Resource Taxonomy for a Fog System

Lisbeth López, Kirill Krinkin
Saint-Petersburg Electrotechnical University "LETI"
Saint-Petersburg, Russia
lisbetholinda85@gmail.com, kirill@krinkin.com

***Abstract*—Fog computing has emerged as a novel technology for solving the latency, network traffic management, and power consumption issues faced by Internet of Things ecosystems. It is a complementary computing paradigm to cloud computing, enabling data processing and storage at the edge of the network, closer to the end devices. The resources involved in a fog ecosystem are very heterogeneous and can be described by different standards and models. This heterogeneity is not suitable for collaborative environments such as the fog system, where a common understanding of resources is required when provisioning applications. In this paper, we propose a semantic approach to address this issue of heterogeneity. We design a taxonomy whose purpose is to unify the representation of resources in a fog system. We consider this work as the first step towards the construction of an ontology that supports the strong variety of the involved nodes of the cloud, the fog and the IoT, which would contribute to the homogenization and simplification of the way in which IoT applications are provisioned over these nodes.**

I. INTRODUCTION

Internet of Things (IoT) represents one of the most disruptive technologies of recent years and is the basis of new developments and trends such as Smart Home, Smart City and Smart Factory. According to [1] the IoT is "an open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment".

IoT is experiencing explosive growth in the number of devices and applications, which generate a large number and variety of data types. Sending this massive amount of data to the cloud for processing causes problems such as high latency and low bandwidth availability. Fog computing (FC) has become a promising solution to address these challenges by allowing data produced by IoT devices to be processed and analyzed at the edge of the network, avoiding having to send them to a cloud platform.

In [2] this paradigm is defined as "a highly virtualized platform that provides computing, storage and networking services between end devices and traditional cloud computing data centers, typically, but not exclusively located at the edge of the network". By distributing computing resources closer to users and things, this computing model can be a better choice for building applications for the IoT. A survey of fog computing applications in this context can be found in the work done by [3]. Some examples of use cases include healthcare applications [4], [5], connected vehicles applications [6], [7], and smart living and smart cities applications [8], [9].

The basic architecture of fog computing consists of a three-layer hierarchy. The bottommost layer is composed of the IoT devices, which consist of sensors and actuators. The Fog layer includes network components like routers, gateways, switches, Base Stations, PCs, set-top boxes, etc. This layer receives data directly from the edge devices, processes it, and then transfers it to the Cloud layer. The upper layer is composed of Cloud data centers where massive storage and computation is carried out.

Resources in the fog and cloud layer are very heterogeneous in terms of computational and storage capacities. There are also differences in the way these resources are described by the providers of the different strata and domains. Therefore, it is critical for the fog system to be able to cope with this heterogeneity. From an architectural point of view, this heterogeneity needs to be considered when deciding which application component(s) should be deployed and where [10].

There are several works that offer potential solutions to address the heterogeneity issue (e.g., [11-13]), but none has proposed a semantic-based approach. In fact, some authors place the burden of handling heterogeneity on application developers. (e.g., [14-17]).

In general, an ontology can be defined as an explicit formal description of terms used in a domain and the relationships between those terms [18]. One of the main uses of semantic ontologies is to share a common understanding of the structure of information among those involved in a given area of knowledge. This common understanding can be achieved by using well-defined taxonomies and vocabularies, which allows restricting the possible interpretations of the related concepts.

As mentioned above, in a fog ecosystem, a wide variety of interconnected heterogeneous devices coexist, stretching from the edge to the cloud. In this scenario, the development of an ontology that covers this heterogeneity could contribute to the homogenization and simplification of the way in which IoT applications are provisioned over the nodes of a fog system. In fact, several standards have been defined to describe the resources of the IoT and cloud stratum. For example, IoT devices can be described by models like the one proposed by [19], while cloud resources can be described by standards such as OASIS TOSCA [20] and OCCI [21]. Obviously, the heterogeneity of the models is not suitable for collaborative environments such as the fog system, where providers of all strata and domains need a common understanding of resources when provisioning applications [10].

This paper aims, precisely, to design a taxonomy that describes the resources involved in the fog domain. We consider this work as the first step towards the construction of an ontology in this context.

The rest of this paper is organized as follows. In Section II, we analyze various architectures and surveys of fog computing, in order to identify and classify the resources of this domain, as well as to determine what are its main features and attributes. In section III, we present the resource taxonomy for a fog system. Finally, the main conclusions and future work are given in section IV.

II. LITERATURE REVIEW

A. Fog computing architectures

Reference [22] propose a hierarchical distributed architecture, which includes as main components several physical resources (computing resources, network resources, and storage resources), the abstraction layer, the fog service orchestration layer, and some APIs for applications. The role of the fog abstraction layer is to hide the platform heterogeneity. The layer provides a set of generic APIs for monitoring and managing physicals and virtual resources, and to specify security, privacy, and isolation policies for different components of the architecture. In addition, this layer includes different techniques that support virtualization, specifically the ability to run multiple OSes or service containers on a physical machine to improve resource utilization. In this paper, the authors do not explicitly define a taxonomy of the fog system resources, but we can get an idea about the classification of the resources involved, as well as their properties. They say that fog computing is envisioned to address applications that cannot be efficiently supported by the cloud paradigm, such as low latency, geo-distributed applications, and large-scale distributed control systems. Also, it has features like heterogeneity, mobility, support to virtualization, multi-tenancy, and so on.

The authors in [14] present architecture and algorithm for resource allocation in a fog environment by using a virtualization technique. They argue that the main characteristics of fog computing are low latency, mobility, geographic distribution, and location awareness. It is a highly virtualized technology, providing data, computing, storage, and network services between the cloud stratum and the end-user stratum. The proposed architecture includes three layers: client layer, fog layer, and cloud layer. The client layer consists of mobile devices, sensors, actuators, autonomous devices, and so on. A set of fog data servers (FS) are housed in the fog layer and the cloud layer is composed of data centers. Each FS contains a module called the fog server manager and a number of virtual machines to handle the request sent by the user. The fog server administrator is responsible for verifying the availability of computational resources to respond to the request sent by the client, and in addition to managing VMs' lifecycle. In case there is no available resource, the request is propagated to the cloud data centers. This article does not offer a clear definition of the resources involved in a fog system, but the authors argue that virtualization plays an important role in managing these resources. In addition, analyzing their work we have been able to identify the main features of a fog system.

Reference [23] focus on the communication between the fog layer and the cloud layer. The authors present an architecture called Hybrid Fog and Cloud (HFC) Interconnection Framework to enable the simple, efficient, and automated provision and configuration of virtual networks to interconnect different geographically distributed fog and cloud sites. The proposed architecture consists of three layers: device - fog - cloud. The bottom layer is comprised of mobile devices requesting applications. In the fog layer, the fog nodes are implemented as micro-clouds, and managed by a fog management platform (similar to a cloud management platform such as OpenNebula). The cloud consists of cloud nodes managed by the cloud management platform. Each cloud and fog node includes a special network element called the HFC agent, which is responsible for building the HFC virtual network as the interconnection of the different network segments deployed in different cloud and fog sites. The HFC virtual network is built through an L2 and L3 overlay network on top of the physical network. Additionally, the architecture includes an HFC manager through which the application tenants interact with the framework. In this paper we have identified some elements of interest for our work. Related to network management in fog environments, the network virtualization technologies involved in the proposal are presented, as well as the standards, protocols and types of network devices used. Regarding the classification of resources, the authors describe a fog computing node as a computing infrastructure that includes computing, storage and networking elements, and fog instances as physical or virtualized resources, deployed on top the fog node infrastructure, in charge of run the applications consumed by the end users.

Reference [24] propose a fog architecture for resource allocation and latency reduction. The proposed architecture consists of two parts: computing and networking. The networking part includes three layers: wireless technology, single-hop/ad-hoc communications, and a software-defined network concept. The computing side is composed of four layers: a software and virtualization platform, a hardware platform, functional components, and a fog computing applications interface. The authors formulate the resource optimization problem and solve it using a genetic algorithm combined with a Dirichlet distribution sampling approach. Following the proposed architecture, we have identified both the software and hardware components involved in a fog system, their main characteristics and behavior. In terms of hardware the authors consider the integration of FPGA for the processing of complex algorithms. Furthermore, we find that network technologies are involved in its architecture and that one of the key aspects to classify resources in a fog environment is power. Security and privacy issues have also been addressed by the authors, with their respective potential solutions.

Reference [25] discuss a detailed architecture where the components are divided into eight groups based on their functionality, which defines the layers. Concretely, these are physical (physical and virtual sensors), fog device (responsible for managing information about the hardware configuration, storage configuration, and connectivity of devices and servers), monitoring, pre- and post-processing, storage, resource management (resource allocation, scalability, reliability), security (privacy, encryption/decryption, authentication) and application layers. In this paper, the authors also present a taxonomy of fog computing, which represents a significant contribution to our work. According to them, the infrastructure requirements in a fog environment can be classified into three categories: infrastructure requirements (processing power, storage capacity, network, memory), network requirements (connection, mobility), and fog devices (IoT devices, fog processing devices, fog Gateway devices). From the platform perspective, they considered the requirements related to resource allocation and scheduling, security and privacy, multi-tenancy, and management. Finally, the taxonomy also includes the features required by the applications to run in a fog environment.

OpenFog [26] is a hierarchical architecture proposed by Open Fog Consortium, which includes perspectives and three views (software, system, and node). The perspectives or cross-cutting concerns cover aspects such as security, performance, manageability, control, and data analysis. The node view is the lowest level view in the architecture. It consists of two layers: the sensors, actuators and control, and the protocol abstraction layer, which enables the communication between the fog nodes and other components of the system. A fog node includes computing, networking, storage, and acceleration elements. The node also needs to implement sufficient security mechanisms as well as management agents. The system view is comprised of one or more node views coupled with other components to create a platform. The software view sits at the top of the architecture and includes three layers: Application Services, Application Support, and Node Management and Software Backplane. The design of the Openfog architecture can be considered as one of the main initiatives that have been created with the purpose of achieving a standardized approach in the fog environment. Therefore, we believe that it can serve as a starting point to define the properties, types and relationships of the entities that set up a fog system.

B. Taxonomy proposals for Fog computing

In the scientific literature, we have found several works that provide taxonomies for fog computing from different perspectives. Some efforts have been dedicated to the classification of research in this area, with the aim of defining the challenges and trends imposed by the paradigm, as well as shaping future directions [10], [27-29]. Following their contributions, we have identified some characteristics and attributes of the resources of a fog system. For their part, the authors in [30] focus on determining what features fog platform designers can or not integrate into their systems to support specific types of applications. In this article, a clear classification of the functional and non-functional requirements that a fog system should have is presented, which helps to contextualize your work with respect to our interest. A useful taxonomy and model to describe the resources of the Fog-to-Cloud paradigm is provided in [31]. To classify system resources, the authors propose five categories: 1) Device attributes (hardware, software, network specification, etc.), 2) IoT components an Attached components (sensors, actuators, RFID tags and other attached device components), 3) Security and Privacy aspects (device hardware security, network security and data security), 3) Cost information (chargeable device, non-chargeable device), and 4) History and Behavioral information (participation role, mobility, life span, reliability, information of the device location, etc.). We have used this work as a starting point to define our taxonomy.

Based on the analysis of the literature, it can be concluded that, in most cases, the researchers have considered the following aspects to describe the fog resources: hardware components (that is, storage capacity, memory, processor), software (i.e., OS, API) and network requirements. Additionally, in terms of hardware, some authors have proposed other components such as FPGA and GPU. We have also found in our study the researchers' concern for efficient energy management to ensure the QoS of the fog platform. Therefore, it is another important aspect to consider in our classification. In relation to the network, we identified that the information related to standards, connection technologies, and bandwidth are key parameters to characterize resources. Finally, we identify several inherent features of this paradigm, such as high virtualization, reliability, multi-tenancy, and support for mobility. The resources in fog computing are geographically distributed close to the edge of the network, making them suitable for providing real-time services. Also, these systems are very aware of your work location.

III. PROPOSING A TAXONOMY FOR FOG RESOURCES

In a fog-cloud ecosystem, a wide variety of providers that offer their heterogeneous resources for users to execute their applications coexist. Different users' applications have different constraints, while providers' resources have different capabilities. Each entity of the ecosystem uses its own vocabulary to describe the properties of the resources and the requirements of the applications according to different schemes and models, which makes it difficult to integrate them in a uniform way to allow a proper assignment of resources to the users' applications in an automatic way. In this scenario, we have considered using the technologies of the semantic web to facilitate a common understanding of the capabilities of the resources of the different providers and the requirements of the application and as a potential solution to the problem of resource allocation.

According to [32], an ontology can be formally represented as follows:

$$O = \{C, R, F, I, A\} \quad (1)$$

where C is a set of classes (domain concepts), R represents the relationships between domain concepts, F is the collection of functions, I is a set of instances (represent elements or individuals in an ontology) and A refers to the set of restriction rules or axioms, that is, theorems that are declared on relations that the elements of the ontology must fulfill.

Following the ontological model described above, this work analyzes the basic elements of the parameters C (classes) and R (relations) to build a taxonomy whose purpose is to unify the representation of the resources involved in a fog environment. Based on the literature analysis performed in Section II, we identified the main concepts of the domain. For the design of the class hierarchy, a top-down process was chosen, since, based on the generic concepts identified, more specific classifications were established. Fig. 1 shows the proposed taxonomy in the form of a class diagram. Next, we present a brief description of the classes and subclasses identified.

1) Infrastructure attributes: The resources involved in a fog environment, can be described considering the following aspects: hardware, software and network.

- Hardware requirements: This aspect includes information related to storage capacity, power source,

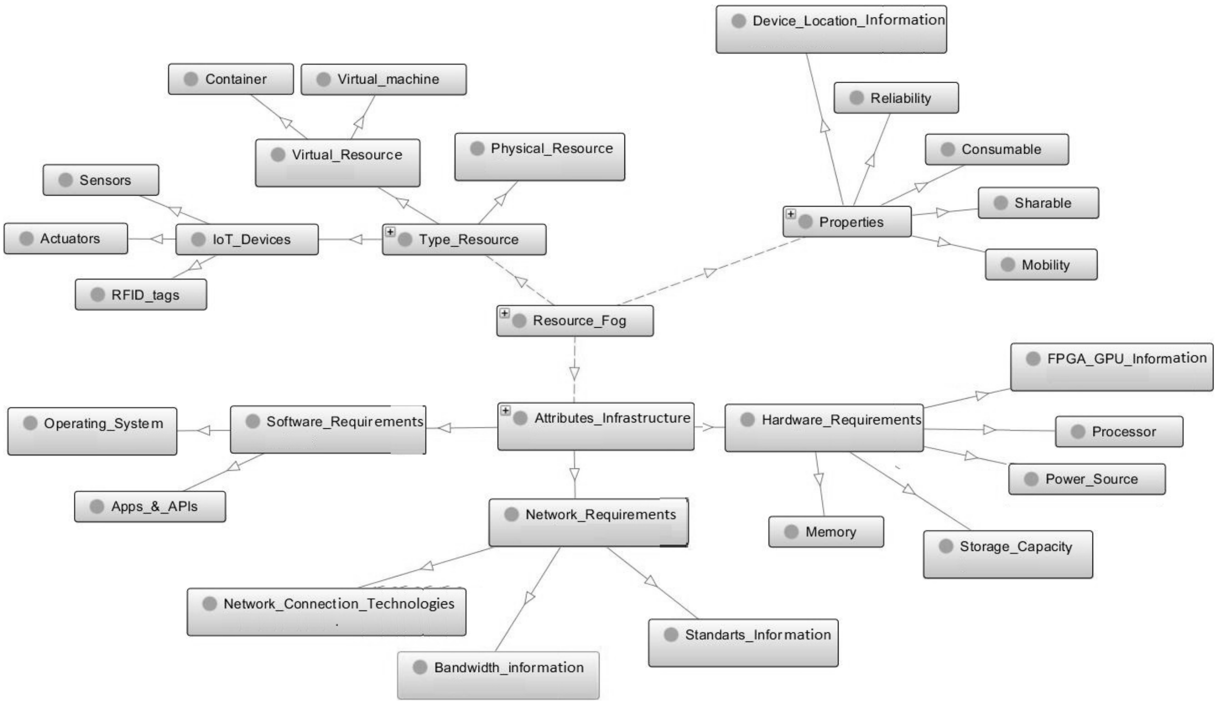

Fig. 1. Resource taxonomy of a fog system

processor, and memory. Other hardware components such as FPGA and GPU have also been considered.

- Network requirements: In a fog domain, a variety of interconnected devices coexist, using different standards and network technologies. Therefore, the information related to these aspects needs to be included to describe the resources, as well as the bandwidth information.

2) Resource type: The resources that participate in a fog environment can be classified as IoT devices (actuators, sensors, and RFID tags), physical resource and virtual resource (virtual machine and container).

3) Properties: In addition to considering information about attributes and components, the resources of a fog system can also be described based on information about mobility, reliability, and location. We have also considered other properties such as sharable, if a resource can be shared by several users and consumable, if the usage of this resource can make it unavailable.

In summary, as a result, a taxonomy consisting of 30 classes (subclasses - superclasses) was obtained. Due to the great heterogeneity in this domain, the proposed conceptualization constitutes a first version of the taxonomy, which will be enriched in future works.

IV. Conclusion

In this paper we present a taxonomy whose purpose is to unify the representation of resources in a fog system. Based on the analysis of the literature, the main concepts of the taxonomy were obtained, that is, the components, attributes and characteristics that describe a fog device. We consider this work as the first step towards the construction of an ontology that supports the strong variety of the involved nodes of the cloud, the fog, and the IoT, which would contribute to enhance, facilitate, and automate the processes of allocation and provisioning of applications over these nodes. Therefore, there are several challenges to solve. For example, integrating information related to the requirements of IoT applications and defining a set of rules which model the allocation policies of resources.

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