A Low Power IoT Network for Smart Agriculture

Soumil Heble, Ajay Kumar, K.V.V Durga Prasad, Soumya Samirana, P.Rajalakshmi, U. B. Desai
Department of Electrical Engineering
Indian Institute of Technology - Hyderabad, India
E-mail: soumilheble, ee15resch2002, ee15mtech11023, soumyasamirana, raji, ubdesai@iith.ac.in

***Abstract*—Traditional agriculture is transforming into smart agriculture due to the prominence of the Internet of Things (IoT). Low-cost and low-power are the key factors to make any IoT network useful and acceptable to the farmers. In this paper, we have proposed a low-power, low-cost IoT network for smart agriculture. For monitoring the soil moisture content, we have used an in-house developed sensor. In the proposed network, the IITH mote is used as a sink and sensor node which provides low-power communication. We have evaluated our network with state of the art networks, proposed for agriculture monitoring. Power and cost are the two metrics used for evaluation of these networks. Results show that the proposed network consumes less power and has on average 83% prolonged lifetime at a lower cost compared to previously proposed network in the agriculture field.**

***Index Terms*—Smart Agriculture, Internet of Things, Soil-monitoring, Environmental-monitoring.**

I. Introduction

Every field, from health to environment, education to entertainment and industry to home is embracing the Internet of Things (IoT) revolution [1]. Agriculture has seen many transformations and has adopted many machines to increase the yield. Field (soil and environmental parameters) and crop health monitoring are important factors for the yield to be of better quality and in larger quantities. In recent years, there have been many technological advancements in agriculture which have led to an increase in productivity and immunity of the crops. About 70% of the fresh water available in the world is consumed by the agriculture sector [2], with the help of soil moisture sensor we can optimize the irrigation process and use of water [3], [4]. The technology which plays a key role in this is the Internet of Things (IoT) [5]. Traditional agriculture is transforming into smart agriculture due to the penetration of the Internet of Things (IoT) in the agricultural sector. The IoT networks are reducing human labor requirements by monitoring crop health and field environment remotely. IoT uses a wireless sensor network (WSN) as the backbone for gathering information for these monitoring and control applications. The monitoring-system consists of end devices equipped with a variety of sensors to monitor various parameters like temperature, humidity, solar radiation, soil moisture, etc. and is capable of communicating this data to the other devices [6], [7]. IoT is helping the farmers by monitoring growth stages of the crop, diseases, and estimation of the yield by giving otherwise restricted low-power, low-cost devices access to greater processing capabilities via the Internet.

Recently, for remote sensing, drones are widely being used in agriculture [8]. They are diminishing the role of satellites in monitoring and capturing images for agriculture by providing finer control and flexibility [9].

IoT systems for agriculture monitoring should be of low-cost such that it is affordable to the farmers and low-power for prolonged life of the network. In a typical monitoring network, there are many sensor nodes, a few sink nodes and a gateway depending on the network topology and area of the field. The sink collects data from the sensor nodes and uploads it to the server [10]. In most of the wireless networks, the sink is always in an active state and thus consumes a lot of power [11].

K. O. Flores *et al.* [12] have proposed a low-cost sensor system, they have used Xbee radios as sensor nodes for monitoring the agriculture parameters along with a Raspberry Pi, which acts a gateway to the Internet. The authors in [13] proposed a three-layer architecture for precision agriculture wherein the processing of collected data happens on the server. It has a higher power consumption due to redundant transmissions. In the paper [14], for agriculture monitoring, Multi-mode, Multi-parameter, Multi-application Soil Sensing (M3SS) sensor node has been proposed. They have made the node capable of communicating in three wireless protocols namely WiFi, ZigBee, and Bluetooth which allows for greater flexibility in range, connectivity options and redundancy at the cost of higher power consumption.

These have motivated us to propose a low-power IoT network for smart agriculture. In this paper, we have proposed an IoT network based on the IITH mote [15] in which the sensor nodes are solar powered, which makes them self-sustaining by using an ambient energy source.

The rest of the paper is organized as follows: Section II discusses the proposed network architecture and its deployment. Section III evaluates our network for power consumption and cost analysis. The paper concludes in section IV with the future scope of work.

II. Proposed Low Power Low Cost IoT Network

We have considered an outdoor agriculture field of 648 square meters area, sown with maize crop. This field is divided into 27 plots, each spanning 24 square meters. In agriculture, the soil and environmental parameters both play an important role in crop health and yield. The network, nodes, and sink measure a total of 6 parameters. The soil moisture and soil temperature sensors are used for measuring the soil parameters. The environmental parameters measured include light intensity, relative humidity, and ambient temperature. The carbon dioxide and total solar radiation (TSR) sensors are interfaced to the sink. Each plot has one sensor node, totaling 27 nodes plus one sink in the maize field. Sensor nodes from each plot will send their data to the sink which will then upload it to a server for processing and consumption. The wireless hardware platform used for the sink and sensor node is the IITH mote (Fig. 1), an 802.15.4 compliant wireless mote which is developed in-house at the Wireless Networks (WiNet) lab, Indian Institute of Technology Hyderabad (IITH), India. We have designed a gateway to upload the data to the server and make it available online. An Intel Edison along with a 4G modem forms the gateway which communicates with an IITH mote acting as a sink (Fig. 2). The real-time hardware implementation of the network is discussed in the next section.

Fig. 1. IITH Mote

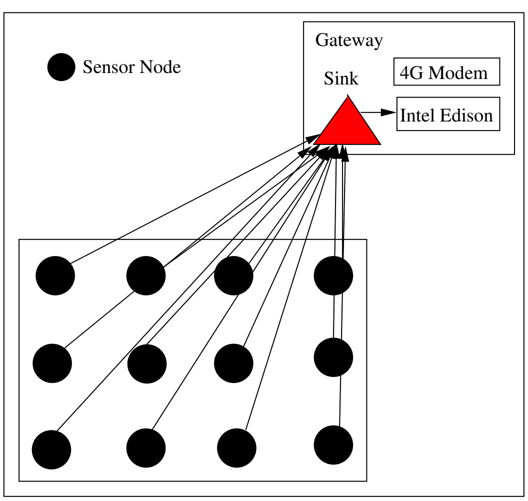

Fig. 2. Agricultural Monitoring Network Architecture

A. Field Deployment

1) Sensors Used: The proposed IoT network measures six environmental parameters, namely solar irradiance, carbon dioxide concentration, ambient temperature, soil temperature, relative humidity and illuminance (light intensity). The solar irradiance sensor is from Davis Instruments, model 6450 TSR sensor with a solar spectrum range from 300 - 1100 nanometers. The 10 kΩ thermistors are used to monitor the soil temperature. A signal conditioning circuit is designed and coupled to provide maximum sensitivity and accuracy for temperatures between 15°C and 45°C. The DHT11 is a low-cost integrated sensor which measures relative humidity and ambient temperature. It provides the measurements using a proprietary single wire communication protocol. The light intensity sensor BH1750 has a measurement range from 1 to 65535 lux. The sensor has a small package and it communicates over the I2C bus. Carbon dioxide is an important part of the photosynthesis process, hence a solid electrolyte based CO_2 sensor is used which provides good accuracy at a reasonable cost. Figaro's CDM4161A is a solid electrolyte sensor which comes pre-fabricated with a heating and signal conditioning circuit.

2) Soil Moisture Sensor: Soil moisture is one of the most important factors for plant growth. Plants behave differently at different levels of soil water content. If the soil is dry, plants feel stressed and the adverse effects of stress are reflected in their growth. Stress also makes them vulnerable to diseases and pests. The irrigation process can be optimized to precisely meet the demands of the crop by observing the moisture level. Listed in descending order of cost and accuracy, the Time domain reflectometry (TDR), frequency domain reflectometry (FDR), tensiometry, capacitance and resistance based methods are some of the popular methods used to measure soil water content. TDR sensors give most accurate results but are bulky and expensive. The resistance based technique is the cheapest method to measure soil moisture but, it offers poor accuracy and lifetime [16]. We invested our time in the design of a capacitance-based soil moisture sensor, Fig.3, because the capacitance-based soil moisture sensors provide reasonable accuracy and lifetime for the cost.

The in-house designed sensor has a probe structure like an Inter-digital Transducer (IDT). It is a comb-like structure whose two electrodes form a capacitor. The electrodes of the transducer represent the plates of a capacitor, which are co-planar to each other allowing the electric field to fringe out of the transducer. This electric field then interacts with the measurand altering the dielectric in between the electrodes thereby altering the capacitance. The dielectric permittivity of air is about $\sim$1, and that of soil is anywhere between $3-12$, which is small compared to dielectric permittivity of water which is about $\sim$80. This huge difference is exploited by capacitance-based sensors to measure soil moisture. The probe is manufactured using standard PCB fabrication technology making it very cheap to mass-produce (Fig. 3. The probe's capacitance modulates the frequency of a square wave generator, which is measured by a high-speed timer circuit within a microcontroller. The frequency is then calibrated to soil moisture using gravimetric soil moisture measurement technique (Fig. 4). From Fig. 4, the three soil moisture probes SM1, SM2, and SM3 are calibrated with average, maximum and minimum frequency. We can observe the non-linear relationship between frequency and moisture.

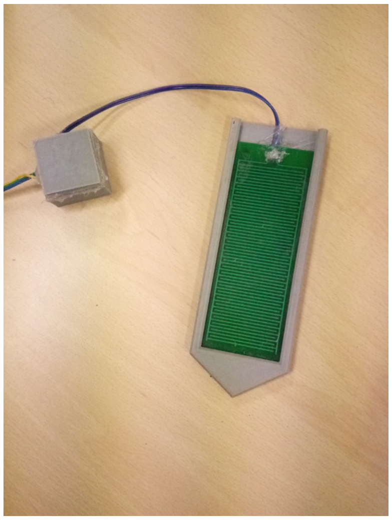

Fig. 3. Soil Moisture Sensor

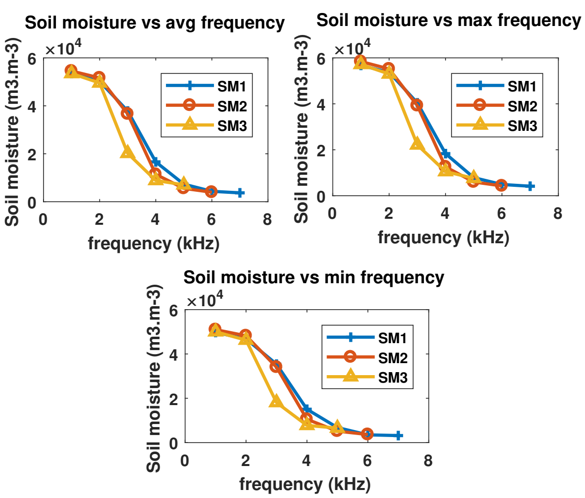

Fig. 4. Calibration and Repeatability Performance of the Sensor

3) Hardware deployment: The proposed network for agricultural monitoring is composed of spatially distributed nodes, each an IEEE 802.15.4 based wireless platform (IITH mote) with sensors and a solar based power circuit. The sensor nodes have a line of sight range of about 80 meters which means that the sensor node's transmission range covers the whole field and can easily reach the sink. The nodes sample their sensors hourly and send the data via the reliable unicast protocol to the sink and then go to the sleep state to conserve

Fig. 5. Sensor Node Deployed in the Field

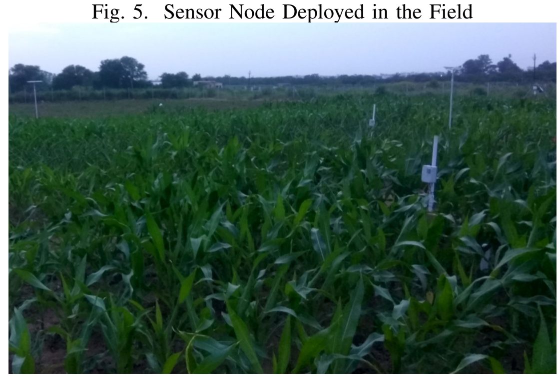

Fig. 6. Field Deployment of IoT Network in the Maize Crop Field

power. The sink is always on, but since every node uses the ContikiMAC RDC (radio duty cycling) to reduce its power consumption, it is a small price to pay for increased power saving. The sink transfers the collected data to an Intel Edison serially which then pushes the data to the server with the help of 4G modem. Since the maize crop field is in a remote location devoid of Internet hardline, we are using a 4G modem to connect the sink to the internet. The gateway is wall powered since the Intel Edison, and 4G Modem requires 7-12 V supply. The network is deployed in a maize crop field at the Professor Jayashankar Telangana State Agricultural University (PJTSAU), Hyderabad, India, Fig. 5 and Fig. 6.

Architecture II: The current requirement of the Intel Edison gateway could be a potential drawback for monitoring networks deployed at remote locations and agricultural fields, where laying electrical lines can be hazardous or impossible. To overcome this problem of running wires we have replaced the sink to internet link with a LoRa link which is a low-power, long-range modulation technique [17]. To emulate the gateway, we are using the Adafruit Feather 32u4 LoRa module, Fig. 7, as the LoRa gateway. It houses a LoRa transceiver based on Semtech's SX1276 LoRa modem running in the 868 MHz ISM band (Fig. 8). After widespread deployment of LoRa, we will see mobile service providers commissioning their own high-power LoRa gateways on cellular towers and provide cheap service for upcoming LoRa end nodes.

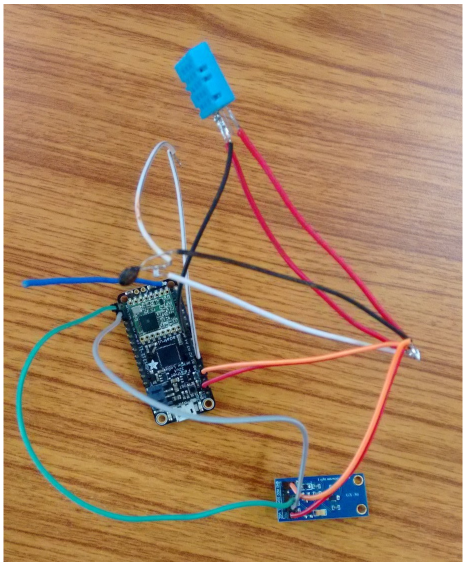

Fig. 7. LoRa Setup Prototype

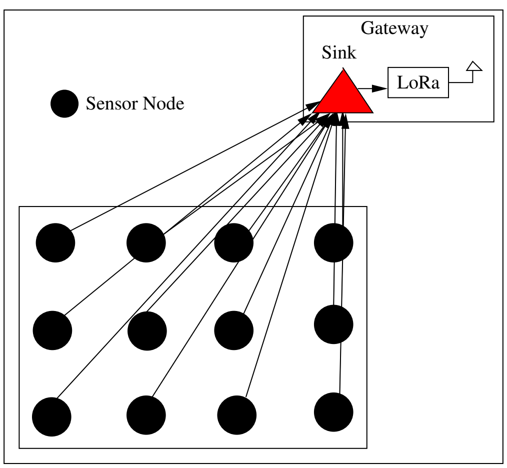

Fig. 8. Agricultural Monitoring Network Architecture II

III. Evaluation of the Proposed IoT Network

We have evaluated our proposed low-power, low-cost IoT Network by measuring power consumption and cost. In the following section, we have compared the power consumption and cost of our proposed network with the already proposed networks in the literature.

A. Power analysis

For evaluating power consumption we have considered current consumption of different sensor nodes [19]-[25]. The current consumption of IITH mote (sensor node) and different sensor nodes is measured at different modes like sleep mode I_{sleep}, idle mode I_{idle}, transmit mode $I_{transmission}$, and receive mode $I_{receive}$.

Our sensor node based on IITH mote consumes less power compared to the sensor node proposed in [14]. It consumes only $180uA$ (I_{sleep}) current in sleep mode, $11.58mA$ I_{idle} in idle mode, $26.58mA$ $I_{transmission}$ in transmit mode and $25.58mA$ $I_{receive}$ in receive mode, refer table I. From the table it is clear that the proposed network consumes less power compared to that of beforehand proposed networks.

1) Enhanced battery life: The solar panel is used to power and charge the battery of the sensor node, and it enhances the lifetime of the network by harvesting ambient energy. We have optimized the sleep time of sensor node to save power and prolong the lifetime of the network. In general, there will be no rapid changes in agriculture parameters, hence the sensor nodes are sending the data every hour which saves power thereby enhancing the lifetime of the node in the field. The sensor node stays a maximum of 18 sec, 373 msec and 20 msec in idle, receive and transmit modes respectively. If sink acknowledges the data in the first transmission, then the end node can go to sleep earlier than the above mentioned time(s). We are using a $2000mAh$ lithium ion battery and considering a loss of 30% charge we have a realistic power budget of $1400mAh$. Using ContikiMAC RDC at 128 Hz channel check rate and the sampling rate mentioned above we calculated a node lifetime of around 5835 hours or 243 days, if used without solar power. Comparatively the M3SS mote and ECO mote, [21], will only work for 7 hours or 0.291 days and 697.58 hours or 29.07 days respectively, assuming same operating conditions and battery capacity. In table II, we have listed the probable lifetime of different sensor nodes (without sensors) powered by a 2000 mAh battery with an effective capacity of 1400 mAh as considered above. We are improving the life time of the network on an average by 83% at a lower cost. Refer table III for the power consumption of the various sensors used.

TABLE I

Power analysis of proposed low power IoT network			
Sensor node	I_{sleep}	I_{active}	$I_{transmission}$
IITH mote	180 μA	11.58 mA	26.58 mA
M3SS	200 mA	500 mA	600 mA
DZ50 SPS	3.3 μA	3.25 mA	26.5 mA
MicaZ SPS	170 μA	4.35 mA	18.5 mA
TelosB PIS	13 μA	1.72 mA	19.12 mA
ECO	2 mA	3 mA	22 mA
TinyNode	5 μA	3 mA	62 mA
Waspmote	62 μA	9 mA	20 mA

B. Cost analysis

The cost of the sensor and sensor node should be as low as possible for agriculture monitoring application. We have compared the cost of our sensor node with commercially available sensor nodes. The cost of the sensor node used

TABLE II

Battery life analysis of proposed low power IoT network		
Sensor node	*Hours*	*Days*
IITH mote	5835.52	243.15
M3SS	6.95	0.29
DZ50 SPS	63073.05	2628.04
MicaZ SPS	7262.24	302.59
TelosB PIS	59718.33	2488.26
ECO	697.57	29.07
TinyNode	53599.82	2233.33
Waspmote	12865.84	536.08

TABLE III

Power Analysis of Sensors Used			
Sensor	Volts (V)	Current(mA)	Power (mW)
DHT11	3.3	1.5	4.95
BH1750	3.3	0.2	0.66
Thermistor	1.2	0.1	0.12
Soil Moisture	3.3	1.4	4.62
Solar Radiation	3.3	1	3.3
Carbon Dioxide	5	60	300

in the proposed IoT network is $\$63$. From the table IV, it can be observed that the cost of our mote is comparable to commercially available platforms [19]-[23] and already proposed sensor node [14]. Comparing with the waspmote [23] and [24], the cost of our sensor node is low. From the table, we can conclude that the proposed IoT network can be deployed at an affordable price for smart agriculture.

TABLE IV

Cost analysis of proposed low power IoT network			
Sensor node	Processor unit	Radio unit	Cost
IITH mote	ATmega1281	AT86RF230	63$
M3SS	Intel SoC X1000	CC2420/WiFi/BT2.0	53$
SADmote	MSP430F1611	MRF24J40	100$
Tmote Sky	MSP430F1611	CC2420	100$
Waspmote	Atmega 1281	Xbee	200$
ECO	8051 controller	nRF24E1	57$
TinyNode	TI MSP430	SEMTECHCHSX1211	180$
Waspmote	ATmega1281	CC2420/Wi-Fi/BT4.0	147$

IV. Conclusion

We have proposed and implemented a low-power IoT network for smart agriculture. We have used our in-house built IITH mote as a sink and sensor node. We have designed a low-cost soil moisture sensor. We have used soil moisture and soil temperature to measure soil parameter. The humidity, light intensity, ambient temperature sensors are used for measuring other environmental parameters. The proposed architecture is evaluated based on power consumption and cost. The evaluation results conclude that our network has on an average 83% prolonged lifetime at lower cost compared to previously proposed sensor motes due to the optimized sleep time of sensor nodes and less power consumption by sensor nodes. The solar-powered feature of sensor nodes extends the lifetime of the network. We have proposed a LoRa based gateway to solve power line problem and to cover large area in agriculture field. In future, plan to use drone based remote monitoring for precision agriculture.

V. Acknowledgment

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