Multi-agent Topology Approach for Distributed Monitoring in Wireless Sensor Networks

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***Abstract* — In this paper, the multi-agent technology is applied in wireless sensor networks domain in order to adapt software architecture, and to optimize its performance in monitoring. We explore in particular the issues of topology control, especially some related work using multi-agent systems. In the third part, we will propose an agent-based algorithm for fault tolerance and topology control in a wireless sensor network. Our proposal consists of embedding an agent at each node that is responsible for selecting its parent or the next hop to the sink when transferring packets. The main contribution is the proposal of a new process of changing parent, which is based on the computation of a fault tolerance degree, calculated each time by the agent in cooperation with its neighboring nodes. Several parameters are exploited to calculate this metric, such as the number of hops, the energy and the quality of links. Simulation results show that this method of changing parent allows an enhanced lifetime, as well as network fault tolerance, when compared with the collection tree protocol.**

Key words: wireless sensor networks; multi-agent systems; monitoring; topology control.

I. INTRODUCTION

Wireless sensor networks (WSN) [1] require large amount of data to be transmitted with high reporting rates, leading to consume specific resources, such as bandwidth, storage, computation, and energy. Research in WSNs aims to meet the above constraints by introducing new design concepts, creating, improving existing protocols such that optimization in this field has been a topical issue of many works in the last decade.

Multi-agent systems (MAS) have a principle that can be easily adapted and integrated in complex systems due to their fully decentralized and "intelligent" approach [2]. They can be used to model phenomena where global behavior emerges from the local behavior of system entities and components. These components have the ability to percept, process, act and react in their environment.

The wireless sensor networks structure, distributed processing ability and complexity considerations especially when the number of nodes increases, conducts us to exploit recent developments made in multi-agent systems field to improve networks performances and simplify the design process in order to have reliable and fault tolerant sensors.

The multi-agent approaches for WSN are introduced in many levels and operating aspects. Some works propose software architectures for applications and services [3][4]. Others are interested in network organization and cooperation between nodes [5][6], clustering being the dominant approach in this area. Furthermore, many agent-based works treat routing problems in WSN with different applications [7]. Finally, monitoring and mobility are also subjects of several studies [7][8], where the use of bio-inspired principles seems interesting with multi-agent systems to solve mobility and scheduling tasks problems.

These works can be divided into two classes: the first class considers the sensor network as a multi-agent system, in this case, the application of agent technology consists of deploying the same agent to all nodes in order to have cooperation between them. This seems to be better adapted to wireless sensor nodes, and it will be considered in our approach. The second class provides multi-agent systems adapted to the logical structure of a WSN where different kinds of agent cooperate in the network.

Supervision or monitoring, which aims to avoid or detect failures, is a set of techniques used to increase the performance of a WSN, optimize its lifetime and ensure fault tolerance using all network parameters.

The main approach for load balancing [9] and fault tolerance in sensor networks is the maintenance of a topology that guarantees good conditions of transfer. Indeed, the use of multiple paths helps to balance the energy consumption of nodes by distributing the flow of packets on better possible paths [10]. This mechanism based on topology control contributes to reducing the delay and packet loss by reducing the number of hops between nodes and the sink. Thus, the quality of service will be improved.

Topology control consists of the use of network characteristics or parameters to generate and/or maintain a topology. Despite the fact that MAS technology is the only approach that allows nodes to take into account information from their environment, only few works on WSNs topology control include agent systems.

Our work targets to increase the lifetime of WSN nodes by introducing a new topology control approach and then compare it to the collection tree protocol (CTP). In our work, the main contribution, which is introducing MAS in WSN, is performed when using neighborhood information to give a metric called tolerance degree for each node. This

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metric is calculated by the node itself in cooperation with its neighbors. When transferring packets, this degree will be used to choose qualified nodes for the transfer. We shall see that this approach increases the fault tolerance lifetime of a network, without affecting the quality of service. This method is implemented as an embedded multi-agent system.

Section II is devoted to a classification of the state of the art that uses multi-agent systems in wireless sensor networks. In Section III, a new proposal is introduced on distributed agent based topology control in WSN. Performances of this proposal will be studied in Section IV, and finally, we will give some concluding remarks and future work in the last section.

II. USING MAS IN WSN

Using agent technology in a WSN consists in associating agents to nodes which cooperate between them in order to calculate topology parameters. Each agent has a proper code that can be executed by a node, with the ability for the agent to move between nodes for processing or searching information. According to Rijubrata [11], the multi-agent approach in WSN has many advantages: the easy network scalability, extensibility and adaptation tasks, energy efficiency, and progressive system.

In recent years, several research works are interested in the WSN distributed processing based on agent technology. A classification of these contributions is given below, according to their objectives and the level of integration in a WSN.

A. Software architecture of applications and services

Biswas et al. [12] presents an interoperable multi-agent architecture through layers. The authors demonstrate the effectiveness of their method by comparing the client/server approach and the multi-agent systems in terms of execution time and energy consumption. The work is an extension of an existing model called interoperable agent model: the new MAS model includes eight agent types: Sensor Agent (SA), agent management system (AMS), Directory Facilitator (DF), which helps other agents to cooperation, agent communication channel (ACC), Controller synthesizer (CS), Data Manager (DM), Application Agent (AA) and Agent Interface (AI). These agents are distributed in a sensor network that may contain both wired and IP nodes. The communication between agents is provided by XML messages.

After their work on the MWAC model (Multi-Wireless-Agent Communication) and DIAMOND method [3], which is interested in embedded multi-agent systems, especially in wireless infrastructure, the authors present in [2] a discussion on embedded systems design specifics that use multi-agent systems.

Smarsly et al. [4] proposes a system design-based on migrant agents to define a dynamic operation in a WSN according to nodes requirements, this system was really tested on a platform for thermal variations treatment in an experimental environment.

Rahal et al. [13] propose a formal model based on real-time temporal logic for multi-agent system specification and evaluation when it is integrated into a WSN environment. Reactive decisional agents are used to take advantage of their ability to cooperation, reaction to events, communication and concurrence.

B. Organization of the network, clustering and cooperation

In order to facilitate the design and implementation of WSN, Wang et al. [5] propose a model as combination between mobile agents and MAS. The proposed architecture is hierarchically structured according to the roles played by each sensor in the network. These roles are assigned to the nodes using some elective algorithms, the MAS is used for collaboration and mobile agents for data exchange purpose. The objective is localization and classification of acoustic targets.

In [6], the optimization of energy consumption and reply time is based on MAS applied to a data collection algorithm used for monitoring emergent events where the WSN is divided into dynamic clusters. This is defined by the event importance which determines the size and the lifetime of a cluster. Mobile agents traverse the network through cluster heads; itinerary planning is determined by the residual energy and the packet loss degree in the path. Simulation results show that the multi-agent model has better performance in terms of energy consumption and replay time.

Logical clustering model adapted to multi-agent operation is presented by Jabeur et al.[7]. It divides the nodes into a four levels hierarchy: atomic level which is the node itself, micro level that represents a group of nodes managed by a cluster head, meso level which is the upper level grouping a number of clusters of the same area, and finally, a virtual cluster representing the entire network. This logical structure can change after an event. At each level, is assigned a type of agent cooperating with the higher level agent to accomplish the distributed network operations.

C. Routing

Many works study the routing problem in WSN, the classical problem consists in routing data from source node to a destination node (sink). According to the application goal, multipath routing may be used in order to increase the reliability of data transmission i.e., fault tolerance. Liu et al. [8] propose a new agent-based routing algorithm with quality of service in WSN. By participating in routing and maintenance of paths, agents are used to manage the topology changes and communication flow. The method is based on a Swarm Intelligence principle [33], which is inspired from the collective intelligence system of insects. In this case, latency, packet loss, and energy conservation are considered in general as quality of service factors.

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The MAS has two agent types: Forward agent FA (to establish a connection with a neighbor in searching path) and Reverse agent RA (in response to build a path). As in [8], Dario et al. [14] propose a model called MAM (Markovian Agent Model) which is based on Swarm intelligence, but using a Markov model. The operation of agents is based not only on local transitions from a node itself, but the probable transitions of other nodes too (local transitions and induced transitions).

D. Monitoring and Mobility

A Bayesian model named BNGRAZ (Bayesian network algorithm grazing) is proposed by Matthew et al. [15] for managing mobility in WSNs. It is bio-inspired model that emulates the behavior of herbivores grazing pastures. The WSN in question contains some mobile nodes to adjust coverage and connectivity. The choice of itinerary taken by a mobile node is based on the probability of disconnection or inaccessibility, this probability is calculated using information provided by neighbors.

As in [15], Saamaja et al. [16] propose a similar principle but with the aim of optimizing the lifetime and satisfy requested quality of service using data collectors that form clusters by changing position, the movements are made according to objective rather than probability. A self-adaptation strategy for scheduling tasks in a WSN is presented in [17], where a mathematical model is proposed for dynamic allocation tasks. The algorithm has a collective intelligence functioning called PSO (Particle Swarm Optimization algorithm).

In [3], Jamont proposes that each node plays a specific role in its neighborhood. This role is determined by an embedded agent in the node itself. If the node is in the area of intersection of multiple clusters, it has the role of liaison or gateway; else it has the simple data capture role. Finally a representative node or a cluster head is elected in the cluster to manage communications. Mobility and node failures are well treated by this structure.

To optimize the task scheduling problem and data transmission in video WSN, the work presented by Huang et al. [18] is based on a set of intelligent procedures associated with agents by using ant colony algorithms, genetic algorithms, or mixed algorithms. Security problem is also pointed out by this recent trend through bio-inspired methods.

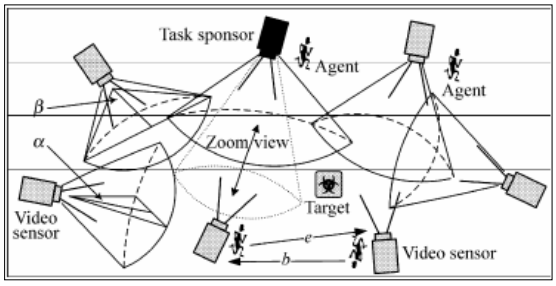

Figure 1. MAS for tasks allocation [18].

Each agent (representing a node) decides to participate or not in target detection according to the following factors:

- S: denotes the status set {busy, free} of the current node;
- E: depicts whether or not the current node has enough energy to accomplish the assignment;
- α: angle of vision of the camera on the x-axis (right to left);
- β: angle of vision on the y-axis (up and down);
- q: determines the required quality of picture by the monitoring process.

The results show that the algorithms require less energy than AODV protocol.

E. Topology control

Topology control consists of using different parameters of the network in order to provide a well organization achieving some important tasks. These parameters could be radio range, state or role of the node, etc. The majority of works that use multi-agent systems in topology control are based on hierarchical structures with clusters, more adapted for MAS running on multiple levels [6]. First of all, we recall the principles and techniques used in this field and related work. According to [19], there exist three main techniques:

E.1. Power Adjustment Approach

The power adjustment approach allows nodes to vary their transmission power in order to reduce energy incurred in transmission. Rather than transmitting at maximum transmission power, nodes collaborate to adjust and find the appropriate transmission power, yielding to a connected network. For example, in Figure 2, the links N1 - N4 and N2 - N4 are unused by reducing the radio range of these nodes.

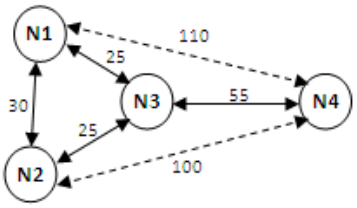

Figure 2. Topology control by adjusting the radio range.

Protocols representing this technique are Minimum Energy Communication Network (MECN) [34] where each node uses the minimum power level to communicate, and COMPOW [20] which uses a common minimum power level for all nodes in order guarantee the connectivity of the network.

E.2. Power Mode Approach

In addition to the techniques used by the MAC layer protocols and when the number of deployed nodes is sufficient, redundancy of nodes can be exploited to get a better topology by changing the state of a node between active and sleep. GAF (Geographical Adaptive Fidelity)

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[21] is an example of a protocol that uses a principle of equivalent nodes, it allows a node to switch between sleep, discovery and active states as shown in Figure 3.

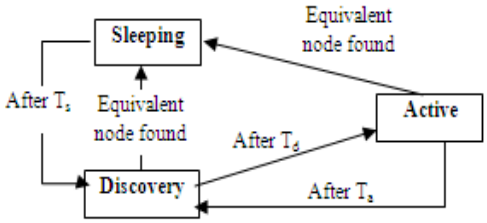

Figure 3. State Transitions in GAF.

Also, in ASCENT (Adaptive Self-Configuring Sensor Network Topologies) [22], a self-reconfigurable algorithm that allows nodes to locally measure the operating conditions is presented. Based on these conditions, nodes then decide whether they need to participate in routing or not.

E.3. Hierarchical structures

This technique is to find a structure with hierarchical clusters for the network. Choosing cluster heads presents a problem for this technique. Several contributions have tried to propose approaches to obtain more efficient clustering. Most algorithms construct a virtual backbone based on the connected dominating set concept (CDS). From these algorithms, we can talk about PACDS (Power Aware Connected Dominating Set) [23], ECDS (Energy Efficient Distributed Connecting Dominating Sets) [35], and TMPO (Topology Management by Priority Ordering) [24].

E.4. Hybrid approaches

The hybrid approach for topology control uses in general a combination between a clustering method and other techniques, like CLUSTERPOW algorithm [25] (Figure 4).

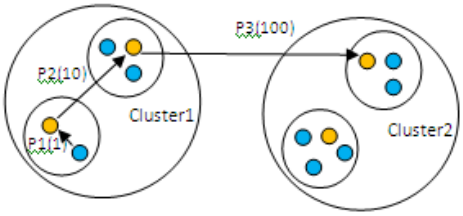

Figure 4. Principle of the CLUSTERPOW algorithm.

This algorithm defines several levels of clusters with different radio powers for communication within and between clusters.

III. PROPOSED METHOD

A. The problem

Our contribution consists of proposing a hybrid and distributed method using MAS for wireless sensor network topology control. This method bears on local decisions taken by the node itself using a function of several parameters: residual energy, number of neighbors, links quality, etc. The main objective is to have at any time a connected, homogeneous and fault-tolerant network which should be capable to predict and avoid as much failures as possible. We have been inspired by influence systems [36] which require strong cooperation between nodes.

When transmitting data, the principle consists of selecting the most fault tolerant nodes that ensure safe transfer. The use of MAS seems to be a suitable approach according to the distributed, cooperative and emergent principles that characterizes this operation.

The role of MAS here is to calculate for each node a parameter determining its state and its capacity to go further without energy depletion or congestion failure before the end of data transfer. The calculated parameter is called the degree of tolerance of a node.

Some works in this context have a similar principle which is based on computing one or more metrics to control the topology such as Rong-rong et al. [26] which calculates the probability of node's failure, and Bo-Chao et al. [27] based on the evaluation of the link quality between two nodes to predict the lifetime of each node. So the main difference between these works is the choice of network parameters and how to calculate these parameters. In our approach, we propose another method, where we will use the link quality evaluation of [28] then we add the battery status and the number of hops to the. This principle allows us to express the lifetime and the fault tolerance ability. A thresholding mechanism is implemented to avoid frequent changes in the topology due to minor differences.

B. Related work

We are interested here in the works which are based on local settings of network to predict or estimate other values or states in order to optimize the process of topology control.

We start with Yin et al. [26] which proposes an adaptive method for fault tolerance topology control by calculating the node failure probability FP based on the ratio of the consumed energy E_c, the initial energy E_{init} and another fault probability P associated to hardware and software components. We have:

$$PD = P.\frac{E_c}{E_{init}} \quad (1)$$

In [29], Dario Bruneo et al. show that the introduction of Markov techniques allows estimating the lifetime of a node by taking the active-sleep cycle as a model of transitions with probabilities for each transition. But in reality, lifetime also depends on the node activities when it is at active state.

Failures in a sensor network can be detected by application of "fuzzy inference" according to Safdar Abbas Khan et al. [30] where the sensor measures are compared with expected values by a neural network; the differences in behavior allow detecting anomalies.

The lifetime of a hierarchical network is studied by Bo-Chao et al. in [27]. It proposes an algorithm for lifetime prediction in better and worst cases in a WSN with one hop

clusters where the cluster heads should communicate directly with the sink. The objective of this work is to find the best deployment for this type of topology. A cooperative approach for topology control is proposed by Paolo Costa et al. in [31]. The construction of the topology consists of choosing nodes that guarantee a degree of k-connectivity by using a minimum radio range. The stability of topology is obtained by cooperation between nodes until obtaining the optimal radio level under k-connectivity constraint.

C. Proposal details

C.1. The network model

Related to an application domain, the nodes of network are deployed randomly in a known field to capture specific types of information; the captured data are then transmitted to a control station or sink. When transferring data, the choice of path is based on the choice of the next hop or the parent from the current node obeying to some routing protocol. Here, the next hop is selected from the neighbors using the degree of tolerance at the time of transfer, so the node that has the highest degree of tolerance will be qualified for this transfer. This task is performed by agents implanted on nodes.

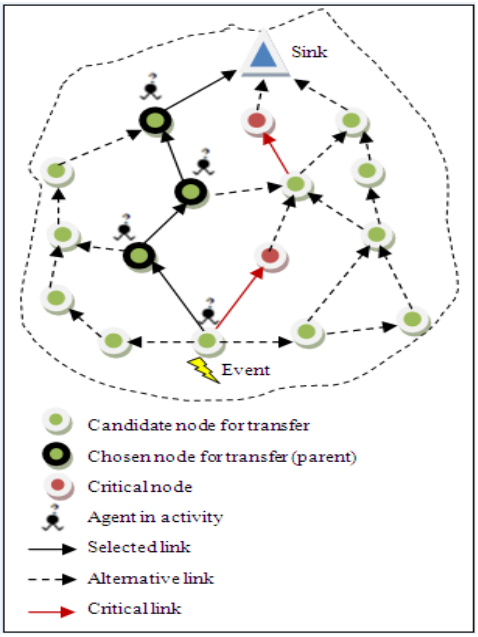

Figure 5. Network model.

Figure 5 shows this principle where the agent is responsible for selecting a parent among candidate neighbors for the node that wants to transmit packets. Some nodes may become critical, so they cannot be parents to other nodes.

C.2. The topology construction

After deployment of nodes, the sink diffuses an initialization message *Init* which is based on the HC (Hop Count) value. For the sink itself, the value is null. The neighborhood discovery is included in this method.

Each node *n* which receives the *Init* message considers the sender of the message as the next hop for the next transmissions if the HC value of the latter, is less than the HC value of the receiver node *n*. So, it does:

if HC (n) > HC (init) then HC (n) ← *HC (init)*

Then, it rebroadcasts the *Init* message. At the beginning, the HC values are set to infinity for all nodes except the sink which is initialized to zero.

C.3. Topology control method

After the stability of the topology obtained by the initialization process (there is no node which rebroadcasts the *Init* message), the nodes calculate their degree of tolerance as follows. Let us consider:

- E_{init}: initial energy of a node.
- E_v: residual energy of the node v.
- N: set of neighbors of v, $N_i \in N$ is a neighbor of v.
- Pin(N_i): number of received packets by v from N_i during a period t.
- Pout(N_i): number of broadcast packets by N_i during a period t.
- Poutc(N_i): number of correctly received packets by the neighbors of N_i (with acknowledgment).
- HC(v): hop count from v to the sink;
- NH(v): the next hop from v to the sink also said parent of v.

For the calculation of tolerance degree TD, we propose to use the link quality and battery status of each node. The calculation of the first parameter is inspired from the link quality estimation proposed by Omprakash et al. [28], where CTP (Collection Tree Protocol) is defined. It is a routing protocol that computes unicast routes to a single route or a small number of designated sinks in a wireless sensor network basing only on the link quality estimation network parameter. It uses periodic messages called beacons to maintain topology. A beacon is a packet that contains the link quality estimation between tow nodes.

In our case, for battery status, we consider the relationship between the residual energy and the initial energy.

We define the quality of outgoing links QS between node v and its neighbor N_i as follows:

$$QS_v(N_i) = Poutc(v)/Pout(v) \quad (2)$$

Similarly, the quality of incoming links QE between a node v and its neighbor N_i:

$$QE_v(N_i) = Pin(v)/Pout(N_i) \quad (3)$$

The node v calculates its TD (Tolerance Degree) in function of its battery status and quality Q of an outgoing or incoming link like it is shown in equation (4), where Q is QS for outgoing links and Q is QE for incoming links as follows:

$$TD(v) = \left(\frac{E_v}{E_{init}}\right).(\alpha_{TD}.Q + (1 - \alpha_{TD}.Q).TD_{old}) \quad (4)$$

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where α_{TD} is a weighting constant that can take values between 0 and 1, it is 0.9 for our case.

The parent change procedure is based on the parameter values of the previous parent and candidate neighbors.

We use mainly the energy E, the degree of tolerance TD (old value) and the hops count HC. By cooperation, nodes use a control message to inform neighbors when there is change in values of energy, HC and TD. To avoid parent change when small variations in these parameters happen, a threshold principle is used for each one. So the node v decides to choose a neighbor N_i as its new parent NH if the following conditions are satisfied:

$HC(N_i) \leq HC(v) + Threshold\_HC$
$E(N_i) > E(NH(v)) + Threshold\_E$
$TD(N_i) > TD(NH(v)) + Threshold\_TD$

It is necessary to know that the verification order of these conditions is very important; it also depends on the nature of application using our approach. Here, we chose the hops count in first with a threshold that depends on the network size (number of nodes in the network) in order to avoid long traffic paths. This may be not useful if the application has no real time constraint. The algorithm below shows the parent selection process according to the previous conditions. T_E, T_{TD} and T_{HC} represent the threshold values for the energy, degree of tolerance and the hops count respectively. The function Change_Parent represents a switching tool between the active parent and the candidate one. The TD function implements the estimation of the tolerance degree.

Algorithm : Parent Selection
1: NH = Current Parent (Next Hop)
2: N_i = Candidate neighbor
3: If $HC(N_i) < HC(NH) + T_{HC}$ then
4: if $Energy(NH) = Energy(N_i)$ then
5: if $TD(NH) > TD(N_i) + T_{TD}$ then
6: Change_Parent(N_i)
7: end if
8: else if $Energy(NH) < Energy(N_i)$ then
9: if $TD(NH) \geq TD(N_i) + T_{TD}$ then
10: Change_Parent (N_i)
11: end if
12: **else if** $Energy(NH) > Energy(N_i)$ **and** $Energy(NH) \leq Energy(N_i) + T_E$ **then**
13: **if** $TD(NH) \geq TD(N_i)$ **then**
14: Change_Parent (N_i)
15: **end if**
16: **end if**

This algorithm allows the node to change its parent as soon as finding a better one. Also, it is used for selecting a new parent among candidate neighbors when detecting a fault (e.g., the current parent dies or moves). A fault of parent can be declared after failing in packets transfer.

IV. IMPLEMENTATION AND RESULTS

A. Simulation

Actually, the MAS platforms are not used in practice to implement WSN simulation because there are no network properties integrated in these software tools.

In order to validate the proposed solution and study its performances, as well as the adaptation of a multi-agent model for this type of distributed algorithm, we have implemented our approach using the Castalia simulator which is based on the simulator Omnet++ [32]. CASTALIA is a commonly used tool in recent years for WSNs simulation due to its gratuity and easy integration of new protocols in its software layer structure presenting a configurable environment as needed. For our study, we used version 3.2 of Castalia with OMNET++ 4.2 turning on an UBUNTU machine. Our distributed algorithm consists of implementing agent on each sensor node. It is the simple manner to view a WSN as MAS where cooperation is provided by exchanging messages at the moment of data transfer to select at each hop, the most fault tolerant node. It is clear that the principle of our algorithm implies that agents must communicate the necessary information like the latest values of TD, energy level and the number of hops. The diagram in Figure 6 shows that the agent on node 3, for example, has the choice to transfer its packets through nodes 2, 6 or 7 depending on the status of each one of these nodes.

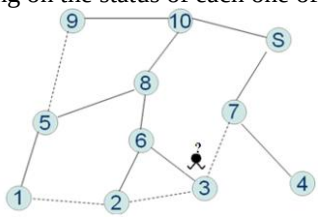

Figure 6. Principle of our algorithm.

B. Hypothesis

To perform simulations, we consider the following hypothesis: initially, each node has an initial energy. All sensor nodes are battery powered with limited energy, except the Sink. Network size is specified at the beginning of each simulation, node 0 is chosen as Sink. Other simulation parameters are shown in the following table:

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of nodes	Up to 300
Field Deployment	250 x 250 meters
Deployment type	Random
Radio model	CC2420
Radio power	0dBm
Initial energy	18720 joules
Simulation time	100, 200, 300,. 1000 sec ..
Thresholds: T_{HC}, T_E and	20% of difference for each

C. Results and analysis

To demonstrate the performance of our approach, we make a comparison with CTP protocol. On figures, our approach is noted ATC for agent topology control. Figure 7 illustrates the execution of our protocol and shows that traffic is distributed across all nodes. This is assured by changing the parents according to the parameters of each node. Applying the algorithm gives the following:

(A) Construction of the initial tree
(B) Node 7 becomes a parent of 3
(C) Node 3 becomes a parent of 2
(D) Node 2 becomes a parent of 3 and 1 becomes a parent of node 2
(E) Node 9 becomes a parent of node 5

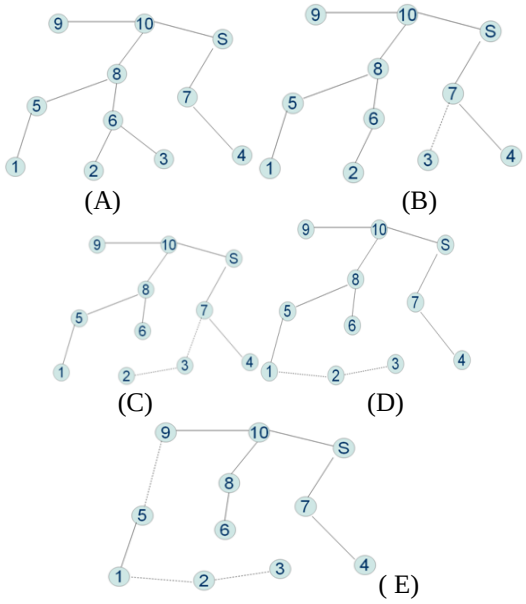

Figure 7. Illustration.

Before giving some results on the performances of our approach compared with CTP method, for the lifetime definition, we consider the duration between the network initialization time until the moment it becomes non convex or disconnected.

The initialization begins by broadcasting the *'init'* message, and then nodes start changing their parents basing on hop count metric until the stabilization of the topology. Time of this operation depends on density of network which is defined by its size and the transmission ray of nodes. We can express this density by using the average number of node's neighbors in the network like it is shown in Figure 8.

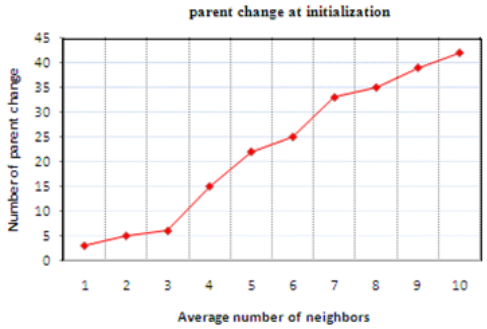

Figure 8. Relationship between WSN density and initialization process.

A proportional relationship is remarked between the average number of neighbors in the entire network and the average number of parent change at initialization. Having a lot of neighbors implies frequent recursive parent changing.

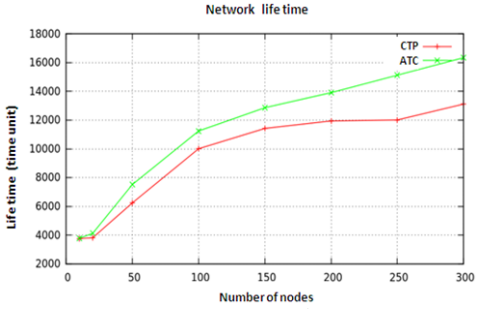

Figure 9. Impact on lifetime.

The curves in Figure 9 show a divergence in case of high density networks because our approach tries to find other paths to conserve energy of those used. However, in CTP, congestion or over-use of a path leads to the premature death of nodes. In case of low density, there is not a big difference because the topology is almost fixed with a small number of nodes.

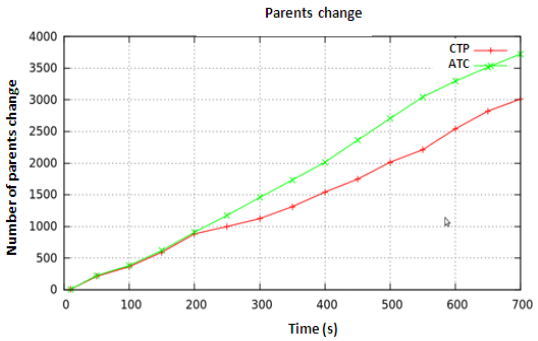

Figure 10. Parent change in the time.

We note from Figure 10 that the difference in the number of parents change in both cases CTP and ATC are not important at first, but, over time, a divergence becomes more significant. This is explained by the diminution of the degree of tolerance calculated by our protocol, which requires change of parents in order to ensure load balancing.

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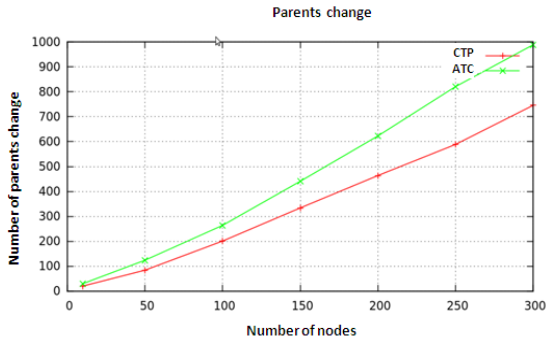

Figure 11. Change of parents with network size.

Figure 11 also shows the curves of parent change, but this time based on the network size. By increasing the size, we observe a difference in the number of parent changes for both protocols CTP and ATC. It is higher for large-scale networks that ensure the existence of other paths where the best one will be selected. The use of several parameters by our protocol gives more opportunities than CTP which uses only the quality of links.

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented a state of the art concerning the use of MAS in wireless sensor networks. In this context, we have proposed an agent-based topology control method for WSNs. According to the state of node and its neighbors, the main objective is to have a fault-tolerant network with an extended lifetime by optimizing the choice of paths from the nodes to the sink. This choice is based on the changing parent method which uses the concept of tolerance degree. Also, to respect the multi-agent principles, the choice of parent node is achieved in a cooperative and distributed manner. The design and implementation using Omnet++/Castalia of our proposal shows the relevance of multi-agent systems approach compared to CTP method.

Indeed, the simulation results show that our solution allows assessing at any time the fault tolerance level of each node leading to a better path selection process, and therefore, a longer lifetime of nodes. Limitations of the proposed approach are related to the reliability of link quality estimation mechanism which is best effort delivery. So, it is well adapted for relatively low traffic rate applications.

The performance of our approach can be enhanced by providing a formula that uses other network parameters to calculate the tolerance degree or even use a probabilistic approach to predict the activities of a sensor node such as packet traffic. In terms of implementation, it is interesting to use a real agent based platform for WSN in order to study performances of MAS and WSN when coupled. Other perspective works could concern to embed security parameters and develop more complex formulas.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey" Computer networks, vol. 38, no. 4, 2002, pp. 393–422.

[2] J.P. Jamont and O. Michel, "Design of embedded multi agent systems: discussion about some specificities", VII Agent-Oriented Software Engineering Technical Forum, Paris, French, December 15, 2010.

[3] J.P. Jamont, "MWAC: Multi-Wireless-Agent Communication", Revue Technique et science informatiques RSTI série TSI, vol. 25, no. 5, 2006, pp. 661-688.

[4] K. Smarsly, K.H. Law, and M. König, "Resource-Efficient Wireless Monitoring based on Mobile Agent Migration", In proceedings of the SPIE: Health Monitoring of Structural and Biological Systems 2011. San Diego, CA, USA, 06 Mar. 2011.

[5] W. Xue, B.Dao D. Liang, and W. Sheng, "Collaborative Target Classification and Localization in Wireless Sensor Networks Agent". Journal of Sensors, vol. 7, no. 8, 2007, pp. 1359-1386.

[6] Y. Lingyun, W. Xingchao, G. Jianhou, and Z. Yanfang, "Data Gathering Algorithm Based on Mobile Agent and Emergent Event Driven in Cluster-Based WSN", Journal of Networks, vol. 5, no. 10, 2010, pp. 1160-1168.

[7] N. Jabeur and P. A.Graniero, "Agent-Based Clusters to Virtually Manage Spatially Distributed Sensors", Projects TDMDSD08 and SII-73 University of Windsor, Department of Earth and Environmental Sciences, Windsor, Ontario, Canada, 2008.

[8] L. Min, X. Shijun, and S.Siyi, "An agent-based routing algorithm assistedQoS-forwireless sensor networks", Journal of Network and Computer Applications, vol. 35, no. 1, 2012, pp. 29-36.

[9] D. Wajgi and N.V. Thakur, "Load Balancing Algorithms in Wireless Sensor Network : A Survey" International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501, vol. 2, no. 4, Aug. 2012, pp. 456-460.

[10] Z. Bidai, M. Maimour, and H. Haffaf, "Multipath Extension of the ZigBee Tree Routing in Cluster-Tree Wireless Sensor Networks", International Journal of Mobile Computing and Multimedia Communications (IJMCMC).vol. 4, no. 2, Apr. 2012, pp. 30-48

[11] B. Rijubrata, "Mobile Agent based Architecture for Wireless Sensor Networks", In proceedings of TKK T-110.5190 Seminar on Internetworking, Helsinki University of Technology, Finland, Apr. 27, 2009.

[12] K.B. Pratik, Q.Hairong, and Y. Xu, "Collaborative Mobile-agent-based sensor fusion", Information Fusion, vol. 9, 2008, pp. 399-411.

[13] R.H.B. Rahal and B.Bounabat, "Wireless Sensor Network Simulation Of The Energy Consumption By A Multi Agent System", Journal of Theorical and Applied Information Technology, vol. 25, no. 1, 2011, pp. 50-57.

[14] B. Dario, S. Marco, B. Andrea, C. Davide, and G. Marco, "Markovian agent modeling swarm intelligence algorithms in wireless sensor networks". Journal of Performance Evaluation, vol. 69, no. 3-4, 2012, pp. 135-149.

[15] D.C. Matthew, A. Djamel, P.H. Barry, and H.Alan, "A Bayesian network approach to a biologically inspired motion strategy for mobile wireless sensor networks", Journal of Ad Hoc Networks, vol. 7, no. 6, 2009, pp. 1217-1228.

[16] V. Saamaja, K.R. Kiran, and R.M.C. Siva, "Using mobile data collectors to Improve network lifetime of wireless sensor networks with reliability constraints", Journal of Parallel and Distributed Computing, vol. 70, no. 7, 2010, pp. 767-778.

[17] G. Wenzhong, X. Naixue, C. Han-Chieh, H. Sajid, and C.Guolong, "Design and Analysis of Self-Adapted Task Scheduling Strategies in Wireless Sensor Networks". Journal of Sensors, vol. 11, 2011, pp. 6533-6554.

[18] H. Hai-ping, W. Ru-chuan, S. Li-juan, W. Hai-yuan, and X. Fu, "Research on tasks schedule and data transmission of video sensor

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networks based on intelligent agents and intelligent algorithms", The Journal of China Universities of Posts and Telecommunications, vol. 16, no. 6, 2009, pp. 84-91.

[19] A.A. Azrina, Y.A. Sekercioglu, P. Fitzpatrick, and M.Ivanovich, "A survey on distributed topology control techniques for extending the lifetime of battery powered wireless sensor networks", Communications Surveys and Tutorials, IEEE, vol. 15, no. 1, 2013, pp. 121-144.

[20] S. Narayanaswamy, V. Kawadia, R.S. Sreenivas, and P.R. Kumar, "Power control in ad-hoc networks: Theory, architecture, algorithm and implementation of the protocol compow", In proceedings of European Wireless Conference (2002), pp. 156-162.

[21] X. Ya, J. Heidemann and D.Estrin, "Geography-informed energy conservation for ad hoc routing", In proceedings of 7th Annual international conference on mobile computing and networking-MOBICOM, New York, USA, 2001, pp. 70-84.

[22] A. Cerpa and D. Estrin, "Ascent: Adaptive Self-Configuring sensor networks topologies", IEEE Transactions on Mobile Computing, vol. 3, no. 3, 2004, pp. 272-285.

[23] D.Z. Du and P. Pardalos, "Handbook of Combinatorial Optimization", Kluwer Academic Publishers, 2004.

[24] L. Bao and J.J. Garcia-Luna-Aceves, "Topology management in ad hoc networks", In proceedings of. 4th ACM International Symposium on Mobile AdHoc Networking and Computing, ACM New York, NY, USA, 2003, pp. 129-140.

[25] V. Kawadia and P.R. Kumar, "Power control and clustering in ad hoc networks", In INFOCOM 2003. Twenty-second annual joint conference of the IEEE Computer and Communications. IEEE Societies, 30 March-3 Apr. 2003, pp. 459-469.

[26] Y. Rong-rong, L. Bin, L. Ya-qian, and H. Xiao-chen, "Adaptively fault-tolerant topology control algorithm for wireless sensor networks", The Journal of China Universities of Posts and Telecommunications, vol. 19, no. Suppl. 2, 2012, pp. 13-18.

[27] C. Bo-Chao, L. Guo-Tan, T. Ryh-Yuh, and H. Ping Hsu, "Network lifetime bounds for hierarchical wireless sensor networks in the presence of energy constraints", Journal of Computer Networks, vol. 56, no. 2, 2012, pp. 820-831.

[28] G. Omprakash, F. Rodrigo, J. Kyle, M. David, and L. Philip, "Collection Tree Protocol", In proceedings of the 7th ACM Conference on embedded networked sensor systems, Berkeley, CA, USA, Nov. 2009, pp. 1-14.

[29] B. Dario, D. Salvatore, L. Francesco, P. Antonio, and S. Marco, "Evaluating wireless sensor node longevity through Markovian techniques", Journal of Computer Networks, vol. 56, no. 2, 2012, pp. 521-532.

[30] A.K. Safdar, D. Boubaker, and D. Karim, "Application of fuzzy inference systems to detection of faults in wireless sensor networks", Journal of Neurocomputing, vol. 94, no. 1, 2012, pp. 111-120.

[31] C. Paolo, C. Matteo, B. Stefano, and C. Luca, "A Cooperative Approach for Topology Control in Wireless Sensor Networks", Pervasive and Mobile Computing, vol. 5, no. 5, 2009, pp. 526–541.

[32] OMNeT++ Homepage http://www.omnetpp.org.

[33] F. Celik, A. Zengin, and S.Tuncel, "A survey on swarm intelligence based routing protocols in wireless sensor networks", International Journal of the Physical Sciences, vol. 5, no. 14, 2010, pp. 2118-2126.

[34] V. Rodoplu and T. H. Meng, "Minimum energy mobile wireless networks", IEEE J. Salt. Areas Communications, vol. 17, no. 8, 1999, pp. 1333-1344.

[35] Z. Yuanyuan, X. Jia, and H. Yanxiang, "Energy efficient distributed connected dominating sets in wireless sensor networks building", In proceedings of the 2006 International conference on wireless communications and mobile computing, New York, USA, ACM 2006, pp. 797-802.

[36] B. Chazelle, "Natural algorithms and influence systems", Communications of the ACM, vol. 55 no. 12, Dec. 2012, pp. 101-110.

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