Blend of Cloud and Internet of Things (IoT) in agriculture sector using lightweight protocol

Meenaxi M Raikar
School of Computer Science and Engineering
K. L. E. Technological University
Hubballi, India
mmraikar@bvb.edu

Padmashree Desai
School of Computer Science and Engineering
K. L. E. Technological University
Hubballi, India
padmashri@bvb.edu

Namita Kanthi
School of Computer Science and Engineering
K. L. E. Technological University
Hubballi, India
kanthinamita@gmail.com

Sachin Bawoor
School of Computer Science and Engineering
K. L. E. Technological University
Hubballi, India
sachinbawoor88@gmail.com

Abstract— **The emergence of the disruptive technologies such as cloud computing, IoT (Internet of Things), machine learning and data analytics has made its mark in different sectors like transportation, agriculture, healthcare, environment monitoring, renewable energy systems, retail, and industry. The IoT provides connectivity of things dynamically to the network whereas cloud computing provides virtualization in storage and processing. In CloudIoT paradigm, cloud and IoT are merged together to provide complementary features in smart applications/services.**

CloudIoT solutions make it possible to envisage ubiquitous and pervasive connectivity to the users. The source of livelihood for a majority of the population is agriculture; it mantles a dominant role in the economy of the country. The proposed work focuses on CloudIoT architecture for providing any smart solutions in different sectors. A case study of a smart irrigation system is discussed in the paper. A smart irrigation system is developed using the lightweight protocol, MQTT (Message Queue Telemetry Transport). MQTT protocol is 22% more energy efficient and 15% faster when compared with other protocols. The temperature and soil moisture data are collected and managed by Amazon cloud. The data analysis is performed using the Weka (Waikato Environment for Knowledge Analysis) tool.

The cost-effective solution is demonstrated and results speak the strength and performance of the system.

Keywords— Amazon Cloud, Raspberry, MQTT, sensor, data analysis.

I. Introduction

Water is one of the important resources for the life of animals, plants and human beings. We need to conserve the existing water resources and manage efficiently for the betterment of Plantlife. Effect of exhausting freshwater resources could be worse than depletion of oil. It may cause a complete destruction of numerous life forms on earth. It is our responsibility to save and use the water properly. Agriculture is one of the important sectors which depend on the freshwater resource for food production. Efficient water utilization in agriculture requires technology intervention in the traditional method of farming where they depend on rainwater. Efficient water utilization in agriculture includes many aspects such as Sensor-based field and resource mapping, Smart irrigation, Remote equipment monitoring, remote crop monitoring, Predictive analytics for crops and livestock, Climate monitoring and forecasting, Livestock tracking and geo-fencing, etc. We know that Indian agriculture is mainly depending on monsoons rainfall. The gambling of monsoon disturbs the food production in the agriculture sector. As the monsoon rainfalls are unpredictable, the irrigation is necessary for agriculture throughout all the seasons. In India, 80% of rainfall is during June to October. Hence it is necessary to irrigate farmland during the rest of the months safely and efficiently [1].

With the invent of IoT and Cloud computing, the agriculture sector has opened up a new door for "Precision agriculture". Precision farming can be thought of as anything that makes the farming practice more controlled and accurate when it comes to raising livestock and the growing of crops. In this approach of farm management, a key component is the use of IT and various items like sensors, control systems, robotics, autonomous vehicles, automated hardware, variable rate technology, and so on. The adoption of access to high-speed internet, Cloud data store, mobile devices, and reliable, low-cost satellites (for imagery and positioning) by the manufacturer are few key technologies characterizing the precision agriculture trend. This paper focuses on design and development of the CloudIoT based irrigation system for conservation of water.

Smart irrigation is capable of supplying the water to the entire field uniformly, schedule and controls the water supply remotely so that each plant has the adequate amount of water it needs, neither too much nor too little as shown in Fig 1.

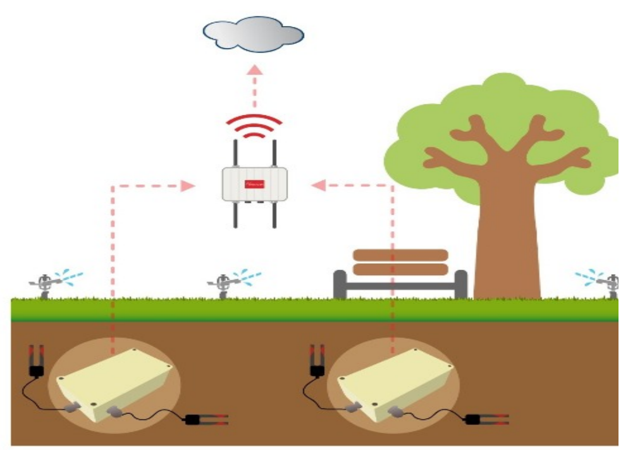

Fig.1 Irrigation system using CloudIoT paradigm

Water use efficiency in the field can be determined by Field Water Efficiency (%) = (Water Transpired by Crop ÷ Water Applied to Field) x 100. The system is designed to develop an automatic irrigation system which switches the pump motor ON/OFF on sensing the moisture content of the soil. The network of wireless sensors has provided ample opportunities for automation. These help to obtain details from resources like water, soil, or air in the field and analyze them to take the decision to improve the yield and save resources. Lightweight publisher-subscriber protocol MQTT is used for communication purpose by which harvests will be evaluated for soil moisture, humidity, temperature, water supply to crops. Monitoring these parameters will help in comprehending and managing agrarian varieties for prominent yield. The environmental parameters are stored in Dynamo DB for further reference. AWS gateway with AWS Lambda is used to notify the user/farmer. The advantage of using this method is to reduce human intervention and still ensure proper irrigation. Smart Irrigation system using CloudIoT is shown in figure 1.

Main advantages of MQTT for IoT agent are Security, Central Broker, Quality of Service, Last will & Testament and Retained messages and Flexible Subscription pattern. MQTT has been replaced HTTP as the throughput of MQTT is 93 times faster than HTTP's and it is more data-centric. The MQTT is an M2M publisher-subscriber protocol which follows client-server architecture, every sensor is a client and a broker is a server. The lightweight and efficiency of MQTT make it possible to significantly increase the amount of data being monitored or controlled.

II. RELATED WORK

The authors Alessio Botta et al, [1] have discussed the CloudIoT paradigm, a combination of cloud computing technology and IoT in development of smart applications. The different drivers for integration stated are communication, storage, and computation. The challenges in integrating these technologies are security, privacy, heterogeneity, performance and big data. The open issues in these are standardization, intelligence, pricing, service level agreement and energy efficiency.

The authors Antonis Tzounis et al [2] describe the different application of IoT in the agriculture sector. The integration of cloud and IoT for climate monitoring is proposed in the paper. Tracking in the food supply chain, livestock applications for monitoring the animals and the agricultural fields are discussed in the paper.

A. Zanella et al [3] have proposed the architecture of IoT application in the smart cities with the example 'Padova' city. The protocol stack for the constrained and unconstrained devices is mentioned.

A. Zanella et al [4] point out the different sections where the IoT could be embedded in the healthcare sector. The different services in healthcare such as m-health, wearable device access, child health and drug reactions are described. The applications such as blood pressure, temperature, ECG, glucose level monitoring, wheelchair management are discussed.

In [5] the amalgamation of cloud and IoT technology is applied in the conservation of the architecture to preserve the heritage. The structural health of the architecture is captured and monitored through the system. The revolution in the disruptive technologies such as cloud computing, IoT, machine learning and data analytics has made its mark in different sectors such as transportation, agriculture, healthcare, environment monitoring, renewable energy systems, retail and industry

In [6] authors discuss general aspects of agriculture Agricultural people typically follow three prominent methods of irrigation namely channel system, sprinkler system, drip system. This system consumes much time and effort. Automation of irritation makes agronomist work much easier this motivated us to structure a smart irrigation system. Authors in [15] discuss smart irrigation system and also speaks about the measures taken and issues identified to automate traditional methods in agriculture.

In [7] and [8] author discusses a WSN based the irrigation control and collection of data from the sensor for vegetable crops is through a system with collects weather parameter through Smartphone. In [9] the uses of sensors and data analysis are discussed. In [10] the IoT application in smart irrigation using low-cost devices is proposed. Authors in papers [11]-[14] summarize about the use of a lightweight MQTT as the most suitable and the most efficient and prominent one. After its invention in 1999, it is widely implemented across many sectors. Different devices used in the IoT systems such as raspberry pi is also quoted in the paper.

In [17] the authors discuss the applications developed using IoT alone. In [18] the authors explore the open source software environment for implementing the cloud services such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service(SaaS). In [19] the authors propose a curriculum with IoT as a course suggested in the 3rd year for enabling the students to develop interdisciplinary projects. In [20] a FarmBot used for precision agriculture is described. The data-driven decision support system is included to assist the farmer in making the decisions.

In [21] the fertigation along with automated irrigation is an IoT application described. In [22] the Cloud-based architecture for the farming is presented. In [23] the role of big data in making the farming decision is discussed.

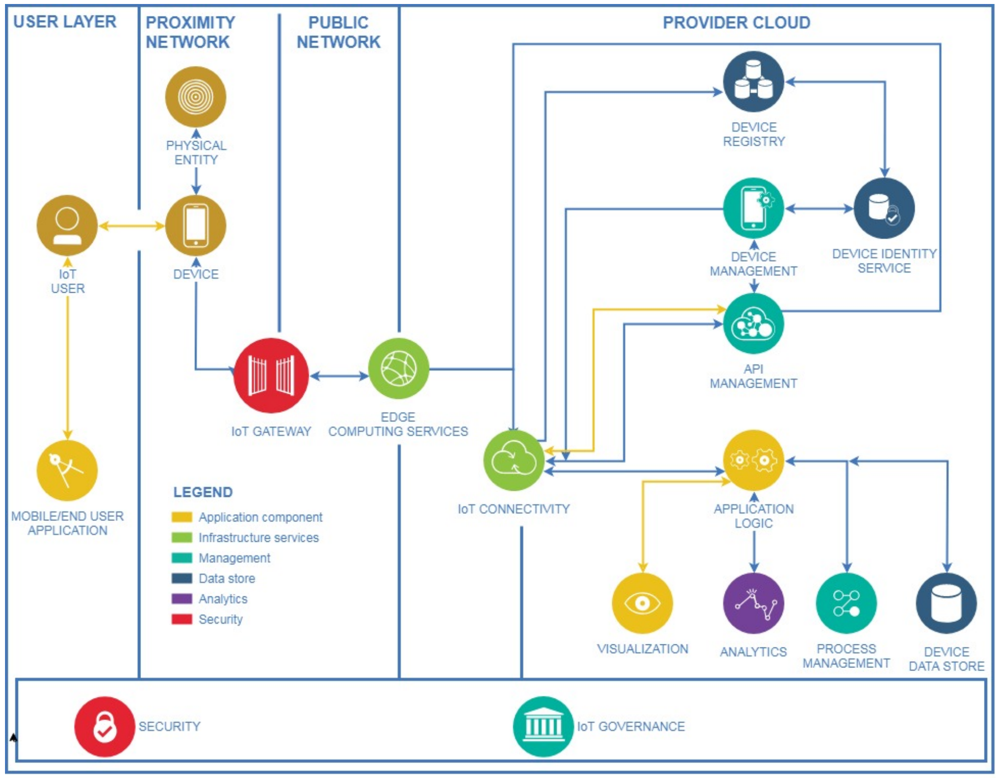

Fig 2 Blend of Cloud and Internet of Things architecture [23].

III. THE CLOUD IOT ARCHITURE

The different layers adopted in the CloudIoT architecture are user layer, proximity network, public cloud and provider cloud as shown in fig 2. The user devices such as mobile, tablet, laptops connect to the cloud services using the internet. The users within the coverage area (proximity network) are only able to connect to the services. The aggregated data from the sensor devices (things) is gathered at the IoT gateway devices. The edge computing devices connect the gateway devices to the data centers, the backend infrastructure of the provider cloud. The services provided by the cloud provider fall into the public network category. The device registry, management, and identity services are provided by the service providers. To connect to the cloud infrastructure the developer need to obtain the access control permission keys, performed using the API (Application interface) management module of the provider cloud. The visualization, data analytics, process management and data storage services are available for the applications developed using provider cloud infrastructure. At each of the layers in the CloudIoT architecture, the security module is embedded. The cloud users have to sign a Service Level Agreement (SLA) to use the services of the cloud provider, which are governed by the authorities in the region.

IV. PROPOSED SYSTEM

The CloudIoT architecture layers are applied to the case study smart irrigation system in the agriculture sector as shown in fig 3.

A. *User Layer*

The mobile app is used to on/off the water motor remotely by the user to increase the water efficiency. Option is provided to the user to on/off the motor manually also. The user can schedule the watering of the plants based on the soil moisture content in the field. The efficiency of the water used in the field is computed as:

Field Water Efficiency (%) = (Water Transpired by Crop ÷ Water Applied to Field) x 100

B. *Proximity network*

The devices within the coverage are able to communicate with the gateway device.

- IoT Device: The temperature sensor (DHT11: Digital Humidity and temperature), a soil moisture sensor, light sensor are connected to the controller device. The temperature, moisture, and light intensity data are sent to the IoT gateway device.
- IoT gateway device: The Raspberry Pi 3 is used as the gateway device which is connected to the AWS provider cloud. Is used to execute the AWS client along with the embedded service to read sensor values in the digital format, AWS client called AWS MQTT SDK is the standard package provided by the AWS to interface the hardware pi device with the AWS IoT MQTT server.

C. *Public network*

The application built is hosted on a public network, using the provider cloud infrastructure. The cloud application developer has to select a server in the region of the application developer; these form the edge computing service module.

IoT connectivity: The lightweight protocol, MQTT is used for the communication between the client nodes and the service provider. MQTT protocol uses the 'publish-subscribe' type of communication model. The components of the protocol are publisher/subscriber, messages, topic and broker. The message between the publisher and the subscriber node are exchanged with the help of the broker node. The broker agent receives the messages, filters the message and publishes the messages to the subscriber nodes. The subscriber subscribes for the messages published by the publisher. If the subscriber loses the connectivity with the MQTT broker, the broker notifies the subscriber with the 'Last Will and Testament' feature, in this case, the subscriber can publish new message.

Criteria for the subscriber to receive the data: The subscriber subscribed topic should be the same as the topic published by the publisher. Both the subscriber and the publisher should be connected to the same broker.

Topics: Topics are case sensitive; wildcards are allowed when registering a subscription. The topic matching is performed using the hierarchical structure.

Security: The authentication of the MQTT subscribers' nodes is performed by the broker. The protocol guarantees privacy by encrypting the payload using SSL/TLS.

Application-level QoS (Quality of Service): The QoS is of three levels zero, one and two value. The value zero indicates 'fire and forget', the value one indicates 'delivered at least once' and the value two indicates 'delivered exactly once'.

MQTT Strengths: Space, time and synchronization decoupling features, security, QoS, 'Last will and testament' are the strengths of the MQTT protocol.

The CoAP is the other lightweight protocol, with four-byte compact header, strong DTLS security, asynchronous subscription and built-in discovery.

D. *Provider cloud*

The visualization, analysis, process management, and data storage services are taken from the services provider.

Device management: AWS IoT is used for executing the MQTT server where an instance of a physical device is created along with the certificates required for security purposes. To publish the soil moisture sensor values on to AWS IoT MQTT server the topic name chosen is 'pi2aws'[16].

API management: The access control keys are obtained for reading and writing data and also to implement AWS alarms and cloud watch services.

Process management: The actual lambda functions are written inside this service so whenever a sensor data is published on to the MQTT server the corresponding lambda functions associated with the events are triggered and the corresponding action written in the function is executed.

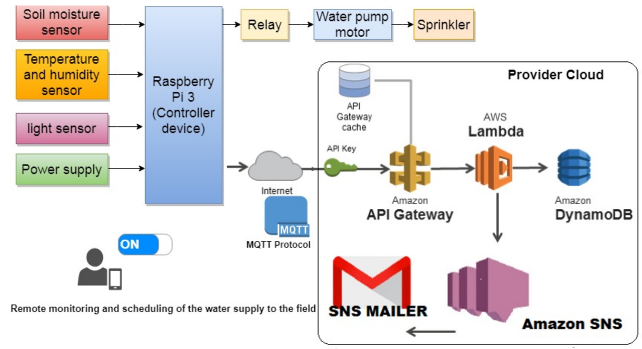

Fig 3. Proposed CloudIoT smart irrigation system

(Alarms like forwarding the soil data to the AWS dynamo database)

Device data store: It is used to store the sensor values in the database for further referral and also for the analysis of the data sent to the cloud. DynamoDB a NoSQL database is used to store the two attributes of the sensor: the sensor values and the timestamp at which it was generated. NoSQL is a scheme less database. Each record in the database can have a variable size attributes.

Notification as a Service: This service is used to push the notifications on to the client or the farmer whenever low moisture values are encountered in order to specify that the soil is dry and corresponding actions are taken, the reminder is sent via email, by using SNS mailer of SNS.

Data analysis: The Weka (Waikato Environment for Knowledge Analysis) tool is used to perform the data analysis. It consists of machine learning algorithms for preprocessing, classification, clustering, association mining, analysis, prediction and visualization of the data set using the graphical user interface.

The Sequence of steps executed is as follows:

1. The moisture content in the soil is sensed through the soil moisture sensor placed at various locations in the field.

2. The sensed data is read by the pi through GPIO 21 (General Purpose Input Output pin) sent via ADC (Analog to Digital Converter)

3. The sensor value is analyzed for its meaning

   (a) if sensor data==1 then the soil is dry.

   (b) if sensor data==0 then the soil is wet.

4. The analyzed data is then published to the MQTT server on AWS IoT platform based on the value sensed in the topic name of 'pi2aws'.

5. The alarms get activated on AWS in cloud watch and the corresponding triggers are executed:

   (a) the sensor data is pushed to AWS dynamo database

   (b) if the sensed value says that the soil is dry then the SNS is triggered and the SNS mailer is used to notify the farmer via mail.

6. The farmer then can take decisions accordingly.

Mobile Application: The 3rd party mobile application, “MQTT Dashboard”, is customized for the use in remote switching (on/off) of the water pump in the field.

V. RESULT ANALYSIS

Performance of MQTT: The performance of the system is increased using MQTT with an average time 4.38 msec for responses. As the packet header of the MQTT is 2 bytes smaller than CoAP (Constrained Application Protocol) packet header the performance of MQTT is 30% better than CoAP.

Sensor data analysis: The analysis of sensor data obtained through different attributes as shown in table I. is performed.

TABLE I. ATTRIBUTES AND DESCRIPTION OF THE SENSOR DATA SET

Attributes	Description
timestamp	represents the date and time of sample collected.
mac	mac address of the device generating data.
boardtype	type of the microcontroller board generating data.
boardid	board identifier
temp	temperature at that instance of time.
humidity	humidity at that instance of time.
Light_intensity	light intensity at that instance of time.
longitude	longitude at the place of collection of sample data.
latitude	latitude at the place of collection of sample data.
elevation	elevation of the place above sea level in metres.
Location	location name
Soil_moisture status	Dry (1) or wet (0)

Table II shows the analysis of the temperature and the light intensity needed for the plant growth in the data collected location. Analysis of the temperature, light intensity and humidity help to determine the supply of water to the plants. Fig 4 shows the analysis of the humidity at the location of the data collection is performed using WEKA tool. Fig 5 shows the data analysis performed using the Cloudwatch service provided by the service provider. The number of successful connections for one-week duration is monitored as shown in fig 5. Visualization of the MQTT and HTTP protocol messages exchanged between IoT devices and the provider

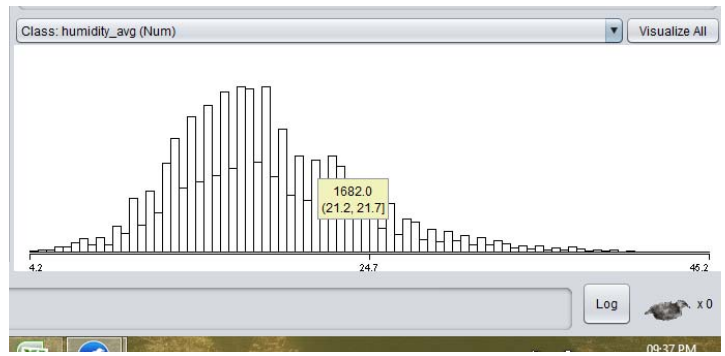

Fig 4 Analysis of the humidity at the location of data collected using WEKA tool.

cloud is shown in fig 6. The connection establishment ping, publish and subscribe are the different types of messages exchanged between the IoT device and the service provider cloud. The direction of the inbound and the outbound messages are monitored and represented in the dashboard.

TABLE II. ANALYSIS OF THE AVERAGE TEMPERATURE AND LIGHT INTENSITY IN THE DATASET

Statistic	Temperature	Light intensity
Minimum	4.2	0
Maximum	45.2	98.7
Mean	18.523	48.675
Standard Deviation	5.4999	43.973

VI. CONCLUSION

The integration of Cloud Computing and Internet of Things (CloudIoT) has given the next big leap ahead in the solution domain in the form of smart applications. Wireless Sensor Networks which is considered as one of the important components in IoT encouraged a new path of research in agricultural and farming domain. In recent times, WSNs are widely applied in various agricultural applications to improve the productivity by making use of existing resources in an optimal way to cut down the costs incurred in farming. The key contribution of the proposed work makes use of lightweight protocol MQTT to provide efficient and secure communication between the users and the device/sensors thereby increasing the performance of smart irrigation system.

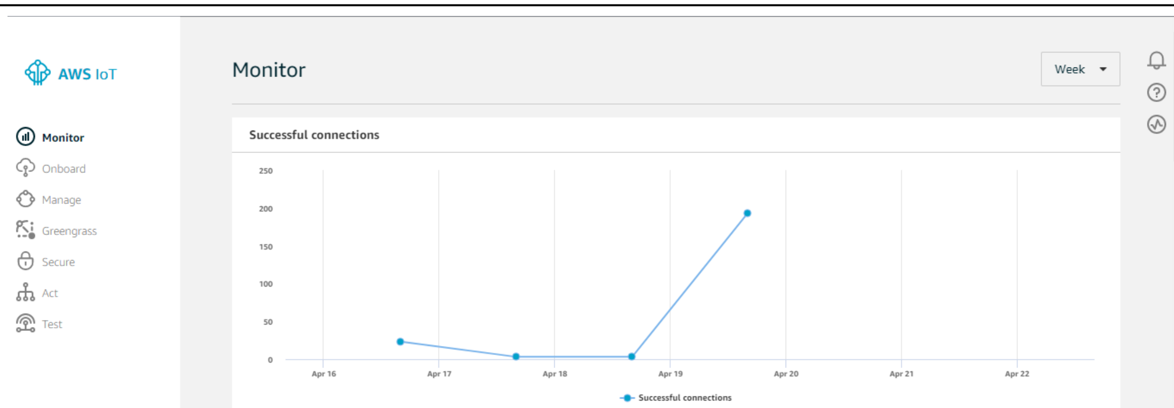

Fig 5. Data analysis of successful connections using Cloudwatch Services.

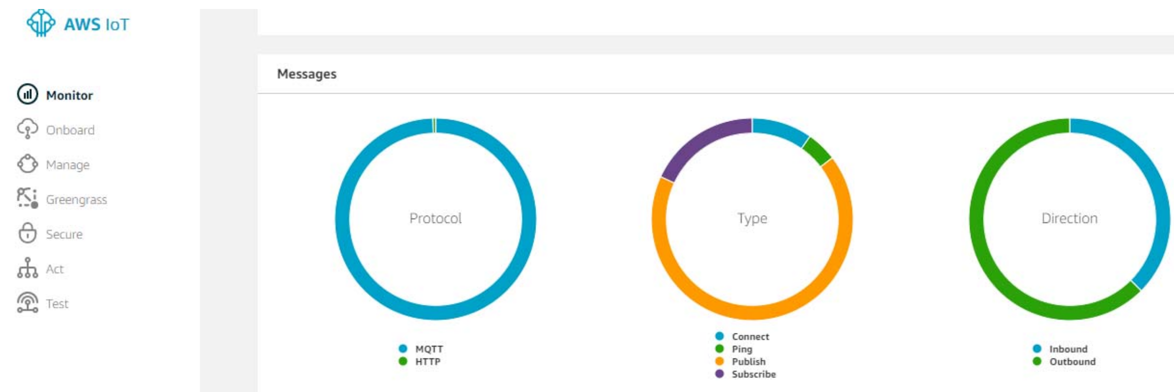

Fig 6 Visualization of messages used in MQTT protocol.

The sensor data is analyzed using WEKA tool to control the water supply to plants and helps in scheduling the proper flow of water only when it is needed for plants. The blend of CloudIoT technology has reduced the human interventions in the monitoring of plants. This helps in achieving scalability if extended to the entire rural region.

VII. FUTURE WORK

The proposed system can be improved by recommendation engine and prediction module for the complete automation of the irrigation system.

Recommendation engine uses historical data of a user, soil moisture, temperature, humidity, light intensity and elevation to recommend the type of crop that can be sown to improve the yield in that location. Prediction module can be used to analyze current conditions of the environment to control the sprinkler or water supply to plants without the human interventions.

REFERENCES

[1] Alessio Botta, Walter de Donato, Valerio Persico, and Antonio Pescapé. 2016. Integration of Cloud computing and Internet of Things. Future Gener. Comput. Syst. 56, C (March 2016), 684-700. DOI: https://doi.org/10.1016/j.future.2015.09.021

[2] Antonis Tzounis and Nikolaos Katsoulas and Thomas Bartzanas and Constantinos Kittas"Internet of Things in agriculture, recent advances and future challenges",Journal of "Biosystems Engineering",volume 164, pages 31 - 48,2017.

[3] A. Zanella, N. Bui, A. Castellani, L. Vangelista and M. Zorzi, "Internet of Things for Smart Cities," in IEEE Internet of Things Journal, vol. 1, no. 1, pp. 22-32, Feb. 2014.,doi: 10.1109/JIOT.2014.2306328

[4] A. Zanella, D. Kwak, M. H. Kabir, M. Hossain and K. S. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," in IEEE Access, vol. 3, pp. 678-708, 2015. doi: 10.1109/ACCESS.2015.2437951

[5] Angel Perles,"An energy-efficient internet of things (IoT) architecture for preventive conservation of cultural heritage", Future Generation Computer Systems,Volume 81,2018,Pages 566-581,ISSN 0167-739X,https://doi.org/10.1016/j.future.2017.06.030.

[6] H.N.Kamalaskar, P.H.Zope, "Survey of smart irrigation system", International journal of engineering sciences & research technology(IJESRT), ISSN: 2277-9655, 3(6), pg 224-228, June 2014.

[7] Benjamin Aziz, "A Formal Model and Analysis of the MQ Telemetry Transport Protocol", International Conference on Availability and Security, 2014

[8] Stefanos A Nikolidakis, Dionisis Kandris, Dimitrios D. Vergadoschristos Douligeris, "Energy Efficient Automated Control Of Irrigation In Agriculture By Using Wireless Sensor Networks", Computers And Electronics In Agriculture" 0168- 1699/ 2015 Elsevier.

[9] Ashwini Raut, Mrunal Panse, Darshana Chaware,Aniruddha Koparkar "Sensor Based Automated Irrigation System", IJERT, ISSN: 2278-0181, Vol. 4 Issue 05, May-2015.

[10] Chandan kumar sahu and Pramitee Behera, "A Low Cost Smart Irrigation Control System" IEEE SPONSORED 2ND INTERNATIONAL CONFERENCE ON ELECTRONICS AND COMMUNICATION SYSTEM, (ICECS 2015)

[11] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, Maui, HI, USA, 2000, pp. 10 pp. vol.2.

[12] P. R. Deshmukh and D. Bhalerao, "An implementation of MQTT through the application of warehouse management system for climacteric fruits and vegetables," 2017 (ICCES), Coimbatore, 2017, pp. 844-849.

[13] Joshua Velez Russell Trafford, Michael Pierce, Benjamin Thomson, Eric Jastrzebski, Brian Lau, "IEEE 1451-1-6: Providing Common Network Services over MQTT", 978-1-5386-2092-2/18/$31.00 ©2018

[14] Mayur Bhole, Karan Phull, Arun Jose, Vishwas Lakkundi ,"Delivering Analytics Services for Smart Homes", pg 28-33 2015 IEEE Conference on Wireless Sensors.

[15] Sanket Salvi, Pramod Jain S.A, Sanjay H.A, "Cloud Based Data Analysis and Monitoring of Smart Multi-level Irrigation System Using IoT", International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2017)

[16] Sachin bawoor, "Connecting Raspberry Pi | AWS IOT | MQTT | Dynamo DB | AWS SNS", https://youtu.be/HPp6LHOxRdU 2018.

[17] M. M. Raikar, P. Desai and J. G. Naragund, "Active Learning Explored in Open Elective Course: Internet of Things (IoT)," *2016 IEEE Eighth International Conference on Technology for Education (T4E)*, Mumbai, 2016, pp. 15-18.

[18] M. M. Raikar, P. Desai and Vijayalakshmi M , "Augmenting cloud concepts learning with open source software environment", 2018 IEEE Seventh International Conference on Advances in Computing, Communications and Informatics (ICACCI), Bangalore.

[19] M. M. Raikar, P. Desai and Vijayalakshmi M , "Upsurge of IoT (Internet of Things) in engineering education: A case study ", 2018 (ICACCI), Bangalore.

[20] Rory Landon Aronson, "FarmBot:Humanity's open-source automated precision farming machine", September 19, 2013.

[21] Shah Abd Hafiz Zainal Abidin and S.Noorjannah Ibrahim," Web-based Monitoring of an Automated Fertigation System: An IoT Application", 2015 IEEE 12th Malaysia International Conference on Communications (MICC), Nov 2015.

[22] J.W. Kruize, J. Wolfert, H. Scholten, C.N. Verdouw,"A reference architecture for Farm Software Ecosystems", Computers and Electronics in Agriculture 125 (2016) 12–28.

[23] Sjaak Wolfert, Lan Ge, Cor Verdouw, Marc-Jeroen Bogaardt," Big Data in Smart Farming – A review", ScienceDirect Agricultural Systems 153 (2017) 69–80.

[24] IoT Cloud Architecture, Cloud Standards Customer Council, www.cloud-council.org.