ssnx/ssn) describes sensor resources, observations and their related concepts such as the measurements, timestamps and locations. SSN also includes a lightweight quality model describing the quality aspects of collected data.

(Xiang, S., et al., 2014) have conducted a survey on formal knowledge representations in various formats that can be potential candidates for representing sensor data. Their aim was to evaluate the resource usage of different alternative formats in a sensor system. Their experiments have shown that the choice of the format influences the packet size and processing cycles needed for embedding the semantic information into the sensor message and often format. Both of these aspects have significant impact on the sensor's resource consumption.

The backbone technologies of the Semantic Web are RDF, OWL and SPARQL. Those standards have been adapted to the specificity of an IoT environment. stSPARQL and stRDF (Koubarakis M., et al., 2012) are built on top of SPARQL and RDF. They extend the basic concepts with spatial and temporal dimensions in order to facilitate the representation and the querying of sensor data.

C-SPARQL (Barbieri, D., et al., 2010) has been developed to perform real-time and continuous queries over streaming data.

Many XML-based languages have emerged from various R&D projects. Product Markup Language (PML) describes physical devices in terms of Electronic Product Code Networks (EPCN) but does not allow reasoning in its basic form. There is a need to develop languages on top of PML in order to enable reasoning based on description logic.

SensorML proposes a standard model to describe sensor systems and processes but also lacks the reasoning and annotation capabilities needed for automated service discovery.

Sensor Observations Service (SOS) is a service-oriented approach that defines an interface for requesting, filtering, and retrieving data from sensors but no implementation is currently available.

Recently, a promising standard, named HyperCat (Rodger, L., et al., 2013), has emerged for services interoperability and discoverability within IoT networks. It is based on RESTful Web standards like HTTPS and JSON and it will allow any developer to provide applications that work across multiple servers.

3 THE ARCHITECTURE

A high level view of the architecture is provided in the following diagram. The architecture of the platform we propose is composed of the following layers: the border routers layer that interfaces with the sensors and IoT devices is described in further detail in section 3.1; the cloud services layer that provides data storage and device management capabilities, which is described in section 3.2; the semantic layer that provides the data model and formal description of resources, which is detailed in section 3.3; and last but not least the high-level and application level services that are described in section 3.4.

3.1 The Border Routers Layer.

Sensor networks are gradually moving towards full-IPv6 architecture and play an important role in the upcoming Internet of Things. These smart objects will be integrated into existing network infrastructure using a Low Power WPAN IEEE 802.15.4 (Gutierrez, J., et al., 2001) link layer. This technology has the advantage of providing efficient low-bitrate network connectivity at a minimal cost. It can also be used with both networks stacks, Zigbee and IPv6. In order to run IPv6 over IEEE.802.15.4, an adaptation layer is necessary to provide header compression mechanism, link specific fragmentation and reassembly. The 6LowPAN (*IPv6 over Low power Wire*less Personal Area Networks) (Kushalnagar, N., et al, 2007) is designed to provide such a service.

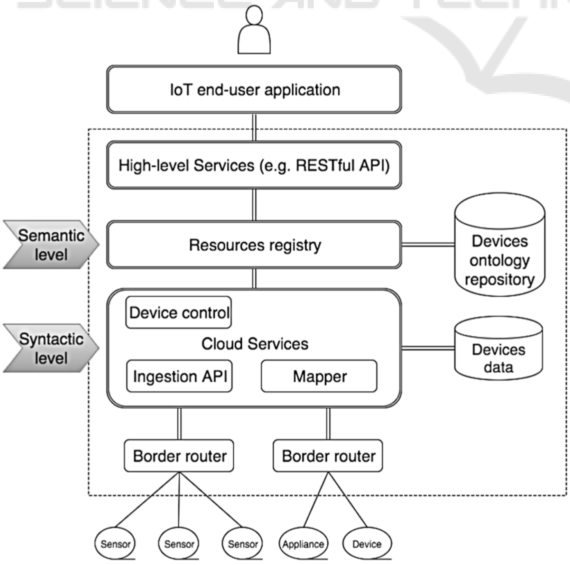

Figure 1: Diagram of the proposed Architecture.

The border router (BR) acts as a gateway to interconnect the IoT network to the Internet. It is designed to forward packets between IPv6 and 6LoWPAN networks, to configure the IP-nodes and to provide context sharing and multi-hop routing (RPL). The BR has two interfaces, the 802.15.4 one on the WSN side, and Ethernet or WiFi on the other one. Most of the current deployments have a unique BR, which represents a critical point of failure. In our architecture we consider the 6LBR implementation (Deru, L., et al, 2013). This solution proposes a redundant BR deployment to enhance fault tolerance and sensors mobility without compromising the energy-efficient control mechanism provided by the routing protocol. This implementation supports the RPL (Routing Protocol for Low Power and Lossy Networks) to route packets using the route over approach (Winter, T., et al, 2012). Then, packets are routed on the IP level with a low networking overhead. Going back to our smart energy use case. Data from both energy producers/providers and consumers is collected thanks to sensors and sent to the cloud through the border routers. With this inter-connexion between sensor networks and the rest of the IP world, we enable dynamic access to the Data.

3.2 The Cloud Services Layer

Data Storage

The various sensors produce large amounts of information in time series format, i.e. arrays of measurements indexed by timestamp. This data is stored in a time series database that can be efficiently queried to obtain aggregated information on specific geographic regions, periods of time, measurement type, etc.

The time series database scales horizontally by allowing the cloud infrastructure to add or remove computing and storage resources to the database as required.

To optimize resources usage, the cloud services layer also provides long term archiving capabilities for the data that does not need to be accessed on a regular basis.

Device Management

This component provides the various functionalities needed to manage the IoT devices connected to the cloud. Each device of the fleet can be automatically provisioned, configured and updated. The device management provides a control panel for the users to view the status of the device fleet and manage it, e.g. add or remove a device, update a device, view device status and query sensor.

Service Management

Like the devices, the services described in this architecture are automatically provisioned with the help of composite cloud templates; they are managed through a control interface that exposes monitoring information and configuration settings.

3.3 The Data Semantics Layer

The Semantic technologies and data semantics level is composed of the ontology repository, the semantic mapping services and the ontology that formally describes the resources used and the data provided by the border routers.

As demonstrated in (Rodger, L., et al., 2013) and in (Xiang, S., et al., 2014), adding semantics to thin and light sensors and IoT devices can be achieved by choosing more compact representations of the descriptions together with appropriate encoding of the messages that are sent by the devices. It is interesting what can be achieved by formally describing the IoT devices and by providing context to the data that the devices are producing. Knowledge representations of both the devices and the data allow logical reasoning that is able to infer new information from existing assertions. In addition to this approach, in our solution we can add semantic information at the border router that is either inferred or known at deployment time because of the localization of the devices controlled via the border router. This knowledge of the type of devices and interlinking or associations between the data that they produced can be made available dynamically at the services one level above, the cloud services layer, if this knowledge has not been provided already.

The Ontology Repository (Chondrogiannis, E., 2011) manages resources and stores information about their attributes and metadata based on a pre-defined data model. The data model can be designed and built using either an XSD schema description or an OWL-RDF ontology model. The repository provides a RESTful storage API that acts as a backend for WebUI components. It also provides an API for enabling queries - that can be relatively complex - on the resources in order to assist discovery and exchange of information about the stored resources. The discovered resources are cached at the application level for performance purposes. The Ontology Repository core and its standard REST API are domain independent, and can easily be extended in order to add or customise its functionalities according to the use case requirements.

The mapper component is providing mappings between the raw data schema, which is coming from the sensors and stored in the cloud, and the resource ontology in the repository using a mapping file. The ontology repository contains the formal description of the device resource and the description of the data. The streaming data from the device as well as the details of its schema or format is only available at the cloud service layer. The mapping enables querying the data with semantic technologies such as the SPARQL language using SPARQL endpoints and ensures seamless integration of raw data with the devices' data model in the ontology (Matskanis, N., et al., 2015).

This three-way approach of inserting semantics to the IoT devices and device data enhances discovery and inference of information that can be used to create more dynamic and flexible services over the IoT infrastructure.

3.4 Data as a Service

We suggest to tackle the challenge of data integration in IoT by developing a service-oriented approach based on a "Data as a Service" architecture. That solution has many potential benefits: ease of query (heterogeneous data sources and sensors expose the same interface), support for any sensor hardware (the generic service specification is not bound to specific hardware features), performance (data can be cached at any node or any level of the architecture), integration with any web data source such as web services or open data repositories.

In this type of architecture each data source (file, database, sensor data) is wrapped by a standardized Web Services API (RESTful), which provides an easy and standard way to access the resource by using the standard HTTP methods. Data as a Service consists in making available any data source, i.e. databases, log files, media collection through a standardized interface such as REST. This kind of architecture offers many advantages in an IoT configuration such as flexibility, the possibility for dynamic services composition or proven security methods (e.g. HTTPS).

Figure 1 depicts our Data as a Service architecture in an IoT context. Each sensor continuously generates data; that data is stored inside log files or in structured databases (e.g. file-based and lightweight database systems like SQLite). Some types of sensors provide their data through a Web API but, for any other sensors, a mapper component is needed to wrap the data within a RESTful access service.

Standard API or languages like SensorML or PML are used to provide a unique and transparent way to read or write information from the sensor network. Finally, a service repository serves as a central database for any IoT application that wants to use data coming from sensors as a data source.

IoT applications can use basic services providing unilateral raw data or high-level and cloud-services that combine different types of data, working like mash-up services.

4 CONCLUSIONS

This paper proposed an innovative architecture for bringing dynamics to IoT networks. Border routers, cloud services and semantics are the technological building blocks composing that architecture. We believe that we can take advantage of those concepts and build flexible, reliable and secure IoT applications in various domains such as energy, agriculture or weather forecast.

Border routers have a real-time knowledge of the status of the network, the localisation of the sensors/devices and their deployment status. Thus they serve as an endpoint to any external component that will make use of the sensors. We have also shown that, with their self-expressiveness and their formal description, Semantic Web languages/standards are well suited to describe the data provided by IoT devices. Additionally cloud technologies provide solutions that can otherwise be challenging to the IoT networks such as storage and compute scaling, as well as IoT device and service management.

An architecture that provides semantically rich data and services, combines the meaning of data of the IoT devices with the additional context provided by the Border Router as well as enables dynamic discovery and management of the devices, we believe that it can enable dynamic composition of data and services, dynamic response to conditions and assist implementation of new client services, business models for services providers in energy and in other use cases.

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