Kubernetes: Towards Deployment of Distributed IoT Applications in Fog Computing

[Demonstration Paper]

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ABSTRACT

Fog computing has been regarded as an ideal platform for distributed and diverse IoT applications. Fog environment consists of a network of *fog nodes* and IoT applications are composed of containerized *microservices* communicating with each other. Distribution and optimization of containerized IoT applications in the fog environment is a recent line of research. Our work took Kubernetes as an orchestrator that instantiates, manages, and terminates containers in multiple-host environments for IoT applications, where each host acts as a fog node. This paper demonstrates the industrial feasibility and practicality of deploying and managing containerized IoT applications on real devices (raspberry pis and PCs) by utilizing commercial software tools (Docker, WeaveNet). The demonstration will show that the application's functionality is not affected by the distribution of communicating microservices on different nodes.

CCS CONCEPTS

• **General and reference** → **Experimentation**; • **Networks** → **Network architectures**.

KEYWORDS

Fog computing, IoT, fog nodes, microservices, Kubernetes, Docker

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1 INTRODUCTION

The objective of fog computing, as described in a reference architecture presented by the OpenFog consortium [9], is the dynamic pooling of unused local resources from participating end-user devices which are referred as *fog nodes*. Fog nodes are the computational, networking, storage and acceleration devices that establish a communication network, which we refer to as *fog network*. Instead of developing large monolithic applications, companies are now delivering applications in small discrete pieces, called *microservices*, by adopting the microservice architecture [6]. Microservices can be installed in application *containers*, which are lightweight and portable runtime environments provided by operating systems. These containerized microservices communicate with each other to achieve application functionality. Docker [1] containers are quickly becoming the go-to technology for building and running distributed applications. The limited capacities and heterogeneity of fog nodes demand efficient orchestration mechanisms for resource management in fog environments. Although containers already provide a high level of abstraction, they still need to be properly managed, specifically in terms of resource scheduling, load balancing, and server distribution, and this is where integrated solutions like Kubernetes come into their own.

Kubernetes [2], the Google-incubated open-source container orchestration tool, is quickly becoming the de facto standard for managing large container deployments. Companies like Red Hat, Microsoft, IBM, Amazon, Mirantis and VMWare have integrated Kubernetes into their cloud platforms. Despite the increasing recognition of fog computing in industrial environments, container orchestration in fog environment is less explored. Thus the analysis of the performance and usability of Kubernetes for the deployment of containerized applications in the fog computing environment is a new direction of research. This paper aims to establish the feasibility and industrial practicality of deployment and management of containerized applications in fog computing. The demonstration confirms that even if communicating containers are distributed on different fog nodes, the application functionality can be kept intact without a significant penalty in terms of the application's QoS and time delay. It also establishes the future scope of integrating other user devices like smartphones and smart cameras as fog nodes.

2 BACKGROUND

We consider the model of distributing IoT applications on the network of fog nodes from [7, 8]. Figure 1 shows an example of a containerized IoT application consisting of five microservices, indicated by cubes, distributed over a network of four fog nodes depicted by hexagons. The arrows between the containers indicate that they exchange data with each other. The bidirectional edges between the fog nodes indicate the communication links. The allocation of applications in fog computing can be done in two ways as shown in Figure 1. In Figure 1(a), the entire application is placed on a single fog node, similar to the cloud deployments. This approach not only reduces latency but also improves the application QoS. However, in a fog computing environment, due to limited resources

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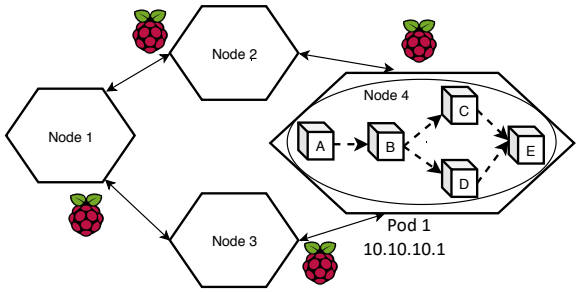
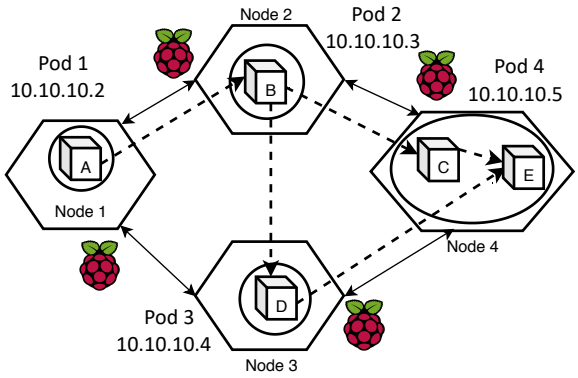
of fog nodes, it is often not possible to deploy the entire application on a single fog node. Therefore, the application needs to be distributed over the network of communicating fog nodes as shown in Figure 1(b). Deploying communicating containers on different fog nodes leads to data exchange between the fog nodes over the network which may incur some latency.



(a) Application on a single fog node.



(b) Application distributed over fog network.

Figure 1: Distribution of IoT Application.

We implement the design by utilizing the feasibility results from [5], where authors used raspberry pi devices to implement a fog network and deployed Docker containers for IoT applications. We use a video streaming IoT application that requires real-time, low latency services. Further, we use Kubernetes as an orchestration and monitoring tool to automate the deployment of application containers across a cluster of raspberry Pis. *pods* and *nodes* are two features of Kubernetes that are essential to the comprehension of our work. A pod is the basic control and management unit of Kubernetes consisting of one or more containers. Each pod is assigned a unique IP address. Kubernetes nodes are physical devices and run services like Docker, kubelet, and kube-proxy, necessary to run pods. Kubernetes architecture has a master node and worker nodes. The master node manages the Kubernetes cluster, and it is the entry point for all the administrative tasks. A worker node runs the application pods and is controlled by the master node. Next, we describe our experimental environment that compares the performance results in two scenarios shown in Figure 1.

3 IMPLEMENTATION DETAILS

Our testbed consists of a PC (Intel x86 architecture) serving as Kubernetes master node and four raspberry pi 3 (32-bit arm architecture) acting as worker nodes and forming a network as shown in Figure 1. All devices have Ubuntu 18.04 LTS as the operating system and run Kubernetes v1.17.3 and Docker-engine v19.03.6. The installation instructions for configuring raspberry Pis are available on GitHub at [3]. Kubernetes master node initializes a cluster and generates a token that is used by worker nodes to join the cluster. We use a video streaming nodeJS application (node v13.5.0) with five microservices communicating as shown in Figure 1. Each microservice of the application is containerized as a multi-platform image using Docker Buildx CLI plugin and pushed to the docker hub repository.

A Kubernetes pod is defined as a YAML file that consists of the details of one or more container images. Kubernetes runs a scheduling algorithm that assigns nodes to the pods. For the deployment strategy depicted in Figure 1(a), we place all the Docker containers of the application in the same pod and the pod is deployed on a single raspberry pi. Every container in a pod shares the network namespace, including the IP address and network ports and communicate with one another using the localhost without any network delay. On the other hand, in order to implement the placement depicted in Figure 1(b), the containers distributed on different Kubernetes nodes are placed in different pods. Kubernetes assigns a different IP address to each pod and communication between two pods placed on two different physical devices is performed over the network. We use Weave Net[4] to create a virtual network that connects Docker containers deployed across multiple nodes and enables their automatic discovery. This deployment strategy introduces a network delay in achieving the same functionality. We further use Kubernetes services that bind a port to exposes the pod. This allows us to access the pod on the Nodes IP address by sending a REST request.

4 DEMONSTRATION OVERVIEW

We start the streaming of video packets from container A and packets follow the path as shown in Figure 1. We will observe the output of the streaming on container E by sending an HTTP request to node 4. The demonstration will show that the functionality of the application is not affected by the distribution of communicating containers in separate pods placed on different raspberry pis. In the demo, we will show the quality of video streaming achieved with the two deployment strategies and the time lag experienced in the second scenario (Figure 1(b)). We also show how the application functionality, in terms of time delay, is affected when we consider mobile nodes and change the distance between the devices.

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