Designing a Semantic Digital Twin model for IoT

Shapna Muralidharan*, Byounghyun Yoo*, Heedong Ko†
Korea Institute of Science and Technology, Korea*, University of Science and Technology, Korea†
ko@kist.re.kr

Abstract—Today there is exponential growth and convergence in technologies like the Internet of Things (IoT), machine learning, and other forms of Artificial Intelligence leveraging the way we collect and analyze data from smart sensors. A Digital Twin (DT) technology is the creation of the virtual replicas of physical IoT devices that helps to monitor the applications, analyze data collected, and predict future behavior and performance of devices. In this paper, we propose a semantic DT based IoT model with support at the edge with container technology to mimic the IoT devices and enhance the interoperability of the heterogeneous IoT devices.

I. INTRODUCTION

With the unprecedented increase in various embedded sensors providing smart services in our daily life, we need a novel IoT model to efficiently embrace applications to interoperate with each other horizontally. New technologies like Digital Twin (DT), microservices are gaining popularity since they are bridging the main prevailing issues like interoperability, device discovery, real-time data collection, and analysis in the IoT scenario. Firstly the concept of DT technology dated back to 2002 from the University of Michigan and prevailed stable from its initiation [1]. DT is the creation of virtual replicas of physical IoT devices, typically mirroring them in the cloud. Figure 1 illustrates the concept of DT as a virtual doppelganger of IoT devices, enabling device-as-a-service. The main asset of a DT is to implement an abstraction layer that allows IoT applications to communicate with devices continuously. The main goal of a DT is that it pursues the lifecycle and the data integrated with the device. DT’s enable features like device simulation during development, their characteristics, behaviors in time, and integration of analytics. In the proposed model to create DT’s in an IoT scenario, we rely on the microservices-based docker containers, and it is explained below.

Currently, a majority of IoT applications depend on edge and fog computing to store data and perform computations. However, the prevailing issue with edge devices is they lack high computing resources to run large-scale IoT operations independently [2]. It is challenging to achieve a scalable solution in the IoT scenario, with hypervisor nodes at the edge. Conceptually, containers are similar to virtual machines (VMs) and a lightweight approach to virtualization that helps developers to rapidly develop, test, deploy, and update IoT applications at scale. Each container has sufficient virtual resources, filesystem (memory, CPU, disk, etc.), isolated from other applications and containers [3]. In recent years IoT containers provide possible options to solve challenges faced in edge computing [4]. Docker is a widely adopted tool to create, deploy, and run applications using containers [5]. Docker envisions any developer to bundle up an application with all its libraries and dependencies, and give it as one package. Since docker images packed in containers can mimic IoT devices and applications similar to the concept of DT, it can be used to create the virtual IoT environment.

Although docker enhances the interoperability feature with DT based model, we need a semantic model for device discovery and uniform data format. The W3C Web of Things (WoT) has proposed Things description (TD) that specifies a semantic way to map IoT devices in the physical world to virtual things that can facilitate interoperability among IoT applications [6]. TD can provide a semantic, structured description of the Thing’s capabilities, its interactions, communication protocols, data model, and security mechanisms [7][8].

In this paper, our main contributions are we have proposed an IoT model using the DT concept that represents an IoT device or application virtually in its lifecycle. We have augmented connected IoT devices with the help of DT with the processing power and storage capacity at the edges assisted by docker images. To enhance the interoperability among devices and applications, we have used W3C based TD regardless of the platform dependency of the device and the networking protocols. The semantic DT model, along with microservices, can orchestrate various IoT devices and applications in a simplified way.

II. PROPOSED SEMANTIC DIGITAL TWIN MODEL

In our proposed semantic DT model, we envision the DT concept with the help of docker images. Docker containers create digital replicas of the IoT devices on edge. Docker is an open-source application-oriented project and helps in building containers from base images [9]. The images mimic the IoT devices, and they play the role of a template to set up containers. The ultimate goal of a DT is to create, test, and build an IoT system in a virtual environment, and it can be envisioned with the help of Docker containers as shown in...
Figure 2. Each change in a docker image is versioned similarly to Git, and it helps for learning purposes as well as maintaining the lifecycle of the IoT device with minimal overhead and maintenance. Most of the IoT devices have enough resources to have a digital twin in the device itself. In case if the devices are resource-constrained, then the docker images reside in the IoT gateway [10]. The docker containers need orchestration to monitor these virtual DT images and orchestrate the containers dynamically. We have explored a platform called Kubernetes, which is a multi-host container management platform [11]. Kubernetes holds one or more containers together and reports the status when there is a failure or an update. Kubernetes enables easy tracking of the DT’s deployed in the form of docker images in multi-hosts.

The semantic modeling is performed using the TD, which offers preliminary information about an IoT device and illustrates interfaces and interaction prototype among the IoT devices. Figure 3 shows a sample of TD for an air quality sensor. For example, the air quality sensor is an IoT device that records the air quality every 5 minutes addressed by a username. The TD also expresses the address, along with the location of the device. Further, it holds measurements like humidity, temperature, particles in the air, pollution levels, and many more details along with a timestamp for each detail. The TD implementation relies on JSON-LD format as in default. Semantic modeling can enable resource-constrained IoT devices to communicate through web API to their DT.

The proposed model enables IoT devices generating data with a mirror image as docker images in the edge or sometimes in itself. All the data is in the form of TD enabled with the help of TD server and can be accessed by the clients through the web. The Docker containers store all the data generated and exchanged in the form of logs with versions [4]. The containers help us to track the data and all the records pertaining to the device from updates to functioning issues. The Kubernetes platform helps us in scaling a new DT image when one fails. Resource provisioning and scaling are inbuilt features of Kubernetes. Altogether the semantic DT model enables efficient device discovery, data retrieval, and they also help in imitating the physical IoT device as mirror images in the edge. The monitoring process, with the help of Docker and Kubernetes, helps to locate issues and to enhance the reliability of large-scale IoT applications. Most of the existing DT technology is used in few sectors of IoT like smart industries and needs wider adoption. The semantic DT model enables interoperability among IoT devices eliminating vertical silos and it plays an essential role in interoperability among various IoT applications. We can evaluate the proposed semantic DT model for efficient data storage, retrieval, and monitoring IoT applications.

III. Conclusion

In this paper, we have proposed a semantic DT model using a docker image to clone an IoT device and monitor them using a Kubernetes platform. The proposed DT model can maintain the IoT device details, monitor the IoT devices through their lifecycle, and sync the data generated, ensuring the reliability of IoT applications. The proposed semantic DT model can solve some of the significant challenges hindering IoT sector growth like service discovery, reliability, scalability, and monitoring devices from various applications. In the future, we propose to evaluate the semantic DT model among various IoT applications.

References