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Development of Energy Efficient Wireless Sensor Networks Protocol for Precision Agriculture

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Abstract—*To meet the flaws associated with the traditional precision agriculture such as poor real-time data acquisition, smaller monitoring area, excessive manpower requirement, wireless sensor network (WSN) based precision agriculture has come into play. Proper agricultural practices result in good yield. These agricultural practices include varying crops and crop production techniques under different conditions. These conditions include soil moisture content, soil texture, etc. . A Wireless Sensor Network is established with sensor nodes buried inside the soil to transmit the sensed data to the sink node or base station. Existing protocols are studied for their possibility for implementation into precision agriculture in this paper. A new protocol is proposed that aims to enhance the network life time by reducing the per node energy consumption and maintain balance between energy consumption and energy disparity.*

1. INTRODUCTION

Precision Agriculture is a farming management concept based on observing, measuring and responding to inter-field variability of crops [1 and 5]. Farmers have been doing crop management to suit varying conditions like moisture content, humus content, soil texture etc. since ages for maximizing their production. But now with the advancement of the technology, these varying conditions can be found more accurately. In short "Precision Farming" is an agriculture concept in which new technologies are used to predict the crop production parameters more precisely.

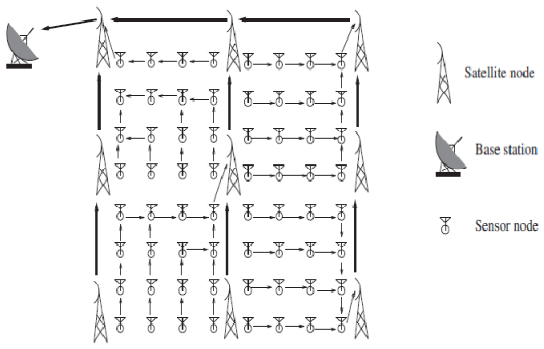

Fig. 1: A typical arrangement of sensor nodes, satellite nodes and base station in field

A Wireless Sensor Network (WSN) is a network of spatially distributed wireless sensors to monitor physical or environmental conditions such as soil moisture content, fertility of soil etc. for precision agriculture and to cooperatively pass their data through the network to a main location [2, 3 and 6].

The main aim of WSN in precision agriculture is to collect data from its part of the field, process them and then forward it to the Base Station (BS). However, the resource constrained sensor nodes have limited size, computing power and battery power with them. So adirect communication pathway between theBS and sensors may drain the nodes' power very quickly, because of higher energy requirement in transferring messages from sensor nodes to BS. Therefore it is required to find means and modes to save the energy resource of sensor nodes and utilize the energy efficiently to enhance their life time. The enhanced life time of sensors in return will enhance the network life time.

Communication from the sensor nodes to the BS can be in any of the following ways:

Direct Communication

Every sensor node is capable of transmitting information directly to the sink or Base Station (BS) by adjusting its transmission power. Howeverenergy of the nodes may drain very rapidly while communicating to the base station which may be installed far away. Efficient band width utilization is also not possible due to the occurrence of collision by the nodes communication. This protocol affects the scalability of the network. Example: DCP.

Tree Based Communication

In this type of protocols, a tree is being formed with the root being the BS. The node that desires to send data to the BS, searches for an optimal route to the root by any path search mechanism and then it transmits the information via that path. This reduces the energy consumption by the leaf nodes as they communicate to their parent nodes in the tree only.

However,nodes near to the Base Station (root) may exhaust their energy very rapidly while forwarding the data of the lower level nodes in the tree. Some of the examples are CTP, PEGASIS.

Hierarchical Communication

In this method, the network isdivided into number ofvirtual clusters. Each cluster has a cluster head (CH) which communicates directly with the BS. The nodes in a cluster transmit their information to the corresponding CHs. The heads do the data aggregation and processing for eliminating redundant data before sending to the BS. The clustering mechanism distributes the energy consumption of the nodes by selecting the heads on a rotation basis. The head nodes consume more energy while allowing the other nodes to enter into sleep mode. LEACH is an example of Clustering method of communication.

2. LITERATURE REVIEW

With the deployment of WSN, precision agriculture has taken a front seat in the area of research. Precision agriculture is the science of precise understanding, estimating and evaluating the land and crop condition to apply the proper fertilizer and irrigation to it. WSN has become a boon for such precision agriculture. Gutierrez et al. [2] has done an intensive study for the automated irrigation system and have tested in Baja California Sur, Mexico for sage production. Wang et al. [3] provides architecture of intensive irrigated agriculture monitoring system based on wireless sensor networks in China. Several others also have experimented the deployment of WSN for precision agriculture in different areas of the globe [7, 8, 9, 10 and 11].

2. 1 Direct Communication Protocol (DCP)

Direct Communication Protocol is the simplest protocol that can be implemented in Wireless Sensor network. Heizalman et. al [15],used this protocol as the base protocol to compare with other protocol. Each Sensor nodes send its data directly to the BS. Here distance comes into factor. If the BS is situated at a considerable distance from the sensor nodes or the network area is large in size, then more energy will be consumed by each sensor to transmit the data. In case multiple sensors of the same region are sensing same data and sending them to the base station, then the bandwidth is utilized for redundant data resulting in under-utilization of the resources. As distance plays a vital role here, the distance nodes die first.

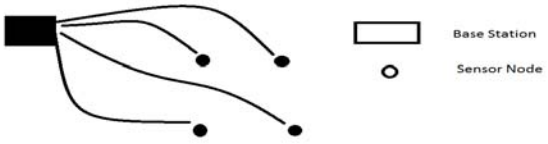

Fig. 2: Direct Communication Protocol

2. 2 Collection Tree Protocol (CTP)

This is a tree based communication protocol. Here, a tree is created by keeping the BS as the root node. A node that wants to communicate to the root finds an optimal path in the tree and communicates data through that path [17].

This protocol is an improvement over Direct Communication Protocol in the sense that transmission distance coverage by each node is lowered considerably resulting in low power consumption. But nodes closer to the root node consume more energy while forwarding the data of other others.

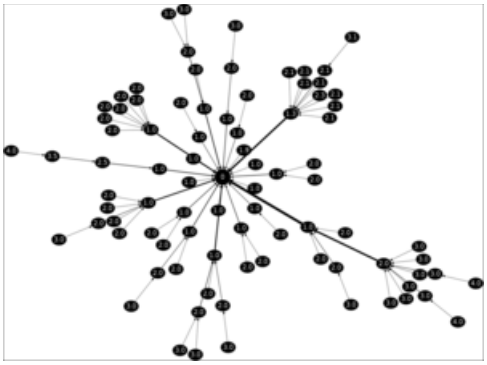

Fig. 3: A general CTP network with nodes and BS

2. 3 LEACH

LEACH stands for Low Energy adaptive clustering Hierarchy [19]. It is a hierarchical communication from the sensor to the BS. In this protocol, the whole network is divided into virtual clusters. Each cluster has a cluster head. The cluster members send their data to the corresponding cluster head which in turn relay the information to the BS. The number of cluster heads is decided prior to the set-up of the network by probability. The role of cluster heads is changed on rotation basis among the sensor nodes to fairly distribute the load on each sensor and to reduce its energy consumption. Most important feature of LEACH is distributed probabilistic clustering. It is distributed because any sensor node on its own decides to become a cluster head. It is probabilistic because of the randomized probabilistic algorithm used for the selection of cluster heads.

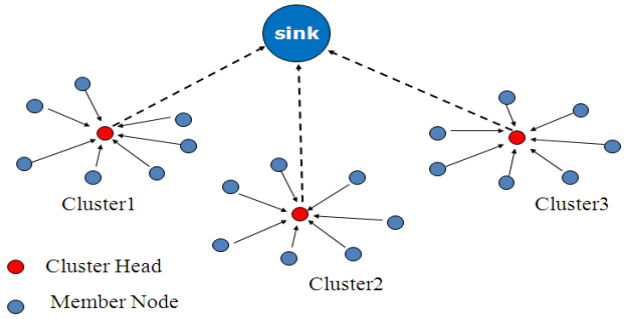

Fig. 4: Fig. showing clusters with cluster head, Non-cluster head nodes and Sink Node

LEACH has two phases:

1. Set-Up Phase : In this phase cluster head are chosen
2. Steady-State Phase : In this phase, the cluster heads chosen in the set-up phase are maintained and data transfer takes place

3. THE PROPOSED ALGORITHM

There are certain issues in the designing of routing protocols for WSNs due to various constraints in the network. WSNs suffer from the drawbacks of several network resources such as bandwidth, energy, storage and computation power. The proposed algorithm aims to achieve an improved network life time by considering the following issues:

1. Battery

Since sensor nodes run on batteries which have a certain limit to their capacity, energy is a major limiting factor for network designers in hostile situations. In military usages, for example, it is almost impossible to get access to the sensors and to recharge their batteries. Also, when a sensor's energy exceeds a certain threshold, it becomes faulty and may not function properly, which can ultimately have a huge impact on the performance of the network. Hence, the protocols that are designed for WSN's should be extremely energy efficient so as to prolong the lifetime of the sensors in turn extending the lifetime of the network.

2. Location of Sensors

In precision agriculture, nodes are generally static. Most protocols assume that sensors are either attached with GPS transmitters/receivers or they use certain kind of localization techniques in order to learn about their positions.

3. Scalability

Protocols must be designed to support scalable network. Scaling may be in terms of number of sensor nodes or the area of the field.

4. Deployment

Deployment of sensor nodes in WSNs is function dependent and affects anyprotocol's performance. Sensor nodes may be scattered randomly or may be placed in grid fashion or may be in uniform topology. Clustering protocol should ensure the uniform distribution of cluster heads throughout the network.

5. Data Aggregation

Data aggregation techniques are being used for achieving energy efficiency and to optimize data/message transfer in the routing protocols. Also, since packet loss increases with increases in packet payload size, payload size should be kept as minimum as possible [3].

The proposed Cluster Head Tree (CHT) Protocol has the following features:

3. 1 Basic Features of the Proposed Protocol

- Every node has a distinct ID.
- The base station has the ID 0.
- Base Station has infinite amount of energy.
- All the sensor nodes are capable of sending and receiving data by adjusting their transmission power.
- All the sensor nodes have the ability to put themselves in sleep state when no data is available to transmit.
- All the sensor nodes may or may not be in the communication range of the base station.
- All the sensor nodes are static.

3. 2 Cluster Formation

A random based algorithm is used to choose cluster heads similar to LEACH. It guarantees that a node can become cluster head only once in 1/P rounds where P is the probability of number of cluster heads. A random number is chosen between 0 and 1. If for a node belonging to set G in a round that random number is less than the Threshold T(n), then that node becomes the cluster head. G is a set of nodes that haven't been a cluster head in 1/p rounds. During the first round, each of the nodes has a chance of becoming a cluster head with probability p. Cluster Head nodes then advertise them.

And the Non-Cluster Head nodes then decide which cluster to join on the basis of Received Signal Strength Indicator (RSSI).

3. 3 Tree Formation

All the cluster heads in the network form a tree as in Cluster Tree Protocol (CTP). Tree formation process consists of the following phases as**Link Estimation**, **path selection** and **Forwarding**of data.

- Link Estimator is for estimating the communication quality between two adjacent cluster head nodes.
- Path selection phaseuses the information provided in the link estimator phase to select a node through which data forwarding to the root node may occur with least cost.
- Forwarding phase forwards the data from the cluster heads to the base station through the path selected in the previous phase.

4. RESULTS AND ANALYSIS

The proposed protocol is implemented in TinyOS which is a free and Open-Source Operating System designed for wireless devices [5]. TOSSIM simulates entire TinyOS applications [6]. It is a Command Line Interface (CLI) Simulator. TOSSIM supports two programming interfaces: C++ and Python. Python programming interface has been used for simulations.

JTOSSIM is a Graphical User Interface (GUI) Simulator. Underlying architecture is same as that of TOSSIM. PowerTossimZ is a plugin which models energy consumption[8]. It is an improvement over PowerTossim. It is based on a trace model.

Simulation Parameters

The default micaz energy model of PowerTossimZ is used for the simulation. The sensor nodes are deployed in a random topology.

- Total number of nodes =32
- Simulated Seconds =300 (5 minutes)
- Mote Battery Starting Energy =21600000mJ

VOLTAGE	3. 0 V
CPU_ACTIVE	8. 93 mA
CPU_IDLE	4. 93 mA
CPU_POWER_DOWN	0. 0003 mA
CPU_POWER_SAVE	0. 009 mA
CPU_STANDBY	1 mA
CPU_FREQ	7382800 Hz
RADIO_TX	17. 4 mA
RADIO_RX	19. 7 mA
RADIO_OFF	0 mA
LED	2. 2 mA
SENSOR_BOARD	0. 69 mA

Relationship between varying probabilities and the number of sent packet, received packets and packet loss is indicated in Fig. 6.

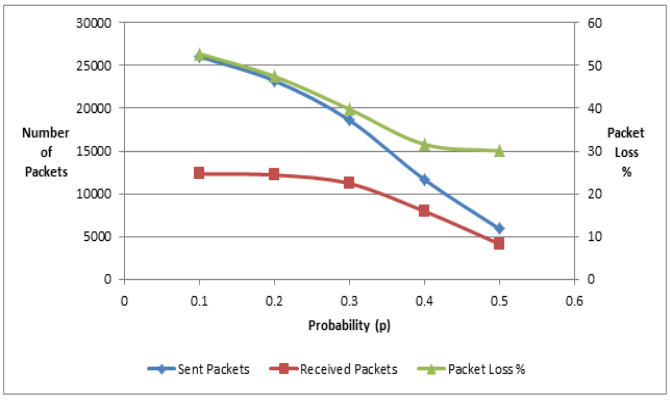

Fig. 6: Packet loss for varying probabilities

It can be seen that, as the probability is increased, the number of clusters will increase and so as the number of cluster heads. Hence the number of member nodes per clusterin the network decreases. As a result, the number of packets sent to the cluster heads per cluster decrease considerably. Percentage of Packet Loss isalso decreased as a result of reduced interference and collision in intra-cluster communication.

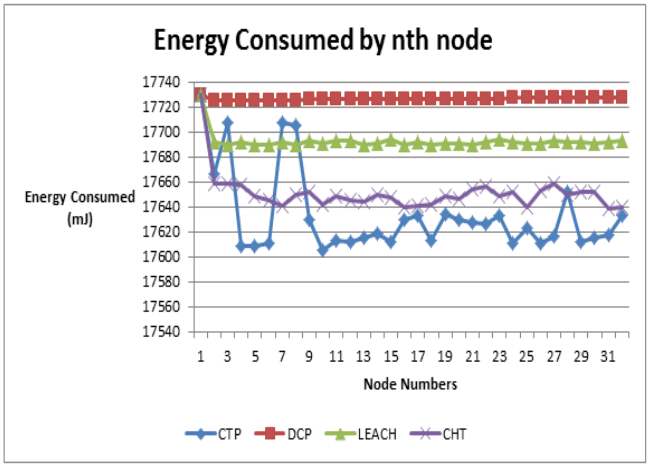

Fig. 7: Avg. Energy consumed by nth node

As shown in Fig. 7 average energy consumed by nodes in LEACH is lower than that of DCP but higher than that of CTP. In both analogies, distance comes into factor. Nodes in DCP directly communicate to the sink node resulting in higher energy consumption. CTP is more effective because of the comparatively smaller distance that the data has to be transmitted by the children nodes to their parents. But the standard deviation of the energy consumed by the nodes in CTP is higher which is shown in Fig. 8. The proposed protocol CHT has a better standard deviation of energy consumption in comparison to CTP and lower energy consumption in comparison to DCP and LEACH as shown in Fig. 7.

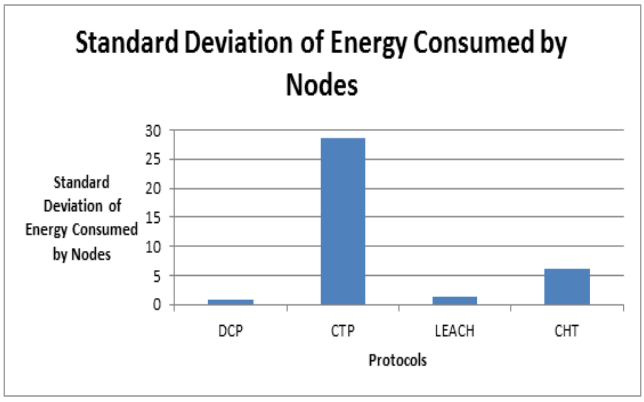

Fig. 8: Standard Deviation of Energy Consumed by the nodes

The standard deviation of the energy consumed by the nodes in different protocols is indicated in Fig. 8. This explains that the energy consumed by the sensor nodes in LEACH is more even. This will prevent the some of the nodes to die out more quickly. However, the average energy consumed by the sensor nodes in LEACH is higher than that of CTP. From Fig. 7 and Fig. 8 it can be concluded that CHT results in a better solution in comparison to the existing protocols.

4.1 Visualization using simulator JTOSSIM

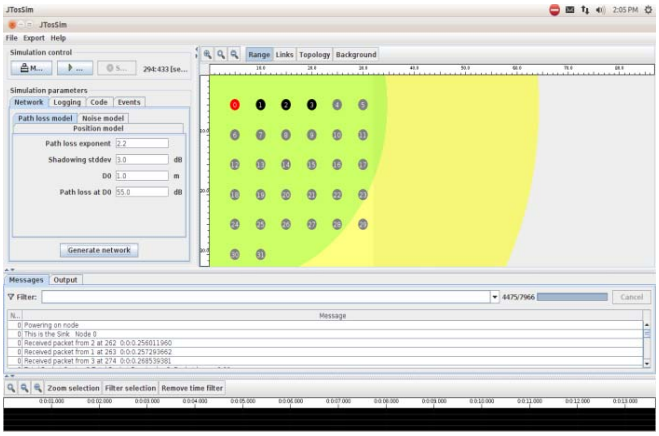

Fig. 9: A field of 32m x 32m with 32 nodes deployed in Grid fashion.

5. CONCLUSION

In this paper, we considered the existing protocols for implementing in WSN for precision agriculture. The vast field size, real time working, and energy consumption of the nodes are some of the challenges considered while designing the protocol. The existing protocols either fail to provide a longer network life time due to higher energy consumption or fail to distribute the per node energy consumption uniformly. This may result insome of thenodes dying out more quickly. The proposed protocol CHT maintains balance between energy disparity and energy consumption. Formation of tree of the cluster head nodes will result in lessening the distance for transmission, thereby resulting in less consumption of the energy and a longer network life time.

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