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An Exploration and Impact Analysis of Fog Computing in Healthcare and Tactile Internet Applications

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Abstract

Dispersed computing along with its three crucial elements and its inherent options continues to encounter several challenges. The division between the endpoint devices and the cloud can pose a problem for latency-sensitive applications such as disaster management and content delivery systems. Fog computing presents a novel paradigm to address these issues. The purpose of this paper is to present an in-depth analysis of fog computing, its evolution from early computing models and its impact on healthcare and the emerging Tactile Internet technology. It offers an exploration of concepts underpinning fog computing and outlines evaluation guidelines with focus on heterogeneity, Quality of Service, variability, mobility and outsourcing-insourcing decisions. The study emphasizes fog computing's potential in real-time data processing, privacy enhancement and ultra-low latency provision and it suggests further research on cooperative algorithms and service quality improvement.

Keyword : Fog Computing, Distributed computing, key aspects, models

1. Introduction

The evolution of computing needs has led us from distributed, grid and cluster computing to a more modern model known as dispersed computing. Dispersed computing offers several inherent benefits including scalability, resource allocation on-demand, lessened administrative burdens, a flexible pay-as-you-go pricing structure and the swift establishment of applications and services [1][2]. The three main service models under this umbrella are Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS) that deliver virtualized resources, programming environments and software applications respectively.

Dispersed computing is now widely used. However, it does have a significant limitation. It has the latency caused by the distance between endpoints and cloud devices and it can intensify any latency already caused by inter-cloud communications. Fog computing, a new computing approach, has been developed to tackle these issues [3]. Championed by the OpenFog Consortium and also referred to as a

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cloud closer to the ground, fog computing extends traditional cloud computing to the network edge. Fog computing allows processing of certain application components near the network while others, such as delay-tolerant and computation-intensive components, can be handled in the cloud [4]. The physical infrastructure, storage and networking services fundamental to both the cloud and fog computing are similar but fog introduces new capabilities. It offers low latency by processing at the network edge, close to the endpoints to use fog nodes. Fog also provides densely distributed nodes for data collection from endpoint devices, facilitated by gateways, access points and switches near the source [5][6]. Thus, fog's uses extend beyond Internet of Things (IoT) and include fields like content delivery which will be further discussed in this paper. It is crucial to remember that physical infrastructure, storage and networking services form the backbone of both cloud and fog computing models.

The purpose of this paper is to offer a comprehensive review of fog computing. Primarily, it closely examines the current state-of-the-art guided by a precise set of assessment criteria. It investigates the structures and algorithms that make up fog platforms and examines the challenges and potential research directions in this field. In addition, it discusses future possibilities while considering the significant role that fog computing is anticipated to play in upcoming technologies like the Tactile Internet.

2. Current Overviews and Tutorial on Fog Computing

Numerous educational resources have been published to formally elucidate fog computing and its related challenges. Significant contributions to this corpus of knowledge have been made. L.M. Vaquero et al. provides a comprehensive definition of 'fog computing', a term referring to the migration of the cloud to the edge of the network where routers could become the virtualisation infrastructure. The authors note that many complementary technologies are reaching a high level of maturity and their interaction could dramatically shift the landscape of information and communication technology in the upcoming years. They also highlight the main challenges faced by this potentially transformative technology amalgamation [7]. More recently, the convergence of the cloud and the fog into unified end-to-end platforsm is anticipated to provide integrated services and applications [8]. However, these tutorials and surveys have not provided an all-encompassing analysis of each explored facet grounded in well-defined and clearly articulated criteria. From the in-depth examination of the existing literature, this paper aims to extract a set of lessons critical to the understanding of fog systems. Moreover, the potential impacts of fog computing in the context of emerging technologies will be discussed with a particular emphasis on the Tactile Internet.

3. Fog Computing and Related Concepts

Delivering resources at the fringes of networks (nearer to endpoint devices) presents numerous benefits such as diminished latency and enabling new services like mobile data offloading. This section delves into and distinguishes the primary notions that facilitate application delivery at the edge.

3.1 Cyber Foraging

Cyber foraging serves as one of the core notions underpinning edge computing, albeit being superseded by more modern concepts such as Multi-access Edge Computing (MEC), fog computing and cloudlets. The concept of cyber foraging was first introduced in 2001 [9] and subsequently refined by Balan et al. in 2002 [10]. It describes a scenario where resource-limited mobile devices leverage the computational power of nearby servers connected via high-bandwidth networks to enhance their capabilities. These servers, referred to as surrogates, undertake computing tasks and data hosting. In this setup, data staging denotes the act of preloading data from remote locations to local surrogates. Consider an instance where a mobile device must process a computation-heavy task such as facial recognition which requires access to a significant volume of data. The device captures raw images and offloads the complex processing to a surrogate. This surrogate, employing a database, executes facial detection and matching procedures and potentially hosts this database on its local storage. In this way, the surrogate completes all or part of the processing on behalf of the mobile device. The processed results are then relayed back to the mobile device with minimum latency due to the surrogate's network proximity.

3.2 Cloudlet

Following cyber foraging, the notion of a cloudlet was introduce in 2009 [11] and it sometimes referred to as cloudlet-based cyber foraging. Cloudlets take advantage of modern distributed computing approaches, specifically virtual machine (VM)-based virtualization. Cloudlets can be resource-rich servers or server clusters situated within a single-hop proximity to mobile devices [12]. They operate one or more VMs that allow mobile devices to offload portions of their computationally intensive tasks. Take the facial recognition application as an example again. With cloudlets, the face detection and matching tasks would be executed on VMs rather than physical servers. Due to the use of VM technology, cloudlets can dynamically scale up or down to provide flexible capacity that adapts to the service demands of mobile users. The VM separates the software stack of the guest (mobile device) from that of the host (cloudlet) and broadens the pool of mobile users who can find suitable cloudlets for offloading their computation-intensive needs regardless of their location in the world [13].

3.3 Fog Computing

Fog computing extends cloud computing to the network edge. This shift allows for processing closer to IoT and end-user devices. Like cloudlets and MEC, it employs virtualization. However, unlike cloudlets and MEC, fog relies on the cloud's existence, which indicates that it cannot function independently. Hence, the cloud-fog interaction warrants specific consideration [14]. Fog offers an n-level architecture and brings enhanced system flexibility [15]. The fog layer may consist of one or more fog domains overseen by the same or different providers. These domains comprise fog nodes that include devices like edge routers, gateways, PCs and others. The IoT/end-user layer includes two sections - end-user devices and IoT devices, one of which may not be present. Communications within this structure vary with Local Area Networks (LAN) linking the IoT/end-user layer and the fog layer while Wide Area Networks (WAN) connect the IoT/end-user layer to the cloud layer. In other words, though cyber foraging was an essential concept for edge computing, it is now superseded by newer concepts such as fog computing, cloudlets= and MEC. Leveraging cloudlets, resource-limited mobile devices can offload their heavy computations, thereby to ensure prompt and interactive responses.

4. Evaluation Guidlines

This section introduces a standard for evaluating the evolution of fog platforms to cover both engineering modules/interfaces and algorithms. These standards align with the use cases of fog platforms currently under study [16][17]. All proposed criteria include both algorithmic and architectural perspectives. A framework satisfies a model if the calculation either underlies the primary objective or is part of the constraints that the calculation must meet.

First, calculations need to consider heterogeneity. Individual node limitations should be integrated into the models and algorithms. For instance, a scheduling algorithm in a Content Delivery Network (CDN) use case should account for potential outlet capacity constraints.

The second criteria revolves around maintaining the Quality of Service (QoS) necessary for each application hosted on the fog infrastructure. Given the proximity of fog nodes to IoT/end-user devices, the fog infrastructure is ideal for real-time applications and results in reduced latency. Yet, latency could vary significantly depending on the application components' location. Hence, QoS management modules are crucial, for instance, a routing engine for the CDN use case, which facilitates data transition within the fog and cloud layers.

Third, calculations should also consider variability. All system components, architectural modules and algorithms should scale remain functional over broad ranges. For example, a content distribution calculation should remain effective in the CDN use case even during high-demand periods.

The fourth criterion requires support for mobility as IoT/end-user devices and fog nodes can be portable. The system should accommodate this mobility. For instance, a mobility engine in the CDN use case should maintain a video stream for a user moving between fog-enabled access points. If multiple users are watching the same video, the mobility management algorithm could instruct the mobility engine to duplicate and push the video to the destination fog-enabled access point.

Lastly, each fog provider must make outsourcing and insourcing decisions considering other fog providers within the same alliance. Cooperative algorithms at each provider's end are required for these decisions while considering resource availability and associated costs.

5. Fog System Architectures

5.1 Architectures for Healthcare

Healthcare applications are critically sensitive to latency when processing vital patient data such as heart rate and glucose levels sourced from IoT devices like Body Area Networks. These applications also send real-time alerts like warnings of potential heart attacks to relatives. This need for immediacy has led to an increasing reliance on fog architectures for designing such applications to overcome the inherent latency issues of cloud-based solutions. Up to date, there has been one architecture proposed for general healthcare while several have been tailored for healthcare applications focusing on specific health conditions including Chronic Obstructive Pulmonary Disease (COPD), Parkinson's disease, speech disorders and ECG and EEG feature extraction.

Fog computing brings significant benefits to real-time healthcare applications by bringing processing capabilities closer to the source of data, often referred to as the 'edge' of the network [18]. IoT devices can constantly track a patient's heart rate, glucose levels or blood pressure. This data is processed and analyzed at the edge of the network by the fog nodes that allow healthcare professionals to monitor the patient's health status continuously and react quickly to any alarming changes.

With fog computing, sensitive health data can be processed locally at the edge of the network to reduce the need to transmit it over the internet to a centralized cloud server. This limits the exposure of sensitive data and enhances patient privacy and data security. For patients living in remote areas or with mobility issues, fog computing enables remote healthcare services. IoT devices can collect a patient's health data which is then processed by fog nodes. These nodes can run algorithms to analyze the data and provide real-time feedback such as adjustments to medication dosage or alert healthcare professionals if there are serious concerns [19].

5.2. Architectures for Tactile Internet

The Tactile Internet is an emerging field that envisages the use of the Internet beyond just transferring information but as a medium for transmitting physical experiences remotely [20]. It combines ultra-low latency with extremely high availability, reliability and security. It is about allowing the touch and manipulation of remote things in real time with the same perception and effect as local actions. The Tactile Internet requires response times in the order of a millisecond to create the feeling of real-time interaction. Fog computing can help achieve this by bringing processing and decision-making closer to the devices, thereby reducing latency [21]. As the number of Internet-connected devices continues to grow, fog computing provides a scalable solution to process this increasing volume of data. This scalability is vital for the Tactile Internet to manage and process the high volume of data produced by these connected devices. By decentralizing computation, storage and networking tasks to the edge of the network, fog computing enhances the overall system's reliability and resilience. This decentralization is critical for the Tactile Internet where reliable and continuous operation is essential. Thus, fog computing provides a strong foundation for the emerging field of the Tactile Internet with its decentralized architecture and ability to deliver low-latency and high-reliability services. Its implementation could bring us closer to realizing real-time remote interactions and a new era of Internet usage.

6. Conclusion

In conclusion, the evolution from traditional computing models towards dispersed computing has resulted in fog computing, an approach that alleviates latency issues by bringing computational resources closer to the data source. As explored in this paper, the paradigm shift has broad applications such as in healthcare where real-time data processing and improved data privacy can enhance patient care. In addition, fog computing shows promise for emerging technologies like the Tactile Internet to offer the ultra-low latency and high reliability necessary for real-time interactions. The paper also outlined comprehensive evaluation criteria for fog platforms and highlighted the need for further research to maximize the potential of this transformative technology.

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