FoGMatch: An Intelligent Multi-Criteria IoT-Fog Scheduling Approach Using Game Theory

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***Abstract*— Cloud computing has long been the main backbone that Internet of Things (IoT) devices rely on to accommodate their storage and analytical needs. However, the fact that cloud systems are often located quite far from the IoT devices and the emergence of delay-critical IoT applications urged the need for extending the cloud architecture to support delay-critical services. Given that fog nodes possess low resource capabilities compared to the cloud, matching the IoT services to appropriate fog nodes while guaranteeing minimal delay for IoT services and efficient resource utilization on fog nodes becomes quite challenging. In this context, the main limitation of existing approaches is addressing the scheduling problem from one side perspective, i.e., either fog nodes or IoT devices. To address this problem, we propose in this paper a multi-criteria intelligent IoT-Fog scheduling approach using game theory. Our solution consists of designing (1) preference functions for the IoT and fog layers to enable them to rank each other based on several criteria latency and resource utilization and (2) centralized and distributed intelligent scheduling algorithms that capitalize on matching theory and consider the preferences of both parties. Simulation results reveal that our solution outperforms the two common Min-Min and Max-Min scheduling approaches in terms of IoT services execution makespan and fog nodes resource consolidation efficiency.**

***Index Terms*— Internet of Things, fog computing, game theory, cloud computing, intelligent scheduling, edge computing.**

I. Introduction

THE IoT (Internet of Things) is becoming part of almost every person's daily life [4] thanks to the wide set of benefits it offers ranging from simple wearable devices and smart meters down to connected cars and smart cities. This led to an unprecedented increase in the number of IoT devices that are deployed and operated around the World. For example, Cisco estimates that the number of IoT devices will hit 30 billion by 2030 [5]. Cloud computing [6]–[10] has long been the first choice of IoT manufacturers and providers to accommodate their storage and analytical needs, due to the unlimited and high-performance computing and storage capabilities it provides. Nonetheless, the fact that cloud data-centers [11], [12] are usually deployed in locations that are quite far from the IoT devices entails high response time for high-end systems due to the long-distance communications and multi hopping. This of course entails risks since IoT devices are used in many verticals to which time is of essence. For example, consider the case of a patient using a wearable device that sends a piece of data from her brain for urgent analysis. In such a case, the longer the data analysis request takes to reach the intended server [13], the higher is the risk on the patient's health. This causes a serious problem in cloud-based environment in which the analysis needs to take place in geographically cloud data centers. Therefore, this becomes a serious problem when it comes to delay-critical services that often require responses in milliseconds such as healthcare management and intelligent transportation system applications.

Fog computing is a relatively recent technology which aims to overcome the latency problem through enabling data analytics at the edge closer to the origins of the IoT devices [14], [15]. In fact, IoT devices have limited computing and network resources as well as small-sized storage facilities [16], [17]. For instance, whenever IoT devices request or send data back and forth, they will consume huge amounts of network resources. This might entail bottlenecking issues and make the entire network slower. Fog nodes contribute in mitigating this problem through providing the IoT devices with fast data analytics and decision-making capabilities at the edge of the network [18], [19]. In spite of its benefits, the fog computing technology suffers from non-negligible challenges which are mainly related to the limited amounts of resources that are usually available on fog nodes. Therefore, such resources should be efficiently utilized and managed to increase the amount of tasks they can serve as well as the Quality of Service (QoS) [20] provided to each task. To fully benefit from the fog computing technology, another important metric has to be taken into consideration, i.e., the latency between the two sides. In other words, IoT devices need to connect to the fog nodes that are the closest to them in order to guarantee fast and efficient transfer of data and messages.

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