W-DaM: Weather Data Management in Smart Agriculture using Blockchain-as-a-Service

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***Abstract*—Weather plays a vital role in growing and securing the yield of crops. The data collected from forecasts through different sources have been helpful in avoiding some calamities. The forecast applications are built with conventional database systems; processing and reaching real-time data without being tampered with for farmers is a bottleneck. Most of the time, weather providers' data doesn't match what happens in the farming fields. These differences can lead to heavy damage, especially during unexpected weather strikes. In the current age, smart agriculture makes use of modern equipment such as sensors and satellites that give forecasts more precisely and carefully compiled. The present paper shows an Edge hub near the IoAT device that controls all sensor devices to establish bidirectional communication and embeds Blockchain-as-a-Service (BaaS) for weather data integrity in immediate time. We present a novel architecture with algorithms for this weather data management system and implement the system to see the performance with real-time sensor data.**

***Index terms*—** Smart Agriculture; Agriculture Cyber-Physical System (A-CPS); Internet-of-Agro-Things (IoAT); Blockchain; Distributed Ledger (DL); Edge-Computing

I. Introduction

Weather data for farmers has a significant impact on understanding the availability of water, the fertilizer amount for growing crops, and the occurrence of diseases and pests. The farming techniques mainly depend on meteorological conditions. The meteorologists observe and calculate the atmosphere's basic settings, such as temperature, humidity, pressure, wind, and precipitation. For this process, they use maps, satellite data, and radar information coming from different sources and locations to compare and analyze. Many research works show that even a 1-degree difference in the forecast accuracy can make a difference in the farmers' lives and deaths [1]. The findings in the research show that more accuracy in forecasts could save many farmers' lives globally.

While people are moving towards the Internet of Things (IoT) in every field, using the Internet-of-Agro-Things (IoAT) provides a lot of convenience in bringing large amounts of data to the network [2], [3]. The weather data on these IoAT devices includes sensitive data that must be kept accurate and treated appropriately. Providing data hubs for storage in data centers can easily manage enormous IoAT devices and communicate through them. Some of the confronts IoAT faces and the motivations for the current system are shown in the Fig. 1. However, relying only upon centralized IoAT hubs, the data owners can lose control of data and require blind faith in service providers. Therefore, we combine blockchain service with the IoAT hub in this current application system. The service provides a decentralized system for storage and sharing information and immutability to the weather data, thus increasing the accuracy.

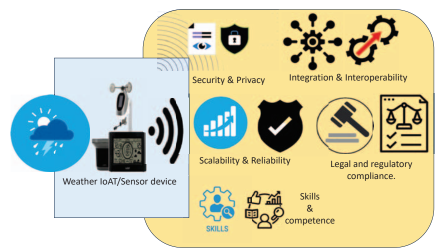


Fig. 1: Challenges of IoAT and motivations for current paper.

The paper is in the following order: We address the problems of traditional weather data management systems and suggest a new contributions in Section II. We explain the previous approaches and the data sources for weather forecasts in Section III. In Section IV, we elaborate on the importance of weather data in agriculture and propose a novel architecture for W-DaM. The algorithms for the current paper are projected in Section V. The implementation and experimental evaluation are in Section VI. In Section VII, we give conclusions and further research probabilities for the current system.

II. Novel Contributions

- Connecting Internet-of-Agro-Things towards IoT-Hub for real-time weather data storage and bi-communication between various devices.
- The Blockchain-as-a-Service technology for added security and storage for weather data flow to mitigate uncertain facts and improve data quality.
- Increasing weather data precision and avoiding 1-degree differences in the forecast accuracy.
- Propose a novel architecture for a weather-quality data management system with hashing refuge through blockchain service in IoT Hub.
- Results comparing traditional weather data management systems and current W-DaM.

III. Prior Related Works

The authors improve the database design for the storage of weather data through social media in the paper, [4]. They propose a conceptual, logical, and physical method for database improvement using domain structure. The whole storage system is built on central technology to take in the data from the sensor locations and automatically send the data to Twitter. The paper [5] explains the drawbacks of space weather information and forecasts storage systems based on single servers. This central system is unreachable when it comes to collecting the latest information from space due to server downs. The proposed method has a new model for incorporating the Interplanetary distributed storage File system (IPFS). A cloud-based weather information system is designed and shown in the paper [6]. With the IoT, different sensors things are communicated using the internet in various domains; the system proposes an IoT through a microcontroller to collect the data from the central cloud data management systems to show the weather reports and to allow remote access.

Bringing heterogeneous information into a single platform faces a bigger challenge. In [7], the authors introduce a message queuing telemetry information transport (MQTT) into a communication layer for migrating complex and diverse data from the traditional to distributed environment. The system develops a weather monitoring system that collects climate data from various devices. In paper [8], a central network and storage web application system is built to transmit the weather data in real time and provide a robust data communication and processing system inside the application. With the enhancement through sensors and central systems in real-time, the paper proposed overcomes information delays and predicts the weather data more accurately.

Table I illustrates some of the prior works and their storage approaches with the current application. With technological advancement, the equipment used to collect and monitor has changed over the past decades. Some of the tools used to gather data are Doppler Radar, Satellite data, Radiosondes, Automated surface-observing systems, Supercomputers, and AWIPS. Here, we discuss and refer to the map locations for accumulating weather data in the United States [9].

IV. The Proposed System- A Broad Overview

A. *IoT-Hub & Blockchain as a Service (BaaS)*

IoT hub is a cloud service that acts as a bi-directional communication center between IoT applications and the devices that it manages. It can collect data and send instructions from a central hub to multiple Internet of Things devices. There is a lot of processing and managing with massive data coming from various sensor/IoT devices in business and real-time perspective, which can be avoided using a central hub device and make the data flows easier. An organization with wireless internet thing devices benefits from an IoT hub because it can manage and register through various services, establish smooth interaction with billions of IoT devices in an organization, and provide built-in Security at a larger scale while establishing communication. The Hub can communicate through various MQTT, AmQP, and HTTPS protocols for device-side communication to maintain and store all the messages on the cloud [10]. BaaS a service that is provided by a third-party cloud that includes all the tools and infrastructure for implanting the Blockchain into applications. It is a web host that runs as a backend of an application on a decentralized network and a way for organizations and application businesses to benefit from blockchain technology without implementing it from scratch. Some of the pros that the BaaS brings are transparency, saving time and money for organizations, avoiding building Blockchain ground up, and customizable templates, i.e., easy integration into an existing system and application. Since organizations don't have to build from scratch, they are left with more time to focus on additional developments of applications [11].

B. *Architecture*

In the architecture shown in Fig. 2, we present the weather data flow from the IoAT / Sensor devices towards the Hub and the Blockchain. The IoAT device senses the weather and sends the weather data over the network to the cloud. The data is pushed through HTTPS onto IoT Hub from the cloud. The services from the Hub are requested by using a function application to convert the weather readings into decimal values. The weather values are collected with the help of service bus routing to logic application. The Blockchain consumer services listen for incoming messages through the service bus, where data ledger technology is responsible for forwarding the metadata for transactions that are to be written onto the Blockchain. With the help of a router, each and every transaction is signed and delivered to the Blockchain service. Every public Blockchain consists of a wallet owner that is generated using the private key. This private key is fundamental in retrieving the tokens associated with the wallet and making data recovery possible. In our current system, with the Azure IoT Hub, the users can have dedicated wallet private keys inside the system's boundaries without risking their personal wallets. An Azure key vault provides a cloud service used mainly to store and access secret keys more securely. An Azure key vault and its hardware security modules (HSM) allow the usage and management of cryptographic keys, where the private key never leaves the vault, and the risk of loss of private key (wallet owner) is very much reduced. The Blockchain service is designed with plug-and-play interaction tools for web application development.

V. The Proposed Algorithms for W-DaM

Algorithm 1 shows a detailed data flow from the IoAT/Sensor to the IoT Hub. In the application's first step, we connect to the IoT Hub using MQTT Protocol. A DHT11 device for sensing the temperature and humidity is connected to the Raspberry Pi. We generate a DeviceID (D_{id}) for registering the IoT device to the Hub in the clientID (Cl_{id}) field and creating the hostname H_{name}. The protocol has two network entities: a message broker ($MQTT_{broker}$) and a number

TABLE I: Weather Data IoT communications and Storage approaches in Smart Agriculture.

Application	IoT/Sensor	Communication	Data storage	Security level	Computation
Purwandari et al. [4]	Yes	Single	Centralized	Low-High risks	High
Andrian et al. [5]	Yes	Single	Decentralized-IPFS	High	High
Kodali and Sahu [6]	Yes	Single	Centralized	Low-High risks	High
Tsao et al. [7]	Yes	Single	Distributed-(MQTT)	Low-High risks	High
Osiorio et al. [8]	Yes	Single	Centralized	Low-High risks	High
W-DaM [Current-Paper]	**Yes**	**Bi-Directional**	**IoT Hub+Decentralized**	**High**	**Low**

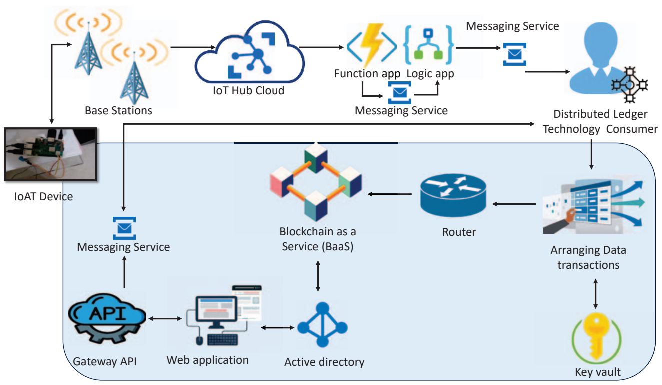


Fig. 2: Proposed architecture for W-DaM.

of clients (ClientsA, B, C, so on to n). The broker helps in routing the messages to the appropriate clients. The password (PwD) of the system is the authentication provided by the X.509 certificate. The current application is built in Azure IoT Hub to transfer data between IoT devices and applications. The Hub provides authentication services that can include SAS Token-based authentication, Individual X.509 Certificate Authentication, and X.509 CA Authentications for each and every device in a secure way. The device certificate, also called a leaf certificate, is set with a subject name for the deviceID. The setting is essential for the authentication of the device. MQTT connection has three message types: Connect, Disconnect, and publish. The first message from client B is stored with the retain flag R_{flag} to wait for the connection to be established with the server and links between the nodes.

The subscription is continued across different sessions of endpoints if the flag is set to 0 and transfers messages, and if the flag is set to 1, the device does not receive any messages from the IoT hub. In disconnect, the action pauses for the client to finish the work it must do and disconnect the TCP/IP session, and in publishing, the application returns to the thread after passing the request to the MQTT client. From the IoT Hub, the data is sent to the Blockchain workbench service. Here in the IoT Hub, the endpoints are initialized and added, and a route and a fallback route are also added. The user is created in the logic app (l_{app}), and the telemetry data (T_{data}) is delivered. The logic app is configured by default and gets triggered every minute whenever a new message comes from IoT Hub. Once the new message is generated, the logic app executes the function for "IngestTelemetry". Before sending the new message to the Blockchain workbench service bus, the logic app makes an SQL call to stored procedures (SP). The DevideID D_{id} is taken as the input in the stored procedure and returns the data through a specific contract instance. After placing the message on the Blockchain (BC) workbench service bus, the blockchain service requests get initialized, and appropriate actions are taken. The smart contracts (SC) are executed through the stored procedures, and in turn, the stored procedures are invoked using the authorized IoT Device ID's.

Algorithm 1 Data from IoAT to Hub.

1: H_{name},PwD $\longleftarrow IoT_{Hub}$.
2: Data transmission using MQTT Protocol between different entities. Client A is the IoT Hub, and Client B is the IoT Device/Sensor.
3: Generate $D_{id} \longleftarrow Cl_{id}$.
4: MQTT $\longrightarrow MQTT_{broker}$,ClientsA,B,C..n
5: Cl_ACONNECT $\longrightarrow MQTT_{broker} \longrightarrow Cl_B$
6: **if** Cl_A equalto D_{idA} **then**
7: Cl_BPUBLISH$_{temp,hum} \longrightarrow MQTT_{broker}$
8: $MQTT_{broker}$ stores $Cl_{B,temp,hum}$ through R_{flag}
9: $MQTT_{broker} \longrightarrow$ CONNACK $\longrightarrow Cl_A$
10: Cl_A subscribes to $MQTT_{broker}$
11: $MQTT_{broker}$PUBLISH$\longrightarrow Cl_{A,temp,hum}$
12: Cl_A DISCONNECT $MQTT_{broker}$
13: $IoT_{Hub} \longrightarrow$ Initialize and Add End_{points}
14: $IoT_{Hub} \longrightarrow$ Add Route and fallback Route
15: $l_{app} \longleftarrow IoT_{Hub,new\ message}$, user, T_{data}
16: $l_{app} \longrightarrow_{call}$ SP
17: $SC_{initialize} \longleftarrow SP \longleftarrow_{input} D_{id}$
18: $BC \longleftarrow SC \longleftarrow IoT_{Hub,new\ message}$
19: **else**
20: Discard operation.
21: End the Process
22: **end if**
23: Repeat the steps from 1 through 22 every time IoT Collects Weather Data.

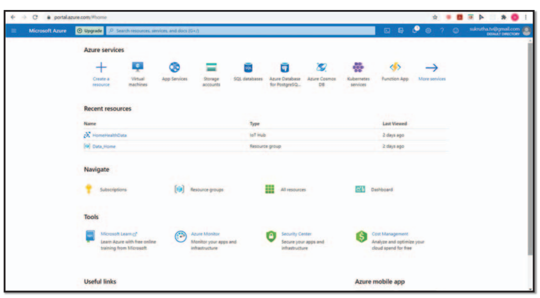
VI. Implementation and Results of the System

The application monitors the temperature and Humidity using an IoAT device and sends the Data to Azure IoT Hub to store the data. The weather information is collected using the sensor DHT11, which is connected to the Raspberry Pi 3 B+ Model acting as IoAT. A programming language is used to communicate with the board to perform specific actions, such as reading the data and sending it to the hub and blockchain. The data is collected every 2 seconds and stored on the blockchain. An Azure IoT hub cloud service contributed by Microsoft is used in our current application. A smart contract is used to write the logic for executing the terms of the agreement from outside the chain. It automates the actions and completes the actions an application should accomplish.

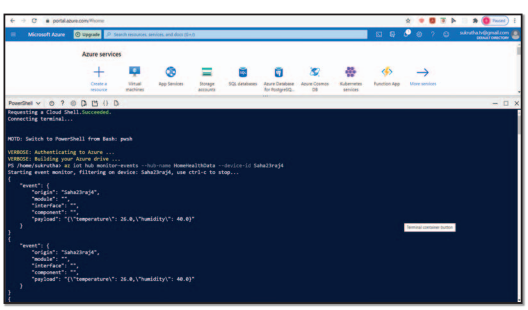
TABLE II: Performance analysis of W-DAM in terms of time, cost and Accuracy.

Application	Storage	Time Taken	Cost	Accuracy
Purwandari et al. [4]	Centralized	2.23s [14]	High	Low
Andrian et al. [5]	Decentralized-IPFS	13s [13]	High	High
Kodali and Sahu [6]	Centralized	2.23s [14]	High	Low
Tsao et al. [7]	Distributed-(MQTT)	3s [13]	High	High
Osiorio et al. [8]	Centralized	2.23s [14]	High	Low
W-DaM [Current-Paper]	**IoT Hub + Blockchain**	**4.3s** [13], [14]	**Low**	**Very High**

We create an Azure IoT Hub account, a resource for saving the primary key and connection string, and a device ID inside the resource to authenticate the Device. A cloud shell is connected to see the data coming from the Raspberry Pi device. We add an endpoint and a route for the IoT Hub to recognize the relevant smart contract. The process of building applications and outputs for the current paper W-DAM are given in Fig. 3(a), and 3(b). As the IoAT sensors are sending raw data, Azure has the logic apps to parse the data to JSON files that the Blockchain workbench can use to read the sensor data. The performance of the system is compared with the previous works to see the enhancements of the current W-DaM, as shown in Table II. The Data loading times are calculated for 250KB, and 1MB data storage takes 14 sec in Distributed Ledger [12], [13].



(a) Creating Resource and Device ID in IoT Hub.



(b) Weather data from Raspberry pi to IoT Hub and Blockchain.

Fig. 3: W-DaM Application Building.

VII. Conclusion and Future Direction

In the current paper, we have introduced a novel way of weather data management with the help of IoT Hub and using Blockchain-as-a-Service. We solve the issues related to multiple IoT device communication through Hub and provide weather data security with the service of Blockchain. The system is resistant and reliable to threats and data attacks through the authentication of devices. As already discussed in the introduction, A 1-degree fault in the weather readings can lead to drastic effects for farmers and the researcher; therefore, accuracy plays a vital role in weather communications. Thus, we show that IoT Hub and Blockchain have proven to be accurate in storing and sharing weather data. In the future, the current work can be enhanced to other domains for data security and accuracy.

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