Next-Generation, Data Centric and End-to-End IoT Architecture Based on Microservices

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***Abstract*—The early Internet of Things (IoT) systems have been infrastructure dependent. But these systems are evolving due to the advent of data centric IoT architectures, applications and services that are independent of infrastructure. Cloudification, virtualization and softwarization of IoT devices and services are heavily used to design, develop and deploy new End-to-End IoT applications. Scalability, extensibility and interoperability challenges are now coming to forefront regarding the new IoT services and platforms. This paper proposes to tackle these challenges using microservices in the Cloud. We are extending our previously developed DataTweet IoT architecture and services to cover a high degree of heterogeneity, information systems, integration of virtual IoT devices, gateways and micro-granular architectures. The paper investigates the new challenges and describes solutions for integrating microservices with more flexible and scalable architectural meta models. We present a prototype of the enhanced architecture, its operational steps and a use cases on roadside assistance.**

***Keywords*-Autonomous Vehicles; Extensibility; Internet of Things; Interoperability; Microservices; Roadside Assistance; Scalability.**

I. Introduction

Market research companies like Gartner have predicted that by 2020 more than 50 Billion of IoT devices will be operational as a part of the Internet of Things (IoT) ecosystems around the world. The low cost connectivity, computing power, and enormous volume of devices are major drivers of the ongoing industrial revolution or Industry 4.0. Several successful IoT pilot experiments from EU H2020 Projects like BIG-IoT[1], VICINITY[2], and Smart City Pilot described in [1] have demonstrated their values to individual consumers, cities, and enterprises. The next frontier is to scale up the prototypes for mass adoption. But scalability, service extensibility, data privacy, and cross-platform interoperability are increasingly coming to the forefront. Cloudification, virtualization, and softwarization IoT services are the keys to support the vision of next-generation IoT systems and address the mentioned challenges. Microservices have the ability to support these design requirements of the IoT systems.

The microservice concept is considered as an extension of Service Oriented Architecture (SOA). In the context of IoT, microservices enable constructing and deploying loosely-coupled services in a Cloud or Edge Computing platform. Also, they are increasingly finding their utility in the IoT because of their following properties - self-containment, monitoring & prevention of fault cascading, orchestration, handling different service versions, extensibility and container based quick deployment. As a result, the IoT systems are advancing from 'Things' oriented ecosystems to a widely and finely distributed microservices-oriented ecosystems. This approach can combine patterns for loosely coupled services, virtualized gateway APIs, service distributions, dynamic discovery, containers, and access control [2]. Other features of microservices include - (i) complexity driven, (ii) lightweight in nature, (iii) rapid development, (iv) single task orientation, (v) broken object avoidance, (vi) load balancing, (vii) enhanced logging, (viii) strong modularization, (ix) decentralized governance, (x) composability, and (xi)plug-and-play.

In this paper, we are transforming our previously developed DataTweet IoT architecture [3], [4] into a next-generation, data centric and End-to-End IoT architecture based on microservices. For this purpose, we have identified, designed, and implemented a new computing model based on microservices. Our main contributions are in - (i) proposing the advanced IoT architecture based on microservices and implementing its cloud based prototype, (ii) demonstrate rapid extensibility by adding a new microservice, and (iii) achieve interoperation among microservices through uniform data exchange.

The remainder of the paper is organized as mentioned. Section II describes the state-of-the-art. Section III presents the advanced IoT architecture, novel aspects achieved using microservices and their application to a use case and Section V concludes the paper.

II. State-of-the-Art

This section reports the current state of microservice and its utilization in the IoT ecosystems. The concept arose from the best practices across software engineering, SOA, and enterprise architecture. According to [5], several technologies including domain driven design, continuous delivery, ports & adapters pattern, Machine-to-Machine (M2M) Communication, and virtualization platforms led to the foundation of microservice framework. Large Enterprises have begun to adopt this approach and have shown that it can support highly scalable, extensible and dynamic IoT architecture.

A. Monolithic Architecture

For such architecture, the software for IoT systems is deployed as a single solution in the Cloud. The services are

[1]http://big-iot.eu/project/
[2]http://vicinity2020.eu/vicinity/content/pilot-use-cases

developed as distinguishable functionalities and are all interwoven in the same back-end [6]. Monolithic architecture based IoT systems are module independent and use a dedicate/set of technology stack. Many early IoT systems were developed following such principles resulting into low re-usability and scalability. To improve that, an Event Driven SOA for IoT was presented [7]. The EU funded OpenIoT project also extends the SOA concept to Web of Things to improve the mentioned aspects [8].

B. System Design

The paper [6] designs a new generation of IoT framework strongly focusing on re-usability and loosely coupled services. Among them are microservices for Geo-location, security, tenant, Big Data, automation, application, and more. The authors have also shown the system design for device microservice for registration and provision.

The authors of [9] describes how to select the technologies to implement a modern microservice architecture deployed in a cloud. Apart from the system design aspect, it provides an empirical evaluation between different JVM based Microservice Application Servers (MAS) in terms of throughput, memory footprint, and binary footprint. In addition to that, it presents an open source testbed that allows integration of programming language agnostic MAS implementations.

Abstract model for IoT systems and patterns that will be used in future IoT systems are examined in [2]. A combination of six patterns (access control, containers, discovery, distribution, API gateway, and microservices) is explained by the authors as building blocks. The paper illustrates the usefulness of the six patterns using two case studies on personal health management and autonomous driving.

C. Integration with Enterprise IoT Architecture

The authors of [10] expand their original enterprise architecture by integrating microservices. In this context, they focus on research questions about architectural properties of microservices, resulting implications for enterprise architecture management (EAM), implications of integrating microservices into an adaptable enterprise architecture. They have illustrated microservices in the context of EAM, integration example, correlation analysis, and integration matrices.

A self-managing programmable IoT platform is presented in [11]. This platform leverages microservices for cloud to create an enterprise architecture. It uses a Core-Cloud and a Edge-Cloud where both the entities exploit microservices for specific purpose. The Core-Cloud use core microservices for visualization, Spark, Cassandra, Swarm Manager, IoT control services and Autonomic Management System (AMS). The Edge-Clouds use edge microservices, aggregator microservices and virtual sensor containers.

Another microservices based architectural approach to develop Industry 4.0 platform is presented in [12]. The Nimble collaborative platform enables many prospective Cloud based IoT platform providers to develop and deploy B2B marketplaces. Nimble makes use of microservices to provide core business capabilities including (i) platform user registration, (ii) publishing product catalogs, and (iii) searching for B2B partners. Also the platform architecture use microservices for the IoT device configuration, service discovery, notification service, monitoring, and identity management.

From the IoT architecture security perspective, it is argued that microservices deployed in Edge devices is more secure that that of Cloud systems [13]. The paper also introduces the concept of MicroELements (MELs) which is composed of Microservices and MicroData (e.g. a piece of information flowing to/from an IoT device). This concept is applied to Cloud, Edge, and IoT device level environments as a part of the OSMOSIS architecture and security membrane. The authors also present a detailed attacker security model for device-centric attacks and network-centric attacks. The mitigations are presented in terms of software defined membrane for security management.

D. Interoperability

Microservices for interoperable IoT platforms are studied in [14]. The authors have pointed to the fragmentation of the IoT market and scalability issues. To mitigate both, they define an IoT platform and its architecture based on orchestration of different IoT building blocks implemented using microservices. This approach is effective in hiding complexities stemming from heterogeneous IoT devices. This approach also brings interoperability and allows extending or removing platform functionalities easily. With microservices and its new software architecture patterns[3], IoT applications can run as services which are in turn running in their own independent process context. The inter-services communications reply on lightweight TCP/UDP based application protocols.

In [15], microservices are used to develop cross-domain IoT applications. They are implemented using a novel platform - Web of Objects that also enable interoperable microservices. They offer service modularity, virtualization and granularity of IoT devices through virtual objects [16]. As a result, the challenges arising due to communication, complexities due to semantic cooperation, deriving meaning from raw sensor data, rapid scalability, recovery and resiliency can be easily supported in the IoT systems.

E. IoT Applications

Many works have been carried out to extend the microservice concept for real-world IoT applications. In [17], a smart building application are deployed using microservices. The overall IoT architecture was composed of microservices achieving the following - (i) connecting and configuring sensors, (ii) programming the sensors, and (iii) data collection in a Cloud. The authors validated their work using a prototype.

The IoT applications now-a-days are an amalgamation of resource preparation, management, processing and offloading. Enterprise applications often require the support of scheduling models. Microservices scheduling model is introduced in

[3]http://microservices.io/patterns/index.html

[18]. Their formal model description is based on processing elements and jobs. Based on that, the authors have portrayed a framework for generic real-time scheduling system and proposed three algorithms.

III. Advancing IoT Architecture using Microservices

As discussed before, next-generation IoT systems require scalability, extensibility, interoperability and integration of heterogeneous devices and protocols. To respond to these challenges, our advanced architecture extensively uses ”micro elements” composed of (i) microservices (specific IoT functionalities that can be deployed and migrated across various virtualized infrastructures) and (ii) micro data (data exchanged among services and devices).

The functional elements of the proposed architecture are drawn in Fig. 1. To cover many use case scenarios, it involves IoT devices as well as connected cars[4]. The architecture integrates microservices in both Cloud and Edge servers as shown in Fig. 2.

A. Microservices in Edge server

The Edge server in the architecture supports in local computation on sensor data and quick reaction using actuators. This saves bandwidth for Cloud communication and de-congests the core network. For this purpose, Virtual IoT Devices (VID) [19] are deployed as micro elements. A VID is defined as a virtualized instance of a physical sensor or actuator and provides a Thing Description (TD) containing the supported capabilities. The provisioned VID contains a communication manager to exchange data with the physical IoT devices and five microservices for IoT data validation, metadata annotation, local data processing, local actuation and local storage. The Edge server prototype is running on a Raspberry Pi 3 with microservices deployed using docker.

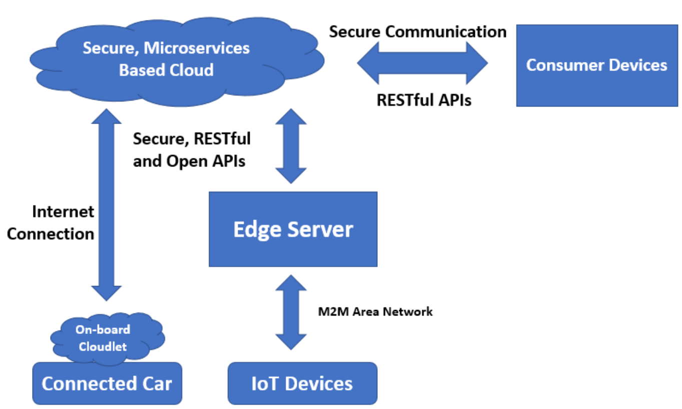

Fig. 1. Functional elements of the microservices based IoT architecture.

[4]Discussion on Cloudlet and Connected Car is out of scope for this paper.

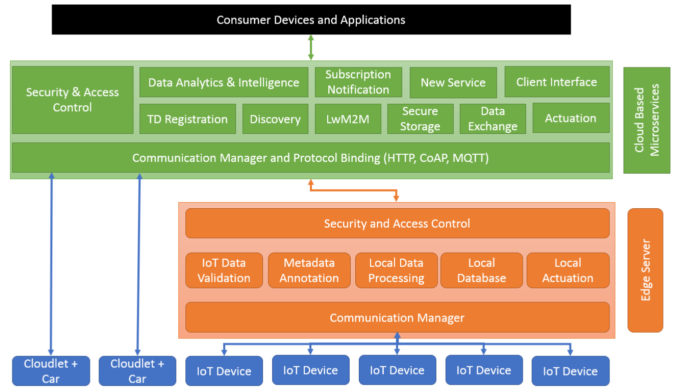

Fig. 2. Micro elements in the IoT architecture.

B. Microservices in Cloud server

Cloudification, virtualization and softwarization of IoT services are performed using microservices. As a first step towards that, the M2M gateway APIs (e.g. discovery, LwM2M for management, sensor data exchange, storage, subscription, and notification) presented in [20] has been virtualized and deployed a Cloud server. The security mechanisms identified in [21] are also integrated in the same. Our micro data implementation is uniform for all services and devices. Such data exchange is based on JSON Schema and is key to maintain interoperability with other IoT systems. The Cloud server prototype is running on a virtual machine in an Amazon Web Server instance with microservices deployed using docker[5].

C. Use case and extensibility aspect

To demonstrate the rapid extensibility of our IoT architecture, we have chosen a use case of road side assistance as shown in Fig. 3. An end user requiring assistance uses a specialized device deployed at the road side to establish an audio channel with a call center side. We propose to use the Cloud server deployed in AWS as a back-end system supporting the use case.

In the current scenario, there is no such microservice. Therefore, we rapidly develop a new service using a Cloud based PBX[6] and a SIP client on a laptop (for call center side). It is deployed using another container and such integration does not impact any of the currently running microservices.

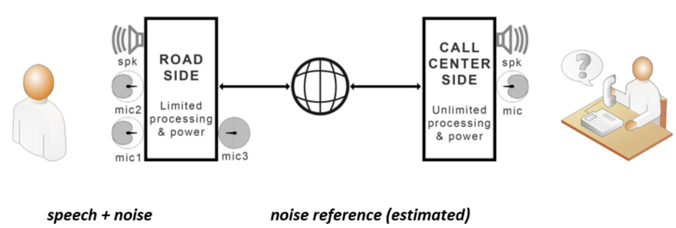

Fig. 3. Roadside assistance use case

[5]https://docs.aws.amazon.com/AmazonECS/latest/developerguide/docker-basics.html

[6]https://www.3cx.com/docs/cloud-pbx-amazon-aws

D. Novel aspects

Utilization of microservices enable collaborative computing in the architecture where the service components can be developed in parallel as long as uniform data exchange format among them is defined. Apart from that, rapid extensibility, and the replication of services allow supporting high degree of device interactions i.e. scalability. Achieving interoperability through uniform data exchange is another distinct aspect of the work. The overall architecture efficiently support a data centric design and End-to-End use cases for next-generation IoT ecosystems.

IV. Conclusion

This paper presents our efforts to transform the DataTweet IoT architecture into next-generation, data-centric and End-to-End IoT architecture based on microservices. As a result, the proposed IoT services are loosely coupled, rapidly extensible, and replicable that are deployed in virtualized environments of a Cloud and Edge server. A prototype of the entire architecture is operational and we show extensibility aspect using a use case on roadside assistance. As a future work, we are using the microservice based system to create an IoT test bed for experimentation.

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