Crop Irrigation Control using Wireless Sensor and Actuator Network (WSAN)

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Abstract—**Physical and environmental sensing is benefitting several domains to solve real time problems. Wireless Sensor and Actuator Networks (WSAN) are emerging as the new generation of sensor networks and providing a boost towards the development of autonomous systems. Use of WSAN towards crop irrigation is one of the top most utilization in the area of Agriculture. In this paper we have presented the crop irrigation control to better utilize water resource which is getting scarce. The one of the major hindrances on the way of WSAN adaptation in the third world countries like Pakistan is the factor of hardware/system cost. To cope up with cost factor, there is a need of the indigenous development of sensor and actuator motes. In addition to crop irrigation control, we also presented our efforts of indigenous design and development of WSAN and its protocol.**

Keywords-WSAN;Crop Irrigation; Sensors; Mote; Indigenous Design;

I. Introduction

Crop irrigation is one of the very important areas of agriculture. Traditional methods of irrigation not only require water in quantity but percentage of water wastage is also high. Globally water is becoming a scarce resource that instigating the need of controlled crop irrigation. Several different methods are now being used like drip irrigation, sprinkler irrigation etc. that provide controlled water supply but some software support is also needed for decision making like where and how much watering is desired. Such intelligent irrigation is an essential part of smart agriculture [1]. Different frameworks to develop intelligent and autonomous systems been offered specifically for agriculture domain [2, 3, 4, 5, 6].

Wireless Sensors and their Network (WSN) presented itself as an essential part of all systems that require physical and environmental attribute measurement [7]. Wireless Sensor and Actuator Networks (WSAN) emerged as a new generation of WSN that offer both sensing and control. This new breed is providing immense support in the development of smart application in the domain of ubiquitous computing like smart university [8], smart hospital [9], smart farm [10] etc.

In this article, cost efficient crop irrigation control using WSAN is presented. The system cost effectiveness is achieved through indigenous design of wireless sensor and actuator nodes and their protocol for network development. The developed decision support system has the limited decisions' support that could be extended. Low power consumption and the reduced system cost are the main key features that have been considered in the sensor/actuator nodes and protocol design rather than the size of nodes.

The rest of this paper is organized as follows: Section 2 provides design details of WSAN and the 'ProtoSense' protocol. Section 3 is presenting the system architecture specifications for crop irrigation control using WSAN. Section 4 highlighting related work in the area of agriculture for irrigation control. Finally, we offer our conclusions and future work in section 5.

II. Indigenous WSAN Design and Development

A. System Design

Modular designed approach is followed for the development of system. The design problem is broken into several smaller problems. The initial requirement is the establishment of a functional architecture and categories of the nodes. The nodes are categorized as follows:

(i) Sensor mote/node
(ii) Actuator node
(iii) Sink node

Sensor mote designs impose the requirement of low power consumption due to the small battery life. The selection of components especially microcontroller and communication module is needed to be battery friendly. In our design, Atmel ATMega64L AVR microcontroller is used due to its support of 6 sleep modes (Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby) and XBee/X-Bee-Pro OEM RF module for its low power consumption features is selected. Preference is given to the power consumption and the low cost properties in design rather to the size of sensor mote. Following is the description about design:

1) Sensor Mote Design

The purpose of the sensor mote is to provide facilities to sense the physical world through some built-in sensors as well as the interfaces to connect external sensors. Fig. 1 is showing the basic components of a sensor mote.

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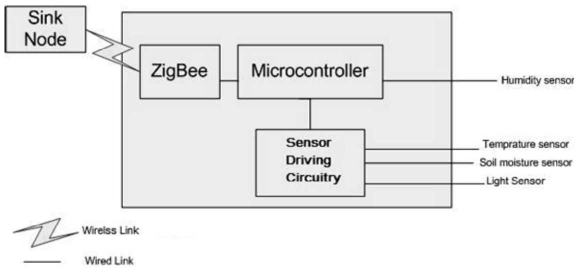

Figure 1. Components of Sensor Mote

The major components of a sensor mote are processing unit, communication unit, sensors driving circuit unit and the power unit. The sensor mote is designed having three built-in sensors (ambient light, temperature and humidity sensors) and one external sensor (soil moisture sensor). LDR is used for light sensing, LM35 is used for temperature sensing while SHT71 is for humidity sensing. Soil moisture sensor is developed using two rods of Lead and Tin material that provide variation in resistance from 1K to 50K for the variation in moisture from 100% to 0% (see Fig. 2). The sensor mote is designed to work on three modes that are (1) Sender (2) Receiver and (3) Forwarder.

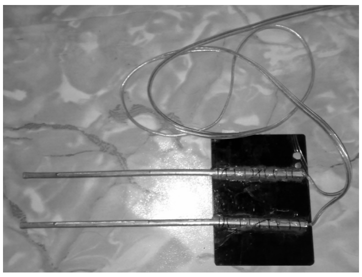

Figure 2. Soil Moisture Sensor

2) *Actuator Node Design*

Actuator node provides the facility to switch ON/OFF the connected actuator device. The main components of an actuator node is microcontroller, communication unit and a control circuit. In the specified design, solonoid valve is provided as an actuator (refer Fig. 3). The actuator node works in receiver mode only.

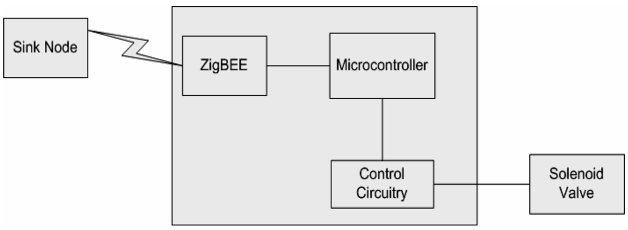

Figure 3. Actuator Node

3) *Sink Node Design*

Sink node is designed (1) to collect sensor mote data packet wirelessly via Zigbee and transfer it to the connected PC via serial interface and (2) to send request and actuator packet generated by the acquisition and control/decision support system towards WSAN network.

B. Protocol Design

The developed protocol "ProtoSense" is a broadcast based protocol. The protocol is made power efficient by reducing extra communications and reliable by introducing request-acknowledgment pattern. The request is broadcasted for data acquisition to the first hop nodes that only forward it to the next hop if the intended node is not among the first hop nodes. This is revealed through the absence of the acknowledgement packet. This request-acknowledgement pattern not only reduces the extra broadcast packets but also improves the packet delivery rate that leads to decrease the packet collision rate and the power consumption. Following are the protocol sequence diagrams to understand the protocol working. Fig. 4(a) is representing the scenario when the intended mote is in range of sink mote (within one hop) and the data request is sent. Fig. 4(b) showing the scenario when the requested node is two hop away from the sink node.

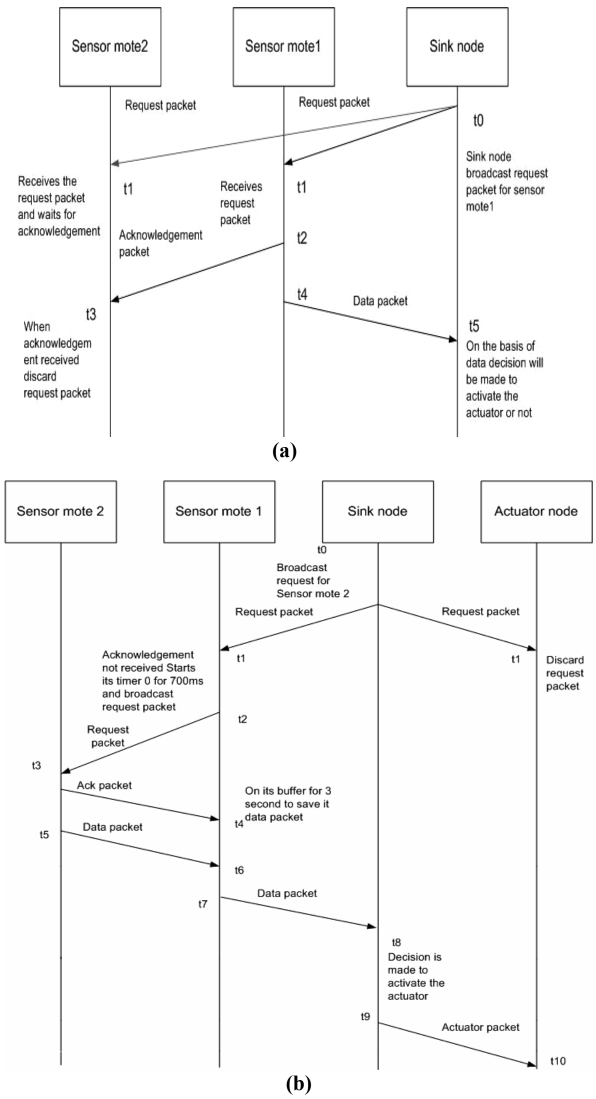

Figure 4. Protocol Sequence Diagrams

III. IRRIGATION CONTROL USING WSAN

Irrigation is defined as the artificial application of water and it is one of the most important areas of agriculture. Water resources are shortening down and it is becoming a scarce resource globally. So there is a need of proper use of water that is water should be provided to only those places where it is needed and in required quantity. Different methods of irrigation are in use like drip irrigation, sprinkler irrigation etc. to cope up with this problem. Controlled water distribution to save the water without compromising the crop water requirements is possible using different IT based solutions. WSAN is one of the technological solutions that provide help in monitoring crop, weather and soil attributes to calculate the water quantity requirement at a particular instance of time as well as to take action to fulfill the need.

In this article crop irrigation control using indigenously developed WSAN with decision support system is presented. Wireless sensor and actuator network can be developed either as fully automated or semi-automated fashion. In this developed system, semi-automated WSAN is produced in which centralized decision making is supported (refer Fig. 5).

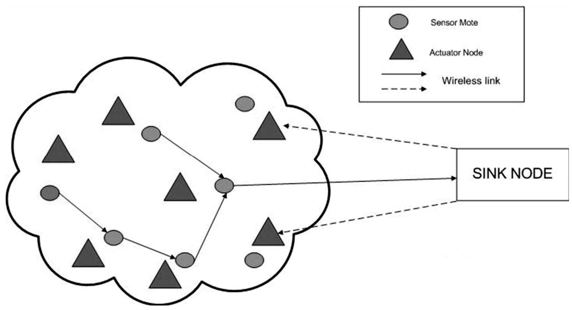

Figure 5. Semi Automated WSAN [1]

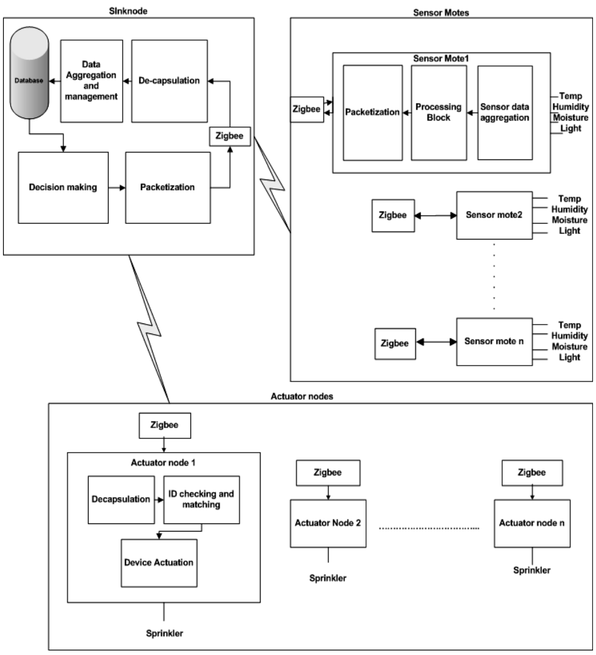

Figure 6. System Block Diagram

The system has the capability to deal with multiple sensor and actuator nodes. Fig. 6 presenting the block diagram of the system while Fig. 7 is showing prototype architecture.

The software for irrigation control using WSAN is developed in Visual Basic 6. Microsoft Access is used for the database development. The software provides the following facilities:

(i) Data acquisition from sensor motes

(ii) Data aggregation and storage of sensed data into database

(iii) Decision support system

(iv) Sending decision for activating the actuators

(v) Sensor data analysis

For data acquisition from sensor motes, request packet is sent via ZigBee module. In response the requested sensor mote sends the data packet having four types of sensors data values. Same process is used for getting data from different sensor motes. The requests are sent after every defined interval (in our prototype this interval is 5 minutes). When the data is received, it is de-packetized and sensor values are separated and then placed in respective database table of the sensor after checking the sensor mote ID from the received packet. The error correction (filling the missing values) is performed by placing the previous value.

For decision support system, different threshold levels are defined for finding temperature, soil moisture, air moisture and light stress levels. Decisions for actuation of sprinklers for irrigation are made when some area of the field is found in stress condition that could be temperature, soil moister, air moister, light or the combination of them. The decision of actuation describes the switching of particular sprinkler for defined time that is also sent within the decision packet.

Following steps are followed at sensor, actuator and sink nodes:

At the Sensor Mote

(i) When the request packet is received by the intended sensor node the sample collection is performed.

(ii) Sensor data aggregation is done of the collected data via attached sensors that are light sensor, temperature sensor, humidity sensor and soil moisture sensor.

(iii) Then the processing of the aggregated data would be done at the processing block.

(iv) At the time of packet formation, sink node ID is added. After the packet formation the packet is sent wirelessly towards the sink node.

(v) Different sensors may take part in forwarding the packet in case the distance is more than one hop.

At the Sink Node

(i) The sink node is responsible to collect all the data sent from sensor node and provide it to base station node that is a PC, connected directly with it, having storage and decision making facility.

(ii) The sink node also takes part in forwarding request packets and actuator packets on request of the software system.

At the Actuator Node

(i) At the actuator node the incoming packet is de-capsulated.

(ii) ID checking is performed and the intended actuator performs the asked task of actuation. In our case the task is to switch ON/OFF the sprinkler for the specified time.

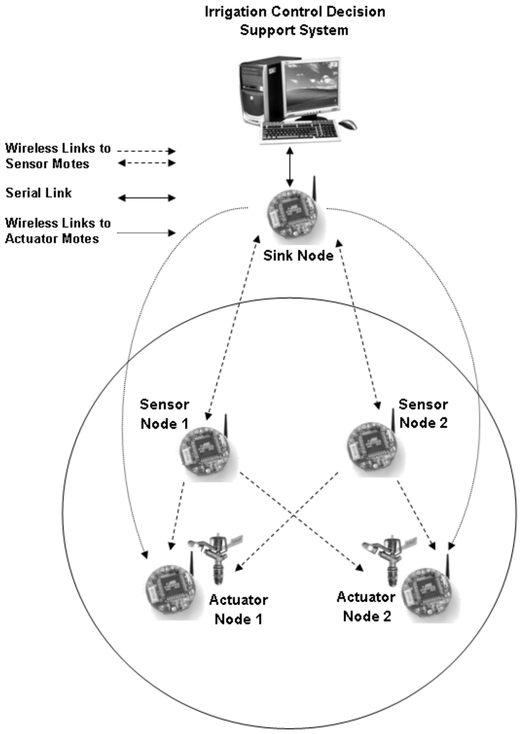

Figure 7. Prototype Architecture

The software for irrigation also provides the facility to see the trends graphically. The graphs can be generated to see temperature, soil moister, air moister and light variations. The current values of the sensed quantities can also be viewed sensor mote / zone wise etc.

The software is primarily designed to test the working of developed WSAN, hence having limited capabilities. Its decision support could be more precise and extensive and it could also be more powerful in providing data analysis feature graphically and statistically.

IV. RELATED WORK

Emergence of Wireless Sensor and Actuator Networks (WSAN) in this decade provided a platform to go further from monitoring to the control. Irrigation control is one of the important areas in agriculture. Keeping the importance of controlling irrigation water for better yield production, several sensor based projects have been developed [3, 11, 12]. Tapankumar *et al.* [11] designed and developed a computer based drip irrigation control system having the facility of remote data acquisition. They also presented the benefits of storing sensors data for statistical analysis to find out the irrigation requirements for different crops. While Yunseop Kim *et al.* [12] developed an electronically controlled sensor based irrigation system that provides the facility to monitor soil moisture and temperature, weather information and sprinkler position remotely using the Bluetooth and GPS technologies. The concept behind the development of their project was to maximize productivity while saving water. Context-aware irrigation control system using TelosB sensor motes and Ech2o soil moisture sensors is offered in [3]. The authors presented system's water conservation over traditional irrigation methods. The use of WSAN is the common feature of all above mentioned crop irrigation control systems.

V. CONCLUSIONS AND FUTURE WORK

Crop irrigation control is the most important concern in the domain of agriculture. Shortage of water globally is also emphasizing the need of systems that not only control the crop irrigation but also provide the intelligent way to provide water to only those places where it is needed and in the required quantity. Such systems require reasonable cost for hardware and software that is becoming one of the hurdles in third world countries like Pakistan for implementation. Keeping the need of cost efficient systems, we have presented indigenous design and development of WSAN in this paper. Following table presenting cost comparison of developed motes with some other commercially available motes for establishing 5 node WSAN (2 sensor motes, 2 actuator nodes and one sink node):

TABLE I. COST COMPARISION

Mote Name	*Avg. Cost Per Unit*	*Qty*	*Total Cost*
TelosB	Rs.15,000/=	5	Rs.75,000/=
Our Hardware	Rs.4,000/=	5	Rs.20,000/=
MICAz	Rs.13,000/=	5	Rs.65,000/=
IMote2	Rs.23,000/=	5	Rs.115,000/=
IRIS	Rs.11,000/=	5	Rs.55,000/=

Our hardware is clearly providing advantage of low cost over others. This cost could further be reduced in case of quantity production.

It is to mention that there is no match of our hardware size with the mentioned other sensor motes but as an initial effort it is comparable in working.

In future we are planning to reduce the hardware size and increase accuracy of the sensors provided as built-in. In the next phase, WSAN will be tested with context-aware irrigation control system software [3].

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