An Edge Computing Architecture Integrating Virtual IoT Devices

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***Abstract*—The current IoT ecosystem is Cloud centric which can not handle a diverse set of IoT applications and services, especially those demanding real time response. This paper proposes an Edge Computing (EC) architecture that provides an intermediate computing layer for IoT data. The proposed architecture utilizes Virtual IoT Devices (VID) for local data processing, management of physical IoT devices and quick reaction using actuators. A prototype of the EC system is developed and early performance results are reported. Applications of the EC system for roadside assistance services and emerging autonomous vehicles are outlined.**

***Keywords*-Edge Computing; IoT; Local Data Processing; Virtual IoT Device.**

I. Introduction

Cloud Computing infrastructures have become central to many IoT ecosystems. Now-a-days, consumers are relying on applications and services that are directly or indirectly (through operators reliance) supported by Cloud Computing Systems [1]. In parallel, advancement in mobile computing and manufacturing technologies have led to an explosion in consumer devices like Smartphones, tablets, smart watches, fitness trackers, virtual reality devices, IoT sensors, actuators and more. It is becoming increasingly challenging to process the diverse nature and huge volume of data generated by these devices [1]. Such Big Data are characterized by volume, veracity, velocity and variety. IoT applications and services dealing with such Big Data rely on Cloud Computing to generate information patterns, high-level abstraction and further processing. But emerging and next generation IoT scenarios (e.g. autonomous vehicles) require real-time data processing and actuation which demand IoT data to be processed near to its origin i.e. the edge of the IoT networks. Edge Computing (EC) [2], [3] enables local and distributed treatment of data and has gained much momentum from both the academia and industry.

EC is characterized by (i) proximity to end-users, (ii) dense geographical distribution, (iii) open computing platform through industry alliances, (iv) support for high mobility and (v) value addition for consumer IoT services. Utilizing the EC platforms, IoT applications and services are operated from the edge of IoT networks and from devices like access points, set-top boxes, road side units and IoT gateways. Such efforts in turn reduce latency, improve QoS, allow real time data analysis and actuation resulting in superior user experience in consumer IoT applications and services. Additionally, EC saves bandwidth as the data are processed at the edge of the network. Due to dense geographic coverage and distributed operations, the EC paradigm promotes fault tolerance and reliability [4].

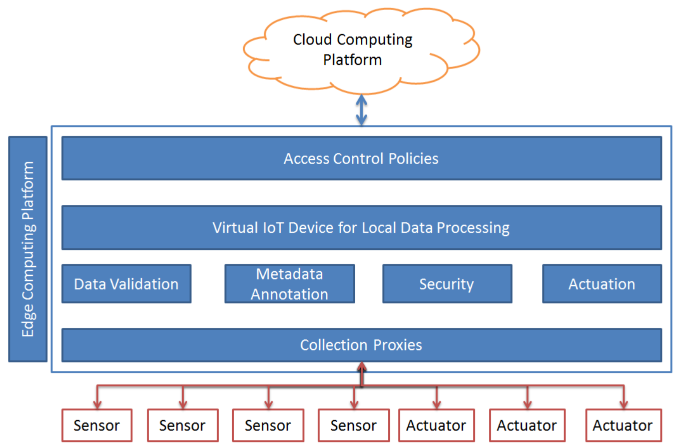

Fig. 1. Edge Computing Architecture

In this paper we explore the benefits of EC for roadside assistance IoT services and sensor data fusion in autonomous vehicles. To achieve them, we propose an Edge Computing architecture that integrates the concept of Virtual IoT Device (VID) for (i) IoT data validation, (ii) metadata annotation and (iii) local data processing based on predefined policies. The VID integration is the novel aspect of the architecture that allows bandwidth saving, avoid computational overhead in a centralized Cloud and provides faster reaction through actuation.

Rest of the paper is organized as follows. Section II describes the proposed ED architecture, its building blocks and operational steps. Section III presents an prototyping of the concept and evaluation results.

II. Edge Computing Architecture

The Edge Computing architecture is depicted in Fig. 1 which includes the support from a Cloud Computing platform for long term data storage and statistical data analysis. The architecture components are described below.

A. Collection Proxies

The sensors and actuators communicate using many different technologies and communication protocols. The collection proxies are a set of software drivers and scripts for such communication technologies (3G, Wi-Fi, BLE etc.) and protocols (HTTP, CoAP etc.). This layer ensures that a variety of IoT devices can connect to the proposed Edge Computing architecture.

B. Data Validation

This is the first step into IoT data processing where the sensor data is checked against some parameters. This is necessary due to the fact that, sensors deployed in smart cities, agriculture fields, vehicles are prone to noise which may alter the sensed data when transmitted. Therefore, checking and validating the sensor data ensures that it is correct. If the data is found to be corrupted, it is discarded. Performing the validation at the Edge saves bandwidth and reduces the load on a central Cloud Computing infrastructure.

C. Metadata Annotation

Once an IoT data is validated to be correct, it is enriched with additional information creating metadata [5]. For example, along with temperature data of an agriculture field, the unit, time stamp, location, unique ID of the sensor are important. This eases the data processing at the virtual IoT devices.

D. Security

IoT ecosystems often deploy numerous constrained devices which can not run complex encryption decryption algorithms needed for data security. In such a case, the Edge Computing platform is configured to encrypt any payload with AES-256 before communicating that to the Cloud Computing platform.

E. Virtual IoT Device

The concept of virtual sensors, its usefulness for data processing and taxonomy has been widely discussed in the state-of-the-art [6]. In [7], we have extended the virtualization concept to actuators as well and introduced the generic concept of "Virtual IoT Device" (VID). It is characterized as - (i) a virtualized instance of one or more sensors or actuators, (ii) hosted in a Cloud or Edge Computing platform and (iii) provides device description including a list of capabilities in terms of events, properties and action to facilitate data processing and communication to actuators. In this paper, we utilize the VID for IoT data processing as well as assist in data validation and metadata annotation. The VID functional architecture is depicted in Fig. 2.

The data processing requirements are written in an application script which is loaded on the VID during runtime. The runtime environment can be implemented using Docker which makes the VID run on a platform independent of the underlying operating system. For data validation, the application script will check the sensor value against its range of output. If the sensor value within the range, it is then considered as correct otherwise it is treated as corrupted and dropped. The range of the sensor is found by searching in the corresponding device description.

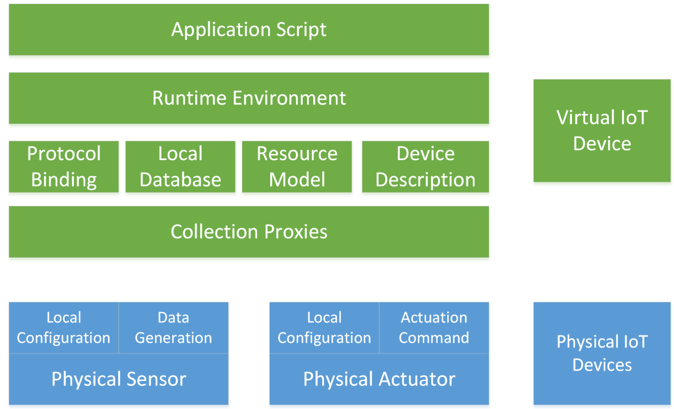

Fig. 2. Functional Components of a Virtual IoT Device

For metadata annotation, we use the parameters mentioned in IETF draft of Media Types for Sensor Measurement Lists (SenML)[1]. A method is written into the application script which allows enables the metadata annotation. This step is important if the IoT data is going to be reasoned with semantic web technologies [8] in the Cloud Computing Environment. A local database houses the processed data temporarily and can also be used as a buffer for incoming IoT data before processing.

The next step performed by the application script is data processing whose logic depends on the use case scenarios. For example, in a large agriculture field, the soil moisture values of several sensors must be averaged before triggering irrigation pump. For a smart city application measuring highest temperature in a city must collect several sensor data to compute the highest among them. Such logics can also be pre-configured into several scripts and used as necessary.

F. Actuation

A unique advantage of the Edge Computing architecture is that it allows quick reaction to events through actuation. Once the local data processing is complete in a VID, if certain conditions are met, it can trigger an actuation. For example, switching on an irrigation pump for an agriculture field. This actuation can be done locally which improves the real-time operational aspects.

III. Prototype and Results

We have created a prototype of the proposed architecture that integrates a VID component for data validation, metadata annotation and data processing. The Edge Computing system is running on a Raspberry Pi 3 hardware and currently supports IoT devices exchanging data using HTTP and CoAP over BLE and Wi-Fi. We utilized the platform in the context of a smart city scenario where connected vehicles provide sensor data about city temperature. We have applied the Edge Computing philosophy to two main use cases. The first use case considers a road side assistance system where a consumer can speak

[1]https://tools.ietf.org/html/draft-ietf-core-senml-10

to a device seeking help. The audio data must be treated locally to remove the background traffic noise before the request is transferred to a service provider. The second use case targets a prototype high precision positioning system in future autonomous cars. Here different subsystems are continuously generating data about the car environment. Local data fusion is critical here to develop and exchange local dynamic maps (LDM). The software environment together with MongoDB takes close to 300MB of spaces on the Raspberry Pi (which supports 32GB memory card). The application script is developed using NodeJS and its memory footprint is less than 1MB. During the operational cycle of the mentioned use case scenario, the CPU load varies between 5-15 percent.

IV. Conclusion

In a nutshell, this paper presents an Edge Computing architecture for local data processing and IoT device management. Virtual IoT Device concept has been utilized to accomplish both computation on IoT data and quick reaction through actuators. The EC system is applied to two scenarios on roadside assistance and vehicular data computation. Our evaluation points at lightweight aspect of the solution.

V. Acknowledgment

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