Empowering the Edge: Innovations and Challenges in User-Provided Infrastructure

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2.4.2024

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Abstract

Fog and edge computing have received a great deal of attraction in recent years. These technologies promise to reduce latency for time critical applications and provide better quality of service for users. Several interesting research papers have been released during the past decade and various models for utilizing edge and fog networks have emerged. Resource sharing networks consisting of internet-of-things devices are seen promising. Although studies have found the technology and models to deliver promising results, there exists a need for proof-of-concepts and innovation. The proposed models displayed in this paper share insight into potential future implementations. It was found that these models complement each other in ways that when combined could enhance the quality of service significantly.

Moreover, this paper conducts a literature review on timely research of User-Provided Infrastructure by going through proposed models for utilizing edge and fog paradigms. Furthermore, technical, and incentive challenges and future study directions are explained and explored.

KEYWORDS: Internet of Things, Edge, Fog, User-Provided Infrastructure, Low Latency

1 Introduction

In recent years, edge computing has shown significant potential as an alternative to traditional cloud computing paradigm [1], [2], [3].

The hopes for enhanced quality of service seem to be filled as the study into edge computing and internet of things (IOT) advances. This research has sprouted an interest in studying whether mobile IOT devices were able to form federations for even greater benefit, like the change from cloud to edge computing. Although the topic is still relatively novel, studies have shown exciting potential in these types of paradigms [1].

Furthermore, as data processing and prediction integrates more to consumer products, there is a growing need for lower latency networks [3]. By moving things from cloud to the edge of the network, or even to the fog, we could harness the untapped computing power of heterogeneous device pool, ranging from smartphones to cars to embedded IOT devices.

Although these technologies promise remarkable benefits and enhancements to our current digital lives, they have yet to deliver their full potential. While the field of edge and fog has a robust background in science, it is still met with the challenges of implementing novel technologies in real world applications. To overcome these challenges, there persists a need for more research with a focus on proof-of-concepts (POC) and innovations.

This paper aims to explore and introduce recent studies, discoveries and inventions related to User-Provided-Infrastructure (UPI). In the following sections, the paper first covers some core concepts, after which it will introduce some proposed models for utilizing edge and fog networks for UPI, and lastly it will go over some of the challenges. In the end, there will also be a discussion based on the findings of this paper and a conclusion on what further studies should focus on.

2 Core Concepts

In this section, the paper briefly explains the core concepts and paradigms around edge and fog computing and how they differ from each other. First the concept of cloud is introduced, following description of IOT, after which, the basics of edge and fog computing are covered. Overall, this section aims to create a base line understanding of the building blocks of User-Provided infrastructure.

2.1 Cloud

As of now, cloud is a more popular choice for hosting various applications, storage, and computing power than ever [4]. The change from maintenance requiring, difficult to scale when the needs, on-premises data centers (DC) has been ongoing for the past decade or two. The clear advantages of cloud over traditional own DC have made it, with its vast selection of pre-built applications and infrastructure, mostly uncontested when it comes to computing. However, due to the usual, distant location of the DCs, the latency associated with cloud is usually significantly greater than closer deployed solutions.

Modern lives, be they at home or at the supermarket, are monitored on a vast scale. This monitoring is powered with an assortment of sensors working together. The data collected is further used for data analysis to yield predictions on human behavior, weather, and so on. For such systems to work in real time, the need for low latency is a key. The solution proposed for this challenge is to, in certain cases, move back from the cloud to the edge or even to the fog. These terms will be explained in the later sections.

2.2 Internet of Things

IOT refers to a network of interconnected devices with sensors, and computing power, that communicate between each other. The core idea around IOT is the introduction of smart systems, e.g., smart homes, where an assortment of connected sensor devices could enhance the experience, in this case living, by providing more optimization from the data collected. IOT as a term did not exist before Kevin Ashton proposed it in 1999. [5] Moreover, IOT devices are strongly linked edge and fog paradigms since both utilize a network of interconnected devices. This connection of different technologies will be touched upon in later sections.

2.3 Edge

The term edge computing refers to, as the name suggests, the area of the network which is at the "edge" of the cloud. Bringing computing and content closer to the end-user lowers the latency providing users better quality of service (QOS) in terms of faster internet connectivity and greater efficiency in data processing. In addition to that, edge computing also offers location awareness, which for some delay-sensitive use cases, might enhance their efficiency. [6] Moreover, as the consumption of internet content is increasing annually, especially on Over-the-top (OTT) platforms [7], there exists a growing need for edge network applications, such as content delivery networks (CDN).

2.4 Fog

Fog computing, first introduced by Cisco [8], is a cloud computing paradigm which extends from the idea of edge computing. It offers even lower latency compared to edge computing with enhanced mobility and widespread geographic distribution. Use cases of fog range from connected vehicles to smart grids and various wireless sensor systems. During the past decade, fog computing has been a raising topic in scientific studies [1], [3], [8], [9].

Especially the interest for low latency applications has accelerated the research for creating models for utilizing fog computing. Although it is a decade old concept, there have not been significant successes so far. However, as technology offers, in certain situations, great advantages over the traditional cloud computing paradigm, it is an appealing topic for researchers and entrepreneurs.

3 Proposed Models

Although the idea of UPI has been around for some time, it has been lacking a working model to implement it for real world applications. While some companies have tried implementing this concept, a great breakthrough has yet to emerge. In this section, the paper aims to display some of the proposed models and frameworks for better utilization of edge and fog.

3.1 3C Recourse Sharing Framework

The 3C framework works by efficient utilization of device-to-device (D2D) connections among mobile devices. This model proposes that with the formation of co-operative groups, mobile devices can experience enhancement in efficiency in accomplishing tasks. Although resource sharing schemes have been proposed before, the key factor setting 3C framework apart from the previous ones is that it considers all three of the resources mobile devices may share, communication, computation, and caching. The article proposing 3C framework, found that energy consumption of participating devices was significantly reduced. With many mobile devices having small battery lives, energy efficiency brings more flexibility to the fog network as it provides greater mobility opportunities. The 3C framework's advantage is that it can utilize a heterogeneous pool of devices which enables better resource allocation for different tasks. For example, some devices might possess more storage than others and some might have faster and more stable internet connection. Therefore, the framework allows these resource rich devices to utilize the overhead they have on those resources. [2]

In addition to providing novel framework for resource sharing, the researchers also outline potential issues and challenges. These include incentive schemes, security and privacy, and the need for carefully designed software and protocols. [2] These challenges will be covered in more detail in later sections.

3.2 Hierarchical Mobile Edge Computing

In a paper published in 2017, Kiani and Ansari propose a hierarchical model for mobile edge computing called Hierarchical Mobile Edge Computing (HI-MEC). This model utilized different tiers of cloudlets, a computer which is trusted, has good connectivity, and is resource rich [10], to offer lower latency for mobile users. The model proposes that there should exist three tiers of cloudlets, field, shallow, and deep, where cloudlets further from the mobile users have more resources associated with them. [3]

The HI-MEC architecture aims to efficiently distribute the workloads from mobile users to different tiers of cloudlets. In case the user demand is greater in the field cloudlet than what its resources can handle, the workload can be moved up in the chain to higher level cloudlets to take care of. This system of delegating workloads to different cloudlets helps to manage demand fluctuations in the network. [3]

The paper suggests that service providers should consider an auction-based pricing model to offer more flexibility. This is important in the sense that well designed pricing schemes can benefit both the users and providers as they could bring more users while for the user it can mean cheaper prices. Moreover, for mobile users, HI-MEC can provide opportunities for offloading certain mobile applications to cloudlets which in turn can have, as discussed earlier, an impact in their device's battery life. Furthermore, the paper found that the proposed hierarchical model could efficiently allocate resources to MEC network. [3]

3.3 MIFaaS

Mobile-IoT-Federation-as-a-Service (MIFaaS) is a model proposed by Farris et al. in their 2017 paper that aims for more efficient utilization of resources in a pool of heterogeneous devices. As the user requirements can differ, so do the resources that certain devices can offer. [1] For example, a smart phone may have a great internet connectivity, but it may lack processing power and storage whereas a smart car could house more storage and better computational resources. Mobile devices of the passengers could then lend their network access to the smart car and the car could borrow its processing power to the smartphones.

Moreover, the paper suggests that instead of the typical device-oriented models, devices could participate in a formation of federations, where all the resources of participating devices would be shared. Although participating devices have their self-interests involved, the paper explains that by utilizing of game theoretic model with Nash-stable solution the MIFaaS model can deliver better results when comparing to device-oriented solutions where little to no cooperation exists. [1]

4 Challenges

Although the edge, fog, and the showcased models show enormous potential in resource sharing capabilities and reduced latency, there are certain challenges that must be overcome before full advantages of these technologies can be realized. The challenges faced can be divided into technical and social challenges, where technical challenges consist of physical, or software related issues and social challenges are related to incentive schemes. In the next two subsections, this paper aims to delve deeper into the challenges these technologies are facing.

4.1 Technical Challenges

Although POCs of the showcased models and frameworks have been successful, there are still technical challenges to overcome. For example, software and protocols should be designed to be compatible with devices regardless of the vendor and solutions regarding security and privacy need to be robust since IOT devices may contain and process user related data [1], [2]. Moreover, a that persist but which is intertwined with incentive challenges, is device discovery. Resource sharing being the fundamental building block of UPI frameworks is dependent on the heterogeneous pool of devices. A lack of, for example storage resources, could mean that certain devices would not gain anything from participating in a cooperative resource sharing scheme.

4.2 Incentive Challenges

While resource sharing frameworks offer enhanced user-experiences [2], [1], [3], the problem of convincing users to adapt these technologies exists. As these models for resource sharing might degrade the users own user-experience by, for example, reducing bandwidth of the network connection, introducing additional costs regarding network connectivity, and increase the energy consumption with energy scarce devices, it does not make it appealing for users [11]. Furthermore, if users are not fairly compensated for participating in the resource sharing pools, they might be left with the feeling that they are not receiving enough resources in exchange for their resources. Moreover, clients, hosts, and services providers may have conflicting interests [11].

A significant challenge will turn out to be convincing users to adopt the technology. This adaptation may be aided by implementing the technology so that it already exists in the user's devices from the moment they purchase them. If the benefits offered are clear and the reward schemes are see-through, users will be more willing to get involved and start using the technology. Furthermore, blockchain technology could be utilized for creating trustworthy rewarding schemes with traceable history of resource sharing interactions.

5 Discussion

The fog computing paradigm has developed significantly during the past decade after the term fog was first introduced [8]. Since that, several models have been proposed to take advantage of the promises fog computing aims to deliver. The models and frameworks displayed earlier are examples of how these technologies can be utilized.

Although the displayed models overlap with the technologies used, they are aimed at solving different challenges. The 3C resource sharing framework introduces a model for increasing the number of different resources which participating devices could leverage. The paper about HI-MEC model proposes a hierarchical tiering model for several levels of cloudlets where tasks requiring heavier computational resources could be delegated to more powerful cloudlets. Furthermore, MIFaaS model suggests that devices could form federations to pool resources for sharing purposes. Therefore, the displayed models do not compete but rather complement each other's functionality and achievements.

All the displayed models show exciting potential for providing the resources needed for ever more powerful mobile machines. However, as of today, this field of technology still lacks major success regarding successful companies. Regardless of that, this field of networking has a great scientific foundation which offers excellent opportunities to build things on.

6 Conclusion

This paper's aim was to gather existing information about UPI in the style of a literature review and propose new directions for research and innovation. The paper displayed three proposed models for UPI utilization and discussed the challenges faced by different proposed models and frameworks. Although the models presented in this paper have significant potential behind them, there have not been seriously successful use-cases presented to be solved by fog paradigms. Therefore, this paper concludes that more POCs and innovative companies, focusing on fog computing and UPI, are necessary steps for the future. Moreover, this paper strongly encourages to explore different incentive schemes for UPI models since without a reason for users to take part in these models they are useless. Models to explore and study include, for example, blockchain technology. Lastly, due to the nature of the resource sharing in UPI models, it is necessary that more studies are conducted on security and privacy issues as compromises in this area could severely hinder users trust in the technology.

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