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Intelligent Wireless Sensor Network Management Based on a Multi-Agent System

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***Abstract*—The main goal of wireless sensor networks (WSN) is to gather data from their environment. This gathering should take into consideration the life of the battery of each sensor node to maintain the continuity of the network. The technology of multi-agent system (MAS) can be adopted in large scale WSN for reliable wireless communication with high energy efficiency. In this paper, we propose a scheme for data collection based MAS for sensor networks based on clustering with the use of a mobile agent to collect data according to a routing scheme. The main idea is to assign nodes to the data processing function rather than providing data to the base station (Sink). For this, an agent is introduced into each node of the network to process data locally and to judge their importance to remove any irrelevant redundant data. Then, the nodes are clustered together, each consisting of a Cluster-Head. The latter will then determine a scheme for the nodes belonging to the same group, using the Local Closest First (LCF) algorithm. In addition, for the agents (nodes) in a cluster cooperate to eliminate inter-node data, we propose a mobile agent (MA) sent by the Sink to collect data between the cluster nodes according to the LCF itinerary. Successive simulations in large-scale WSN with different densities show the capacity of the proposed collecting regime to extend the lifetime of the network in terms of energy consumption and the rate of packet delivery.**

***Index Terms*—Wireless Sensor Network, Data Aggregation, Multi-Agent Systems, Energy and Communication**

I. INTRODUCTION

ADVANCED and integrated technologies in the field of wireless networks, micro-fabrication and integration of microprocessors have created a new generation of wireless sensor networks (WSN) adapted to a varied range of applications.

A WSN consists of a set of nodes that can collect data from a monitored environment and transmit it to a base station (Sink) via a wireless medium. The WSN are often characterized by a dense and large-scale deployment in environments with limited resources. The constraints are the limited processing, storage and energy capacity especially that they are usually powered by batteries. The size constraint of a sensor node requires designers to limit the size of the battery and therefore the amount of energy available. Replacing a battery is rarely possible, for reasons of cost or constraints due to the environment. Therefore, management of energy consumption during operation of the nodes is vital for the network.

Hence, unlike traditional networks concerned with ensuring a good quality of service, the WSN should give importance to the energy conservation. It is widely recognized that energy limitation is an unavoidable issue in the design of WSN because it imposes strict constraints on network operations. In fact, energy consumption of sensor nodes is determinant in the lifetime of the network, which has become the dominant performance criterion in this area. If we want the network to operate satisfactorily, and as long as possible, the energy constraints require a compromise between different activities at both the node and network levels.

Several research studies have emerged with one objective: to optimize the energy consumption of nodes using innovative conservation techniques to improve network performance, including the maximization of its life. In general, energy conservation is ultimately to find the best compromise between the various energy-consuming activities. The field-related literature recognizes that the WSN data transmission is a prominent consumer of energy, because the majority of works stretched to techniques for the reduction of energy consumption due to data transmission.

One method for minimizing energy consumption is the Cluster technique; it is used to partition the network into groups with a Cluster-Head (CH) for each. It supports data exchange with the base station, by receiving the data collected from all nodes in their cluster and sending them to the Sink.

During the last decade, the multi-agent systems (MAS) have blossomed and are applied to various fields such as simulation and artificial life, robotics, image processing. MASs are integrated into the WSN, because of their intelligence and adaptation to the field. Ant colonies, spiders, etc., are examples of MAS applied to the WSN for the captured data processing, as well as routing, and the detection of the shortest paths, etc.

Integrating Mobile Agent (MA) in the WSN solves several problems that can harm the WSN. Indeed, it can be used to significantly reduce the cost of communication, particularly the elimination of redundancies, by moving the data processed by an agent introduced in each node instead of bringing them in their raw state to the Sink by the node itself.

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In this work, a system capable of simulating a network of wireless sensors in the environment, to minimize energy dissipation will be developed. Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm is applied to decompose the network into clusters, with one head for each. The main purpose of this technique is to collect the data by a mobile agent and to send them together to minimize the transmission; instead of letting each node send its data via intermediate nodes. The MA system principle is also incorporated for intelligent data processing collected by the nodes in terms of redundancy reduction, importance assessment, and disposal of useless data. We also proposed a mobile agent activated by the Sink and sent to the CH. This agent will circulate in the cluster nodes in a routing scheme specified by the CH, to collect the data processed and collected by the agents (nodes). Once the agent has returned to the CH with data, the latter will, in turn, forward them to the Sink.

The rest of the paper is organized as follows: section 2 provides an overview of the literature in which algorithms for data gathering solutions to reduce the amount of data transmitted by the sensors were proposed. Next, in section 3, we describe our proposed communication strategy. Our proposed method for reducing communication overhead and data processing at the node level are described in section 4 and 5, respectively. Then, section 6 sets forth the purpose of our application, which is to establish a system to simulate the communication between a set of sensors and a base station forming a wireless sensor network. Finally, section 7 summarizes and concludes this paper.

II. Related work

The fundamental role of a node in a sensor network is to gather data from the environment. This gathering must respect the battery end of each node to maintain the network continuity. However, as advances in WSN technology enabling the deployment of the large amount of sensors that are smaller and less expensive, huge data must be processed in real time. The most energy efficient proposals are based on the traditional Client/Server (C/S), to manage the multi-sensor data fusion in the WSN. Several studies by [1]–[8] have been conducted to optimize the architecture of this model. In this architecture, when a sensor node detects environmental data, it sends them as they are through other nodes to the Sink for processing. The transmission of raw data does not eliminate unnecessary or redundant data, which requires a costly operation in terms of energy.

A number of papers have proposed algorithms for data Compression/Decompression (C/D) to reduce the amount of data transmitted by the sensors. The authors of [2], [3] proposed a correlation algorithm that compresses data in a distributed way through a WSN. In this proposal, only one node is elected to send raw data to the Sink and the other nodes only send coded data. After the Sink receives the data, it decodes them through the correlations between the compressed and uncompressed data. However, it is quite difficult to find a non-complex coding algorithm suitable for sensor nodes, and one that does not consume much processing energy.

The [4] proposed data fusion (DF) of a maximum number of sensors. When a node sends its data to the Sink, the intermediate nodes merge their data with data from the first node. Then, this data is merged into a single message instead of many, which saves energy. However, the intermediate nodes do not always have important data to send and they do not eliminate redundant or unimportant data. In addition, the authors did not take into account the importance of the scalability of such networks.

Other researchers such as [6] have shown that the clustering is a fundamental technique in WSN. Its role is to reduce the role of the nodes by minimizing data aggregation, processing, and therefore, reducing the energy required to move the load to the Sink. The clustering algorithm uses a hierarchical classification, and the nodes organize themselves into groups and elect a cluster node as leader. The latter collects aggregate data from the sensors within its group and transmits them to Sink. In this way, it achieves a significant reduction in energy consumption. Unfortunately, the authors did not address the problem of complexity and the amount of energy needed to build such clustered sensor networks.

In addition to [5], [6], [9] - [12] also proposed a structured strategy (tree cluster) based on data aggregation for the WSN. However, according to [13] and [14], structured approaches are not practical for dynamic scenarios, due to communication cost, and the excessive centralization of the WSN structure management.

Authors such as [5] proposed an ant colony algorithm for data aggregation in WSN. Each ant will explore all possible ways from the source node to the Sink. The data aggregation tree is built by the pheromone accumulated. Nevertheless, the construction of this appropriate tree depends largely on the deployment of nodes, which is typically random, and consumes a significant amount of energy. However, the Euclidean distance calculated from a source node to the Sink may not be applicable in WSN because of the limited communication range of a node.

Other researchers have proposed solutions of distributed and complex multi-agent systems on the adaptation of wireless sensor networks. The work [15] has achieved the community of artificial intelligent sensors using this system. The sensor nodes operate as autonomous agents who develop a network of intelligent sensors. The research [16] proposed a multi agent approach by which an agent is placed in each sensor node to process the locally detected data and cooperate with its neighbors. This solution does not respond to the problem of density imposed in many WSN applications.

The work [1], [7], [8] proposed the mobile agents technology (MA) in the WSN for energy-efficient data collection. In these proposals, the MA is defined as a message that contains an application code, a list of source nodes predefined by the Sink, and a void field to store the data collected.

The disadvantage of such solutions is the difficulty of creating the list of source nodes and setting the data collection start-time. Another limitation is the definition of areas to be covered by the MA. However, as a solution to optimize the route of the MA is data fusion, [17] proposed two heuristic algorithms. A randomly selected route may even lead to worse performance than the traditional Client/Server model. As far as the algorithm for Local Closest First (LCF) is concerned, the MA starts its route from a node and searches for the next destination with the shortest distance to its location. Concerning the algorithm Global Closest First (GCF), the MA starts its route from a node and selects the next destination with the closest to the center of the surveillance zone.

After analyzing the solutions presented above, we can clearly see that there are serious problems in terms of node density and the packet delivery rate.

We can also deduce that there is still much work in terms of energy efficiency, with regard to the ratio of packet delivery and network density. In addition, the solution should be independent of network deployment.

III. THE PROPOSED COMMUNICATION STRATEGY

The main purpose of our strategy is to group the nodes in a wireless sensor network into a cluster. The data for each cluster are grouped together to be sent by the CH to the sink rather than letting the node send its data through intermediate nodes.

The stage of local data processing consumes much less energy than the communication phase; the example presented in [18] actually illustrates this disparity. Indeed, the energy cost required to transmit 1KB over a range of 100m is approximately equal to that required to execute 3 million instructions at a rate of 100 million instructions per second. So it is clear and to promote better treatment of the data before transmission, to improve energy consumption in WSN. There are several clustering algorithms including: LEACH, TEEN, and PEGASE, each with different principles. In this work we chose LEACH as the most recommended algorithm for WSN.

Our strategy has been drawn as follows: an agent is introduced into each network node; it processes the data locally and judges their importance to remove any useless or redundant data. Therefore, these agents (nodes) cooperate in order to eliminate redundant and irrelevant data among different sensors. We propose a mobile agent to collect data from the cluster nodes. See Fig. 1.

The main idea is based on the grouping of nodes into clusters, and each cluster is composed of a Cluster-Head. The latter will draw a diagram of itinerary between the nodes of the group using the Local Closest First (LCF) algorithm. Once the CH receives signals from a source, it will send a message to the Sink, which will send a mobile agent to the Cluster-Head in order that the latter circulates according to the routing scheme LCF. This MA is the aggregation of data processed and collected by the agents (nodes) to go back to the CH, then to the Sink with the data collected.

IV. REDUCING COMMUNICATION OVERHEAD

A. Mobile Agent Packet Structure

Our MA is a data packet that flows through the network; it is used to collect data captured by the sensor nodes. The data contained in an MA package is shown in Fig. 2.

The two attributes SinkID and MA_SeqNum are used to identify an MA packet. Whenever the Sink sends a new MA packet, it increments the MA_SeqNum. The SrcList list specifies the node itinerary LCF to be visited by the MA. This list will be filled when the CH receives the MA packet from the Sink. In the SrcList list, the last identifier of the itinerary node (LastSrc) visited by the MA is the CH.

NextSrc specifically determines the sequence of node identifiers that must be visited by the MA. If NextSrc is equal to CH, it means that it is the last node visited by the MA (the MA, thus, ends its itinerary at the CH).

Processing Code is used to process the sensed data. Data carries the aggregated data of the nodes within the itinerary. Once the MA reaches FirstSrc, it temporarily stores its data. It is from the second node of the itinerary that the MA starts to process the data collected by comparing them with those of FirstSrc.

B. The operation of the MA in the WSN

For the MA to avoid collecting redundant data between nodes, we calculate the size of data detected and accumulated by the MA using the method used by [19]. Under this method, a sequence of captured data can be combined with a fusion factor ρ. N_i is the amount of sensed data accumulated after the MA collects the result of the node, and R_i the size of the data locally sensed processed, and that will accumulated by the MA to $node_i$. So we have:

$$N_1 = R_1 ; \quad N_i = R_1 + \sum_{k=2}^{i} \rho . R_k \quad (i >= 2).$$

Cluster-Head Algorithm

```
If CH receives a MA then
    If MA _SeqNum !=N_MA then // it is a new MA
        CH fill ListSrc and NextSrc ;
        Move the MA to the NextSrc ;
    Else
        CH sends MA to Sink ;
```

Node Algorithm

```
While MA arrives at a node_i non-CH do
    If Node_i has new data then
        If MA is void then
            N=R_1 //put data in MA packet
            NextSrc = read the new destination
            starting from ListSrc ;
            Move the MA to the NextSrc ;
        Else
            If the N_i data already exist in the
            MA packet then // Ignore data
            move to the next ones;
            NextSrc = read the new destination
            starting from ListSrc ;
            Move the MA to the NextSrc ;
            Else
                N=N+ ∑ ρ . Ri ; //Add data
                to the MA paquet
    Else
        NextSrc = read the new destination
        starting from ListSrc;
        Move the MA to the NextSrc ;
```

C. LCF Algorithm

We chose the algorithm Local Closest First (LCF) to trace the itinerary of the MA as it allows finding an optimum way to avoid redundancies, and to manipulate lists of nodes in a consistent manner. According to [17] the itinerary starts from the focal point of a sub-zone, but our strategy requires the CH to be the starting point for the packet itinerary.

```
While true do
  Switch the value of k do
    Case k = 0
      Find sensor node S with the smallest d(CHi , S) from Lij ;
      D = S ;
    Case k = n
      D = CHi ;
    Otherwise
      Find sensor node S with the smallest d(Sk , S) from the rest of Lij ;
      D = S ;
  If D is active then
      Migrate to D ;
      k = k + 1 ;
  Else
      Delete D from Lij;
      k = k+1 ;
```

V. DATA PROCESSING AT THE NODE LEVEL

The importance of data depends strongly on the nature of the application requested. This parameter can be calculated by a local treatment in the node, which allows the agent to assess the importance of the data collected.

An agent considers data as important if the latter contain the desired object, or a new event. For example, in areas such as environmental control (humidity, temperature, etc.), the agent saves the latest data gathered to compare it with newly met ones. If the difference between both is greater than a predetermined threshold, we will consider this data as important. However, the agent drops the old data and saves the recent ones; the lost data are considered as unimportant.

In our system, we use temperature as an example of environmental monitoring, where each data collected is compared with a predetermined threshold in the system, if the sensed temperature is higher than the threshold, the node labels the data as important, if not then it ignores it and labels it as irrelevant data for the network.

VI. SIMULATION SETUP

A. Purpose of the Software

For our platform we have chosen to use C++Builder. The purpose of our application is to establish a system to simulate the communication between a set of sensors and a base station forming a wireless sensor network. Our strategy is based on the cluster technique for the decomposition of the network, and on the use of multi-agent system and the Mobile Agent, which are considered as a mechanism to save energy of a WSN.

B. The Initial Hypotheses

To design our own simulator, we adopted the following assumptions:

1. At first each sensor has an initial energy.
2. The administrator chooses the number of nodes, the radius and position of the Sink.
3. The number of sensors is limited by a minimum and maximum value.
4. The positions of nodes are known.
5. Sensors can be added but before the activation of the nodes.
6. The deployment of the nodes is random.
7. Two sensors do not occupy the same coordinates.
8. After the cluster step, each node is an agent or a Cluster-Head.

We performed our simulations on a 1000m x 1000m with a random distribution of nodes over 1000 seconds. We have limited radio range and data rate of each node to 87 meters and 1Mbps, respectively, as suggested in [20]. The transmission and reception power parameters, which directly influence the radio range, were selected from the ranges defined in the system of sunspots [21].

Local processing time is 40ms. These values are based on the work done by [16].

All the simulation parameters are illustrated in Table I:

C. Results and Analysis

To demonstrate the performance of our approach consisting of a **M**ulti-**A**gent-based **W**ireless **S**ensor **N**etwork with **C**lustering (MAWSNC), we compare it to Client/Server (C/S) and Data Fusion (DF) approaches. The sensor nodes are battery powered (energy limited), except the Sink, which is supposed to have an infinite supply of energy. We assume that the Sink and the sensor nodes are stationary.

To test the scalability of our proposal and its impact on different network densities, the simulations are performed for a number of nodes ranging from 100 to 1000. The obtained results are represented in Fig. 3.

The analysis of the previous figure reveals several interesting features: First of all, as expected, energy consumption increases with the number of nodes. However, for an equivalent number of nodes, energy consumption of our approach is always less than C/S and DF approaches. Moreover, the difference between our approach and the other two begins to widen from 100 nodes (while for others, the gap starts at 400 nodes), and at 1000 nodes, energy consumption with the MAWSNC approach is 71% lower than with the approach DF, and 80% lower compared to the C/S approach.

Moreover, and in another experiment, we varied the size of data captured (Sdata) at each sensor from 0.5Ko to 4Ko. The results are shown in Fig. 4.

The first observation is that energy consumption with our approach is still lower than that of other approaches (whose curves are virtually hand in hand), regardless of packet size. On the other hand, the energy consumption for MAWSNC is lower compared to other approaches: almost 50% for small packets (0.5 Ko), 55% for medium-sized packets (2Ko), and 60% for large packets (4Ko), meaning that the difference in energy consumption is steadily worsening with the increase of packet size.

VII. CONCLUSION

In an environment where the sensor nodes are close to each other, and in which detected data redundancy is considerable, the sensor nodes generate a large amount of traffic on the wireless channel, which causes not only a loss of wireless bandwidth, but also takes a lot of energy. Instead of the traditional Client/Server (C/S) and Data Fusion (DF) approaches, where the sensor nodes send data detected in their raw form to the Sink, we based our approach on a mobile agent paradigm, and on agents at each node for the data processing, by the aggregation and elimination of redundancy in a sensor architecture based on clustering. The proposed architecture is, therefore, a multi-agent-based wireless sensor network with clustering. In terms of performance, it provides a significant gain in energy, and on large scale, a considerable reduction in costs. In addition, the proposed approach appears more successful compared to C/S and DF approaches in terms of packet delivery rate and energy consumption in dense wireless sensor networks.

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TABLE I
BASIC SIMULATION PARAMETERS

Simulation Parameters	Values
The size of the network	1000mx1000m
Distribution of the nodes	Random
Radio range	87m
Debit	1Mbps
Sensored data size per node	variable de 0.5Ko to 4Ko
Sensored data by interval	10 secondes
Simulation delay	1000 secondes
Processing time local	40ms
Size of the processing code	0.4Ko
(ρ) fusion factor	01

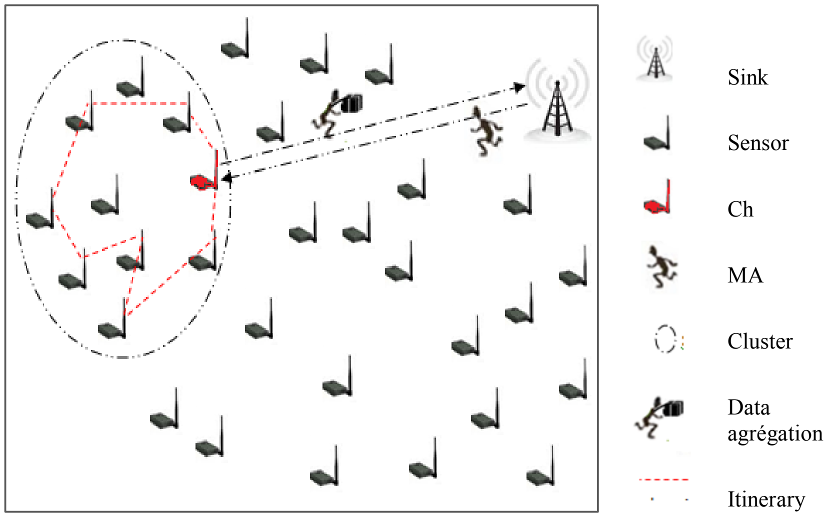

Fig. 1. Communication Architecture (itinerary planning)

SinkID	MA_SeqNum	CH_ID	NextSrc	SrcList
ProcessingCode	Data			

Fig. 2. MA Packet Structure

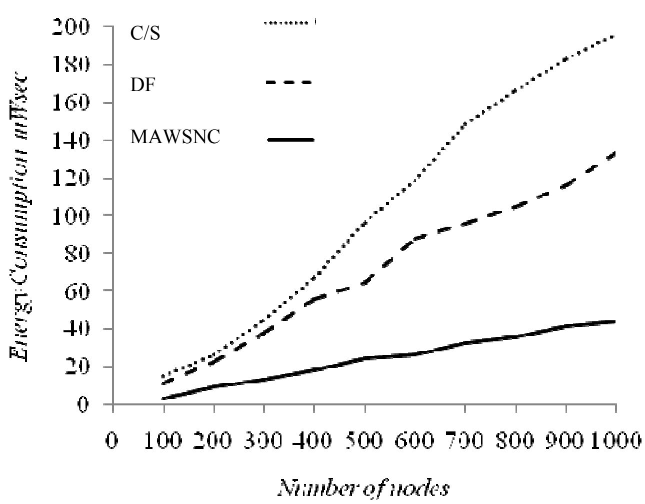

Fig. 3. Energy Consumption in terms of the number of nodes

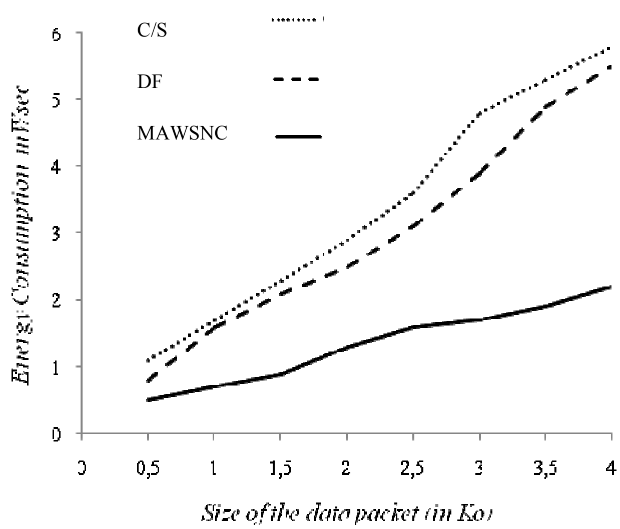

Fig. 4. Energy consumption in terms of the data packet size