Precision Irrigation Control And Dynamic Regulation of Inter-Chak Water Delivery Channels Using Wireless Sensor Networks

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Abstract- Precision Irrigation Control is one of the areas where Wireless sensor networks can be effectively utilized. By using appropriate strategies using WSN with soil moisture meter as one of the sensors, high irrigation delivery efficiency can be achieved. The precision data automation can be done for dynamic regulation of water delivery channels. This paper presents design layout and implementation methodology using WSN for working out irrigation demand in a precise manner. The paper covers various aspects like naming conventions, mote sensor assembly, cluster based layout and installation of sensors at subtask level in detail. Appropriate strategies of Localization, data routing and data aggregation techniques, computation of operational parameters are presented for working out the water demand to regulate inter-chak water delivery channels. The paper also lists some limitations to implement the scheme.

I. Introduction

The embedded systems and their technologies have opened many avenues of their applications, The wireless sensor networks is one the products which are seen as the next-gen alternative to the existing level of technology. With the advancements and maturity of wireless sensor networks technology, the world is looking towards it to solve many existing problems like environmental monitoring, vehicle tracking, defense surveillance, early warning system for natural disasters, flood control, irrigation etc. It has got a very promising use in controlled irrigation systems. The efficiency of any controlled irrigation system depends on the actual demand of water and supply to replenish the demand, There has been always a gap between them due to inaccuracy in predicting the exact demand. The project like FLOWAID [1] has begun to explore this area. Gujarat , a state in India has several irrigation projects including SARDAR SAROVAR with 1.8 million hectare of command area. The project is operational now, there is vision to increase its irrigation efficiency by having dynamic regulation of canals from main canal to subminors. Using sensors an in-situ exact demand can be gathered and appropriate supply can be made. The international projects like FLOW-AID[2] have given due recommendations to go for wireless sensor networks. Cordell-Oliver[6] has shown the reactive sensor network model for soil moisture. The technological advancements and refinements in the field of Wireless sensor networks has opened many avenues which can take its advantage and improve the efficacy of the system. The use of WSN was studied for a conventional canal irrigation project. How, where and when the WSN can be used is discussed in a a stepwise manner,. Common terms of irrigation are given to familiarize the common reader who does nor belong to the domain of irrigation. How the a crossbow sensor mote can be combined with Water Mark Soil Moisture meter is given in Sensor Mote Assembly. The naming conventions of Sensor nodes and irrigation areas are proposed after that. In VI presents the study on various routing techniques and selection and modification of appropriate routing method for the given condition. The sensed data has to be measured and aggregated so that the exact demand can be worked out. In VII we discuss several aggregation strategies and the strategy suitable for our case. In VIII we present the simulation result of effect of threshold value on packet transmission and energy levels. In IX we present various bottlenecks in the practical implementation of the proposed system.

II. The Problem Statement

Vegetative meteorological pattern and soil properties are the key factors used till now to estimate the demand of water using various empirical formula given by researchers and practitioners. The formula are many a times do not confirm to the local factors and the estimated water demand and supply leads to either under irrigation or over irrigation. Here we deal with the problem of calculating the accurate demand of water on all the outlets by working out the possibility of participation of wireless sensor networks . Also we have to consider the factors of the sensor node layout , routing , aggregation strategies and the suitability of the algorithms to carry out the water demand from a subchak level to complete

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irrigation command.

III. Terminologies

To understand the problems following terms must be clearly understood

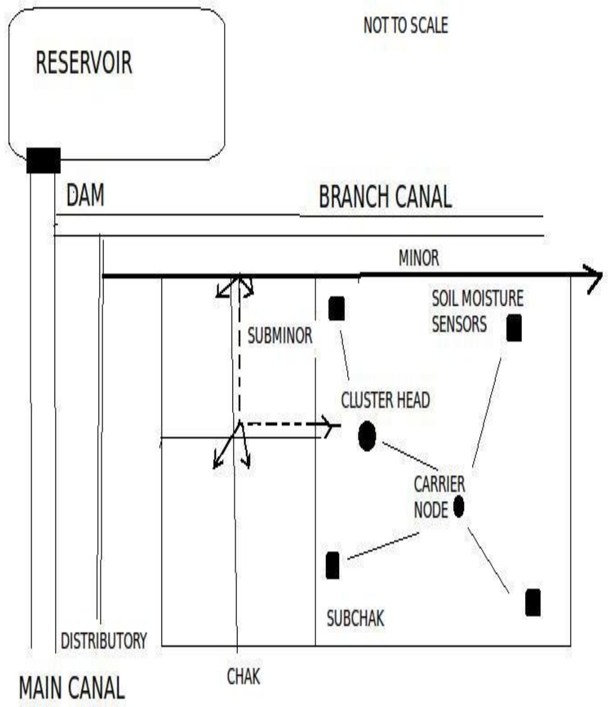

Fig.1 A Standard Irrigation Project

Irrigation Command : The whole area which can be irrigated by a water storage structure like Dams, Weir and Barrages. The reservoir full water level decides the maximum irrigation command which can be covered under gravity irrigation

Chak : An irrigation command area of approximately 40-50 ha and is a unit of irrigation area in command to be served by an outlet on minor.

Subchak : A part of chak of 5-8 ha of area approx to be served by outlet on sub-minor

Irrigation Reservoir : A huge water body created in the upstream of obstruction (dam) created naturally or manually on natural streams like river

Main Canal : The canal exiting from the reservoir head serving the discharge requirement of Branch canals

Branch Canal : The canal exiting from outlets of main canal serving the discharge requirement of Distributories

Distributories : The Canals exiting from outlets of Branch Canals serving the discharge requirement of minor

Minor : The canal exiting from outlets of Distributories . A water delivery canal which can irrigate an area of approximately 8-10 chaks

Sub-minor : The **water delivery canal** irrigating whole chak with its outlets at head of subchaks. This canal is lowest in the hierarchy and is doing the end delivery of water to fields

Chainage : The distance measured along the canal (in m)

Irrigation Interval : The frequency by which water is supplied in the fields, it is fortnightly in India using Rotational Water Distribution System. Fig 1 describes the conceptual infrastructure of the irrigation command.

IV. CONFIGURATION OF WIRELESS SENSOR NODES

A) The Sensor Mote Assembly

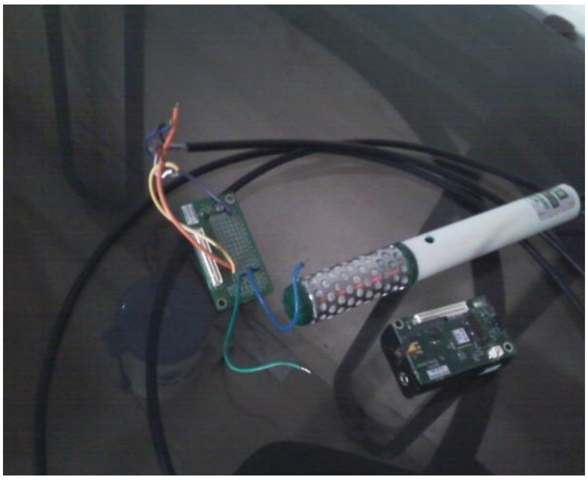

Fig 2: Sensor - Mote Assembly

A soil moisture sensor with electrical resistance device (Watermark Soil Moisture Meter from Irrometer) was attached to the sensor boards (MICAZ from crossbow) . MICAZ sensor boards come with three sensors viz temp, light and humidity, apart from that it has got empty pins and slots to connect the additional sensors. The negative and ground were connected to the pins on board and output was connected to the empty ADC pin. These connected sensor boards was then breadboarded on radio motes. After sufficient calibration . The converter function of changing the measured voltage into water suction potential was found and was incorporated in the nesC function and was deployed on the board. The sensed data became the part of the packet structure which can be transmitted with radio-link. The packet structure can be read by a program on sink or by other node. The assembly is given in fig.2

B) The Naming Convention of Sensor Nodes and Subchaks

Fig 1. shows the complete hierarchy of a irrigation command which can be the used as a reference for naming conventions. Suitable unique code can be given to Main, Branch, Distributory, Minor, Subminor , and subchak, viz **020208031102** can be the identification code of subchak. This code means subchak no 02 which belongs to sub-minor no. 11 which offtakes from minor no. 03, off-taking from branch no 02 served by Main canal no. 02. The 12 character string and 2 character sensor node no can be written in the memory buffer on the chip of sensor board and shall be included in every transmission as a part of packet structure. The code of sample sensor node in a subchak is **02020803110*203*,** indicate third node of the above mentioned subchak. The code convention for sensor identity is

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CONCAT(MAIN_CANAL_CODE, BRANCH_CANAL_CODE, DISTRIBUTORY CODE, MINOR_CODE, SUBMINOR_CODE, SUBCHAK_CODE, SENSORNODE_NO) .

As we propose a clustered environment of sensors in a chak with one cluster head in every subchak whose naming convention can be same as of subchak with "C" suffix, viz **020208031102** ***C.*** As all other sensor nodes in the subchak are reporting to cluster head, it has got the responsibility of carrying out data on the gateway node.

C) **The Functioning of the Sensor Node** Each sensor node with the assembly shown in fig 1 is placed at a predefined location in the subchak. These sensors consist of a porous material in which electrodes are embedded to measure electrical resistance. When placed in the soil, the sensor tends to reach an equilibrium with soil water and the electrical resistance reading can converted to a calibrated reading of soil water suction potential(ψ_m) ,drier the soil, the greater the electrical resistance. The soil

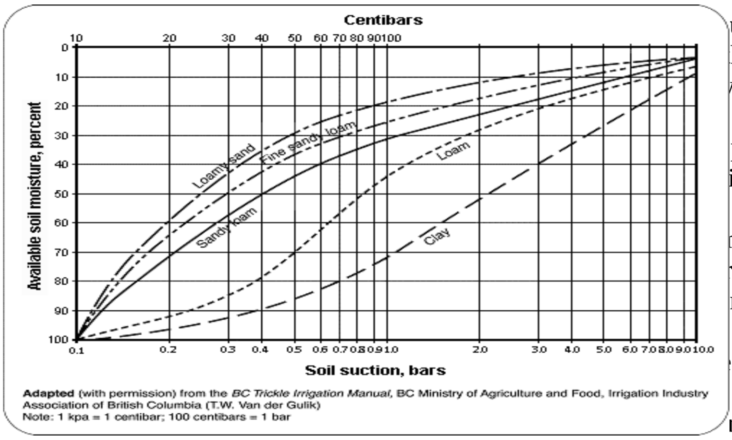

Fig.3 Suction vs. water content calibration

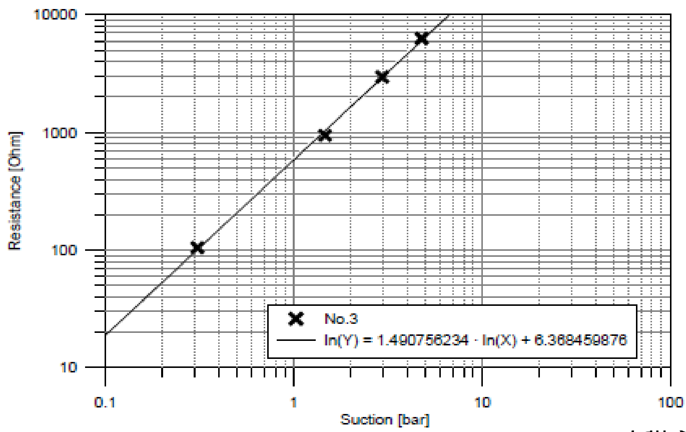

Fig.4 suction vs. electrical resistance

moisture content in the gypsum block will be inversely proportional to the electrical resistance or in other words higher the moisture stress, higher is the electrical resistance. All the soil moisture meters must be calibrated before being installed in the field, and the calibration equation should be developed to get the soil moisture suction in (kPa- KiloPascal) from the electrical resistance(Ohm) by interpolation or regression techniques from the calibration curve. [2][3][4] [5] give a detailed account of how to calibrate and use tensiometers and electrical resistance meter with gypsum block

The measured moisture suction pressure will be the reading which is included as a part of packet structure to be relayed. Now here there can be two options one to calculate the moisture potential at node level or relay only electrical resistance readings and calculate average moisture suction pressure at sink or gateway. Calculating at node level will consume more power on the contrary calculation at sink will give a average or standard conversion and accuracy can be compromised, a trade-off is required in this case. The sample calibration curve is given in Fig 3 and 4.

V. The Layout of WSN at Subminor Level in a Subchak

ut

he head and discharge on subminor head we need the water requirement of the subchaks. To the irrigation water deficit in the subchak we place the soil moisture sensor-mote assembly at ion representing the subchak. As the subchak is an 5-8 hectare i.e. 50000 to 80000 sqm or an nate square of 250 m by 250 m. representing the ea by one sensor node is not sufficient secondly mission range of a standard MICAZ radio boards practically so we need to place other sensors to information to the larger distance. The suggested given in fig 5. Rather than a random distribution rs this problem demands very careful placements with known location, and identities due to constraints of transmission range. The naming conventions for the sensor are given above. The node database at the sink is of

CHAK (subchak_identity, outlet_chainage) ,

SENODE(sensenode_identity, x-coordinate, y-linate isClusterhead, isAssistingNode)

x-coordinate, y-coordinate are longitudinal and dinal value of the sensor positions. As the data is to ayed to large distances, all the nodes cannot directly it data to sink due to distance limitations in nission. So one of the nodes near the outlet can y as cluster head to which all the neighboring nodes can submit its measured data. If the distance of cluster head is more a assisting mote can be kept at a convenient location to simply hop the packet to the cluster head. In general every subchak will posses a sensor node as cluster head responsible for transmitting the representative information of subchak to decide the head and discharge at the outlet. The sink node can be placed at the subchak

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outlet to which the cluster head will report. The above fig give a sample layout of WSN nodes in a subchak.

b) Localization

Localization is very important aspect in this case as the place of the sensor mote is important to find out the effective area. Although several techniques are available for localizing a sensor node in this case the nodes are located at predefined and well thought of positions, so no special localization technique is require to establish the coordinate of the sensors. In this case the chainage of the outlet of subchak and its x,y coordinates is already available as a part of canal design. With reference to the position of outlet the sensors are carefully placed.

[Xsensor, Ysensor] = f(Xoutlet, Youtlet, theta(radians), distance)

The alternate way is to have GPS reciever (even modest cellphones are having this facility now a days). One has to walk down at the sensor nodes are record the Longitude and latitude at the place.

VI. The Routing Strategy

Classification of routing protocols in sensor networks

Routing protocol	Data-centric	Hierarchical	Location-based	QoS	Network-flow	Data aggregation
SPIN	✓					✓
Directed Diffusion	✓					✓
Rumor routing	✓					✓
Shah and Rabaey	✓		✓			
GBR	✓					✓
CADR	✓					
COUGAR	✓					✓
ACQUIRE	✓					
Fe et al.					✓	
LEACH		✓				✓
TEEN and APTEEN	✓	✓				✓
PEGASIS		✓				✓
Younis et al.		✓	✓			
Subramanian and Katz		✓				✓
MECN and SMECN			✓			
GAF		✓	✓			
GEAR			✓			
Chang and Tassiulas		✓			✓	
Kalpakis et al.			✓		✓	
Akkaya et al.		✓		✓		
SAR				✓		
SPEED			✓	✓		

Table 1: Classification of routing protocols in sensor networks. (source : A survey on routing protocols for wireless sensor networks www.sciencedirect.com)

Looking to the layout given in Fig. 5 the data sensed by the sensor nodes to be send to the sink node at the subchak outlet. As the distance of the outlet to the most of the nodes is larger then their transmission range they need to come with single or multi-hopping pattern via other sensor nodes or assisting nodes and reach to the cluster head. Various routing strategies were studied in this regard. It clearly involves the evaluation of data centric routing protocols like flooding and gossiping, SPIN, directed diffusion, table.1 shows the summarized description of network routing protocols Energy aware, rumor, CADR, COUGAR and AQUIRE. To decide the routing protocol we assessed the data requirement pattern. Here in this case the sink node is just interested in the the critical condition of moisture deficit in the soil ie when the moisture stress fall below -1/3 bar. So here as in usual cases sink is not going to query as it happens in above mentioned protocols but the WSN node has to be intelligent to report the sensed reading to the cluster head when the critical reading arrives, Nodes in the vicinity can directly link to the cluster head which farther nodes has to send the data by multi hopping. SPIN seems to be the option of routing as only in this case the sensor advertises the availability of data , in other cases the sink queries the network. A small modification is required in this. The threshold value is to be mentioned in the sensor node memory , The radio link will only send the data when the threshold is arrived. As the arrival of this value is not frequent. The time interval to advertise it with a isActive frame should also be increased to one to two hours. This will save a lot of energy in the network.

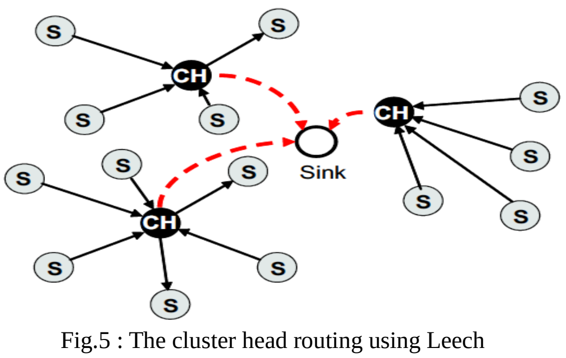

Fig.5 : The cluster head routing using Leech

The ***Modified SPIN ALGORITHM*** can be as under.

1. **Initial** advertising of isActive Packet and meta data frame to all neighboring nodes

2. **All** Nodes know the meta data of next immediate neighbor to whose data will be relayed

3. **Advertisement** time increased from 2 seconds to 1 hour if Neighbor node is Cluster node go for single hop Else go for multi-hop to immediate neighbor.

4. **On** receiving threshold limit of moisture the packet structure includes Moisture data with its data flag on otherwise data flag is off

Crossbow MicaZ motes support SPIN very well with many energy aware routine. The additional frame size is increased by just 5 bytes . One byte for the data flag and 4

Various Aggregation techniques already described in Table 2 were studied to see its usability in the current problem under consideration, but due to the very different nature of the problem non of them were found suitable as it is. The cluster head is responsible for reporting the correct picture of subchak moisture deficit. The aggregation technique or algorithm employed in this is relatively very simple as there is only one cluster head in the subchak and all the nodes are reporting the data to cluster head, the aggregation logic will be to find the MAX deficit in the node representing an area in the subchak. But the problem is all the nodes may not send the data at the same time as moisture level may not reach to the threshold at their respective positions. Due to this a fuzzy situation arises . As the basic irrigation interval is a fortnight.

The maximum waiting for the data to come is 14 days. If one or more sensor nodes report the data before that time . The cluster head can maintain the data, After the fortnight for storing moisture stress.

Similar sensor node layout is in all the subchaks and all have got their respective cluster head. The information in all the cluster head will have to be carried out to the sink located at the chak outlet outlet. So here we have to think about the inter cluster routing. All the cluster heads has got the meta data information about other cluster head. Using distance vector algorithm or energy based selection the cluster data can be hopped to the sink. The protocols like LEECH , TEEN, APTEEN , PEGASIS, GEAR etc can be used for efficient inter cluster routing so that data reaches at the sink placed on minor outlet. Fig 6 shows inter-cluster routing to sink.

VI. The Dynamic Aggregation Strategy

the data from various nodes is gathered and maximum of it is calculated to estimate the irrigation demand.

The IRRISENSE-**AGGREGATION** Algorithm goes as under.

1. Node senses the data below threshold and sends it to cluster head

2. Report sending the data after hourly interval to cluster head if the stress level reading is increasing

3. The cluster head maintains the latest data of the moisture stress level of every node.

4. After 14 days the cluster finds the MAX (Node-stress Readings) and supply it to sink

5. Sink using relationship equation of moisture stress , area to be covered and and the time of supply and discharge will be used to calculate the discharge and the head required at the outlet level.

6. The discharge requirement at every outlet can be calculated in this way. The discharge requirement an any outlet of subminor is

Algo. / Char.	TAG [5]	Directed Diffusion [1]	PEGASIS [3]	DB-MAC [7]	LEACH [2]	COUGAR [4] [49]	Synopsis Diffusion [8]	Tributaries and Deltas [9]
Aggregation method	Tree-based, on-line, driven by the sink	Tree-based, on-line, driven by the sink	Chain-based, centralized or distributed	Completely distributed, asynchronous	Cluster-based, on-line, distributed	Cluster-based, on-line, distributed synchronous	Multi-path based, on-line, distributed	Tree/Multi-path based, driven by the sink
Resilience to link failures	Medium	Medium	Low	Medium	Low	Medium	High	High
Overhead to setup/maintain the aggregation structure	High	High	High	Low	Medium	Medium	Medium	Medium
Scalability	Low	Medium	Very Low	High	Low	Low	High	Medium
Resilience in case of node mobility	Low	Medium	Very Low	High	Low	Low	High	Medium
Energy saving methods	Sleeping periods	None	Rotation of the leader	None	Rotation of the cluster-head, sleeping periods	Local route repairs	None	None
Timing strategy	Periodic per hop adjusted	Asynchronous	Periodic per hop	Asynchronous	Periodic per hop	Periodic per hop	Asynchronous	Asynchronous

Table 2: Classification of aggregation techniques www.sciencedirect.com [7])

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$Q_{required} = Q_{outlet} + \Sigma$ Q outlets in the downstream of the outlet concerned

The in-network aggregation techniques are used for sensing and aggregating the data on sink
out of various protocols and algorithms is presented in table.2 [7] to [15] presents various aggregation protocols and scenarios to used in various cases. Studying them PEGASIS, LEACH COUGAR are to be used in our case. All the protocols are capable of sending the collected data in a multi-hop pattern. The discharge requirement will be calculated as under . The *Event Oriented Data Aggregation* techniques proposed by Ying Guo et al can be used with cloud membership model to disseminate the values of event and check accuracy and consistency of event parameters

$Q_{chak\ head}$ or $Q_{minor\text{-}outlet} = \Sigma$ Q outlet for i= I to N outlets.

As meta-data of all the cluster heads are stored on the sink and advertised , each cluster knows the next hop.

The routing and aggregation techniques are limited to a chak only are completely based on above mentioned protocols.. Beyond that it will be difficult to have inter node routing due to limitation of transmission range

VIII. Simulation and Results

The test bed is prepared on the omnet console specifying nodes with Zigbee stack, we suppressed the TinyDB layer and 2AA energy level taken as the initial energy level with current of 1 mA and 2.4 GHz frequency. The cluster head was simulated as Aggregation node and data sensing node. The frequency of the energy depletion on cluster was considered as it is the only calculating node spending more energy. With in fortnight all data sensors were programmed to relay data when the output voltage (simulating moisture stress falls below 0.3 V. decreasing this threshold increased the transmission rate and so the energy consumption at the cluster head. The simulation was done a minor level and 8 chaks were considered for the data transmission based upon the threshold value of moisture content. Decreasing or relaxing the moisture stress increases the data transmission volume on the cluster head in the fortnight. 8 chaks with 5 subchaks each were taken for simulation, totaling to 200 sensor nodes and 40 cluster nodes. Although the the transmission volume from cluster node remains almost constant but the frequency of transmission increases for data sensing nodes.

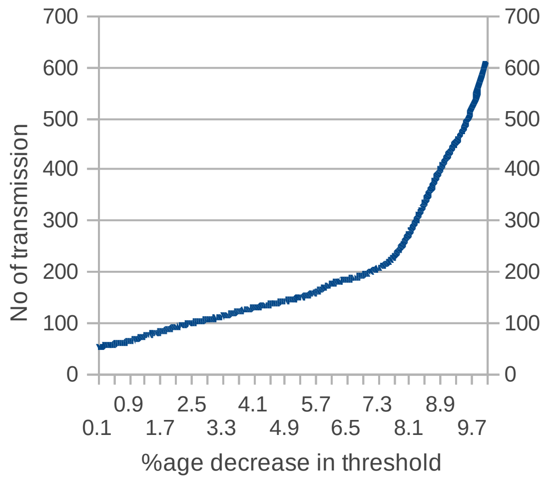

Fig.6 %age decrease in Threshold value vs no of transmission

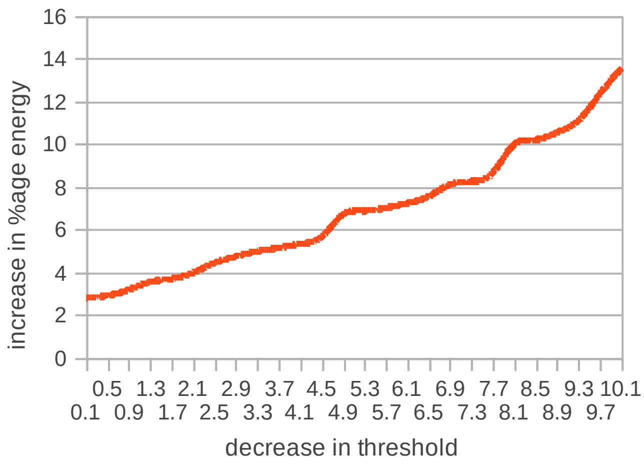

Fig 7: Increase in the energy consumption vs %age decrease in threshold

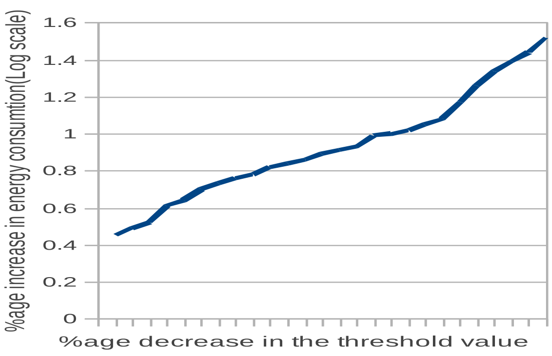

Fig 8: Decrease in the energy consumption vs %age decrease in threshold

It is clearly evident that fixing the event value or threshold is of great importance. Actually speaking there is no constant threshold value for moisture stress. The soil moisture sensor should be calibrated for different type of soil. The clay may have lesser threshold while alluvial soil

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may have more. This directly affects the efficiency of network, the life of sensor nodes and cluster heads. Fig 7 and 8 gives a plot of results obtained from simulation

IX. Implementation Bottlenecks

Using wireless sensor networks in case of gravity irrigation is a very challenging task , the difficulties are as under.

The installation of sensor mote assembly on field requires specialized skill and utmost care.

1. This can't be used in free flooding or basin surface irrigation methods as it can flood the whole assembly and motes may become useless, for this a water protection casing may be required which will make it very costly.. It can be useful in controlled irrigation methods like furrow and slope
2. Suitable for dry season crops like wheat, millet, bajra, groundnut, pulses etc but completely unsuitable for crops like paddy.
3. The cost is the serious bottleneck. As the WSN is still the state of art, the cost of mote is very high looking to Indian economics, but when in use the bulk production may reduce the cost and saving in the water may increase the irrigation delivery efficiency

X. Conclusion

A possibility of employing wireless sensor networks is shown for controlling the irrigation and calculating the real time water demand. The soil moisture and mote and board assembly is done taking the reading after sufficient calibration. The limitation is to carry the data for distant places, which can be achieved by using the existing communication infrastructure with GSM, CDMA, WIMAX etc. The routing and aggregation protocols were examined for such conditions and improved algorithm is suggested for our scenario. The routing scenario after being simulated gets a better power efficiency than the conventional protocols

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