Cost-Effective, Energy-Aware, Hierarchical-Based routing algorithm for WSN in Precision Farming

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***Abstract*—Precision Farming (PF) involves parameters monitoring related to different agricultural systems. This control is mainly based on intelligent techniques such as Wireless Sensor Networks (WSN) which can provide periodically data reports via the wireless communication relating sensor nodes to each other. However, sensor nodes are energy constrained and limited to their remaining battery power. Therefore, prolonging their lifetime is consequently an issue to be highly considered. The communication between the nodes including transmissions and receptions is the major source of energy waste. The purpose of this paper is to design an energy aware routing algorithm for a WSN deployed in an agricultural system. This algorithm takes in consideration the requirements of a typical PF system and merges them with power management techniques to get the nodes' lifetime extended.**

***Index Terms*—Precision Farming, Wireless Sensor Network, lifetime, energy-aware, routing algorithm.**

I. Introduction

Precision Agriculture [1] has a major contribution in everyday people livelihood as it provides food production. It intervenes by an important grant in the economy of each country. Progression in agriculture affects directly the nation's state and enhances its status relatively to others.

Consequently, a particular care has to be accorded to the techniques used in automated farming in order to improve the quantity as well as the quality of crops and animals to be competitive with other agricultural products abroad. To do so, these products should be controlled and placed in very precise climatic and environmental conditions. Many parameters have to be monitored in order to avoid threatening the harvest. In fact, the need for an intelligent monitoring and control of physical phenomena such as temperature, pressure or brightness is essential for many agricultural and food industry applications. In the past those monitoring systems have transmitted their data to a base station over a wire. Although it can lead data to the adequate destination, wiring is expensive and cumbersome. It may cause maintenance effort and the wired solution itself is not flexible considering changes in the system. Today, thanks to recent advances in wireless technologies, new products based on WSN [2] are used to collect environmental data.

The data collection process has to be efficiently realized because the sensor nodes are energy constrained. Replacing batteries by new ones is very costly especially in large-scale fields where the deployment of sensors is very dense. The maintenance effort would be very high. The adequate management of the communication between nodes is then the best solution to conserve power and extend the lifetime of the whole network.

One of the most important aspects for communication is the routing task. It is responsible of all transmissions and receptions. Routing answers the question which node should be used next for the transmission [3]. This destination should be the least power consuming, more accurate, reliable and quicker than others. Finding the best path to the destination contributes to the conservation of a significant power amount as well as to a balanced-distribution of the power loss between nodes. Therefore, the better the routing is realized, the less expensive the system becomes.Throughout this paper, the interest is oriented to the creation of a compromise between energy conservation and accuracy in the designed algorithm. The main contribution of this paper is to enhance the fact of minimizing the communication wastage by routing hence reducing the cost of replacing the batteries.

The plan of the paper is distributed into five sections. In the second part, a brief overview of the state of art of routing protocols used in PF in the literature is given. In the third section, a detailed description of the proposed approach is shown. Simulation results prove the efficiency of the new routing method. This paper is enclosed by a comparative study with other existent energy aware protocols to prove the performance of the proposed algorithm. At the end a conclusion and outlook for future work are given.

II. Related Work

PF [4] includes three types of systems, which are fields, greenhouse and animals monitoring. Many efforts have been taken to monitor agricultural parameters such as temperature, moisture, humidity, etc. In fact, Corke et al. deployed 30 sensor nodes spaced 10 meters from each other [5]. The transmission occurs every half hour in a clustering topology providing information about Soil, pH, temperature, moisture, salinity, Ambient light, etc. Riquelme et al. chose to control the previous parameters already mentioned except that the transmission is done every hour [6]. It used a star topology in which 24 nodes communicate directly with the base station. The thresholds used in some transfers are: For the salinity in the range 2–4 mmhos/cm, the temperature goes from 10°C to 24°C and the humidity range is between 60 and 90%. In another agricultural project, AbdElkader et al. monitored a field of potatoes in Egypt [7]. Mika nodes are placed in a distance of 10 meters. It aims to control the crops from pests' damage in order to improve their quality as well as their quantity. Tik et al. deployed the network in a 640m² covered greenhouse to monitor temperature, light intensity, acidity and salinity [8]. The space between two nodes is below 50 m. 70% of the packets have been delivered successfully during one month.

All of these examples suffer from problems of packet errors, bottleneck nodes, limited energy resources, power consumption, bad weather conditions, etc. To avoid such obstacles, their focus was oriented to improve the routing process. Indeed, huge gains are to be harvested if the data is intelligently circulating from the sender to the receiver. These gains are in terms of accuracy, power consumption thus cost reducing. As Figure 1 shows, energy aware routing protocols can be classified according to three criteria which are network organization, route discovery and operation mode [9].

The operation concerns the mode of communication within the network and how the process of transmitting data takes place. It may be following an order from the BS. This is called Query-based operation. The route discovery depends on how often should the information be transmitted to the BS. Some protocols need to collect data periodically. They are called proactive. Others just want to get information if there are emergency situations. According to the application requirements, both proactive and reactive aspects can be merged in the same algorithm to constitute a hybrid protocol. The network organization encloses the hierarchy of data circulation from one node to another. This aspect is among the most important factors to manage the energy dissipation. In large scale networks, information should pass intelligently between the motes in order to guarantee its arrival to the adequate destination with minimum cost, less latency and without error.

For instance, AbdElkader used in [7] APTEEN [10], which is a hybrid query based clustering protocol [11] to fit the needs of its field. According to many researches, it is advisable to use the clustering topology when the focus is on reliability

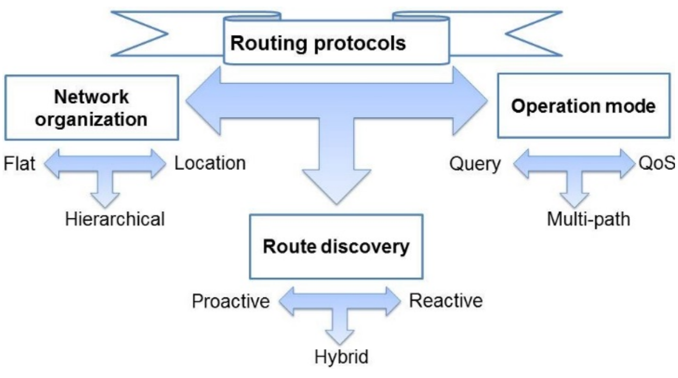

Fig. 1. Classification of routing protocols

and minimization of the power waste in large scale networks. Clustering is dividing the network into groups and elects a Cluster Head (CH) for each group. The CH is a coordinator between its group members and the Base station (BS). It aggregates the data from its referring nodes according to a TDMA [12] schedule and sends them to the BS. Each cluster member undergoes successive wake up and sleep cycles determined either by the CH or by the BS. The election of the CH is the most crucial process in such kinds of protocols. At this level, the differences between the existent protocols occur. There are many features to be considered in making this choice such as the node having the biggest residual energy amount or the nearest to the BS. It may be a compromise between both of distance and residual energy as it can be randomly chosen. Table 1 sums up these criteria, their advantages and their drawbacks.

III. Hybrid Energy-Efficient, Hierarchical-Based Routing Algorithm

A farm can be composed of many agricultural systems as already mentioned. The requirements of each one of them differ from others and may depend on specific parameters.

A. Network Achitecture

In the last section it has been shown that hierarchical-based protocols are more efficient in terms of energy management [17] as they minimize the amount of losses. The data aggregation and TDMA scheduling contributes to the prevention of wastages. A possible architecture of the deployment and communication process is given in figure 2. There are three sub-BS for each monitoring case. Each sub-BS collects data and sends them to the central BS. The BS transmits them to a distant Data server and to a user application to make the farmer able to monitor his farm from his computer. All the BSs are powered via solar panels as an energy harvesting device in order to have enough energy to be able to manage the huge data flow coming from the sensor nodes. Clusters are formed and CHs are elected according to a routing algorithm that is explained later in the next section. CHs aggregate data from the cluster members then send them to the sub-BS to which they are belonging to.

The algorithm should suit the needs of PF. First of all, the focus is oriented to the requirements of PF. Sensing the environment from time to time to get a report about the states of crops for example is indispensible. Moreover, there are some changes in the sensed attributes that should cause an alert immediately. Also, a tradeoff control between power monitoring, response time and accuracy should take place. So, the algorithm ought to be hybrid to support both proactive and reactive features. The time count Tc which designates the time separating two data collection cycles can be changeable to fit the amendment of crops development. It means that there are parameters that do not need to be controlled every time but can be monitored once a day or once a week when plants get into a certain stage of growth. Thresholds are also flexible to be up to date of the system progress. The algorithm is partitioned into

Category	CH election parameters	Ups	Downs
Type I - LEACH [13] PEGASIS	Probability of being CH p: if a node is a CH in a round r it cannot be a CH only after n/p rounds (n: network nodes).	CHs are chosen in terms of energy dissipation distribution	Neither residual energy nor distance to BS is considered. CHs elect themselves and announce that fact. Higher energy waste.
Type II - DBCH [14]	Distance to BS and/or distance between nodes.	More efficient than Type I. Energy conservation by considering distances.	Residual energy of the nodes is non-sufficient in choosing the best CHs. Distances are non-considered.
Type III - DEEC [15]	Residual energy of nodes. Initial energy of the network.	More efficient than Type I and II. Less energy consuming than Type I and II.	The distances between nodes and to the BS are not taken in consideration. Can be improved.
Type IV - DCE [16]	Residual energy of nodes. Distance to BS and/or distance between nodes.	More efficient than Type I ,II and III. Less energy consuming.	Complexity

TABLE I
CLASSIFICATION OF HIERARCHICAL-BASED ALGORITHMS ACCORDING TO CH ELECTION PARAMETERS.

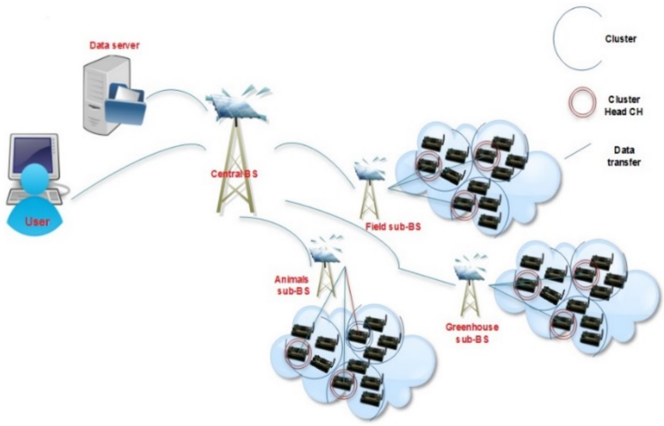

Fig. 2. Network topology.

three parts which are BS mission, CHs mission and Normal Nodes NN mission.

B. BS mission

The BS draws the cluster formation plan based on geographical inputs of the field. Then, it broadcasts the plan to the whole network. It waits until the clusters are formed. In this way, the cluster members know themselves. Afterwards, a well-defined CH election algorithm is applied on each cluster to elect the suitable node to take the responsibility of the cluster during a data collection cycle. This algorithm is defined in the next part. Once the CHs are chosen, their identifiers IDs are broadcasted to the network.

Hence, each node knows which its CH is. The BS sends a query to request data from the CHs. After data aggregation processing, CHs send packets to the BS containing data as well as the remaining energy in its battery. The aggregation permits to save also the remaining energy of each cluster member in the packet sent it to its CH. When receiving data, the BS sends it to the farmer who has a user application in its computer and it saves a report in a data server to make an archive of different states of the field.

After achieving a cluster period, the residual energy of each CH is compared to its previous amount. If the difference between these two quantities is above 3%, the BS reclusters the group. Otherwise it keeps it unchanged for another data collection cycle. This process results in avoiding power loss by avoiding the periodic clustering.

The CH election algorithm is the most important and challengeable tasks in hierarchical protocols. The differences between the implemented protocols reside in this setup phase. Since energy is the objective of this work, the residual energy as well as the distances between clusters members and between a cluster member and the BS are crucial factors. Other issues consider the distance to BS or to CH and neglect the inter-distances.

The idea of this algorithm is to sum up the distances that separate each cluster member from the rest of cluster members and the distance to the BS. Then, the ratio of the residual energy by the sum of distances, expressed in (1) is computed for each node.

$$Energy\_vs\_dist(i) = \frac{E_{res}(i)}{Sum\_dist(i)} \quad (1)$$

Where $E_{res}(i)$ is the residual energy of the node i.

It refers to an optimization problem, as indicated in expression (2), to find for each cluster the member having the maximum ratio. It is so elected as a CH.

$$CH: \quad \max(Energy\_vs\_dist(i)) \quad (2)$$
$$1 \leq i \leq n\_cluster\_members$$

If two of the nodes have equal qualifications to be CHs within the same cluster, The BS chooses the nearest node to it. It is still to define the exact mission of this CH.

C. CH mission

After receiving the plan and the query from the BS, the CH transmits to its group the appropriate parameters for the thresholds and the schedule. The schedule is supported by the TDMA protocol to avoid packets collisions. Afterwards, it demands them to collect data and send it to the CH. It aggregates and transmits this data to the BS. CHs are also scheduled basing on TDMA. If the distance between the CH and the BS overtakes the threshold, it sends a route request to other CHs. This fact may lead to some power amount conservation. A strict synchronization between the CH and NNs should be respected to avoid the problem of clock drift.

D. NN mission

After receiving the schedule from their CH, each member knows his timing and the timings of the other nodes. They sense the environment periodically and save the last sensed value. Their radios are off when it is not their time slot. Each mote wakes up when its time slot starts. It sends the last data saved in its memory to the CH.

However, in the case where there is a threshold exceeding and the node has not the right to send to its CH because it is not its time slot, the corresponding node is obliged to find another path to the BS. Also, if there are other nodes sending to the same CH and a member wants to send an urgent packet, the corresponding CH may become in bottleneck. As a consequence, there will be a waste of packets as well as energy because neither the normal nor the urgent data can reach the CH. This is what we call reactive aspect of the routing.

In this urgent case, the node should find a way to the BS, but this way should be less energy consuming. A modified version of the AODV protocol is used to remedy this situation. The AODV is based on sending packets RREQ, RREP and DATA. RREQ is sent from a node to its neighbors demanding a route to the BS. RREP is sent from the destination to the sender via a certain route. DATA is the packet containing the sensed value. RREP and RREQ consist of a reduced size. When sending RREQ, there are many paths leading to the BS. The BS tries to choose the best way in terms of energy consumption. The decision is made after attributing a weight W_{ito} each route according to equation (3).

$$W_i = \sum_{j=0}^{nbr\_route\_nodes} \frac{E_{res}(j)}{nbr\_hops} \quad (3)$$

nbr_{hops} is the number of hops characterizing each route. The BS chooses the path with the biggest W_i. If two paths have equal weights, BS selects the route with minimum nbr_hops to minimize the number of transmissions and receptions. Then, it sends directly to the corresponding node the RREP containing the route to be followed when sending DATA packet. After receiving the RREP, data can reach the destination. The NN saves the path in its routing table. Also all the nodes that form the picked path save the way to the BS.

IV. Simulation Results

The radio communication is the part the most energy consuming because it is responsible for transmission and reception. The other parts such as the processor, the sensing unit or the sleep modes consume negligible amounts.

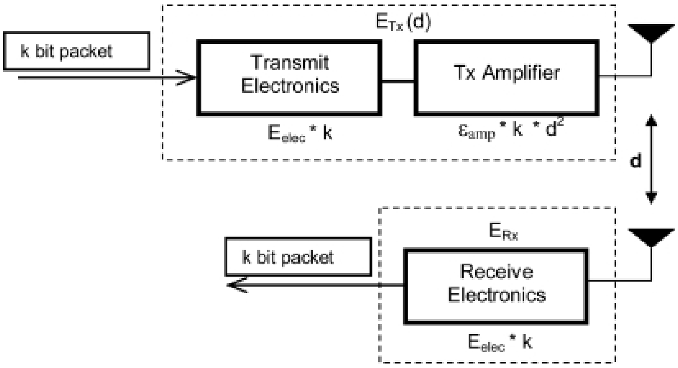

Fig. 3. Radio energetic model.

The focus is restricted by the energy for receiving and transmitting, respectively Erx and Etx, whose expressions are determined according to equations (4) and (5).

$$E_{RX}(k) = k * E_{elect} \quad (4)$$

Where k is the length of a packet and E_{elect} is the electric energy of the transceiver.

$$E_{TX}(k,d) \begin{cases} k * E_{elect} + k * \epsilon_{fs} * d^2 & if \quad d < d_0 \\ k * E_{elect} + k * \epsilon_{amp} * d^4 & otherwise \end{cases} \quad (5)$$

Where

$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{amp}}}$	The threshold
ϵ_{amp}	Multipath fading channel model
ϵ_{fs}	Free space channel model
E_{elect}	Energy consumption of the radio.

In order to study the energetic aspect of the defined algorithm as well as to compare it to other existent algorithms, 100 sensor nodes are deployed randomly in a 100*100 m² field. The evaluation criteria are in number of three; the network energy dissipated during the rounds (data collection, transmissions and receptions), the evolution of the number of dead nodes in each round and the number of packets received by the Base Station. Simulation results are presented in the figures 4-6.

The first node depletes its battery after 1500 rounds whereas the last node went offline after 3600 rounds. The packets transmission flow is important with this algorithm. Other protocols from the literature are simulated in the same conditions, the same initial variables declarations of the already proposed algorithm. These protocols are from different types; LEACH referring to type I, DEEC from type II and DBCH from type III. The lifetime (stability period) and the accuracy (number of transmitted packets) are the main factors that make the difference between all the mentioned algorithms and judge which one of them is the most performing. The results are recapitulated in the table 2.

The values are expressed in terms of rounds. A round is a data collection cycle. T_c is the time count that separates two

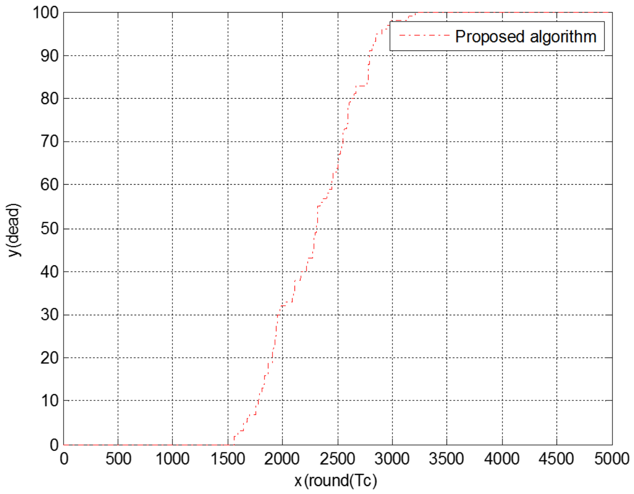

Fig. 4. Dead nodes.

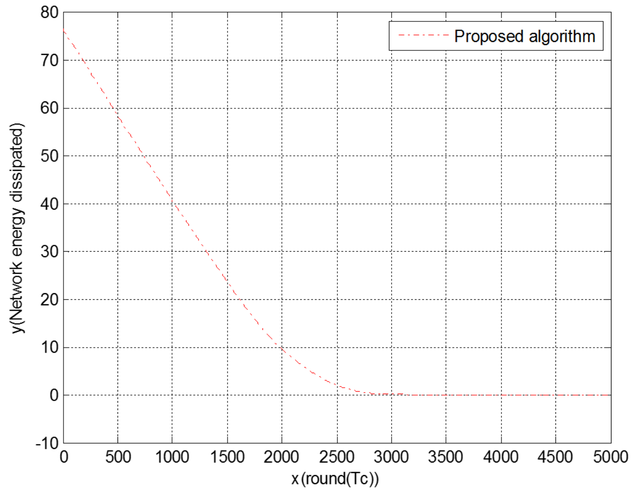

Fig. 5. Network energy dissipation.

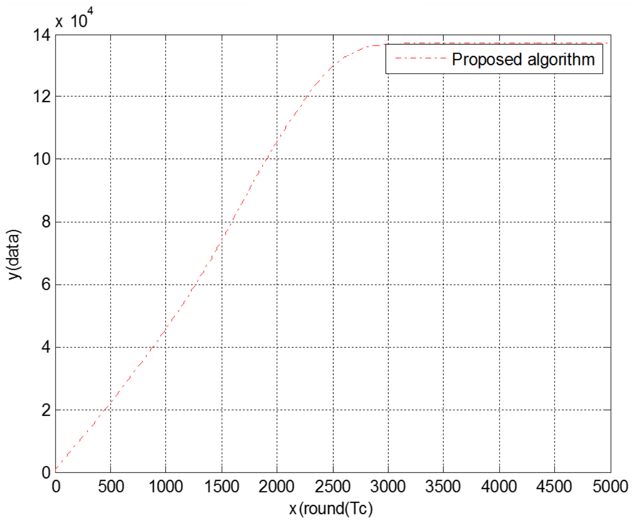

Fig. 6. Packets transmitted.

Algorithm	Stability time (First node death)	10% dead nodes	Lifetime (Last node death)	Number of transmitted packets
LEACH (type I)	965	1186	2344	$1.5 \cdot 10^4$
DEEC (type II)	1173	1287	2345	$4.7 \cdot 10^4$
DBCH (type III)	1057	1300	2394	$2.7 \cdot 10^4$
Proposed algorithm (type IV)	1502	1774	3421	$13 \cdot 10^4$

TABLE II
PROTOCOLS PERFORMANCES IN TERMS OF STABILITY PERIOD, NETWORK LIFETIME AND TRANSMITTED PACKETS.

successive rounds. It is larger in our protocol compared to others.

The proposed algorithm presents many performances compared to other existent protocols in terms of energy consumption, network lifetime, transmitted packets and stability time.

V. CONCLUSION

Throughout the paper, the requirements as well as the constraints of a typical PF system are educed. Energy management, accuracy and reliability are among the most demanding needs to be provided. Routing should then guarantee these features.

The proposed algorithm is hybrid and hierarchical-based. It is hybrid to accommodate both active and reactive aspects. Therefore, it gives data reports and responds immediately to urgent situations. The hierarchical-based organization is to provide the energy efficiency via data aggregation and successive sleep periods.

Some features of the proposed protocol are studied and simulated. They are related to the energy dissipation, network estimated lifetime, stability time and packets transmission. The comparison with other existent algorithms reveals a remarkable outperforming and shows very acceptable outputs in terms of energy management and reliability. This fact ensures the efficiency of the routing protocol.

As future work, a real implementation of an automated irrigation system and a real application of the routing process will be realized.

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