A Novel Aggregation Approach Based on Cooperative Agents and Self-Stabilizing Clustering for WSNs

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***Abstract*—In this paper, we present novel ideas for an intelligent aggregation approach based on cooperative agents and a self-stabilizing clustering scheme for Wireless Sensor Networks (WSNs). This aggregation solution aims at optimizing communications by combining an efficient self-stabilizing clustering approach and an intelligent cooperative aggregation process. On the one hand, the clustering approach reorganizes the network nodes into groups of nodes (i.e., clusters) so that it minimizes communications between nodes, their cluster-head and the Sink. On the other hand, the aggregation approach reduces communications by merging and sending only pertinent information to the Sink, in a distributed way.**

***Keywords-Wireless Sensor Networks*; *Self-stabilizing Clustering*; *Aggregation*; *Cooperative Agents*;**

I. Introduction

Due to their good properties and wide applications, Wireless Sensor Networks (WSNs) have known a growing interest in both industrial and academic fields. They are used for many applications like: medical, scientific, military, environmental, security, etc. In a WSN, sensor nodes have a limited energy in their battery due to their size. This energy is consumed by three main operations: sensing, communication and processing. Communication of messages is the one consuming the highest quantity of energy for a sensor. Thus, saving communication power is crucial in a WSN. It is stated in [6] that the necessary energy power to transmit a 1 KB message over a distance of 100 meters is approximately equivalent to the execution of 3 million CPU instructions by a 100 MIPS/W processor. Consequently, to extend network lifetime it is more urgent in these networks to optimize communications than processing. It is also stated in the literature that organizing the network into groups of nodes enables the control of the network communications and thus saves energy. From this, several clustering approaches are proposed. These approaches are used in the design of energy-aware routing mechanisms

Several clustering approaches are proposed in the literature and used, for example, in the case of a WSN for routing collected information to a base station (Sink). However, most of them are based on state model [10], [11], [13], [14], so they are not realistic in the context of WSNs compared to message-passing based clustering ones [7], [8], [17], [18]. Moreover, approaches in the last category are generally highly costly in terms of exchanged messages, while in the case of WSNs clustering aims at optimizing communications and energy consumption. Thus, in Ba et *al.* [2], we have proposed a self-Stabilizing Distributed Energy-Aware k-hops Clustering protocol for ad hoc networks (SDEAC). SDEAC prolongs the network lifetime by minimizing the energy consumption involved in the exchanged of messages. Furthermore, in terms of energy consumption in WSNs, data aggregation has been presented as a particularly useful capability for routing [1], [6], [12], [16], [21]. However, existing self-stabilizing clustering solutions like [7], [8], [10], [11], [13], [14], [17], [18] do not provide data aggregation mechanisms based on their clustering algorithms.

Therefore, by considering the fact that in a WSN communication of messages is by far the most important source of energy consumption, we propose in this paper a novel aggregation approach that optimizes these communications by combining an efficient self-stabilizing clustering scheme proposed in Ba et *al.* [2] and an adaptation of the intelligent cooperative aggregation process proposed in Sardouk et *al.* [19] [1]. Thus, on the one hand, the clustering approach reorganizes the network nodes into groups of nodes (i.e., clusters) so that it minimizes communications between nodes, their cluster head noted CH and the Sink. On the other hand, the aggregation approach reduces communications (in terms of number of messages and their size) by merging and sending only pertinent information to the Sink, in a distributed

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TABLE I
THEORETICAL COMPARISON OF SDEAC WITH OTHER APPROACHES BASED ON STATE MODEL

	Stabilizing Time	Memory space per neighbor	Neighborhood
SDEAC	$n+2$	$\log(2n+k+3)$	1 hop
Datta *et al.* [11]	$O(n)$, $O(n^2)$	$O(\log(n))$	k hops
Caron *et al.* [10]	$O(n*k)$	$O(log(n)+log(k))$	k+1 hops

way. Thus, collected information about the environment is processed locally by nodes on the route before it reaches the Sink. By reducing the amount of information, important power consumption could be saved. In addition, this strategy deals with the density of the network around each node by eliminating redundancy of information.

The remainder of the paper is organized as follows. Section II summarizes SDEAC protocol. In Section III, we explain our ideas for the establishment of an intelligent cooperative multi-agent aggregation approach by using SDEAC protocol. Section IV presents the validation framework used to evaluate performances of our aggregation approach. Finally, Section V concludes this paper and presents our working perspectives.

II. SDEAC: SELF-STABILIZING DISTRIBUTED ENERGY-AWARE CLUSTERING

In [2], we have presented SDEAC: a self-Stabilizing Distributed Energy-Aware k-hops Clustering approach for ad hoc networks. SDEAC is based on message-passing model and structures the network into non-overlapping clusters with diameter at most equal to $2k$. This structuring does not require any initialization. Furthermore, it is based only on information from neighboring nodes at distance 1 contrary to other self-stabilizing clustering algorithms. SDEAC uses a unique type of message to discover the neighborhood of a node at distance 1 and to structure the network into non-overlapping *k-hops* clusters.

On the one hand, we have validated SDEAC through a formal proof and simulations in [2]. We have proved that a legal configuration (i.e., stabilization) is reached after at most $n+2$ transitions and each node u requires $(\Delta_u+1)*\log(2n+k+3)$ memory space, where n is the number of network nodes and Δ_u is the degree of u. As illustrated in Table I, we have formally compared SDEAC with self-stabilizing clustering approaches based on state model [10], [11]. Furthermore, in Ba et *al.* [3], we have compared SDEAC with one of the most referenced papers on self-stabilizing solutions based on message-passing model [17]. This shows that SDEAC reduces communication cost and energy consumption by a factor of at least 2.

On the other hand, in Ba et *al.* [4], we have proposed an evaluation study of SDEAC's cluster-head election criteria in the context of WSNs with energy constraint. For this, we consider the most important criteria: node's identity, residual energy and degree. SDEAC optimizes energy consumption and then prolongs the network lifetime by minimizing the number of messages involved in the construction of clusters and by minimizing stabilization time. It also offers an optimized structure for routing. Furthermore, SDEAC is generic and complete. It can be easily used for constructing clusters according to multiple criteria in the election of cluster-heads.

Moreover, SDEAC is fault tolerance and adapted to topological changes. In fact, in [5], a fault-tolerance mechanism has been proposed and simulation results have shown that that after faults occurrence, the re-clustering cost is minimal compared to the clustering cost.

Therefore, in this work, clusters provided by SDEAC are used for an intelligent cooperative multi-agent aggregation approach in order to reduce communications by merging and sending only pertinent information to the Sink, in a fully-distributed way.

III. INTELLIGENT CLUSTER-BASED COOPERATIVE MULTI-AGENT AGGREGATION APPROACH

We propose an intelligent aggregation approach based on the clustering mechanism SDEAC [2] described above and on a cooperative Multi-Agent System (MAS) [19]. This aggregation approach enables the communication of only pertinent sensors information to the base station (i.e., Sink) in fully-distributed way.

A. Aggregation scenario

Basically, in this approach, each sensor that collects important information sends it in the direction of its CH and then, the CH sends the aggregate in the direction of the Sink. Each sensor node that receives information from one or multiple sensors will process it by merging and combining it with its local information in order to minimizing the amount of information. Then, it sends the resulting aggregate to its intermediate node (i.e., relay node that knows the next node in route to the CH or to the Sink) in the direction of the Sink. An autonomic agent is installed on each sensor node in order to control it and to define its behavior by analyzing collected information and making decisions. This agent uses routing information to establish a one-hop situated view (or situadness) [9] and thus to maintain a knowledge base. Each agent will decide by itself according to a given strategy if it cooperates or not with other agents. By using a situated view, each node reduces the amount of maintained information by a view limited only to its direct neighbors.

When a sensor collects information about its environment, its agent decides if this one is important. If so, it initiates the aggregation process by sending a cooperation request to its neighboring agents. If a neighbor decides to cooperate, it sends its local information (i.e., sensed by its sensor) to the requesting agent. If the node that receives the cooperation request is the default intermediate node, it does not answer to the requesting node. But, in order to save time, while

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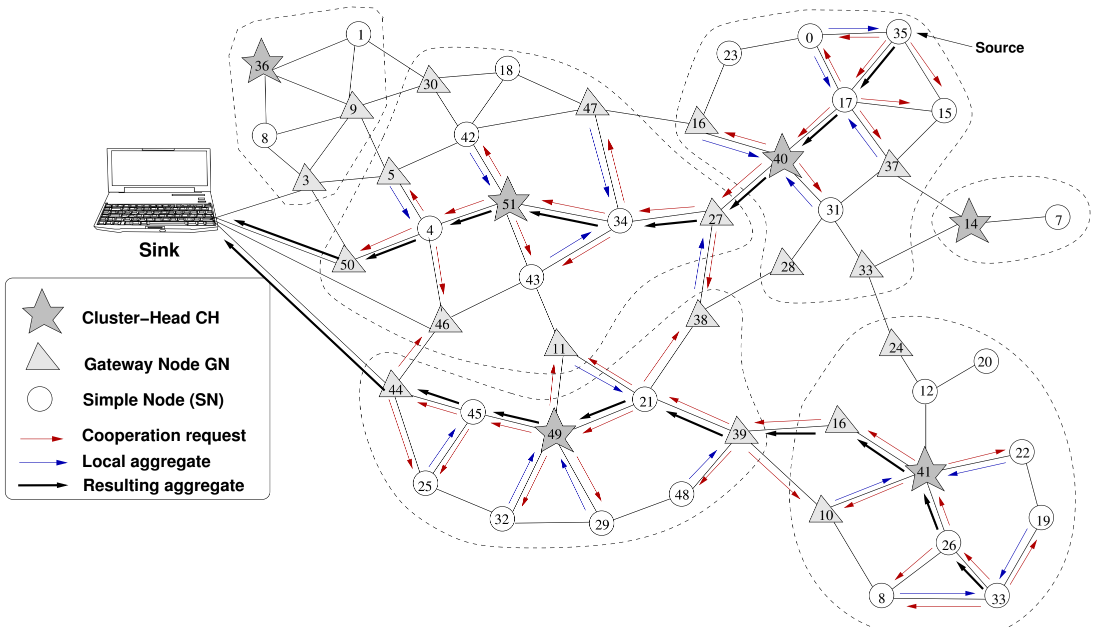

Fig. 1. Overview of our multi-agent cluster-based aggregation scheme

waiting for the aggregate of the requesting node, the relay agent directly sends a cooperation request to its neighbors.

Once the requesting node receives local state information from its neighbors, it merges the given data and eliminates redundancy before sending the result (aggregate) to its default intermediate node. The latter merges the received aggregate with the gathered information of its neighbors to compute a new aggregate and then it sends the result to its intermediate node. The aggregation process continues until the sensed information reaches the Sink.

Figure 1 illustrates one scenario of the proposed cluster-based aggregation scheme. Here, a simple source node 35 sends its sensed information to its CH (40) through node 17 and the CH sends the resulting partial aggregate in the direction of the Sink. Each node on the path aggregates data.

B. Cooperative agents

We define a distributed multi-agent cooperation strategy considering different parameters in the decision-making process [19]. These parameters are: importance level of collected information (I), level of energy power on sensors (E), position of nodes in the network (P) and network density (D). For example, when the battery power on a node is critical (i.e., less than a certain threshold) the agent of this node refuses to cooperate and will use this energy only for sensing and sending its own information.

Thus, according to the value of these parameters, an autonomic agent selects by itself the best behavior and decides to cooperate or not in the aggregation process. For this, it computes a coefficient R that denotes the relevance of cooperation like shown in equation 1.

$$R = w_e \times E + w_d \times \frac{1}{D} + w_p \times P + w_i \times I \qquad (1)$$

TABLE II
EXAMPLE OF NEIGHBORHOOD TABLE

Routing table of node 51				
Node_ID	**Cluster_ID**	**Status**	**Dist_CH**	**Dist_Sink**
4	51	SN	1	2
34	51	SN	1	4
42	51	SN	1	4
43	51	SN	1	4

where w_e, w_d, w_p and w_i are the influence factors (i.e., weights) for, respectively, energy, density, position and information importance.

C. Communication policy

The communication policy used in our aggregation is an adaptation of the routing protocol Dynamic Source Routing (DSR) [15] that limits its communications in the case of a WSN. Our approach consists in two operations: route discovery and route maintenance. Note that initially, each node knows how to reach its CH through the reutilization of clustering information. Thus, CHs need to know the route to the Sink. For this, the route discovery phase allows CHs to obtain information about their direct neighborhood and about the default intermediate node in the direction of the Sink. Each node on the path between a CH and the Sink will learn its intermediate node. Then, the route maintenance phase enables nodes to have the last updates about their neighborhood. Table II illustrates an example of a neighborhood table of a node 51 on the path between CH 40 and the Sink (Figure 1).

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IV. Validation of the proposed approach

In order to validate our aggregation approach, we plan to carry out a simulation campaign under the *OMNeT++* simulator [20] when we have implemented SDEAC protocol. For this, we implement our intelligent cooperative multi-agent aggregation approach described in Section III and we validate it according to three scenarios:

i Fully-decentralized aggregation approach: aggregation is done on each node on the path to the Sink;

ii Partially-decentralized aggregation approach: aggregation is done only on cluster-heads;

iii Non-aggregated information: sensed information is directly sent to the sink without intermediary merging (aggregation).

Thus, in the case of non-aggregation scenario, during each sensing cycle, each node in the cluster sends its information to the Sink through its cluster-head. As soon as a cluster-head receives an information from a node in its cluster, it forwards this message directly to the Sink through its path. At opposed, in the case of aggregation on each cluster-head, the cluster-head collects all messages from all nodes in its cluster and aggregates data. Thus, during each sensing cycle, only one message containing all information from other cluster's nodes is send to the Sink by each cluster-head.

To validate these three scenarios (i.e., *(i), (ii) and (iii)*), we plan to evaluate our approach according to the most used criteria under the same clustering approach and testing framework:

- Communication cost: in terms of number of messages and their size;
- Energy consumption: total and distribution of battery power consumption of sensors;
- End-to-end delay: necessary time to send information from source nodes to the sink;
- Network lifetime: time until i nodes of the network die (empty battery), where we vary the value of i.

V. Conclusions and perspectives

In this paper, we have presented novel ideas for the proposal of an intelligent aggregation approach based on cooperative agents and a self-stabilizing clustering for WSNs. The goals of this intelligent aggregation approach is to reduce communications by merging and sending only pertinent information to the Sink, all this in a distributed way.

Currently, we are working on the validation of our protocol in *OMNeT++* simulator in order to evaluate its communication cost in terms of messages, energy consumption, end-to-end delay and the network lifetime.

As future work, we plan to compare our aggregation approach with other existing aggregation solutions.

References

[1] K. Akkaya, M. Younis, and M. Youssef. Efficient aggregation of delay-constrained data in wireless sensor networks. In Proceedings of the ACS/IEEE 2005 International Conference on Computer Systems and Applications, pp. 904–909, 2005.

[2] M. Ba, O. Flauzac, B. S. Haggar, F. Nolot, and I. Niang. Self-stabilizing k-hops clustering algorithm for wireless ad hoc networks. In 7th ACM International Conference on Ubiquitous Information Management and Communication (IMCOM'13), pp. 38:1–38:10, 2013.

[3] M. Ba, O. Flauzac, R. Makhloufi, F. Nolot, and I. Niang. Comparison between self-stabilizing clustering algorithms in message-passing model. In 9th International Conference on Autonomic and Autonomous Systems (ICAS'13), pp. 27–32, 2013.

[4] M. Ba, O. Flauzac, R. Makhloufi, F. Nolot, and I. Niang. Evaluation study of self-stabilizing cluster-head election criteria in wsns. In 6th International Conference on Communication Theory, Reliability, and Quality of Service (CTRQ'13), pp. 64–69, 2013.

[5] M. Ba, O. Flauzac, R. Makhloufi, F. Nolot, and I. Niang. Fault-tolerant and energy-efficient generic clustering protocol for heterogeneous wsns. International Journal On Advances in Networks and Services, pp. 231–245, 2013.

[6] S. J. Baek, G. de Veciana, and X. Su. Minimizing energy consumption in large-scale sensor networks through distributed data compression and hierarchical aggregation. IEEE Journal on Selected Areas in Communications, pp. 1130–1140, 2004.

[7] A. Bui, A. Kudireti, and D. Sohier. A fully distributed clustering algorithm based on random walks. In 8th IEE International Symposium on pages Parallel and Distributed Computing (ISPDC '09), pp. 125–128, 2009.

[8] A. Bui, A. Kudireti, and D. Sohier. A random walk based clustering with local recomputations for mobile ad hoc networks. IEEE International Symposium on Parallel Distributed Processing, Workshops and Phd Forum (IPDPSW'10), pages 1–8, 2010.

[9] T. Bullot, R. Khatoun, L. Hugues, D. Gaïti, and L. Merghem-Boulahia. A situatedness-based knowledge plane for autonomic networking. International Journal of Network Management, pp 171–193, 2008.

[10] E. Caron, A. K. Datta, B. Depardon, and L. L Larmore. A self-stabilizing k-clustering algorithm for weighted graphs. Journal of Parallel and Distributed Computing, pp. 1159–1173, 2010.

[11] A. K. Datta, S. Devismes, and L. L. Larmore. A self-stabilizing O(n)-round k-clustering algorithm. In 28th IEEE International Symposium on Reliable Distributed Systems (SRDS '09), pp. 147–155, 2009.

[12] E. Fasolo, M. Rossi, J. Widmer, and M. Zorzi. In-network aggregation techniques for wireless sensor networks: a survey. IEEE Wireless Communications, pp. 70–87, 2007.

[13] C. Johnen and L. H. Nguyen. Robust self-stabilizing weight-based clustering algorithm. Theoretical Computer Science, pp. 581–594, 2009.

[14] Colette Johnen and LeHuy Nguyen. Self-stabilizing construction of bounded size clusters. In International Symposium on Parallel and Distributed Processing with Applications (ISPA '08), pp. 43–50, 2008.

[15] D. B. Johnson, D. A. Maltz, and J. Broch. Ad hoc networking. chapter DSR: The Dynamic Source Routing Protocol for Multihop Wireless Ad Hoc Networks, pp. 139–172. 2001.

[16] R. Makhloufi, G. Doyen, G. Bonnet, and D. Gaïti. A survey and performance evaluation of decentralized aggregation schemes for autonomic management. International Journal of Network Management (IJNM), pp 29p, 2013. To appear.

[17] N. Mitton, E. Fleury, I. G. Lassous, and S. Tixeuil. Self-stabilization in self-organized multihop wireless networks. In 25th IEEE International Conference on Distributed Computing Systems Workshops (ICDCS'05), pp. 909–915, 2005.

[18] N. Mitton, A. Busson, and E. Fleury. Self-organization in large scale ad hoc networks. In Proceedings of the Mediterranean ad hoc Networking Workshop (MedHocNet'04), 2004.

[19] A. Sardouk, Rana Rahim-Amoud, L. Merghem-Boulahia, and D. Gaïti. Power-aware agent-solution for information communication in wsn. Telecommunication Systems, pp. 329–338, 2011.

[20] A. Varga and R .Hornig. An overview of the OMNeT++ simulation environment. In Proceedings of the 1th IEEE International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUTools), pp. 60:1–60:10, 2008.

[21] Y. Wen, T. A. F. Anderson, and D. M. W. Powers. On energy-efficient aggregation routing and scheduling in IEEE 802.15.4-based wireless sensor networks. Wireless Communications and Mobile Computing, 2012.