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► **To cite this version:**

Chaima Bejaoui, Alexandre Guitton, Abdennaceur Kachouri. Efficient data for monitoring rice field based on WMSN. ACS/IEEE International Conference on Computer Systems and Applications (AICCSA), ACS; IEEE, Oct 2017, Hammamet, Tunisia. hal-01574727

HAL Id: hal-01574727

<https://hal.science/hal-01574727>

Submitted on 16 Aug 2017

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Efficient data monitoring of rice-fields based on WMSN

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Abstract—Wireless Multimedia Sensor Network (WMSN) can be well suited in precision agriculture especially in rice fields to increase productivity and reduce risks. Real time data are collected from scalar, audio or video sensors to monitor the rice fields and to help farmers in the rice cultivation cycle. In this paper, a new clustering based routing protocol and an integer linear program was proposed, that balances the number of nodes in clusters. It aimed to balance the number of members in each cluster in order to reduce intra-cluster congestion as well as the number of congested cluster-heads and provide efficient multimedia data. Simulation results indicate that our proposed scheme outperforms other protocols proposed in the literature in terms of lifetime, number of members per cluster and the forwarded packets per CH.

Index Terms—WMSNs, precision agriculture, congestion, balancing clusters, ILP.

I. INTRODUCTION

The transition from traditional agriculture to precision agriculture improve the quality of production and reduce many diseases in plants. The precision agriculture has several applications such as irrigation, monitoring field, measuring water temperature and humidity sol. We are interested in this work, in monitoring rice field.

Wireless Sensor Networks (WSNs) can built solution to overcome many problems for farmers [1]. It is characterized by a simple and inexpensive architecture that can be uses in rice field. Many sensors are distributed in the field and are connected in wireless manner in order to collect data and transmit it to a base station via Internet. Those sensors provides a real-time data (water level, water temperature, sol humidity...) from environment that help farmers to make fast and right decisions.

Wireless Multimedia Sensor Networks (WMSNs) can be also used in the context of precision agriculture. Recall that WMSNs are WSNs that sense, process and transmit multimedia data such as audio or image. Examples of precision agriculture with WMSNs include ultrasonic audio sensors to detect wild rodent in fields [2], automatic detection of diseases and certain types of insect with camera sensors [3]. The camera sensors can detect the color of the leaves, the shape of leaves of rice plants, also they can compute the height of leaves. Note that the color of leaves is often an indication of disease in

rice. Those parameters should be delivered with a variety of predefined levels of Quality of Service (QoS) aiming to transmit data according to the application requirements to ensure an efficient energy transmission, low delay, and high bandwidth.

In this paper, we are interested in routing protocols based on clusters that aim at reducing the congestion in order to have a reliable data transmission and a reduced loss rate. This is achieved by balancing the traffic load, which results in a balanced energy consumption within the network. More specifically, we focus on balancing the size of clusters in order to balance the processing load of cluster-heads (CH).

The remainder of this paper is organized as follows. Section 2 describes the related work on WSNs and WMSNs for precision agriculture, and a description of load-balancing clustering protocols . Section 3 presents the proposed protocol. Section 4, evaluates our protocol. Section 5 concludes the paper.

II. RELATED WORK

In this section, we describe some examples of WSNs and WMSNs applied to precision agriculture. Then, we present some load-balancing clustering protocols.

A. Precision agriculture with WSN

Precision agriculture presented characteristics that support the usability of WSNs technologies.

In [4], the authors proposed a real deployment of a WSN for precision agriculture in a pepper vegetable greenhouse. They designed a low cost architecture which allow farmers to collect data on temperature, humidity, or illumination, from locations previously inaccessible on a micro-measurement scale. The architecture composed by sensor nodes and base station, that was able to collect data from pepper field in order to improve the monitoring and to help farmers to increase the quality of the crop.

In [5], the authors proposed a new WSN architecture in order to monitor a rice field. The sensed data is transmitted from a disconnected static sensor nodes to a mobile nodes, which in turn transmit them to a gateway, connected to a database. This architecture help the farmers to collect data of water level for example. Also, the authors proposed a new MAC protocol

to guarantee a little possible consumption of energy of static nodes, and they proposed a delay-tolerant routing protocol to transmit data over the mobile nodes.

In [6], the authors proposed an architecture for precision agriculture based WSN with a specially type of sensors is the moisture sensors. This sensors help the farmers to measure the water quantity in the irrigation system to avoid the waste of water in the greenhouse.

B. Precision agriculture with WMSN

In [7], the authors proposed a platform named Integrated WSN Solution for precision agriculture based on video monitoring. They focus on the communication aspects of the solution. Their objective was to reduce the transmission delay, and to increase the network lifetime by reducing the energy consumption of the nodes. It is important to notice that in WMSNs, the energy consumption required by the image capture, processing and transmission is very high. This cost also increases when the crop areas are distant by several kilometers. Their solution synchronizes nodes to have them save energy periodically. The authors also proposed a mechanism to reduce the collisions caused by concurrent transmissions of large multimedia data frames.

In [8], the authors designed a system named Precision Agriculture Sensing System (PASS) that composed from both hardware and software for supervision in agriculture field without human intervention. The PASS was equipped with image sensors and physical and chemical sensors. The authors aimed to collect data about plants such as disease and growth that can not be monitor by scalar sensor. PASS used a sensors with single chip that reduce energy consumption.

C. Avoid congestion based on clustering protocols

In order to avoid congestion in network, some protocols aim to reduce the traffic rate and some others aim to balance the load between nodes or to balance the clusters in term of number of nodes. As solution in our work, we consider the works that balance the number of members per clusters. The equal size clustering protocols reduce congestion within clusters and avoid congested CHs, as they reduce the redundant packets and thus alleviate the load, which increases the network's lifetime and ensures reliable transmission of multimedia data.

In [9], the authors proposed a protocol called Balanced Clustering Algorithm (BCA) that aims to reduce the collision ratio between clusters as well as the number of nodes that communicate directly to the sink. It uses three phases: the first is for node density detection, the second is for cluster construction, and the third for data transmission. During the node density detection phase, nodes send their advertisement message randomly in broadcast. During the cluster-head election phase, BCA uses a threshold $\bar{T}(n)$ and a specific formula of neighbor detection. BCA reduces the energy consumption by using the duty-cycle in the steady-state to make nodes sleep.

In [10], an Optimized Algorithm for Balancing Clusters (OABC) was proposed that aims to balance clusters in order to reduce energy consumption. It uses two phases for cluster-head election, and one phase for data transmission. In the cluster-head election phase, OABC elect temporary cluster-heads (TCH). And in the data transmission phase, CHs are elected based on the TCH. The nodes which receive messages from two TCHs or more are candidate to become CHs. A probability based on the residual energy and the overlapping degree is computed to elect CHs, so each elected CH announces the nodes within $2R$ (where R is the communication range), to avoid that two adjacent nodes become CHs. TCHs that do not receive messages from a CH elect themselves as CHs. Then, all CHs send messages over the network to announce their final status. The non-CH nodes join the nearest CH, which in turn creates a TDMA schedule and sends it to its members.

In [11], the authors proposed a clustering method for equal size clusters. Their clustering phase is composed from two steps: the initial formation step and the transmission step. They used the same CH formation step and they use the same schedule calendar as LEACH [12] to send data. The authors used a threshold for the number of members per cluster, and this threshold is updated at every round. Nodes join the closest CH with the highest RSSI. If the selected CH has fewer members than the threshold, the node joins this CH and waits for the transmission step. A distance threshold is used to ensure that nodes join CHs that are closer to them. Figure 1 explains more the different phases proposed in [11].

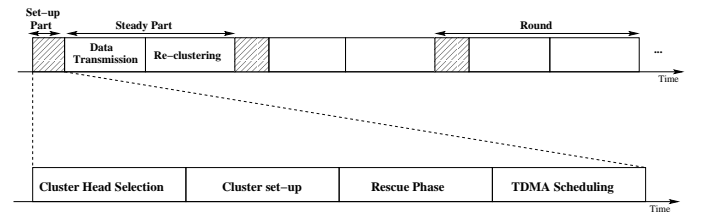


Fig. 1. Operating diagram of protocol cited in [11].

III. PROPOSITION

In WMSNs, CHs receive and aggregate multimedia data from all their members. Thus, their load and energy consumption is related to the number of their member nodes. Subsequently, we propose an optimal cluster-head election algorithm and our algorithm.

A. Optimization by Integer Linear Program (ILP)

In order to compute the optimal number of members per cluster, we decided to model the problem as an ILP that takes as input the whole network topology and the number of cluster-heads. The objective function and the constraints of our ILP program are summarized below.

minimize MCUR

$$\forall n \in N, \sum_{v \in N} (1 - f(n, v)) \geq 1 \quad (1)$$

$$\forall (n, v) \in N^2, f(n, v) \geq 1 - neighbors(n, v) \quad (2)$$

$$\forall (n, v) \in N^2, f(n, v) \geq 1 - CH(v) \quad (3)$$

$$\forall (n, v) \in N^2, f(n, v) \leq 2 - neighbors(n, v) - CH(v) \quad (4)$$

$$\forall n \in N, \sum_{n \in N} CH(n) \leq \alpha \quad (5)$$

$$\forall n \in N, \sum_{v \in N} member[n, v] = 1 \quad (6)$$

$$\forall (n, v) \in N^2, member[n, v] \leq 1 - f(n, v) \quad (7)$$

$$\forall n \in N, member[n, n] = CH(n) \quad (8)$$

$$\forall v \in N, NMC(v) = \sum_{n \in N} member[n, v] \quad (9)$$

$$\forall n \in N, MCUR \geq NMC(n) \quad (10)$$

The inputs of this model are as follows: N is the set of nodes, and $neighbors(n, v)$ represents the adjacency matrix of the topology. The variables we use are: $CH(n)$ which indicates whether n is a CH or not, $f(n, v)$ is equal to 0 and only if n is a CH and v is neighbor of n , and the function $member[n, v]$ indicates whether n and v are neighbors or not.

$NMC(n)$ represents the number of members for the CH n , and α is the maximum number of CHs in the network.

Our objective is to minimize MCUR, which is the maximum number of members for any CH.

The constraints of our program are as follows: Constraints (1), (2), (3) and (4) model the fact that each node is either a CH or a neighbor of a CH. Constraint (5) indicates that the number of CHs should not exceed the value of α . Constraint (6) indicates that each node in the network is associated with exactly one CH. Constraint (7) ensures that a node cannot have as its CH as node that is neither its neighbor nor a CH. Constraint (8) indicates that a CH is considered as its own member. Constraint (9) calculates the number of members per CH. Finally, Constraint (10) computes the maximum number of members for any CH.

B. Our algorithm

Our solution aims at reducing the number of members per cluster in a distributed manner. It adds a new period to the election phase of [13] called balancing phase, to balance the size of clusters using a Force-Join message.

In [13], the authors modified the CH election method of LEACH in order to reduce the number of adjacent CHs and to eliminate the isolated nodes (which are nodes without CH). In their election phase, the nodes do not send their advertisement (ADV) messages simultaneously but after a random delay. Thus, if a neighbor receives more than th ADVs before

sending its own ADV, it decides to become a member. In their join phase, the nodes that did not receive any ADV message, called isolated nodes, decide to become CH or member of a new CH (as isolated nodes become CH in the join phase) in order to maintain connectivity over the network.

Algorithm 1 Balancing members

Require: m_{CHc} , m_{CHmin}
wait for random delay
find $CH_{neighbor}$ with $min_{members}$
if $m_{CHc} \leq m_{CHmin} + 2$ **then**
send message FORCE-JOIN to CH_{min}
end if

Algorithm 1 describes the procedure used by members to balance nodes in clusters. m_{CHc} represents the estimation of the number of members for the current CH of the node, and m_{CHmin} represents the estimation of the minimum number of members of a neighbor of the current CH.

After a random delay, the member of CH finds a neighbor CH with the minimum number of nodes. It compares the number of nodes of the current CH with the number of members of CHs found in the neighborhood plus 2 ($m_{CHmin} + 2$). We use this inequality to ensure that one CH with the most members does not have less than its neighbor after donating members. If the inequality is valid, a FORCE-JOIN message is sent after a random delay from the member to its new CH.

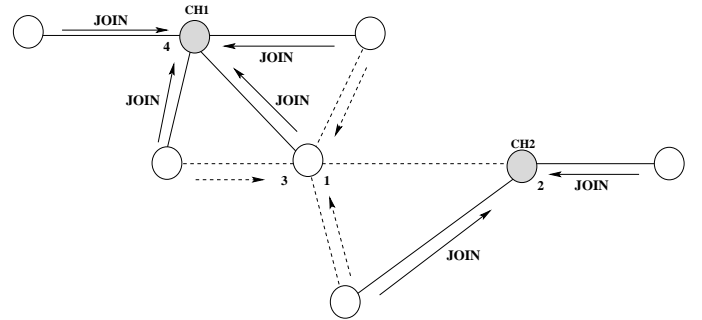


Fig. 2. Example of balancing of two clusters.

Figure 2 shows an example of balancing two clusters. The continuous arrows represent the JOIN message, and the discontinuous arrows represent the JOIN message heard by nodes. Indeed, the node n sends a JOIN message to CH1, but over it has to know about the CHs in neighboring area. It receives the other JOIN messages, and it identifies that CH1 has three members while CH 2 has only two members.

IV. SIMULATION RESULTS

In this section, we present both the simulation results and their analyzes. We compare the performance of our proposition with the protocol cited in [11]. We used the NS2 [14] simulator for our comparison. Each result is averaged over 100 repetitions. We deploy 10, 20 and 30 nodes in an area of 100 m x 100 m. We use the MAC layer of 802.11. The initial

energy of each node is 1 joule.

In our simulation, we evaluate the percentage of network lifetime based on the first node die, the number of members per cluster and the forwarded packet per CH. Figure 3 shows the

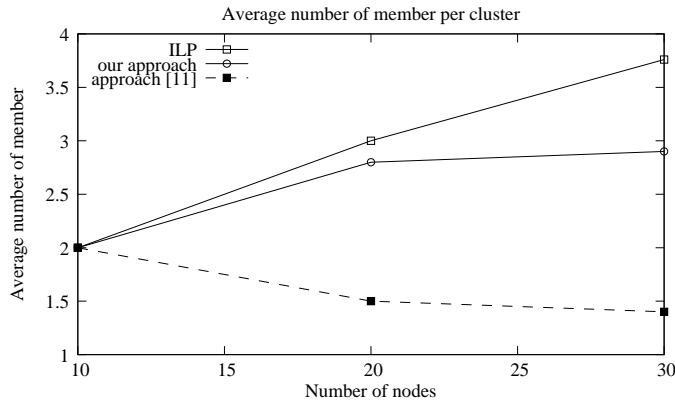


Fig. 3. Average number of members per cluster.

average number of members per cluster for different number of nodes for our proposal, approach [11], and the ILP program. Since the ILP and our approach have less CHs than the other approach, so we have more members but with balanced clusters. We notice that the result of our proposal is near the optimal result.

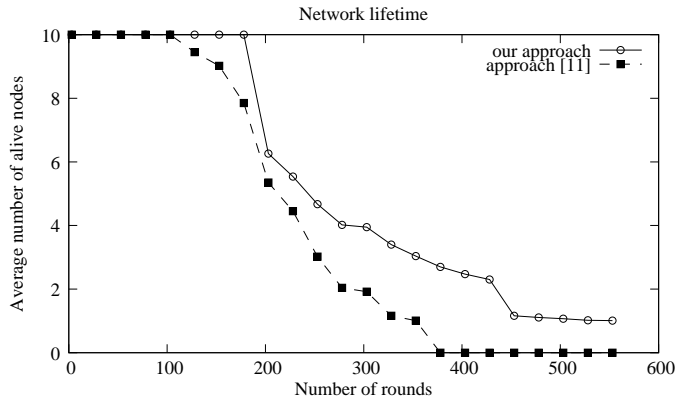


Fig. 4. Network lifetime.

Figure 4 shows the number of rounds as function of the average nodes alive for our approach and the approach [11]. We can see that the first node death in our approach occurs several rounds after the first node death in the other approach, so our method prolongs the network lifetime compared to [11]. Our stability period (that is, the time interval between the start of operation of the network and the death of the first node) is longer than with [11], by approximately 20%. This improvement is mainly due to the balanced clusters and the decrease in the number of control messages.

Figure 5 shows the average forwarded packet per CH as function of the number of nodes. Our method present less number of packet which proves that our CHs are less congested and the data is distributed between nodes due to the balancing

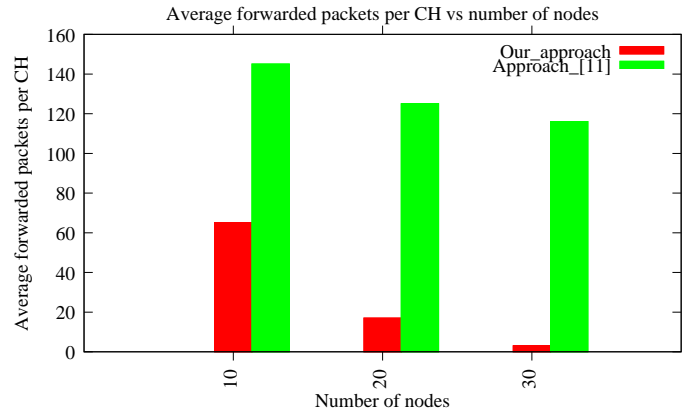


Fig. 5. Average forwarded packets per CH.

clusters.

Our approach presents a high performance in terms of network lifetime, the balanced clusters and the congested CHs.

V. CONCLUSION

In this paper, we discussed the precision agriculture with WSN and WMSN, and the protocols that avoid congestion in WSN. We proposed an integer linear program to compute the optimal number of members per cluster and we designed an approach that balance the number of members per cluster in order to reduce congestion in Wireless Multimedia Sensor Networks. Simulation results show that our work presents a significant improvement during the reduction of number of forwarded packet in the CHs and it presents a less congested CHs. Also, it increases significantly the network lifetime (for 10 nodes) compared with approach [11] and it presents a longer stability period by 20%. This improvements are due to the balanced clusters.

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