Cloud-Fog-Edge Computing for Smart Agriculture

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Cloud Computing is a well-established paradigm for building service-centric systems. However, ultra-low latency, high bandwidth, security, and real-time analytics are limitations in Cloud Computing when analysing and providing results for a large amount of data. Fog and Edge Computing offer solutions to the limitations of Cloud Computing. The number of agricultural domain applications that use the combination of Cloud, Fog, and Edge is increasing in the last few decades.

Keywords: cloud ; fog ; edge ; smart agriculture

1. Introduction

Agriculture plays a fundamental role in the world both as a key source of livelihood and its role in the global food supply chain. It is a foundation of human survival. However, factors such as population growth, expansion of industrial development, and climate change all restrict agricultural development [1]. The UN has projected that the world's population will reach 9.7 billion by 2050 [2]. If these projections materialise, annual world agricultural production would need to increase by some 60 percent between 2010 and 2050 [3]. To meet this demand, farmers, scientists, agronomists, and agricultural industries turn to new technologies, such as Cloud Computing, Edge Computing, Fog Computing, IoT, Big Data, Artificial Intelligence, and Drones.

In recent years, concepts such as smart farming, smart agriculture, or precision agriculture have become more popular [4][5][6]. These concepts are generally regarded as the same, and the terms can be used interchangeably. Smart farming uses the new technologies in the agricultural domain to make maximum use of resources and minimise the environmental impact. Currently, sensors can offer highly accurate measurements of crop status. Based on those values, actuators can manage agricultural processes related to animals, crops, greenhouses, irrigation, soil, and weather. This can result in improvements to harvest forecasting, weather prediction, increase production, water conservation, real-time data collection, and production, lowered operation costs, equipment monitoring, remote monitoring, and accurate farm and field evaluation.

Smart agriculture is always connected with high volumes of heterogeneous data sources such as autonomous tractors, harvesters, robots and drones, sensors, and actuators. Heterogeneous sensors and other devices collect relevant agricultural data such as humidity, temperature, pH, and soil conditions. Similarly, it considers the use of various actuators, such as water sprinklers, ventilation devices, lighting, automated windows (in glasshouses), and soil and water nutrition pumps that react according to the data. The number of cloud-based agricultural standalone systems and physical systems is increasing on an almost daily basis, helping to achieve a range of monitoring and analysing objectives.

Moreover, the last few years of publications have shown that modern computing paradigms such as Cloud, Fog, and Edge play a vital role in agriculture. The main applications of Cloud, Fog, and Edge Computing in agriculture are crop farming, livestock, and greenhouses, which are grouped into different application domains. Some of these applications are implemented with the help of IoT-based sensors and devices by using wireless sensor networks (WSNs), and some other applications are developed with combinations of new computing. For instance, Cloud and Fog, Cloud and Edge, Fog and Edge, or Cloud--Fog--Edge and IoT.

Cloud-Fog-Edge computing is one of the growing technologies in the current computer era. Before analysing this concept, it is important to know and understand what the terms Cloud, Fog, and Edge mean. De et al. [7] summarised the first appearance of the keywords of IoT, Cloud, Edge and Fog. The authors mentioned that Edge computing is the oldest technology whereas Fog Computing is becoming more popular in recent years. At the same time, Cloud Computing and IoT have been introduced between 2005 and 2010.

2. Smart Agriculture

Smart Agriculture or Smart Farming is an emerging concept that uses modern technologies in agriculture and livestock production to increase production, quantity, and quality, by making maximum use of resources and minimising the environmental impact. This is demonstrated when farmers and all stakeholders related to agriculture use modern technologies and smart devices to monitor their farms, equipment, crops, and livestock. Using these devices, they can also obtain statistics on their livestock feeding and production of crops [5][8][9].

In recent years, smart farming has become helpful to all agricultural stakeholders from small to large scale. Smart farming provides benefits not only to scientists and agronomists but also to farmers to access modern technologies and devices that help in the maximization of product quality and quantity while reducing the cost of farming [5]. Smart farming mainly focuses on soil fertility, energy, grassland, water, feed, inputs and waste, machinery, and time management [10][11].

The integration of modern technologies with agriculture achieves the objectives of smart agriculture such as efficiency, sustainability, and availability [12], increased production, water-saving, better quality, reduced costs, pest detection, and animal health [13][14]. The other aims are to increase the reliability of spatially explicit data [5], make agriculture more profitable for the farmer [5], and offer the farmer the option of actively intervening in processes or controlling them [15]. Moreover, big data analysis is another goal of smart farming. Big data consist of massive volumes and a wide variety of data that are generated and captured by agricultural sensors and actuators. In particular, data collected from the field, farm, animals, and greenhouses include information on planting, spraying, materials, yields, in-season imagery, soil types, and weather. Big data analysis provides efficient techniques to do a quality analysis for decision-making [4]. In the coming years, smart agriculture is projected to create a significant impact on the world agricultural economy by applying all modern technologies.

3. Cloud Computing

Nowadays, Cloud Computing represents the most advanced computing paradigm. According to [7], the term “Cloud Computing” was first used by Google and Amazon in 2006. In 2019, Ref. [16] offered the latest definition of Cloud describing it as *a computing paradigm for providing anything as a service such that the services are virtualised, pooled, shared, and can be provisioned and released rapidly with minimal management effort*. The Cloud is composed of five characteristics, three service models, and four different deployment models [17]. Cloud Computing offers key services such as infrastructure as a service (IAAS), platform as a service (PAAS), and software as a service (SAAS) [18]. The four deployment models are private Cloud, Community Cloud, Public Cloud, and hybrid Cloud [17]. The characteristics of Cloud are on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service [17]. Even though Cloud Computing has benefits (cost savings, efficiency, scalability, reliability), it also has some challenges when it deals with a massive amount of data. For example, low latency, high internet bandwidth, real-time analytics, data management, load balancing, energy consumption, security, and privacy are some challenges of Cloud Computing. Moreover, most of the computations happen directly in the Cloud as it is a centralised computing model. In the last few decades, Cloud Computing played a significant role in the agriculture field. Data acquisition and remote storage, low-cost access to ICT resources, online agriculture experts consultation, land records automation, and weather forecasting are the main features of Cloud Computing in agriculture [19]. Similarly, constant and high-speed network connectivity, security, and privacy are the challenges in the use of Cloud in the agricultural domain [19].

4. Fog Computing

The term ‘Fog Computing’ was first mentioned and defined by Flavio Bonomi at CISCO in 2012. According to [20], *Fog Computing is a highly virtualised platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing data centers, typically, but not exclusively located at the edge of the network*. Thus, the user’s computation demand is served at their proximity rather than performing it in the distance Cloud. Moreover, Fog Computing is primarily introduced for applications that need real-time processing with low latency. The Fog layer is composed of large-scale geo-distributed Fog nodes, which are deployed at the edge of networks [21]. Each Fog node is equipped with onboard computational resources, data storage, along with network communication facilities to bridges IoT and Cloud within the IoT network [22]. Moreover, Fog Computing acts as a bridge between the Cloud and Edge by enabling computing, storage, networking, and data management on network nodes within the proximity of IoT devices [23]. In recent years, Fog Computing has supported several applications such as smart home, smart grid, smart vehicle, health data management [24], and smart agriculture [25][26]. For example, a smart home is a well-known application where Fog Computing offers more security, ultra-low latency, and efficient cost and energy [27]. The authors of [27] categorised Fog-based approaches in smart homes as resource management (scheduling, allocation, provisioning, and load balancing) and service management (monitoring, security, energy management, and remote controlling). Moreover, Fog Computing provides vital support for processing large amounts of data produced and consumed by IoT sensors and devices, tractors, drones, applications, machines, and users. The main difference between Cloud Computing and Fog Computing is that the data can be accessed offline as some amount of data are stored in a local data centre in Fog Computing, but this is not true in Cloud. In comparison to Cloud, energy consumption and operational costs in the Fog Computing paradigm are low [28]. Moreover, the unique characteristics of Fog are low latency, real-time interaction, support for mobility, improvement of security, efficiency, and conserving network bandwidth [29][30]. These unique characteristics make agriculture easy for farmers and agricultural stakeholders. For example, the data collected by all devices may contain sensitive information, and they need to be processed quickly and locally. Therefore, Fog Computing can provide a benefit in such a way to do local processing and analysing without sending to the Cloud.

5. Edge Computing

Edge Computing is an emerging area where data processing occurs near proximity to mobile devices or sensors. As discussed above, Cloud Computing faces several severe issues due to centralisation. Therefore, Edge Computing has been proposed to improve the performance and overcome problems of Cloud by providing data processing and storage ability at the end devices locally. Ref. [31] stated that *Edge Computing refers to the enabling technologies allowing computation to be performed at the Edge of the network, on downstream data on behalf of Cloud services and upstream data on behalf of IoT services.* The distinguishing characteristics of Edge Computing from Cloud are dense geographical distribution, mobility support, location awareness, proximity, low latency, context-awareness, and heterogeneity [32]. Edge Computing is more or less the same as Fog Computing in terms of low latency, low bandwidth costs, mobility support, high scalability, and virtualisation service [33]. However, it has more limited resources, limited computation and storage capabilities, and proximity to end devices than Fog [33]. Mist computing is another type of computing that is the extreme edge of a network, typically consisting of micro-controllers and sensors. Mist computing uses microcomputers and microcontrollers to feed into Fog computing nodes [34]. Edge Computing is mainly contributing to agricultural applications such as pest identification, safety traceability of agricultural products, unmanned agricultural machinery, agricultural technology promotion, and intelligent management [35]. Moreover, Edge computing enables the evolution to 5G by bringing Cloud capabilities near to end-users [36][37][38]. However, it is essential to combine Edge with other computing such as Cloud and Fog to get the maximum benefits in agriculture.

6. Edge Computing and Fog Computing

The above two sections explain the details of Edge Computing and Fog Computing. As mentioned in the previous section, it is common in the literature to find that Edge and Fog Computing are defined as the same concept. The principal aim of these two concepts is to bring Cloud services and resources closer to the edge devices generating data. This section explains the view by other researchers, significant differences, and similarities from reviews on these two paradigms.

As described in a review by [7], the idea of Edge Computing first appeared in the literature in 2004–2005 with the concept of pushing the application logic and data to the edge of the network. However, as mentioned before, Fog Computing was first mentioned and defined in 2012 by Flavio Bonomi at CISCO. Some authors believe that Fog Computing is one of the classifications of Edge Computing [32][35]. For example, Ref. [32] mentioned Cloudlets, Mobile Edge Computing, and Fog Computing as classifications of Edge. Other authors consider Edge as another type of Fog Computing [39][40][41]. The Open Fog Consortium [42] revealed that Fog Computing is often erroneously called Edge Computing, but there are key differences. Fog works with the Cloud, whereas Edge is defined by the exclusion of Cloud.

In addition to computation, Fog also addresses networking, storage, control, and acceleration. **Table 1** explores key differences between Fog and Edge.

Table 1. Comparison of Fog and Edge.

Features	Edge Computing	Fog Computing
Location of data collection, processing, storage	**Network Edge, Edge devices**	**Near Edge, Core networking**
Computation and storage capabilities	**More limited**	**Limited**
Resources	**More limited**	**Limited**
Handling multiple IoT application	**Unsupported**	**Supported**

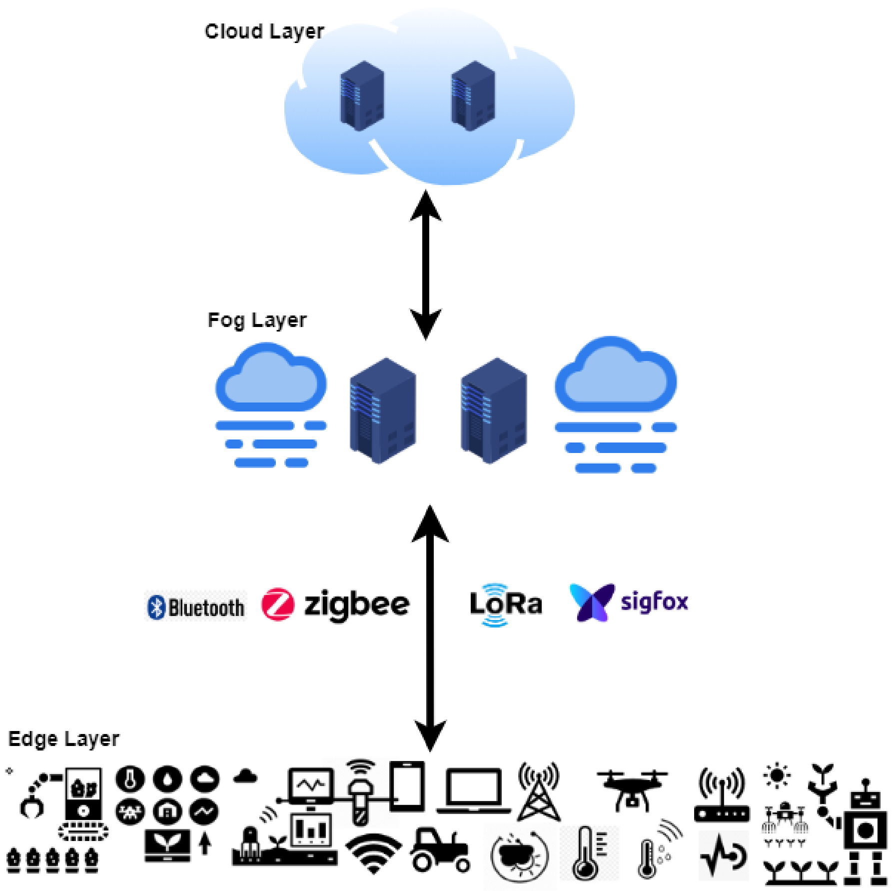
Features	Edge Computing	Fog Computing
Focus	IoT level	Infrastructure level

7. Proposed Architecture for Cloud-Fog-Edge Computing for Smart Agriculture

This proposed Cloud-Fog-Edge computing architecture model for smart agriculture is given in Figure 1. This model can be used for any other application domain with some minor changes based on the domain requirements. In the proposed architecture, the Cloud layer is mainly for ample scale data storage and data analytics. This layer is also responsible for loading algorithms and data analytical tools to Fog nodes. This can also be used to store backup data for future analysis. The Fog layer is essential in this model, and this will be installed in local farms. Fog layers will be responsible for real-time data analytics such as predicting pests and diseases, yield prediction, weather prediction, and agricultural monitoring automation.

Moreover, this will make decisions on real-time data and do reasoning analysis as well. Finally, the processed and analysed data can be uploaded to the Cloud layer for backup purposes or further analysis. The third layer is the Edge, consisting of end devices, tractors, sensors, and actuators. The main goal of this layer is the collection of data and its transfer to the Fog layer.

Figure 1. Proposed Cloud-Fog-Edge Computing Architecture



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