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The Experience of Using Particle Mesh for Large IoT Projects with Power and Range Management

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Abstract: *There is no doubt that the Internet of things (IoT) becomes an urgent and necessary need for the human beings, as it is part of our daily lives. The IoT networks and nodes are often communicate with each other, or store data for processing and making decisions, or publish it to the cloud; this needs the internet service to be always available. Achieving this in urban areas is simple, as the internet nowadays is easily available. However, in the rural areas the availability of the internet is limited to certain places. In times when the internet service is not available, one alternative is the mesh network. In this research, Particle Mesh network is presented with energy budget calculations for large IoT projects such as smart irrigation. Given the fact that these nodes are battery or solar powered, we will calculate the power needed to operate the various parts of the network.*

Keyword: *IoT; smart irrigation; Particle Mesh; power consumption.*

1. INTRODUCTION

Smart Internet of Things (IoT) projects is the goal of designers in last few years; Because of the properties provided by these projects, such as accuracy and human comfort, in addition to save money and natural resources, etc. Smart projects vary in size and in the targeted environment, as there are stand-alone projects that consist of one control unit (one node), placed in a specific place, such as a system to control the garage gate of a house, or coffee machine control system. These systems and many others do not need to be interconnected. Each system is self-contained to perform a certain function. On the other hand, there are large smart (IoT) projects, which target sprawling lands and need to be interconnected, such as agricultural or irrigation projects (smart agriculture), or industrial projects such as (smart factories). These projects and others require many control units (many nodes), which have to communicate with each other to exchange information, making decisions. One of these big projects is targeted in our research.

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Nowadays, most smart projects cannot work perfectly without Internet connection in order to fully perform their functions. Providing Internet to a large number of nodes represents a major challenge, especially in rural areas, where there are many irrigation and agricultural projects, we also know one of the most important benefits of smart projects, is to keep the user in direct contact with his project and make him know the exact details in real time. These projects sometimes require sending information to the cloud, perhaps for storage or even processing, this is of course needs Internet.

Since we are talking about nodes for large projects in remote lands, one of the most important things that have to be taken into consideration is the energy that this node consumes, in addition to the range which these nodes can communicate with each other.

For the sake of all of the above, this research came to provide a brief summary of the possible solutions that meet the needs of those projects, in addition to convey a personal experience to one of the solutions, which is the Particle Mesh Network for large smart irrigation project.

Section 2 gives the Literature Review, where the proposed design methodology is explained. In section 3 problem Statement is discussed. The conclusions are given in section 4. Finally, section 5 suggests the future work.

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2. LITRETURE REVIEW

Iraq has many irrigation projects on the rivers and tributaries that pass through it. These projects irrigate large areas of agricultural land used in the production of many crops such as wheat, barley, rice, dates, citrus and many other vegetables and fruits, these constitute an important and large part of the country's economy, especially after the degradation of oil prices and the emergence of the urgent need to find alternatives to support the economy of the country. Most of these projects are permanent irrigation projects that they remain operational at all times of the year but they lack the use of technology such as Internet of Things (IoT) to achieve the optimum benefit of water and rain for irrigation.

Previously we designed a smart irrigation system with weather forecasting and graphical user interface GUI as shown in Figure 1, which one of its goals was monitoring and preventing Ceratophyllum plant from growing in irrigation channels [1].

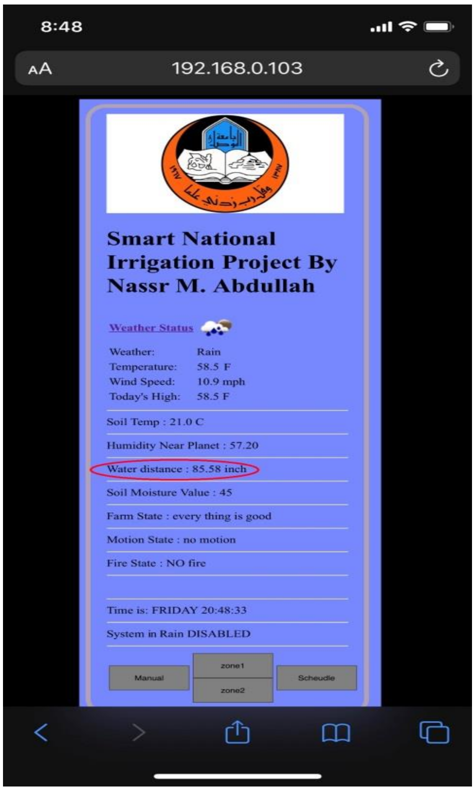

Figure 1 GUI for Smart Irrigation Project [1]

In order to implement the project in real-life, one of the greatest irrigation projects in Iraq (North Island Irrigation Project) has been chosen. We faced a problem of the very vast lands, which lack the presence of the internet except in populated areas, so we had to find a solution to this problem to provide the necessary internet for our project to work, and indeed we found some solutions such as:

Using the cellular data network, it is a great solution but very expensive. It adds a huge extra cost to the project [2].

Using Wireless Mesh Networks (WMNs), to provide network connectivity for both mesh and clients and extend the network coverage for internet [3], but according to [4] this solution needs devices such as routers as shown in Figure 2. This method is not efficient because routers need extra power as they do not sleep, also they cost money. Although it provides high throughput, this is an excellent solution for applications that need high bandwidth. However, this feature is not needed in most IoT projects because there is no high data rate or high traffic in the network.

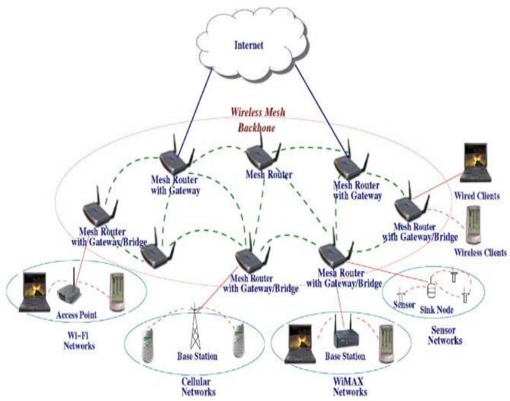

Figure 2 WMNs Infrastructure[4]

Finally, in October 2018, Particle launched Particle Mesh, which is a product that was previously announced in August of the same year, to provide internet but not the internet we used to, it's the internet for sensors and IoT devices. Particle Mesh consists of three parts of the third-generation nodes, namely; Argon, Boron, and Xenon, unfortunately it is not backward compatible with the previous Particle products, this option over-performs the previous ones as it is cost effective, and it looks like it meets our goals.

Argon can be used as a gateway between any Wifi network and local Particle Mesh network. In order to configure the Argon node, it must be switched on and Particle application should be used on a mobile phone. The node will be in the listening mode 'blinking blue', then scan of the data matrix sticker on the Argon node, after that you will be asked whether to create a new mesh network or join an existing one. You must choose an available Wifi network, then enter its password and give a mesh name to create a Wifi mesh network or just simply join an existing one. Finally, you will be asked to add a new device to your mesh and if you choose yes, then all you have to do is to scan the data matrix sticker on your new device, which must be in the listening mode 'blinking blue'.

Boron is a powerful Long-Term Evolution (LTE) cellular board which represents a gateway between the internet and the Particle Mesh. Xenon is the end point of any mesh network; it can be used largely as its price is low.

All the previous boards can be communicated via Bluetooth. They include Nordic nRF52840 with a built-in battery charging circuit.

The Nordic nRF52840 according to [5] is a multi-protocol System on Chip SoC supporting Bluetooth 5, 802.15.4, ANT, 2.4 GHz proprietary, with a 32-bit ARM® Cortex™-M4F CPU, 1MB flash, and 256kB RAM on chip. The nRF52840 is based on the OpenThread Protocol stack makes a great solution for battery powered Thread devices.

Traditional IoT devices that use Wi-Fi and cellular connectivity depend on the cloud to transmit between devices as in [6], it is called *CloudIoT* paradigm which makes the sensors alive as they join the network, of course, it not only allows us to remotely access these sensors, but also allows them to communicate with each other remotely. Figure 3 shows the Particle Mesh boards.

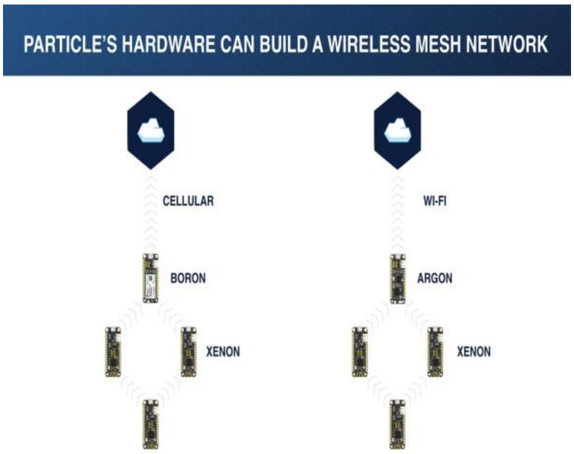

Figure 3 Particle Mesh Boards[7]

In research [8] the authors summarize all the benefits and challenges from using the cloud in IoT by affordable, secure, efficient growth, elastic and scalable, avoiding downtime or delay, disaster recovery, environmental compatibility, incentives to new experiments.

However, Particle Mesh connects to the cloud through building gateways. Other devices can join through creating a wireless grid. Every IoT device in a Particle Mesh can be provided by a local network for connection with the other devices.

The authors in [7] mention the difference between the mesh network and wireless sensor network, where in Wireless Mesh Networks, the nodes are considered as part of the infrastructure, and they are responsible of the routing task. Mesh nodes has limited or no mobility. When compared to traditional ad hoc network nodes, mesh nodes has better processing, memory and bandwidth capacities. In addition, they have less power consumption restrictions. However, sensor devices establish a network called Wireless Sensor Networks (WSN), these devices usually are small size, low cost, limited power supply, low processing and memory capabilities, and also low link bandwidths compared to mesh networks.

Since that sensor networks nodes are battery operated, reducing the energy consumption of that nodes is very important so we will discuss different Particle Mesh operating modes and measure its power consumption.

In [9], the author summed up the total power consumed by the node using the following Equation:

$$E(t) = \begin{cases} E^{sens}(t) + E^{Tx}(t) + E^{Rx}(t) + \\ E^{AckTx}(t) + E^{AckRx}(t) + E^{Idle}(t) \end{cases} \quad (1)$$

where:

- $E(t)$: Complete energy consumption in time (t).
- $E^{sens}(t)$: Sensing and processing energy in time(t)
- $E^{Tx}(t)$: Transmitting energy in time (t)
- $E^{Rx}(t)$: Receiving energy in time (t).
- $E^{AckTx}(t)$: Acknowledgment of successful frame transmitting in time(t).
- $E^{AckRx}(t)$: Acknowledgment of successful frame receiving in time(t).
- $E^{Idle}(t)$: Idle time energy consumption.

Note: We do not need $E^{AckTx}(t)$and $E^{AckRx}(t)$ because Particle Mesh uses User Datagram Protocol (UDP). The state of idle will be replaced with sleep mode, which is recommended by researchers to as an effective way to reduce the power consumption.
The author in [10] mentioned all the parts that consume power in any wireless sensor network and modeled it as:

- Processor Energy Model (PEM)
  - *Processor Operation State*
  - *Processor Energy Function*
- Transceiver Energy Model (TEM)
  - *Transceiver Operation State*
  - *Transceiver Energy Function*
- Sensor Energy Model (SEM)
- Nole Energy Model (NEM)

2.1 OpenThread Protocol

OpenThread is an open-source implementation of Thread® released by Google to make the networking technology which is used in Google Nest products largely available to developers and users, in order to accelerate the development of products for the connected home, factories and any other commercial buildings or industrial projects.

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With a small memory footprint and a narrow platform abstraction layer, OpenThread is highly portable. It supports both network co-processor (NCP) designs and (SoC).

According to [11] Thread can be defined as a wireless networking protocol based on existing open standards such as 6LoWPAN, IPv6, and IEEE 802.15.4, and is designed for low data rate, low power, and short range communications applications.

Thread's primary features mentioned in [12] included:

- *Simplicity:* Simple installation, upgrade, start up, and operation.
- Security: All devices and communications in a Thread network are authenticated and encrypted.
- *Efficiency:* Low-powered Thread devices can sleep and operate on battery for years.
- *Reliability:* Self-healing mesh networking, no single point of failure, and use spread-spectrum techniques to supply immunity to interference.
- *Scalability:* Thread networks can scale up easily to hundreds or thousands of devices.

3. PROPOSED DESIGN METHODOLOGY

Smart irrigation system has been used in which various kinds of sensors are used such as; soil moisture, temperature, and humidity, smoke, ultrasonic and motion sensors. While working on a project, we needed to connect all these sensors to Argon, Boron or Xenon and construct a Particle Mesh network, in that project, the sensed values from the end point will be sent to the gateway through routers or repeaters and then to the particle cloud and Blynk. At the gateway side, all the sensed data will be displayed on a local host site then processed, and according to the weather forecasting sites (rain and wind state for the next 24 hours) the gateway decides whether to start the scheduled irrigation programs for that zone or to stop it and send the decision through the mesh to the specific zone (end point node). If the sensed values of soil moisture sensor is below threshold (we will take one reading per day only), the sprinkler will be automatically switched on regardless of the gateway decision. There are two irrigation programs that can be enabled (one of them or both) according to the maximum temperature of that day from weather forecasting site. By using these systems agricultural engineer can access the details about the condition of the field anywhere at any time by Blynk and he can program the system through Wifi remotely using the mesh without the need to physically reach the far nodes.

Given the mention of the distance, and through our practical experience with the Particle Xenon, (We installed the gateway at fixed point and then moved the final node until the connection was lost then we measured the distance), it is able to provide a connection with the Argon gateway or repeaters connected to its original antenna (Figure 4) equipped with it for about 100 meters away (70 meters without any losses in data 100% of successful ping).

Figure 4 Particle Flexible Wifi/Bluetooth Antenna

Table I Shows the technical specifications of Particle Flexible Antenna.

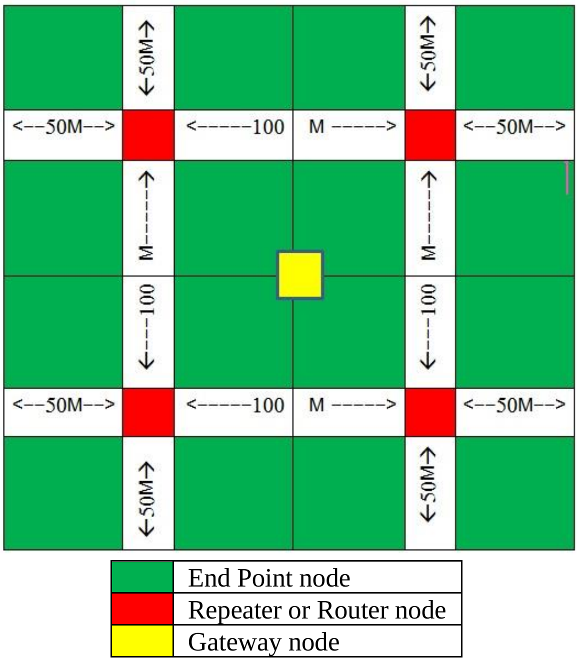

Figure 5 How to Distribute Particle Mesh Nodes to Fields in Our Proposed System

Since the authors in [13] prove that the antenna height ,flat land, line of sight are important and affect Wifi signal distance, we must mention that the reading is taken in about (50 cm) above flat earth and not in completely line of sight, where there were some trees in the field. This serves our need because the target lands in our project are divided into regions, each of (50m × 50m). Nodes are installed in each region; one repeater Argon (serve 4 regions) as shown in Figure 5, and one end point Xenon. Figure 6 shows the meaning of these terms and its places in the mesh network.

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TABLE I PARTICLE FLEXIBLE ANTENNA TECHNICAL SPICIFICATIONS

Operating Range	2400~2500MHz / 4900~5900MHz
Efficiency	90%
Bandwidth	(VSWR: 2.0 max.) 140 MHz / SWR < 2.0
Polarization	Linear
Radiation	Omni directional
Antenna Gain	4DBi
Impedance	50 ohm
Cable	100mm / 4" long
Antenna	40mm x 8mm / 1.6" x 0.3"
Weight	0.7g

According to [14], long distance communication should be avoided to increase the network life time, load-balancing and multi-hop communication could increase the network lifetime. There are three categories of energy efficient routing protocols in sensor network:

- *Flat.*
- *Hierarchical.*
- *Location based-routing.*

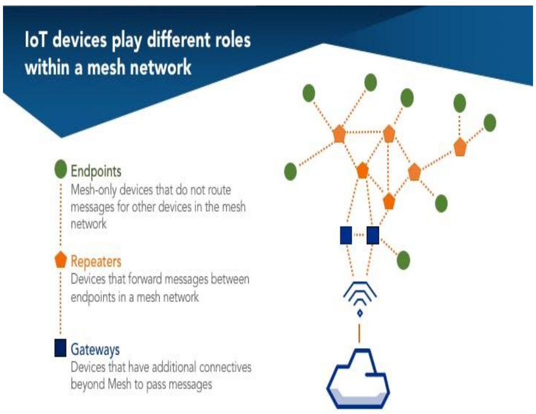

Figure 6 Particle Mesh Network Components [7]

The author concluded that the most efficient and more suitable protocol for WSN applications is the hierarchical because they have the ability to limit the use of energy resources. Fortunately, the protocol used by Particle Mesh namely Open Thread Protocol is very close to the Hierarchical Protocol. Figure 7 shows the TEEN Hierarchical Protocol that is used in WSN, and according to [15] Open Thread Protocol makes use of IPV6 which is the IoT future and in this protocol the end node selects only one gateway or repeater as its parent and always try to stay connected with it. It sends/receives all packets to/from the parent which can improve the battery life time.

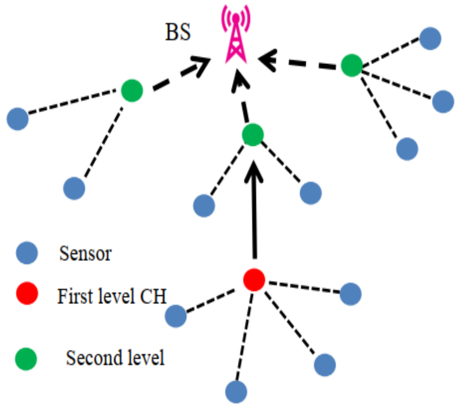

Figure 7 TEEN Hierarchical Architecture [14]

3.1 Problem Statement

To provide a brief view of the Particle Mesh network to be used in a smart irrigation project or any other large IoT projects to reach the optimal performance which is reducing the power consumption by the end point nodes to achieve a maximum battery life.

3.2 Requirements and Circuit Diagram

In order to calculate the power consumption by the Xenon end point or by Argon we need the following tools:

1- Power supply to generate 3.3v.
2- Multimeter.
3- Particle Xenon or Argon node.
4- Web IDL to program the node.
5- USB cable.
6- Some connection wires.

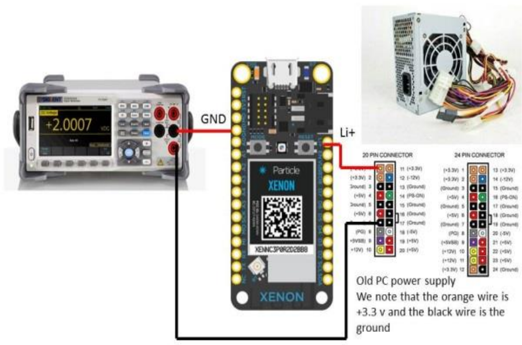

Figure 8 Circuit Diagram for Power Consumption Calculation

Then connect the circuit as shown in Figure 8. Where any Orange cable from the power supply can be connected to the LI+ pin from the Xenon to give it +3.3v necessary to run it, then the Ground of the Xenon GND pin must be connected to the ground of the Multimeter, finally the mA socket from the multimeter must be connected to any black wire from the power supply (GND).

3.3 Current Consumption Measurements

After connecting the circuit as shown in Figure 8, some codes are written using C++ programming language in order to go through the various operating modes of the node, In the first code the node is do nothing, which means idle state and no mesh no cloud, and upload it to Xenon then we take the current measurement which is about (4.8 mA).

After that we turn mesh on by uploading another code but still not connected, and then we connect it and make a mesh publish command, the reading is as follows (5.5 mA and 9.6 mA respectively).

Then we upload a code that publishes an event to the cloud every 20 seconds and records the average current for 1 minute and the reading refers to (13.5 mA).

Then we upload a code to the Argon that does a mesh publish each 20 seconds, also does a mesh subscribe in the Xenon and takes the average current reading for 1 minute and it is about (13 mA).

Recently Particle added Sleep mode and Deep Sleep mode to mesh devices so two codes are written, one with Sleep mode, the current was about (0.06 mA) and the other in Deep Sleep mode the current was (0.04 mA), Table II abstracts the current reading in various operating modes.

TABLE II XENON POWER CONSUMPTION IN DIFFERENT OPERATION MODES

Node State	Current mA/h
Xenon in idle state without mesh	4.8
Xenon as a member in Particle mesh	5.5
Xenon when sending and receiving information in mesh	9.6
Xenon when sending information to cloud	13.5
Xenon when receiving information from cloud	13
Xenon in the Sleep mode	0.06
Xenon in the Deep Sleep mode	0.04

Note that in Deep Sleep mode you will need an external interrupt to awake the Xenon. Finally, we connect different sensors to Xenon and take the current measurement separately, one sensor at a time. The results are shown in Table III. Note that these numbers are after subtracting the current value that the Xenon node consumes. We recommend entering the sleep mode and the wake mode only to take the sensor readings. According to the application we are working on, we can decide the sleep / wake intervals. In non-real time application, you can increase sleep periods. As for the period of waking up, most sensors' data sheets recommend that the period can be one minute to take correct readings.

As for sensors and devices that consume large energy such as smoke sensor, we prefer to use another power source other than the small battery such as a power bank with the possibility of solar charging.

TABLE III DIFFERENT SENSORS AND DEVICES POWER CONSUMPTION

Component	Current in mA/h
Soil moisture sensor during work	30
DHT22	2.5
PIR when there are movement	65
Ultrasonic sensor	15
Flame sensor	15
Smoke sensor (3.3-5)v	275-180
GPS	40
uCAMIII	90

If we take the largest amount of energy consumed by Xenon end point, which is 13.5 mA, and add to it the amount of energy consumes by the rest of the node from sensors and devices except the smoke sensor which is about 271mAh, and assuming that the node takes one reading per hour and send / receive data to and from the gateway node, then it returns To sleep mode that consumes 0.6 mAh, If we put all of that information into a battery life calculation site such the site in [16], the result indicates that the battery with a capacity of 1800 mA remains for about one year and three months as shown in Figure 9.

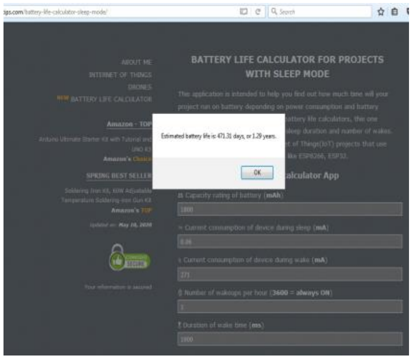

Figure 9 Estimated Battery Life [16]

4. CONCLUSION

The network established in Particle Mesh was able to withstand the traffic generated by the irrigation system and the exchange of information and instructions between the gateway and the end nodes in real-time. Of course, the exchange of information between the Particle Mesh Network and the Internet, whether in terms of bringing weather information or sending / receiving data to/from the cloud or to the blink application took place very smoothly through the gateway node .It is reliable, easy to install and extend, low in power and cost, and finally there is no one point of failure.

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Each group of final nodes related to one router node (repeater) determined during the installation process, this matter remains constant with no change, this reduces a lot of energy consumed in the search for the most appropriate router node for communication and information exchange, so the final node once it wake up from sleep quickly connects to its parent node and sends or receives information then quickly return to sleep mode. All of the final connected nodes to the router node will be lost from the network, if the router node dies (out of power). Therefore, the directed node has to be connected to a permanent source of energy like the solar cell.

Perhaps one of the most important achievements is the continuity of the system's work when the internet is interrupted, because the system remained able to exchange messages within the mesh network and make irrigation decisions correctly, but of course without publishing the data to the cloud.

Also, the power consumption has been significantly reduced when using the Sleep mode, as the battery, of 1800 mA capacity, has been able to withstand for about a year, while without Sleep mode it lasts for about 15 days. The range coverage of the nodes can be extended simply by using any compatible bigger antenna.

5. FUTURE WORKS

This work can be improved by using some types of intelligent sensors that generate a signal when violating a certain threshold (especially the smoke sensors) and linking it to Xenon for the purpose of being able to take advantage of the Deep Sleep mode and reduce the number of awakenings. Thereby reducing the used power, and maintaining the battery for a longer life.

Using other types of larger antennas other than the antenna already supplied with Particle products, this would increase nodes coverage and thus enable us to create a larger network and may be in different topologies to reduce money spent, and energy consumed.

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Authors Biography

Nassr Myasar Abdullah received the B.Sc. degree in Computer Engineering from Mosul University, Mosul, Iraq, in 2009. He is currently working toward the M.Sc. degree in Computer Engineering at the College of Engineering in Mosul University. He has been employed at the Ministry of Water Resources in Iraq since 2010 till now; He is interested in doing research in Internet of Things and smart solution especially in Irrigation and Agriculture field.

Dr. Rabee Hagem is currently assistance professor in University of Mosul which he received the B.Sc. and Msc. in 1998 and 2001 respectively in Electronic and Communication Engineering from it. His Ph.D. degree was from Griffith University / Brisbane / Queensland / Australia in underwater optical wireless communication for real time swimmers feedback in 2014. His current research interests include IoT for smart cities, optical wireless communication, smart sensors designing and implementation, embedded systems for athletes monitoring, and sport data analysis.

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