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A SHIFT IN TECHNOLOGICAL PARADIGM: CLOUD COMPUTING TO FOG COMPUTING

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Abstract

Over the years, we continue to experience changes in the field of information and technology; these changes are initiated and geared towards addressing the dynamic nature of our environment. The ubiquitous nature of mobile devices has continued to create the need to manage and control the flow and transmission of data within our environment. The technological paradigm of cloud computing was conceptualized to deal with the ever-increasing need for data storage resulting from the Internet of Things (IoT) and different mobile computing devices. Due to some shortcomings of cloud computing, Fog computing was conceptualized. The term Fog Computing in this paper is discussed to give clear assertion on the technical term, opportunities, and drawbacks.

Keywords: Cloud computing, Fog computing, Internet of things, Technological paradigm.

1. Introduction

The information technology paradigm has over the decades consistently transformed from one technological concept to another. These changes have created and enabled widespread of mobile computing with users seeking more sophisticated means to access data through the use of a distributed network segment. The shift in technology has created the need for continued exploration of avenues to tackle the need for effective and efficient storage and communication platforms for heterogeneous smart devices that have permeated our environment [1, 2]. Current technology has evolved beyond normal desktop computing to ubiquitous computing, also recent trends in technology have given birth to technological paradigms like cloud computing, internet of things and the most recent of them is the concept of Fog computing.

Internet of Things (IoT) technology refers to the technological ability to enable and equip inanimate objects that surround our environment with computing abilities. It enables communication and a huge stream of data sharing between intelligent objects. As noted by Sriram, this technological concept is a new revolution in mobile computing and communication platform utilizes a wide variety of resources significantly towards sensing capabilities [3].

The network resources of the current computing paradigm would span beyond physically connected computers to incorporate with the multimodal information processing unit. As the technological concept of the Internet of Things and mobile computing technology continues to permeate our environment, there is a need to manage the huge stream of data through an efficient and effective medium for communication and storage. According to Selinger et al. [4], Bowman and Cline [5], this technological concept of the IoT would evolve beyond 50 billion things, which all are connected to the internet and in constant communication and exchanging of data about their status and operations.

Hence, the evolution of the IoT creates more challenges for technologies to address, as objects/things in our surroundings seek better communication platform. According to Miorandi et al. [6], there is a shift in technology from the internet used for conventional interconnectivity between end-user devices to the paradigm of interconnectivity between inanimate objects with the capability of transmission. This paradigm has created the need for a rethink towards new innovative avenues for tackling some conventional approaches in the use of networking, computing, and data storage.

Due to the need to properly manage the huge and enormous amount of data that are in constant circulation in our environment, the concept of storage in the cloud was conceptualized [1]. According to Kodym et al. [7], the philosophy of IoT implementation process and condition entails the existing communication networks, as well as storage and accessibility, requires interoperability in service. The fundamental concept of cloud storage entails a shift from hard-drive storage to cloud data center storage.

Cloud computing storage offers scalability, elasticity, and redundancy of data with easy accessibility of vast stream of resources irrespective of location as well as the size of data. The concept of cloud storage also entails a reduction in physically present hard-drives within our surroundings [8, 9]. The technological meaning of cloud computing has been defined in so many ways but the meaning and working principles refer to the same things. To grasp the technical meaning of cloud computing, it is necessary to observe and understand the different study definition as carried out previously.

According to Moghaddam et al. [10] "Cloud computing is a technology that entails connectivity, storage, virtualization, processing power, and shared pool of resources, store and share them between various devices via a broad network (i.e., Internet) to offer on-demand services to end users in compliance with the concepts of isolation, security, distribution, and elasticity". By extension of this definition cloud computing paradigm has created the next level of on-demand operation and computing via the internet. It has created an avenue, which facilitates proper management and control of a large spectrum of data around us.

The process ensured in cloud computing creates an opportunity which encourages online handling of data without disruption in the operational activities of computing enabled systems. According to Martin and Brohman [11], the concept of cloud computing is an important backbone of the technological concept of the IoT, due to its ability to support large computing and operational activities ensured between smart devices. This fast moves toward the cloud computing paradigm according to Puthal et al. [9] has created concern towards the fundamental principles for the success of information systems, virtualization, communication, data security and data availability. These concerns are due to the continuous need for more effective and efficient meaning for data storage with fast accessibility. The proliferation of mobile computing paradigm has brought about strong computing as well as communication power to the palm of humans irrespective of location.

This variety in computational abilities has changed and revolutionized the pattern in computing, transmitting, and storage. According to Luan et al. [12] "With cloud computing becoming the overarching internet approach for information storage, retrieval and management, and mobile devices becoming the major outlets of service applications, the successful integration of cloud computing and mobile devices therefore represents the key task for the next generation network, this however faces several fundamental challenges". In order to address these issues and challenges as presented through the use of cloud computing service, i.e., agility of service, quick response time, and long-thin connectivity, the prospect of Fog computing was conceptualized in 2012 by [13].

The first section of this paper is structured in a way that it gives insight into key technological components and how different necessities have triggered constant integration and transition from technological paradigms. The remaining part of this paper is structured as follows: Section 2 explains previous related works on Fog computing. Section 3 explains the technological concept of fog computing, why it was conceptualized and its processes. Sections 4 describes some key opportunities the technological concept of Fog computing presents as opposed to cloud usage. Section 5 depicts some challenges that currently affect the adoption of Fog computing usage. Section 6 describes the area of Fog computing applicability and Section 7 summarizes and concludes this research survey.

2. Related Works

The IoT is considered as the biggest transformation in technology and has seen a great increase in wearable technology, smart grid, smart connected vehicles and smart automated office/homes [14]. The technological concept of IoT according to Yi et al. [15] are inadequate in computational power, bandwidth, battery, and storage; hence their processes are backed up through cloud storage. Cloud storage, however, cannot address all the issues as required by IoT and other computational smart devices that are time sensitive; hence some authors [14-16] suggest that the technological concept of Fog computing was conceptualized to address the inadequacies and drawbacks observed in cloud computing. Fog computing, therefore, extends the cloud computing paradigm to the edge of the network [17] enabling the new innovative concept of application and service deployment. Fog computing enables and provides mobility support to smart devices as well as geo-distribution in addition to location awareness with low latency. The technological concept of Fog computing application presents so many benefits both economically and socially [18]. The addition of Fog computing to IoT and other smart mobile computing devices creates new innovative prospects in business, i.e., pay-as-you-drive vehicle insurance, Lighting-As-A-Service (LaaS), and Machine-As-A-Service (MaaS) for the users [13]. However, Fog computing is still in its early stages with many challenges that must be addressed to enable proper service provision [14, 19-20]. The summary of related works is listed in Table 1.

Table 1. Summary of related works.

Authors	Title	Scope Addressed
Bonomi et al. [17]	Fog Computing and Its role in the IoT	Fog computing concepts, applicability, and characteristics.
Stojmenovic and Wen [16]	The Fog Computing Paradigm: Scenarios and Security Issues	Fog computing paradigm, scenarios, and current security issues
Vaquero and Rodero-Merino [19]	Finding your Way in the Fog: Towards a Comprehensive Definition of Fog Computing	Fog computing service/network management and connectivity of Fog scale with issues associated
Wang et al. [20]	Fog computing: Issues and challenges in security and forensics	Fog computing characteristics, applicability scenario, security problems, and generic challenges.
Yi et al. [14]	A Survey of Fog Computing: Concepts, Applications and Issues	Working principle of Fog computing, application, and challenges
Yi et al. [15]	Fog Computing: Platform and Applications	The essence of Fog computing adoption platform and applicability with challenges
Cisco Systems [13]	Fog Computing and the IoT: Extend the Cloud to Where the Things Are	Importance of IoT to business organizations Definition and working principles if Fog computing as well as the importance
Aazam and Huh [18]	Fog Computing: The Cloud-IoT\IoE Middleware Paradigm	Technological aspects of IoT/IoE, Applicability and essence of application of Fog to IoT/IoE, and Differences of Fog and cloud computing

3. Fog Computing

According to Vaquero and Rodero-Merino [19], Fog computing is a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralized devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third parties. These tasks can be for supporting basic network functions or new services and applications that run in a sandboxed environment. Users leasing part of their devices to host these services get incentives for doing so. Fog computing paradigm according to Ruoss [21] is a technological concept or process by which cloud computing is extended towards the network node. This process provides an avenue for a new breed of innovative applications and services. By extension, it provides distributed computational ability, which composes of high-speed data storage and high network services for quick and easy decision-making process during computing. Considering the dynamic nature of our environment, the computing process is becoming more complex with the emergence of new technological paradigms such as semantic web analysis, IoT, big data analytics, etc. Big data analytics and IoT revolves around the processing of data in real-time and are very time sensitive [1].

Cloud computing cannot be applied to all scenario of computing [15]. Fog computing paradigm serves as a leverage towards an improved storage capability and the quick analytical process of stored data with respect to data mining and analytics [14]. Also, the application of fog computing into the technological process of the IoT, according to Cisco Systems [13] would ensure high processing of data between IoT devices; this process is possible due to the ability of fog computing to bring stored analyzed data closer to the IoT device. The fog technological concept entails the extension of the cloud as depicted in Fig. 1. It brings the cloud storage closer to the computing device processing or in communication. This process mitigates the challenges of data explosion, volume, variety, and velocity. Fog computing is a highly virtualized paradigm which ensures computing, storage with networking services intermediate end users and conventional cloud computing data centers [15, 17, 22-23].

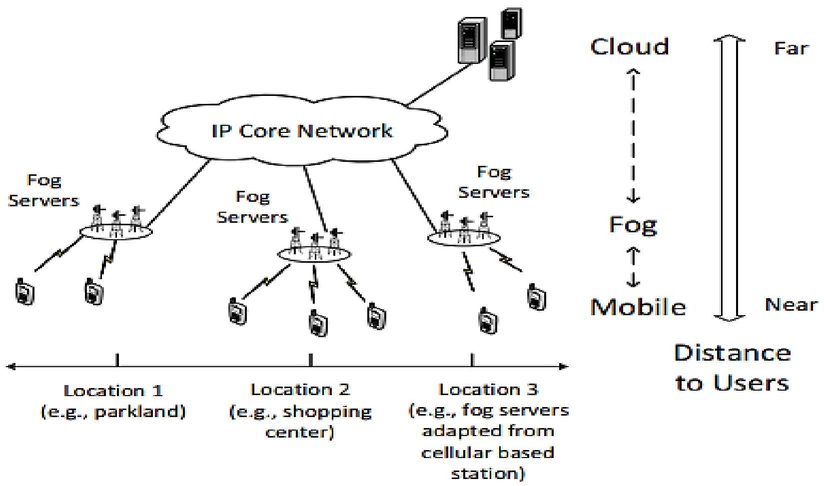

Fig. 1. Fog computing architecture [12].

According to Luan et al. [12] the motive towards the conceptualization of the technological concept of fog computing is to bridge existing gaps between content and application services by bringing both closers to each other, either to the client by addressing the shortage in location-awareness experienced in cloud computing. This technological process, therefore, addresses the time-sensitiveness of data delivery. Table 2 lists the comparison between fog and cloud computing using different parameters as noted by Saharan and Kumar [24].

Table 2. Comparisons of cloud and fog on different parameters [24].

Parameters	Cloud Computing	Fog Computing
Server Nodes	Within the Internet	At the edge of the Local Network
Client and Server Distance	Multiple Hops	Single Hop
Latency	High	Low
Delay Jitter	High	Very Low
Security	Less Secure, Undefined	More Secure Can be defined
Awareness about Location	No	Yes
Vulnerability	High Probability	Very Low Probability
Geographical Distribution	Centralized	Dense and Distributed
Number of Server Nodes	Few	Very Large
Real-time Interactions	Supported	Supported

4. Fog Computing Opportunities

The concept of fog computing is born to address inadequacies experienced in cloud usage, by extending the cloud closer to the smart device or things that generate and disseminate data. This is to ensure high productivity and data efficiency. With fully developed fog computing architecture, users, developers, and product vendors can easily manage, develop and deploy software applications directly on industrial networked components [13, 21]. According to Cisco Systems [13], Yi et al. [15], Madsen et al. [22], Hassan et al. [25], and Krishnan et al. [26], the prospect of fog computing the present enormous amount of benefits to business as well as generic smart device users, i.e., low-cost connectivity, the agility of service and real-time response. It mitigates issues relating to congestion and latency with the provision of computational, storage and high network services at the network edge. This concept also ensures and provides intelligent platforms for managing the distributed and real-time characteristics of emerging IoT infrastructure.

4.1. Low-cost connectivity

Fog computing applied to conserve network bandwidth through the processing of selected data locally rather than sending the data to the cloud for analysis. This process lowers operating expenses and therefore improves productivity in a business environment [13].

4.2. Agility of service

Considering the dynamic nature of our environment where smart devices are constantly configured to function based on user specifications, the concept, and application of fog computing would enable quick development of a product that operates according to the instructions or specifications of the user [12, 13, 18]. It enables easy deliverance of machine-as-a-service or system-as-a-service solution platforms to the users or client.

4.3. Real-time response

The amount of data currently evolving around us is beyond comprehension, hence needs mechanisms to ensure quick analytical process. The application of fog computing according to Yi et al. [14, 15] will provide elastic resources towards large-scale data processing of a system without setbacks as experienced in cloud computing service high latency. The Federation of fog computing components would ensure data acquisition and aggregation reducing the response and transportation period of data. According to Luan et al. [12], the fog computing concept bridges the gap between devices to cloud thereby creating a direct link to the communication pattern for users.

5. Challenges

As the technological paradigm of fog computing continues to grow, different research studies show that this new innovative technology offers interesting and innovative service. According to Vaquero and Rodero-Merino [19], there are so many open issues that need to be mitigated for the actualization of fog computing paradigm. Issues relating to reliability, security, management, privacy, availability, and interoperability are some few fundamental basic issues identified and need to be addressed to ensure the quality of service in the usage of fog computing.

5.1. Fog computing

The concept of reliability over the decades has been a topic of contention between quality assurance enforcers and developers. According to Ahmad [27], Madsen et al. [22], Patrick and Kleyner [28], Yang et al. [29] reliability serves as an important quality assurance mechanism which enables maximum functionality for a computing system. According to Yannuzzi et al. [30], Vaquero and Rodero-Merino [19], Madsen et al. [22], since the concept of fog computing is still at a paucity state, the major challenge that arises is how to guarantee the reliability of the fog component in discharging its functionality to the client or users.

The principal concept of reliability would ensure that every functional component composed of the fog computing paradigm functions in its maximum capacity over a long duration. From the definition of reliability, it entails that every functional system should have the ability to function maximally over the design condition in a specified duration of time without occurrence of failure or faults [31, 32]. Due to the importance of reliability to a system, many research works have also proposed a comprehensive evaluation framework for the IoT. This framework serves as a medium to analyze the reliability level in new technological paradigm. Since the concept of fog computing is still at its infancy stage, it is pertinent that all quality evaluation processes are ensured to enable proper dissemination of service through the fog.

5.2. Security

Security is an important determining factor that is currently applicable to all technological concepts. As stated by Vaquero and Rodero-Merino [19] it can also be foreseen to affect the technological principles and application of fog component hosting any device or applications. The prospect of a secure sandbox for executing droplet applications provides new interesting challenges e.g. trust and privacy. The emergence of this new technology tends to pose and create new threats to the client and users because, from the definitive point of view about fog computing, it serves as a third-party mechanism or a mediator that bridges the gap between the cloud and transmitting smart devices. The question arises as to what extent can these third-party devices be trusted and be secured efficiently to prevent unauthorized users from accessing processing or transmitting data [19].

Sandbox mechanism must be in place to ensure bidirectional trust among processing parties. Table 3 depicts some basic standard security criteria necessitated for computing systems or devices to ensure assurance of service delivery. This standard describes some fundamental security assurance concept necessitated by all computing devices or systems. Nwokedi et al. [33] state that these criteria serve as a prerequisite for security fortification of computing systems or devices. Exposure has over the decades become a big problem to new technological trends. The prospect of fog computing, therefore, raises concern in regard to authentication and privacy of data transmitted through a fog component. As the issue of privacy and authentication needs to be properly addressed, it is suggested that a proper privacy-preserving algorithm is initiated between the fog component and the cloud service.

Table 3. Standards for security evaluation [33].

Security Criteria	Description
Secrecy	The authentication password certainty depends on the system and human factors and should have the capability of safeguarding user's passwords or details.
Privacy	Protecting user's personal details from being compromised This security standard is considered very important due to the sensitivity of data in computing devices or systems.
Breakability	The weakness of systems authentication part of the system should be heavily fortified to prevent unnecessary accessibility.
Abundance	The quality of accessible authentication passwords

5.3. Management

From analysis and estimation carried out, there will be an increase in smart devices within our environment and it would precede 50 billion in the nearest future. As noted in [13, 27, 34-36], it is safe to say managing this technological component becomes a concern to both researchers and technologies. The concept of fog computing was conceptualized in a bid to meet with the growing demand of smart objects around our environment, [19] suggesting that the fog would need to rely heavily on a decentralized management process that is yet to be tested at this unprecedented rate and certainly there would be no full control of all deployed fog devices in our environment hence asymptotic declarative configuration mechanism becomes common.

5.4. Availability

This describes the potential of a technological component to be present at all times when required for usage by the clients or users. The availability of services from the fog devices needs to be guaranteed at all times. According to Yi et al. [15], latency-sensitive applications, i.e., streaming mining and complex event process comprise few typical application services that require fog computing paradigm to address in order to enable real-time processing in place of batch processing; This process is suggested to mitigate delay in the relay of transmitted data.

5.5. Privacy

According to Nwokedi et al. [33], the concept of privacy refers to the number of reserved details that is needed for the authentication of an important part of a computing or mobile systems or devices. A compromised computing system or device violates the essence of information confidentiality of the user; hence can posse a great threat to sensitive data processed by smart devices. Considering the ubiquitous nature of IoT and mobile computing devices, it is pertinent that all security issues relating to privacy and confidentiality of transmitted data through fog devices are ensured and addressed [14, 16, 20, 37]. As noted by Nwokedi et al. [33] determining who to trust with sensitive data over the decades has become very difficult due to the increase in attacks too important computing systems with sensitive data. In addition, the issues relating to privacy serves an important factor that determines systems usage due to the dynamically changing nature of our environment as well as technology.

5.6. Interoperability

Interoperability from the definitive point of view refers to the ability of a system or component of a system or product to function concurrently without other systems or sub-systems without special configurable effort from the client or user. Considering the paucity state of the technological concept of fog computing, the problem of interoperability between fog, mobile device, and the cloud should be addressed. The concept of fog computing needs to address the prospect of functionality between fog device or component, smart device and the cloud storage system [15, 19, 38].

6. Applicability

The technological concept of fog computing is applicable to a broad domain and provides many industrial and economic benefits [13, 15, 16, 21, 39].

6.1. Wireless sensor and actuator network

According to Saharan and Kumar [24], wireless sensor networks are currently difficult during tracking and sensing due to its complex physical disposition. According to Bonomi et al. [17], "Energy constrained WSNs advanced in several directions: multiple sinks, mobile sinks, multiple mobile sinks, and mobile sensors were proposed in successive incarnations to meet the requirements of new applications. Yet, they fall short in applications that go beyond sensing and tracking, but require actuators to exert physical actions (open, close, move, focus, target, even carry and deploy sensors)". Hence, Stojmenovic and Wen [16] suggest that locating actuators and sensors on fog computing devices would help control the measurement process in wireless sensor and actuator network, its oscillatory process and also creates stability through the creation of a closed-loop system.

6.2. Industrial energy management

According to Al Faruque [38], the power grid has over the years become more efficient and smarter due to a new technological paradigm in micro-grid. It is composed of distributed generators, energy storage, and loads connected to a smart grid. Due to the dynamic nature of our environment, it is pertinent to enact appropriate energy management mechanisms that would control the level of power generation and consumption [38]. Hence fog computing offers enormous benefits towards energy management in smart grid, smart connected cities as well as industrial plants through an effective and quick collection of data, analysis, visualization in real-time [13, 14, 21].

6.3. Smart connected vehicles/machines

The basic technological concept of smart connected vehicles/machines revolves around connectivity and interaction between vehicle/machines about their status i.e., Vehicle-to-vehicle, vehicle-to-control point, and control point-to-control point, [20]. The application of fog computing is therefore ideal for this platform due to the high mobility and low latency characteristics of fog computing as well as real-time processing ability. It allows for quick and easy interaction between users and connected vehicles/machines [40] and also provides automatic and effective management of connected vehicles/machines for mobility tracking.

7. Conclusion

As we continue to advance the technological components around us, the need to create awareness arises because all innovative ideas, concepts, and principles are developed and geared towards mitigating issues faced by our environment. This research paper serves as a prototype of previous research works carried out towards awareness of fog computing paradigm and its principal focus. In a bid to comprehend and understand the transition in storage capacities within a technological paradigm, this research paper reviews the technological concept and reason towards the migration from conventional cloud usage to fog computing. Fog computing offers many interesting and promising features and proposes as the appropriate medium for bridging the gap between smart devices and the cloud storage, albeit this technological concept offers an interesting innovative solution, there are some lingering problems which need to be addressed to ensure efficient productivity and service delivery from fog computing.

Abbreviations

IoT	Internet of Thing
LaaS	Lighting-As-A-Service
MaaS	Machine-As-A-Service

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