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An IoT-based Smart Orchard Monitoring System by Employing Wireless Sensor Networks

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Abstract*: In this study, an IoT-based smart orchard monitoring is proposed to gather and transmit environment data from a sensor node to a central node for necessary and relevant actuation in order to have good produce at the soonest amount of time. Wireless sensor motes are deployed based on a simple linear pattern across a square farm and only require the minimum set of specifications to monitor its surrounding. On the other hand, the central nodes will require more processing power, memory and power requirements. Sensor and central nodes communicate in a line-of-sight method and follows a deterministic routing table based on the sensor node's four neighbors. Throughput, latency, and energy consumption results are presented to allow designers and farmers consideration and freedom on how to select which routing protocol can be used to achieve their target objectives.

***Keywords* : Internet of Things, Smart Orchard Monitoring, Route Formation and Maintenance.**

I. INTRODUCTION

Advances in sensing devices, computational capabilities, memory storage, and communications equipment have changed the way how ordinary and repetitive tasks are performed and accomplished. One of the major paradigms most commonly used today is the Internet of Things (IoT) concept. The IoT concept revolves on the presence of communicating and cooperating things to achieve a common goal [1]. IoT applications have been incorporated in information dissemination in vehicular network applications [2], industrial systems [3], household monitoring [4], surveillance [5], and many more routine applications.

Another possible application is the integration of IoT in agriculture [6]. Agricultural applications involve the repetitive and periodic observation and surveillance of the field under consideration to allow fruit-bearing trees and vegetable plantation to grow and produce good and healthy fruits and harvests at the soonest possible time. Also, a huge amount of useful environment data is available in every plantation, such as soil moisture and nutrients, temperature, and humidity to name a few. Analyzing these parameters can aid farmers, engineers, and nature experts to design systems and processes that will supply farms with adequate assistance and appropriate actuations towards attaining goods production.

An IoT-based smart agriculture study was presented in [7]. It employed a robot able to perform agricultural tasks such as weeding, spraying, etc. Also, smart irrigation and warehouse management were also studied. In [8], cloud computing was integrated with IoT to modernize the data collection of agricultural data. The same cloud computing technology was also applied in [9] to improve food and farm technology. The Green IoT Agriculture and Healthcare Applications (GAHA) architecture was proposed in [10]. Their model was a collaboration between sensors and the cloud to reduce energy consumption in agriculture and health care services.

In this work, IoT is employed for gathering relevant farming information to activate the necessary actuators. This work focuses on the study of protocols that allow transfer of important information from a sensor node to a central node. Different from the previous works stated above, this work provides system designers results where they can choose from in order to achieve their agricultural goal. This research work addresses the proposal of a simple and inexpensive sensor and central nodes setup. Such scenario dictates a deterministic routing table for each sensor node when it needs to transfer data. Two default and basic MAC protocols, T-MAC and B-MAC, are evaluated in the design.

This paper is organized as follows: Section II presents the setup and assumptions of the orchard to be monitored. The routing algorithm and maintenance discussions are also presented in this section. Section III analyzes the proposed system by showing the throughput, latency, and energy consumption. Finally, Section IV concludes the research study and provides some research endeavors in the future.

II. IoT-BASED SMART ORCHARD MONITORING

In this section, we present how to achieve an IoT-based smart orchard monitoring by employing wireless sensor networks. We also discuss how does each wireless sensor node communicate in the field by analyzing two know MAC protocols.

A. Orchard Layout

The vegetable or fruit orchard to be monitored is a square lot of size 4.5 km x 4.5 km or 20.25 km2, as depicted in Fig. 1. Red x's represent the sensor nodes while black x's are used to denote the plant/fruit/seed placements (plant for short). The blue circles, located at the center of each orchard section, are the central nodes.

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The environment is assumed to be static in nature, i.e., once the seeds/seedlings are planted, there will be less to no interactions from the farmers and the surroundings. Interactions will only be allowed for special cases such as natural disasters or harvest time. Fertilization and other treatments are automatically done through installed sprinklers. Each wireless sensor node is equipped to gather these important pieces of farm information: (1) soil nutrients, (2) amount of sunlight, (3) soil moisture, (4) temperature and (5) relative humidity. Also, all orchard nodes rely on solar energy to function and recharge its backup batteries.

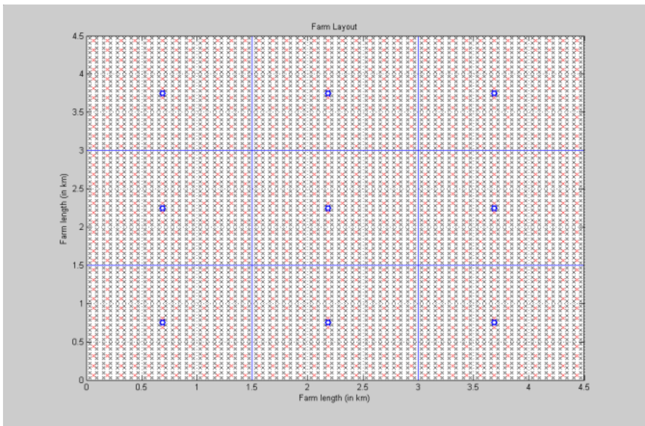

Fig. 1 Node and Plant Placements in an Orchard

There are two types of wireless sensor nodes in the smart orchard monitoring, namely, (1) sensor nodes for capturing environment information and (2) central nodes used to store the important pieces of information, process the received data and activate the important actuators. The deployment of wireless sensor nodes follows the placement seen in [11, 12]. Each sensor node is placed within range of its adjacent sensor node along its horizontal and vertical axes. Adjacent sensor nodes along its diagonal are out of coverage range. The total number of nodes to be used in a single row is:

$$\#of\ \text{sensor nodes} = \frac{4500\text{m}}{125\text{m}} = 36\,nodes \qquad (1)$$

assuming the sensor node's transmission range is 125 m. Therefore, the total number of sensor nodes to be used in the farm setup that we have is: $36x36 = 1296\ \text{sensor nodes}$. The sensor nodes are placed in an array that is spaced 125m apart. The whole farm is divided into nine equal parts, i.e., 1.5 km x 1.5 km each section to provide various possibilities of vegetation and fruits. Such partition will also allow different monitoring conditions to prevail. Central nodes are placed at almost at the centers of each of the nine divisions. This is used to better facilitate each area of the farm for better production and data logging. All coordinate locations of each node are known and identified by a 16-bit ID (for easy scalability for future purposes). Between boundaries of adjacent divisions, nodes are separated by more than 125m apart to ensure that nodes know their cluster and the data will be transmitted to the correct central node. A closer look at one of the nine divisions of the farm is shown in Fig. 2. As shown, sensor and central nodes have a line of sight communication.

Sensor and central nodes need to communicate in order to provide the best orchard results in terms of food output and time of harvest. The transmission of data from one node to another until it reaches the central node is done as shown in the Fig. 3. A node can only transfer data to a nearby node if it is directly located to the right, left, top or bottom of the source node.

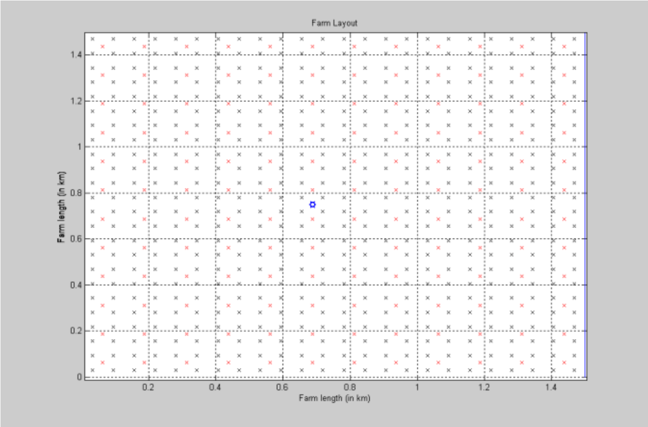

Fig. 2 One of the nine orchard divisions: a closer look at the node and plant placements.

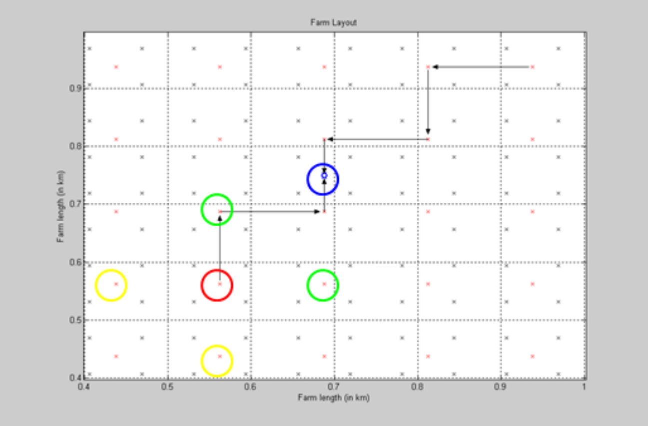

Fig. 3 Conditions for Data Transmission (Allowed Traffic Patterns)

Central nodes are tasked to generate necessary and appropriate actuator actions after receiving environment information from the sensor node. We implement such scheme such that there is a centralized observation and control for the orchard. The actuators used are sprinklers for daily watering and fertilizing and movable roof shade and/or light shade and lights for lighting control.

B. Routing Algorithm and Maintenance

Each of the nine divisions form static clusters, therefore, allowing each sensor node to correctly define its neighbors. Each sensor node's routing table is only composed of the four (4) nodes nearest to it. Sensor nodes nearest to the central nodes are termed "direct-link nodes" while the other nodes are the "indirect-link nodes".

The "direct-link nodes" are the gateways to the central node and flooding is expected to occur especially in times where all sensor nodes transmit their data.

To be able to form a route from the sensor node to the central node, the sensor node contacts the direct-link nodes and tries to establish connection. If one or two of the two direct-link nodes is not busy, then, a route is formed. We note that the first choice will always be the direct-link nodes. The indirect link nodes will only be used in case the direct-link nodes are busy or sleeping.

Fig. 3 depicts the standard routes taken from a sensor to the central node. Each sensor node located not near the edge only stores four neighboring addresses. Sensor nodes found at the edges have two-three stored neighboring addresses. Therefore, routes are only updated when a defective node(s) is(are) detected. For example, from Fig. 3, the origin of data is highlighted by a red circle while the node highlighted by a blue circle is the destination (central node). The nearest nodes are highlighted by green circles. We note that these two nodes are located to the right or top of the source node (direct-link nodes). Once these nodes failed, then a new route is formed. The new routes would now include the nodes located to the left and below of the source nodes (yellow circles, noted as indirect-link nodes), then the shortest path would now continue until the central node is reached. The algorithm designed for this process would determine whether a defective node is nearby or not, then, create a new route from the remaining nodes located at the routing table satisfying the shortest path principle. Given that the two nearest nodes are working properly, the algorithm checks which one is free or not. If both nodes are busy, then it switches to the other two nearest nodes, determine its state and create a new route if possible. The algorithm for the route formation/maintenance is given by Algorithm 1.

Data packets are forwarded to nodes that are the nearest to the central node and is not busy. Each packet contains the relevant environment information and its source address. Forwarding occurs only when the destination node is contained in the routing table.

III. SIMULATION RESULTS AND DISCUSSION

In this section, simulation results and discussions are shown to support the feasibility of the smart orchard monitoring via IoT-based implementation of wireless sensor networks.

A. Evaluation of the IoT-based Orchard Monitoring System

The setup is analyzed and evaluated according to the following performance metrics, (1) throughput, (2) latency, and (3) power consumption. Two well-known and default protocols are evaluated, namely, (1) B-MAC [13, 14] and (2) T-MAC [15, 16]. B-MAC (Berkeley-MAC) targets low power operation by using small codes to implement effective collision avoidance that is efficient at both low and data rate. It is scalable to a large number of nodes and tolerant to network changes [17]. On the other hand, T-MAC (Time-out) transmits varying-length messages in bursts and then sleeps afterwards. This is done to reduce idle listening [18].

Fig. 4 illustrates the throughput percentages between the two said protocols as the packet rate is increased. As expected, when the packet rate increases, percent throughput decreases due to collision. It can be observed that B-MAC is much better than T-MAC at higher data rate. T-MAC suffers too much losses when the packet rate is more than five packets/sec. For the orchard monitoring system, if the environment data, such as weather, are not fast-changing, T-MAC can still be used.

Algorithm 1: Route Formation and Maintenance

```
route_busy = 0;
route_clear = 0;
while (no route(s) is/are established)
    for neighbors = 1:4,
        for direct-link_node = 1:2,
            if direct-link_node is busy
                route_busy++
            else
                route_clear++
                establilshed route[i] = node's location
            end if
        end for
        if route_busy > route_clear
            route_busy = 0;
            route_clear = 0;
            for indirect-link_node = 1:2,
                if indirect-link_node is busy
                    route_busy++;
                else
                    route_clear++;
                    established route[i] = node's location
                end if
            end for
        end if
    end for
end while
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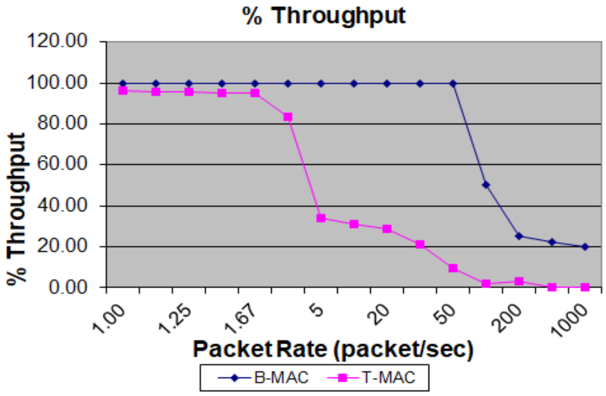

Fig. 1 Throughput comparison between B-MAC and T-MAC protocols

In Fig. 2, the latencies for both protocols are shown. Latency can also represent the transmission delay of a given network. Higher packet rate results to zero latency since all data are transmitted at once. B-MAC presents a more predictable response when compared to T-MAC.

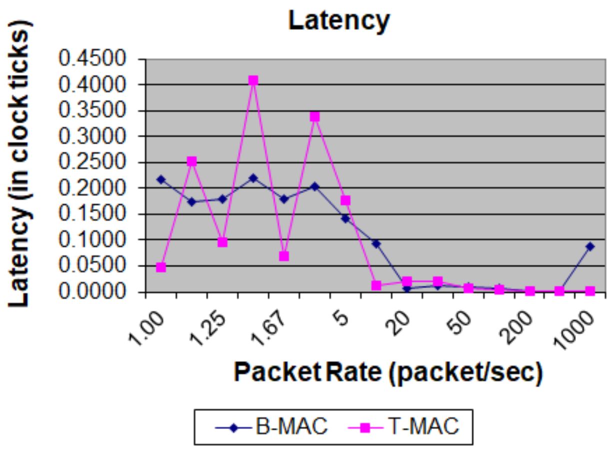

Fig. 2 Latency comparison between B-MAC and T-MAC protocols

In this work, there is no power control scheme implemented to monitor how long does the backup energy storage last on the average, before being recharged. Fig. 3 shows how much energy is consumed during the transmission of data for varying packet rate. There is not much trend we can see between these two MAC protocols.

Both throughput and latency are dependent on the rate at which the source is sending packets. Fig. 4 illustrates how much collision occurs when the sending sensor node is increasing its packet rate. At 100 packets/sec, there is a huge amount of collisions experienced by the network. This will reduce to a lower throughput and a higher latency. As the number of collisions increases, the lesser number of messages being received by the destination node (either another sensor node or the central node). At a packet rate greater than 5 packets/sec, T-MAC does not give a very good throughput, and this contributes to a multi-hop system packet reception degradation.

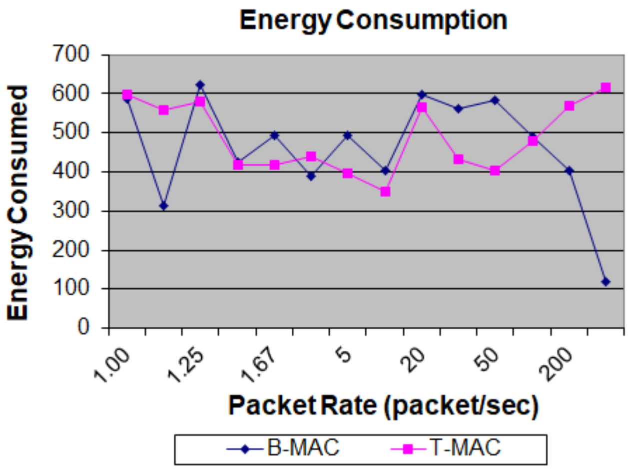

Fig. 3 Power Consumption (in mWh) comparison between B-MAC and T-MAC protocols

From a system designer point of view, these performance metrics provide insights on how the packet rate is chosen depending on how much data and how often sensor nodes need to monitor its environment. Given Fig.s 4 – 6, system designers may opt using the packet rate between 1.67 – 5 packets/sec while reducing energy consumption. This chosen parameter translates to a slow movement of data from one node to another. However, temperature and soil environment are normally first order systems which do not very much change with time. This means that low packet rates can also be chosen for the said application.

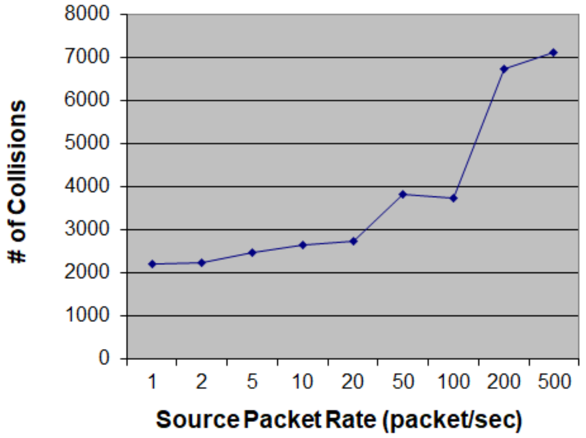

Fig. 4 Number of Collisions when the source packet rate is increased

B. Advantages and Disadvantages of the Smart Orchard Monitoring System

The proposed smart orchard monitoring system can be evaluated on a system point of view. This is achieved by providing the advantages and disadvantages of the said system.

The smart orchard monitoring system is simple and easy to implement because of its periodic placement of sensor and central nodes. The setup also provides deterministic ways of figuring out surrounding noise. Overhearing is also minimized because of the deployment of the sensor nodes. The central node may also be set to be the only node that is of higher specifications, particularly in terms of memory, computational power, and power supply, while the sensor nodes will only need to meet the minimum requirements such as sensing and communication devices. With the routing algorithm, the central node receives the transmitted message twice via “direct-link nodes”. Such method may provide confirmation of transmitted messages from the sending sensor nodes. However, during simulation runs, the system becomes less robust when one sensor node is set to fail. This is exemplary observed when the nearest nodes fail. Another observed behavior with this setup is the prevalence of loop during data transmission. This has been avoided by placing the source sensor node ID to the transmitted message. The receiving sensor node counts how many times the message has been received. If a reception threshold has been met, this is now the guarantee that the message will not go back to such sensor node. Finally, the smart orchard monitoring system relies on the accurate placement of all sensor and central nodes

IV. CONCLUSION AND FUTURE WORK

In this study, we have proposed an IoT-based smart orchard monitoring system to gather and transmit pertinent environment information needed to produce healthy and nutritious vegetables or fruits in a farm. A simple and inexpensive monitoring setup is presented to capture surrounding data that will aid in the farm production. Such setup has been analyzed in terms of throughput, latency, and energy consumption of all deployed sensor and central nodes. Results shown can provide farmers and system designers options in choosing the appropriate packet rate to achieve the necessary throughput at the fastest and least expensive (in terms of energy consumption) manner.

In the future, the actual deployment of the IoT-based smart orchard monitoring system is considered. Such physical deployment will now consider the actual operation of data gathering, compression, and transmission. In compressing the received data, the sensor node can employ index coding techniques [19] to reduce the number of transmissions and transmitted data sizes. Power control in wireless networks can also be integrated to further reduce the deployed sensor nodes or aid the system to be more robust during sensor node failure [20].

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