Fog Computing enabled architecture for smart and resource efficient Farming

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***Abstract*—The Internet of Things (IOT) which is a new era in computer networks has evolved over the years and made its place in many real life applications including farming and agriculture by healping to monitor and automate the processes. The main problem being faced by today's systems is managing the huge amount of data being collected and generated on a daily basis by the IOT sensors and devices.This project seeks to solves these problems with fog based architecture which is custom made for an IOT based company to provide a smart farming application.In this project we seek to utilise the power of fog computing which helps to process the data which is closer to the edge enabling low latency and optimizing resource utilization and also reduces the amount of data which is sent to the cloud. The architecture used in the project sets up multiple sensors across the agricultural farm field which helps to monitor the soil moisture, temperature, humidity, pH and light intensity. All the sensors pass on the data to the local fog node setup which do the basic analysis of the data and help launch real time-alerts which help in managing the crops in the field efficiently. This project helps in reducing the computational load on the cloud systems while also helping to maintain good performance in processing of the data and decision making.We make use of CloudSim and iFogSim libraries to help simulate the proposed architecture and exhibit the usefulness of the fog based architecture in decreasing the levels of energy consumed, bettering the system response times and providing an efficient way to manage resources in Farming.**

***Index Terms*—Internet of Things (IoT), Fog Computing, , Edge Computing,, Sensor Networks,Cloud Sim,iFogSim.**

I. Introduction

Agriculture or farming comes under one of the most important fields when talking about the worldwide economy or the basic human need of food but it also faces serious problems due to the increasing population and growing need, the unprecedented changes in the climatic conditions and the shortage of resources. With the increase in the demand for the food yield every year it has become necessary for the process of food production to become more efficient and viable and inculcate more progressive ways for farming and agricultural practices.To tackle these problems the term smart agriculture is making grounds which involves the use of the smart sensors and IOT devices which are then interconnected using fog and edge computing solutions. These solutions offer real time monitoring of the crops and values like temperature, soil moisture which help in taking better decisions in irrigation and automating multiple processes with the help of the data accumulated from the sensors and IOT devices. This project helps an IOT based company for automating a medium sized agricultural farm which is assumed to be located in a region which has little rain but is not completely dry. For this farm it is very important to manage the water usage efficiently and also keep a check on the soil quality and the moisture level of the soil for maintaining high yield of the crop and restoring the quality. Considering that the agricultural farm produces a variety of crops which include cereal grains and vegetables it is very important for the environment to be quite precise to help in the proper growth of the crop. The operations involved in the farm to ensure good quality of the crop with optimum use of the resources is very hard or close to impossible to achieve with traditional farming. The farm needs to move to more advanced automation systems that can help monitor and regulate the environmental features to achieve the following goals. The first goal is to achieve efficient water management which will help to minimize the wastage of water and also ensure that all crops get the adequate amount of water required for their growth. The second goal is to monitor the quality of the soil which will help to maintain soil conditions suited for each crop which will help to minimize the use of any kind of fertilizers. The third goal is to control other environmental factors like temperature, humidity and lighting conditions which will help the crop to grow optimally even in unprecedented climatic conditions. Finally the goal is to setup alerts which can detect any issue with a particular crop and inform the farmer for early preventive measures to be taken to maintain the quality of the yield.

The following are some of the assumptions that we have made going forward in the proposal of the architecture for this project. The proposed farm will be spread across 200 acres and divided into multiple zones by the type of the crop grown in the zone and the crop requirements. The 200 acres of the farm will be divided into 4 zones of different type of crops like cereals,corn,vegetables and mixed crops with the fog nodes and sensors distributed based on the requirements.The distribution of the number of Sensors based on the zones and the number of fog nodes in that zone and the role of the fog node for each zone is also mentioned and summarised in the following table.

TABLE I
FARM ZONING AND SENSOR ALLOCATION

Zone	Crop Type	Area (acres)	Soil Moisture Sensors	Temp. & Humidity Sensors	pH Sensors	Light Sensors	Fog Nodes	
Zone 1	Cereal	50	10	5	5	4	2	
Zone 2	Corn	50	10	5	5	4	2	
Zone 3	Vegetables	50	12	6	6	5	2	
Zone 4	Mixed Crops	50	12	6	6	5	2	
Total		**200**	**44**	**22**	**22**	**18**	**8**	

TABLE II
FOG NODE ROLE BY ZONE

Zone	Fog Node Role
Zone 1	Collect & process data; manage irrigation and soil health
Zone 2	Monitor moisture, temperature, and pH levels; control irrigation and nutrient delivery
Zone 3	Handle detailed monitoring for sensitive crops; ensure optimal growth conditions
Zone 4	Manage diverse crop needs; balance irrigation, lighting, and soil conditions

II. IoT/Fog System Design

For this project we have made use of a fog based IoT system to implement a smart farming solution as per the IoT company requirement. The project is based on a agricultural farm which is spread over 200 acres of landed which is further divided into four zones of 50 acre each. This specific design of the system ensures the processing of data in real time helping to manage the resources efficiently and enables decision making with the help of a mix of sensors deployed on the farm and interconnect with the help of edge (fog) computing to the cloud services for further analysis. The system architecture is explained with the help of a diagram below.

The Architecture is split into three layers which are the Sensor Layer, Edge/Fog Layer and the Cloud Layer. The sensor layer includes all the sensors like the temperature, humidity and the other sensors which are present in all different zones of the agricultural farm. The Edge/Fog Layer includes all the edge devices which are deployed in each zone who are tasked with collecting the data from the sensors and perform local data processing and also initiate any alerts for real time updates. The final layer or the cloud layer is responsible for storing of data and using the data for advanced analysis and long-term decision support.This data is synced with the edge devices in a timely period to process much more computational heavy data collected over a much longer period of time.

A. Sensor Selection and Deployment

Let us go through the five different sensors being used in our proposed solution: Soil Moisture Sensors : These sensors are important to check the moisture level in the soil which is an indicator for the irrigation system. These sensors have been deployed in the agricultural farm distributed as one each for every 5 acres for capturing the precise moisture levels of the soil throughout all zones. Temperature and Humidity Sensors: These sensors are required to keep a check on the climatic condtions in different zones and are distributed as each per 10 acres in majority of the zones with the exception that in zones with vegetable crops there is a higher density of these sensors because it affects the growth of these crops. pH Sensors: These sensors are useful for monitoring the health of the soil and these have been used with a distribution of each per 8-10 acres. Light Intensity Sensors: These sensors are important to monitor the exposure to light which is important especially for the zones where mixed crops are being produced.This sensors are also disributed each per 8-10 acres across the farm. The trade off here is the coverage of the sensors which will increase the granularity in the data but will also increase the overall price of the project and also the power consumption of the sensors which are already energy efficient but using low power protocols like Zigbee and LoRaWAN can help reduce power consumption

B. Operations to Run on Edge and Cloud

The operations at the Fod/Edge Level include the important tasks like managing the irrigation systems or adjusting the pH levels and also monitoring other environmental features which are done locally. This helps in taking immediate action after analyzing the data from the sensors and automating the trigerring of alerts or even handling events for eg. activating the irrigation system. The fog nodes also help to aggregate the data collected locally before sending it to the cloud to reduce the bandwidth usage. The operations at the Cloud Level include the storage of the complete data of all the operations going on in the farm which can be then used to leverage using machine learning algorithms. This large scale data can be used to perform data analytics and used to predict the yield of the crops and also forecasting. The cloud is also responsible for orchestrating the complete operations of the farm and synchronising with the fog nodes. The trade-off here is that the edge computing will help reduce the latency for important tasks but the cloud is the first choice for resource intensive tasks.The local processing of data locally at the edge helps reduce the data sent to the cloud thereby reducing the bandwidth and cost.

C. Architecture Design and Security

The architecture of the system follows a 3 tier model including sensors, fog nodes and the cloud which enables the data to flow in an efficient manner. This design also ensures the system to be scalable and adapting to various agricultural requirements. The authentication and authorization is managed

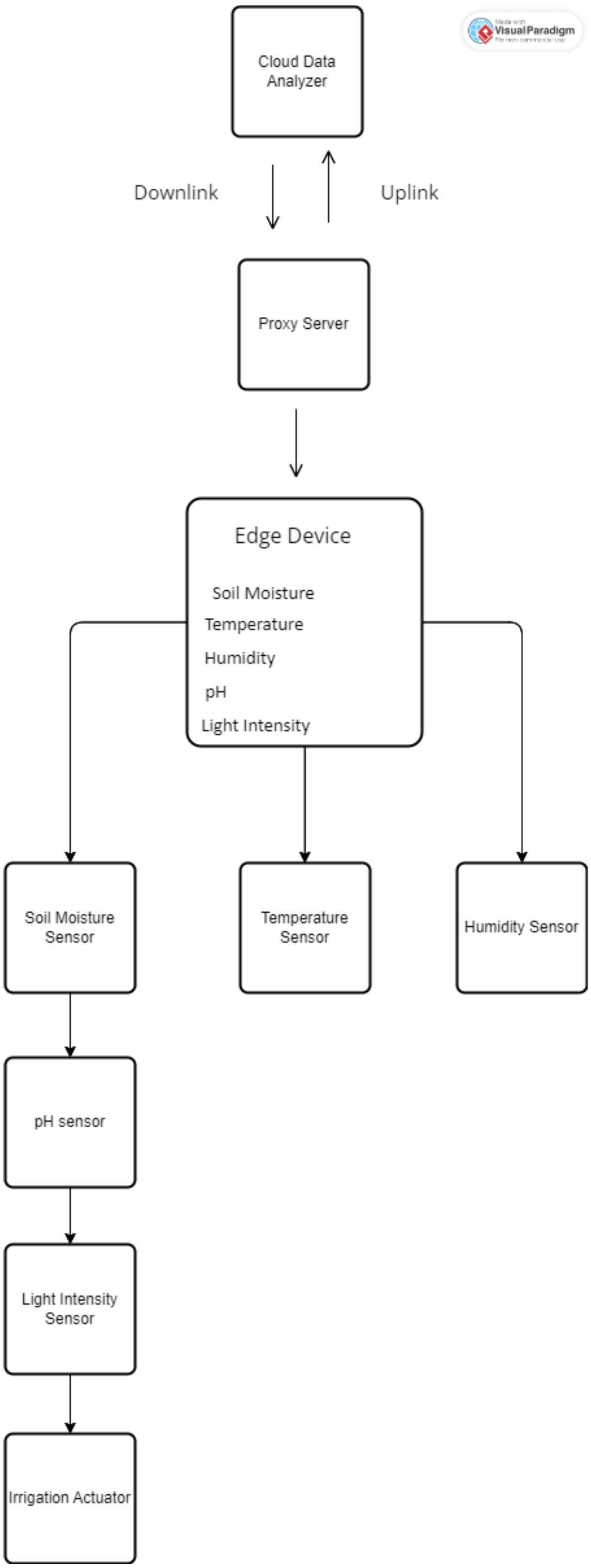

Fig. 1. System Architecture Diagram

by role based access control (RBAC) also the fog nodes make use of secure boot and runtime protection. The trade off here is the enhancement of the security layers adds a level of complexity and also adding to the computing overhead.

D. Selection of Access Technology

For the Access Technology we choose Zigbee due to its capabilities for intra zone communication between sensors and fog nodes with the help of its mesh protocol and also LoRaWAN is used for its long range communication capabilities between zones and the cloud which helps to cover the whole agricultural farm. The trade off here is Zigbee's limited data range which is contrasted by its mesh protocol while LoRaWAN's low power usage convinces its usage for large areas.

E. Selection of Application Protocols and Networks

The protocols used generally for IoT application are MQTT due to its features like lightweight and low bandwidth which enables fast sensor to fog and fog to cloud communication. HTTP is also used occasionally for updates and system configuration. For cloud communication the networks generally preffered are 5G networks due to its low latency and high bandwidth. Lora is also used due to its connectivity in remote areas where cellular network is not accessible.

F. Selection of Data Processing Tools and Approach

The tools that are generally used for processing the data are apache kafka which is a real time data streaming approach and works at the fog layer for processing the data locally and is also used for event driven actions. Apache Spark is used for data analysis and reporting operations in the cloud layer where batching approach is used to work on the historical complete operation data of the solution. The trade off here is the deployment of the data processing tasks at the fog level provides prompt responses but requires extra computational power whereas these can be done in the cloud in more efficient way.

G. Selection of IoT Platforms and Software Deployment Strategy

For the platform we can go with AWS IoT which presents a suitable environment which is secure and scalable at the same time for managing all IoT devices and also help with data analytics and machine learning. The deployment strategy will include the use of docker containers for deploying services on fog nodes to make sure that the services are portable and at the same time provide consistency. The whole deployment will follow a microservices architecture which will enable independent managament of different components and easy scaling based on the requirement. The trade off here is the level of complexity being added by choosing the microservices architecture and using containers but it allows the solution to be more flexible and cater to a bigger crowd.

H. Applications Enabled by the Design

The different applications that are enabled by our design include Irrigation Management which uses the soil moisture data and weather conditions prediction to carry out irrigation scheduling in an optimized manner to increase the yield of the crops in the farm, Crop Health Management with the use of data from the pH and light sensors that capture the health of the soil and the crop with the help of analysis of the historical data to reduce waste and improve on the production, Yield Prediction can be easily implemented with the use of data analysis and machine learning algorithms with the data being stored on the cloud layer of the whole operation over time and also the environmental features monitoring can be implemented using the data coming in from all the sensors to keep a track on any irregularities in the crop health.

III. Simulations

To simulate and validate the propsed IoT/Fog computing solution we used the iFogSim toolkit. The simulations performed were used to evaluate the solution based on some performance metrics like power consumption, latency and the efficiency of the data placement algorithm. The simulations include the following :

Sensor Nodes which are virtual sensors for capturing the soil moisture, temperature, humidity, pH levels and light intensity were simulated over all the zones. These sensors help to provide data to the fog nodes and also cloud for further processing. Fog Nodes were used in each zone which was simulated to enable the processing of the data coming in from the sensors in a local environment around the sensors to help with immediate decision making. The Cloud layer or platform was simulated to handle the storage of the data synced from the fog nodes over a long period of time which helps in data analysis and computationally demanding task like using machine learning models to help predict yield and other solutions. The communication network infrastructure using Zigbee for close range intra zone communication and LoRaWAN for communication between zones was formed to test and analyze data transfer latency. The Data Placement Algorithm like the mapping and edgewards were also simulated to determine the location where the data should be processed to decrease the latency and provide optimized resource utilization.

The metrics that were used to evaluate the simulations are as follows :

Power consumption of the edge devices (Fog nodes) were tracked based on the computational load based on the assumptions made on the zone wise distributed farm from the data transmission in real time. Data Processing Latency was measured which is the difference between the processing time on the fog nodes and the cloud. Communication Latency was also evaluated which is the delay in the transmission of data between the three layers of the application. Bandwidth Utilization was compared between the different access technologies like zigbee, loRaWAN and 5G networks. The CPU utilization was checked by the delay caused in the different modules of the application

IV. Results

The simulation results from the application unfold key performance mertrics such as execution time, application loop delays, tuple CPU execution delays, energy consumption across various devices, cost of execution in the cloud, and total network usage. These results show us the overall performance of our proposed application and validate our architecture. The total execution time of the IoT application across all fog and cloud devices is 726ms. The delay involved in each sensor modules data to actually reach the data analyzer is showcased in the below table

Sensor Module	**Loop Delay (ms)**
soil_moisture_module	102.223
temperature_module	102.225
humidity_module	102.246
pH_module	102.244
light_intensity_module	102.311

The delays observed here are the delay in the transmission of data from the sensors to the data analyzer moduler over different networks.

The CPU Execution Delays for the processing of data tuples are showcased in the following table

Tuple Name	**CPU Execution Delay (ms)**
HUMIDITY	1.907
TEMPERATURE	1.935
LIGHT_ALERT	0.117
PH_ALERT	0.076
PH	0.834
SOIL_MOISTURE	2.884
LIGHT_INTENSITY	2.884
SOIL_ALERT	0.069
TEMP_ALERT	0.111
HUMIDITY_ALERT	0.127

The delays observed here are the time taken for the data to be processed by the respective modules. The energy consumed by the different devices in the solution are showcased in the table below.

Device	**Energy Consumed (Joules)**
cloud	27,19,618.25
proxy-server	1,66,866.60
edge-zone-1	1,99,020.19
edge-zone-2	1,98,871.98
edge-zone-3	1,98,946.09
edge-zone-4	1,99,020.19

The energy consumption of the various devices used in the application specifically the cloud and edge devices.

The cost of execution in the cloud is also calculated on the basis of the charges assumptions (cost per memory and storage) made in the solution which comes out to be 78,851.18 USD (assuming the currency to be in USD) The total network usage is also measured in units which evaluates the bandwidth requirement for the solution which comes out to be 19,931.5 units.

The results are very important to understand the weight of fog computing in IoT applications which underline the low execution time and delays in the execution time for real time processing.The energy consumption analysis shows a clear indication of the heavy power usage of the cloud pointing out the pros of workload distribution to edge zones. The cost evaluation gives us a clear idea of the expenses and optimizing the resources used in the deployment.Finally the network usage stats also help to manage the bandwidth to meet any future requiements to prevent failure due to congestions.

V. Conclusions

The simulation results evaluate the efficiency of the IoT/Fog computing solution that we have proposed for the IoT company in the agriculture domain and highlight the efficiency of the application. The architecture helps in achieving low latency, optimized energy consumption and flexibility in managing resource in real-time with the help of distributing tasks across the three different layers i.e., the clooud, fog and edge layers and the devices. The challenges still remain in designing and managing latency. These challenges can be resolved by including the shift of processing to the edge or implementing dynamic res allocation. The further advancement can include developing a energy aware scheduling solution using the fog/edge device deployment. These methods can be used to create a more efficient and scalable hybrid cloud fog solution which addresses the deployment and operational challenges.

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