Multiple Coverage with Controlled Connectivity in Wireless Sensor Networks

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ABSTRACT

The k-coverage of the area of interest is a classical requirement in wireless sensor networks, for purposes such as redundancy or multiple supervision of the area. We aim in this article at preserving full k-coverage of the area of interest yet minimizing the number of sensors needed for data gathering. Our main contribution consists in a localized layer-based coverage protocol and introduces a "`Sensing-Only` " state for some of the monitoring sensors. Indeed, among active sensors that achieve multiple coverage, a small connected subset can be constructed in order to ensure data multi-hop transmissions from points of interest to sink stations, thus allowing remaining sensors to cut their radio in reception. We evaluate our scheme through different constructions of sets of eligible nodes, ranging from a simple layered k-coverage to a more elaborated cross-layer determination. Ensuring multiple coverage with a reduced connected active node set, the present solution does not only reduce the overall activity of the network and the number of emissions, but also requires only few extra messages to be efficient.

Categories and Subject Descriptors

C.2.4 [**Computer-Communication Networks**]: Distributed Systems; C.2.1 [**Network Architecture and Design**]: Network topology

General Terms

Algorithms

Keywords

Wireless sensor networks, multiple connected area coverage, energy efficiency

1. INTRODUCTION

The k-coverage of the area of interest is a classical requirement in wireless sensor networks, for purposes such as redundancy or multiple supervision of the area. We aim in this article at preserving full k-coverage of the area of interest yet minimizing the number of sensors needed for data gathering. Our main contribution consists in a localized layer-based coverage protocol and introduces a "`Sensing-Only` " state for some of the monitoring sensors. Indeed, among active sensors that achieve multiple coverage, a small connected subset can be constructed in order to ensure data multi-hop transmissions from points of interest to sink stations, thus allowing remaining sensors to cut their radio in reception. We evaluate our scheme through different constructions of sets of eligible nodes, ranging from a simple layered k-coverage to a more elaborated cross-layer determination. Ensuring multiple coverage with a reduced connected active node set, the present solution does not only reduce the overall activity of the network and the number of emissions, but also requires only few extra messages to be efficient.

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2. BACKGROUND AND ASSUMPTIONS

2.1 State of the art

Multiple coverage is a matter of both energy-efficiency and fault-tolerance in wireless sensor networks. Many researchers have recently tackled the issue of connected coverage and we propose to review some of the key contributions. We limited this literature review to the solutions that are close in their assumptions, meaning no centralized approach is considered here. We aim at showing that coverage and connectivity have been addressed jointly so far, thus limiting the ability to control the redundancy of communication paths while ensuring the desired k-coverage. Multiple coverage enables a large redundancy while the set of nodes required to ensure connectivity could indeed be reduced.

In [15], sensors periodically make new decisions about their active or sleeping status. In each round, a single sensor starts the decision process, which then propagates to the whole network. New sensors are selected so that the priority is given to sensors located near optimal hexagonal area coverage, obtained when the area is ideally tiled with equal regular hexagons. First, the computation of this tiling should be achieved by a centralized entity. Second, every node should be aware of the tiling in order to acquire an appropriate priority. Although distributed solutions have been studied, full coverage is not always preserved as shown by the provided results.

The algorithm presented in [12] relies on the same idea, as it divides the area into small grids, each being covered by a sensor. Each sensor that can cover a grid maintains a list of other sensors that can also cover it, in a priority order. All sensors covering the same grid can communicate with each other and accordingly set time schedules for the monitoring task. In addition to having a centralized computation of the grids, the communication overhead for making covering decisions in cooperative manner is nontrivial. This scheme was recently extended by Lu and Suda [9] who guaranteed the required coverage when overflow between time schedules occurs.

Among solutions that rely on local information only, Sheu, Yu and Tu [11] proposed the following protocol. First, each sensor A sends its priority to all sensing neighbors. Then it considers the perimeter of its sensing circle, and portions of perimeters of sensing neighbors with higher priority which are inside its own sensing circle. If all these perimeters are fully covered by other sensing neighbors with higher priorities then A may sleep. To decide about some neighboring active sensors, each of the considered perimeters is subdivided into segments, based on intersections with other considered circles. For each such segment, the sensor with the highest priority, among nodes covering this segment, is active. Although some neighboring active sensors may not be discovered, those discovered suffice to construct connected query tree, for reporting from A to the sink. This localized protocol may induce excessive routing overhead and complexity (i.e. greedy routing).

A randomized algorithm was proposed in [13]. Based on a Markov model, this algorithm allows each node to probabilistically turn off while preserving both coverage and connectivity. Yet, the need for a new analysis when considering non homogeneous settings might be an obstacle in real deployments where exact neighbor information is required to ensure coherent node behavior once the neighborhood is modified for any reason (e.g. mobility, failure).

In [6], authors target connected k-coverage. The proposed solution consists in sending a query to k-hop neighbors and to make the decision based on the received answers. Although this solution manages to reduce the proportions of required active nodes, the complexity of the distributed versions and the communication overhead may indeed be prohibitive. Moreover, coverage and connectivity are tightly interdependant thus reducing the set of solutions to save energy related to communications.

In [4], k-coverage of the area of interest is guaranteed by dividing active nodes into k virtual sets, here called layers. Each node performs single coverage using the method described in [5], where each device locally decides of its activity after a certain timeout, according to activity messages received from neighbors with shorter timeout. This method uses a simple computation scheme and requires only few messages to achieve k-coverage, yet setting a large part of nodes in passive mode. Still, every active node is required for communication purposes as each virtual layer must be connected. Our work is based on this solution, improved by the introduction and construction of a set of nodes, able to cut their radio in reception without impacting global performance of the network.

2.2 Models, assumptions, and definitions

For the sake of uniformity and clarity, we will use the following definitions and notations for the network model in the rest of this paper.

Definition 1. *The Communication Radius (CR) of a node is the maximum Euclidean distance between itself and any other node it is able to communicate with.*

Definition 2. *The Sensing Radius (SR) of a node is the maximum distance between itself and any physical point at which an event of interest can be detected.*

Each node is supposed to be able to evaluate the coverage provided by a set of nodes, knowing their position and their sensing range. Here, the evaluation relies on a discretization-based coverage evaluation scheme, whose efficiency on low computation performances systems has been recently discussed [2].

Assumption 1. *We assume each sensor to be aware of its position in the 2D field. This position can be provided by any individual of collective mechanism, such as GPS or relative positioning to anchor nodes respectively.*

Definition 3. *A set of nodes is said to k-cover a target area if any physical point of this area can be sensed by at least k nodes of the set.*

In this article, we aim at having these k sensors belonging to distinct virtual sets. Each virtual set of covering nodes would therefore 1-cover the target area. These sets are further referred to as activity layers.

Upon event occurrence, nodes able to sense it might emit monitoring reports aimed at reaching on of the sink stations. Multi-hop communication paths are preserved for sure once the set of active nodes is connected, meaning that any two nodes of the set are able to communicate either directly or through multi-hop relaying. The redundancy in terms of available communication paths was recently discussed [10]. We propose to limit these paths by simply reducing the number of nodes involved in the connected set, as discussed further in the paper.

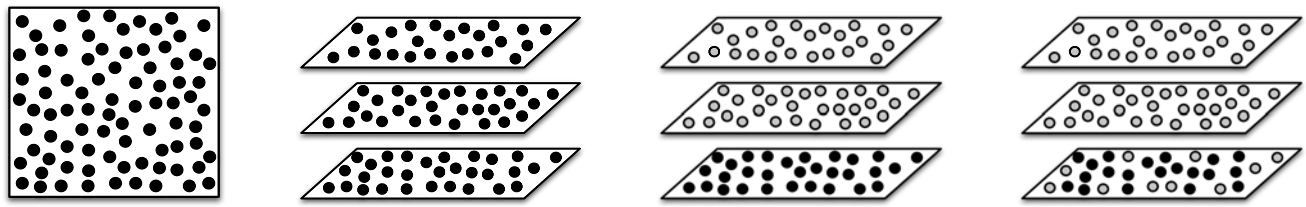
Once communication paths exist, a routing protocol is used. In this paper, we relied on a gradient-based protocol.

Definition 4. *In a gradient field, the rank of a node represent its minimal distance to the sink in number of hops. A node is said to be terminal if it has no direct neighbor of superior rank in its communication radius.*

In this paper, the term *broadcast* stands for message propagation in a sensor's neighborhood while the term *flooding* refers to network-wide message propagation. We will also use the term *active* to designate any node participating in the monitoring application or in multi-hop communications or both. Note that nodes taking both sensing and communicating duties will be designated as *fully active* ones.

3. PROPOSED CONTRIBUTION

As we tackle the issue of multiple coverage by connected sets of nodes in wireless sensor networks, we classified existing solutions into two categories. The first one is referred to as flat k-coverage contributions, in which a target area is said to be k-covered once every physical point is covered by at least k active sensors. The second one is more subtile as it requires the construction of k sets of active nodes, each covering the area once. This approach is referred to as the layered k-coverage. As detailed in this section, we adopted



(a) Flat 3-coverage. Each physical point of the target area is covered by at least three active sensors (black nodes).

(b) Three sets of active nodes, 3-covering the target area.

(c) 3-coverage is ensured while nodes of upper layers are set `Sensing-Only`, thus ensuring limiting redundancy of the communication paths.

(d) `Sensing-Only` nodes might also appear at lower layer, once cross-layer optimizations with the routing scheme are envisioned.

Figure 1: Several ways of ensuring connected k-coverage. Fully active wireless sensors are depicted as the black nodes while grey dashed points stand for `Sensing-Only` motes.

the second solution as we envisioned to better control network connectivity while ensuring multiple coverage of the target area. We indeed propose a new activity mode, noted as `Sensing-Only`. Nodes required for monitoring purposes but inducing redundancy in communication paths should be turned into that `Sensing-Only` state.

Switching a subset of active nodes into `Sensing-Only` state has many advantages. Indeed, most of widespread radio chipsets consume much energy, either in sending or in receiving mode. As we consider highly dense networks, nodes are expected to receive far more messages than they do emit. Finally, even if not sending nor receiving any message, an active node regularly performs costly operations at the MAC layer (e.g. clear channel assessment), thus reinforcing our idea to turn off the radio module for as many nodes as possible in order to increase the overall network lifetime consequently.

3.1 Activity layers

As depicted on Fig. 1(a), a flat approach consists in having a large set of fully active sensors (black nodes) both sensing the target area (the square) and being part of a connected backbone. For the sake of clarity, neither disks (sensing and communication) nor edges between connected nodes were reported on Fig. 1. Passive nodes were also removed from the figure for the same reason. In order to organize activity in a different manner, we opted for a layered k-coverage approach, in which nodes are assigned to distinct activity layers, as shown in Fig. 1(b).

3.2 Reducing proportion of fully active nodes

Our key idea is to use the organization into active nodes sets to address network connectivity at one layer only. In order to build a connected set of active nodes, we rely on a simple criterion [1]. As every node decides once its timeout expires, it is aware of active neighbors that have made their decisions earlier. If this set is connected, then the deciding node is not critical for any communication path meaning its passivity would not endanger local connectivity. Note that this criterion is useless once specific assumptions are considered such as $CR \geq 2SR$ [15]. Here, with layered k-coverage, we aim at introducing this simple rule at one layer only. Then, while most of existing solutions enabling multiple coverage also enhance highly redundant communication paths, we aim at controlling it by imposing connectivity at one layer only. For instance, Fig. 1(c) depicts three activity layers, out of which the lowest one only is composed of connected active sensors. Nodes of upper layers (grey dashed) are set in a `Sensing-Only` state, in which the communication can be switched off until a message were to be initiated by the node itself.

Note that communication paths from every active node (either fully active or `Sensing-Only`) to any other one is preserved. Indeed, `Sensing-Only` nodes are not disconnected from the connected layer, as detailed in property 1.

In this article, as activity is organized in several sets of nodes, this criterion could be applied either at all layers, or at a single one only.

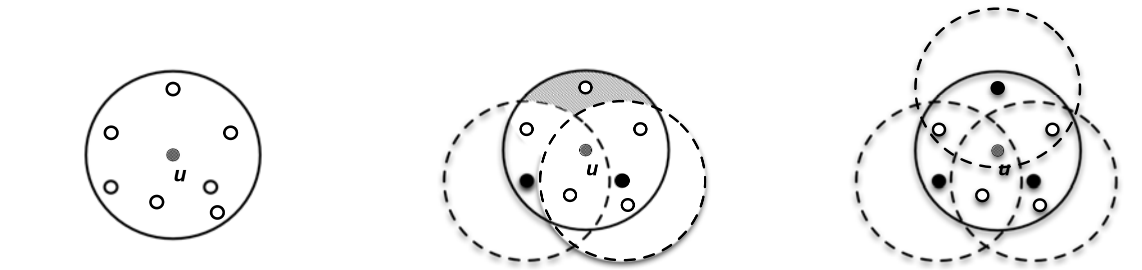
Property 1. *Every `Sensing-Only` node in layer i ($i \in]1,k]$) is connected to a fully-active sensor at layer 1.*

Proof. Every node in `Sensing-Only` mode at layer i ($i \in]1,k]$) has evaluated the coverage provided by nodes of lower layers. A `Sensing-Only` node at layer i ($i \in]1,k]$) therefore necessarily knows about neighbors of layer 1 that are connected and which are fully covering its area. As `Sensing-Only` nodes can emit, all its fully-active neighbors receive its messages and have the ability to forward them along multi-hop paths towards the sink station. $\square$

3.3 Constructing activity layers

In this paper, we adopt an adaptive approach to build the k required sets of active nodes. While the first one must be composed of connected full active sensors, upper layers rely on covering sets of `Sensing-Only` nodes. We use two variants that were already described in [4]. Unlike this proposal of [4], connectivity was addressed at one layer only as described earlier.

Initially, all nodes are fully active. Every sensor launches a timeout. Note that the timeout function could be either based on a random seed or an energy level of the node for instance. Several strategies of timeout determination were investigated in [5]. Once its timeout expires, a node decides whether it will remain fully active, `Sensing-Only` or if it will become passive. This decision is based on previous activity decisions of neighboring nodes. A node deciding with an empty neighbor table will necessarily decide to remain active and will select a layer. Being the first to make a decision within its vicinity (no other notification was received during its timeout), this node decides to be active at

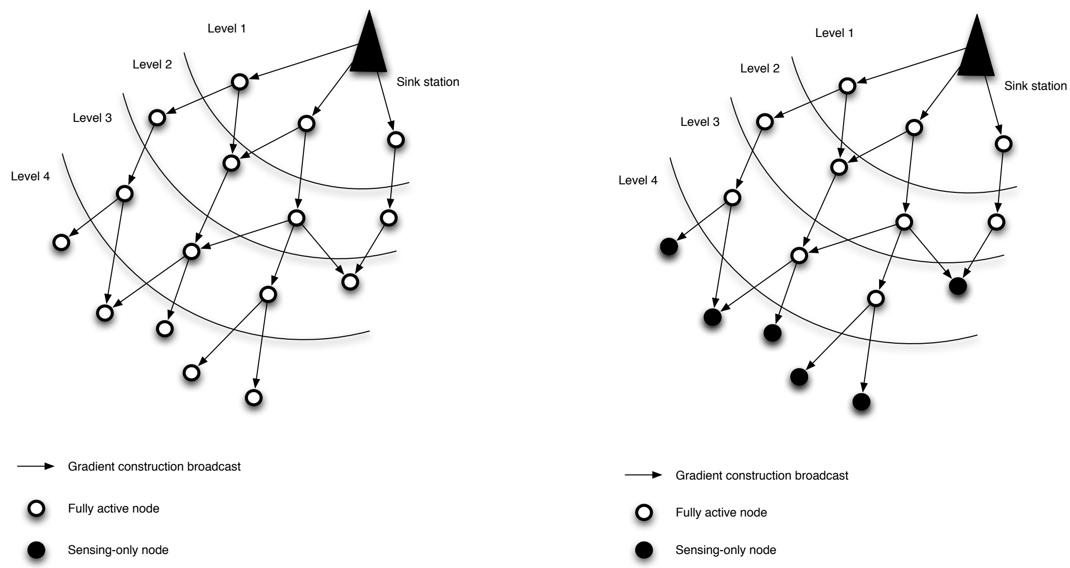


(a) Network physical topology

(b) Black nodes have shorter timeouts. They do not fully cover node u.

(c) A third neighbor has notified its activity decision, thus allowing node u to be fully covered.

Figure 2: Activity decision for PO and PR mechanisms



(a) Construction of the gradient by multiple broadcast.

(b) Terminal nodes can be set into `Sensing-Only` state.

Figure 3: Using gradient construction to determine `Sensing-Only` nodes

first layer. It must remain fully active and sends an activity message notifying neighbors with longer timeouts of its presence. When the neighbor table of a given node is not empty, the deciding sensor evaluates each layer. The first one should be composed of connected neighboring sensors that fully cover its area. Upper layers are only required to fully cover its area. If k layers of neighbors already exist, then the node switches to a passive state without sending any message. Otherwise, it decides to be either fully-active (if layer 1 is not fully covered by a set of connected neighbors) or `Sensing-Only` (if it shall belong to any other upper layer). This method is designated as **Positive-Only** (PO).

The second method, designated as **Positive-Retreat** (PR), performs an optimization of PO as it allows sensors that have already decide to be active to get passive as soon as other neighbors are discovered and checking its connected k-coverage criterion. In this case, the node broadcasts a retreat message within its vicinity in order to update neighbor tables for potential further activity decisions. This variant requires slightly more communication. The Positive-Retreat algorithm is described hereafter.

Both PO an PR are depicted in Fig. 2. On Fig. 2(a), a node u has decided to get active as its neighbor table was empty at the end of its timeout. Then, some new neighbors appear (black nodes) as they decided to be active. Node u gets aware of these nodes as they sent an activity message (Fig. 2(b)). Even though, a part of the sensing area (represented dashed in the figure) of u remains still uncovered. Node u thus needs to remain active. As depicted on Fig. 2(c), once a third node notifies u about its activity, the sensing area of u gets finally covered and u will be able to send a retreat message in order to have remaining neighboring nodes with not yet ended timeouts (white nodes) delete u from their neighbor tables.

Connectivity of a layer can also be guaranteed by adding a simple condition to the layer activity test (both for Positive-

Only and Positive-Retreat). When determining its coverage, a node needs to determine weather the set of its direct neighbors is connected or not. If not, then the current node has to remain active in this layer, in order to preserve global connectivity of the network. Preserving such a local connectivity ensures global connectivity [5].

These methods induce very few messages as knowledge comes with activity decision making. Considering the proportion of involved sensors (either fully active or `Sensing-Only`), our PR algorithm is optimal regarding the knowledge we assume at each deciding node as detailed in property 2.

PROPERTY 2. *Our Positive and Retreat variant is optimal regarding the available knowledge at every node. Indeed, no active sensor is useless as it would have otherwise turned into a passive or `Sensing-Only` mode upon later active nodes decisions notifications.*

PROOF. Let us figure out a node u that would have decided to remain active and whose presence would be useless. If u did not receive any activity message, then no active sensor belongs to its vicinity. If some messages were received from nodes that fully cover the sensing area of node u, then node u would have decided to retreat. □

3.4 Using routing information

We also enhanced our proposal by considering the possibility for nodes of the first layer to turn into `Sensing-Only` mode, as shown in Fig. 1(d). Our idea is to gather information from the routing layer in order to determine whether a node is locally crucial for the multi-hop relaying or not. The decision criterion can be modified in order to evaluate the position of a given node within the routing plan. The set of potential next hops is computed at the routing layer and can be used to determine the set of routing alternatives any node has to reach one of the sink station. Therefore, any node whose passivity would not empty the set of alternatives of its neighbors could get `Sensing-Only`, its monitoring duty remaining essential to k-coverage.

In this paper, we assume the routing layer to rely on a gradient construction, which provides us information about a node and its neighbors relative positions to the sink. Indeed, any terminal node can be put into `Sensing-Only` state yet preserving global connectivity as there is no further neighbors whose communications should be relayed towards the station.

Let us illustrate this point through Fig. 3. The gradient construction consists in every node to emit a message stating at which rank it stands from the sink station. The sink first broadcasts a message informing its direct neighbors about its rank (0 for the sink). Then, at the reception of a gradient message, each node evaluate its own rank as follows.

If current node rank is not yet determined, then the rank is set to the value of the rank field of the message, incremented by one. If current node rank is superior to the message provided rank incremented by one, then the rank is set to the latter and broadcasts its new rank to its direct neighbors. In any other situation, the received message is ignored. The construction of such gradient requires at least one message per node.

Nodes located within the vicinity of this station would get rank 1, while their neighbors, not able to directly communicate with the station would get rank 2 , and so on. These ranks are initialized with a signaling message coming from the sink, with a rank field, initially set to 0. Every node receiving the message increases the rank and retransmits it. By receiving this message, sensor nodes can set their rank and notify their own direct neighbors of their newly determined rank. By recursively doing so, we obtain a gradient in which each node knows the minimal distance to the sink station in number of hops for itself and its direct neighbors (Fig. 3(a)). Here, we use this information to determine a set of terminal nodes, which can set themselves in `Sensing-Only` state without disrupting the network connectivity (Fig. 3(b)).

Simulation parameter	*Value*
Target area	$50m \times 50m$
Deployed wireless sensors	from 300 to 1000 static nodes
Antenna model	Omnidirectional
Radio propagation model	Disk (range: $10m$)
Sensing model	Disk (range: $10m$)
MAC model	IEEE 802.15.4 CSMA/CA
Routing model	Gradient-based routing
Coverage quality	k=1, 2, 3, 4

Table 1: Recap of simulation parameters.

4. PERFORMANCE EVALUATION

4.1 Simulation description

This section presents the simulation results of our algorithm. The results were obtained by simulations using the WSNet event-driven simulator[1]. This wireless sensor network simulator provides various MAC and radio propagation models that allowed us to intensively test our propositions under realistic assumptions.

In our simulation, we consider static sensor nodes and static sink. Sensors are deployed according to a Poisson point process of intensity $\lambda > 0$ over a 50×50 square area. In our simulation, we only consider initially connected topology. The number of sensors nodes in the simulations varies from 300 to 1000 nodes, for average densities varying from 30 to 100 nodes. It is worth noting that the initial topology may not cover the whole area. In this case, the coverage is evaluated based on the initial proportion of covered area.

The sensing radius (SR) is fixed at 10 and is modeled as a disk. The communication radius is also fixed at 10. Due to space limitations, results concerning the impact of a variation in the $\frac{CR}{SR}$ ratio are not reported here. They remain in accordance to former studies [5]. Note that, unlike most of the evaluations proposed in the literature, we use realistic collision conditions and realistic CSMA/CA MAC layer (IEEE 802.15.4 [8]). These assumptions are used to show the robustness of our algorithm against message losses.

The detailed simulation parameters are exposed in Tab. 1.

Both Positive-Only and Positive-Retreat mechanisms are evaluated for 1 to 4-coverage. Timeouts are randomly drawn within a $[20; 120]$ seconds interval. This interval is chosen to shorten the activity decision process and to avoid message losses due to collisions for high density topologies.

For each density, the number of performed iterations is adjusted so that 95% of the results are in a sufficiently tight confidence interval.

[1]http://wsnet.gforge.inria.fr

A node u evaluates its coverage by discretizing its sensing area (using a 900 points regular grid). Node u is said to be covered if every point can be covered by at least one active sensor in its layer. Note that points outside the target area are not considered thus limiting border effects in our experimental results. This discretization step was set in order to remain as close as possible from exact computation schemes.

Simulation results are divided into two parts. We first show the efficiency of both Positive-Only and Positive-Retreat mechanism by only considering the sensors a layer 1 as fully active. These results show that $\sim$ 70% of nodes are in `Sensing-Only` state for both Positive-Only and Positive-Retreat for 4-coverage and 300 nodes. In the second part of the simulation, we apply the gradient construction to try to even more increase the number of `Sensing-Only` nodes especially at layer 1. The results show that (for 300 nodes and 4-coverage) $\sim$ 80% of nodes are in `Sensing-Only` state. The results are detailed in the following section.

4.2 Simulation results

4.2.1 Without gradient use

Figure 4 presents the results for Positive-Only simulations without the use of gradient construction. The figure shows different results regarding the number of nodes and the number of layers. We can see from this figure that the number of `Sensing-Only` nodes increases when the number of layer increases. This is the expected behaviour since in our algorithm only nodes at layer 1 are used for communication, thus are fully active. This figure also shows that our algorithm does not depend on density. Indeed, for different number of nodes in the network, the number of fully active nodes remains roughly constant which shows the efficiency of our decision scheme. Moreover, we can notice that the number of fully active node is independent of the coverage quality required. We can also notice that, at least 50% of the nodes are in `Sensing-Only` mode when we consider more than one layer. This behaviour suggests the energy efficiency of our scheme without changing the coverage quality.

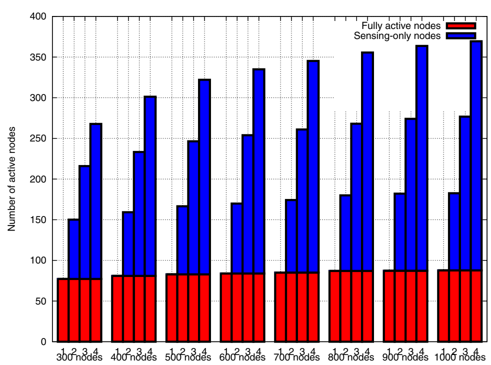


Figure 4: Fully active and `Sensing-Only` nodes resulting from Positive-only mechanism alone.

Figure 5 shows the results for Positive-Retreat scheme without gradient construction. We can see from this figure that Positive-Retreat and Positive-Only have the same behaviour. That is, the number of fully active nodes is independent of the number of layers or the density.

We can see from Figure 4 and Figure 5 that the gain between Positive-Only scheme and Positive-Retreat is around

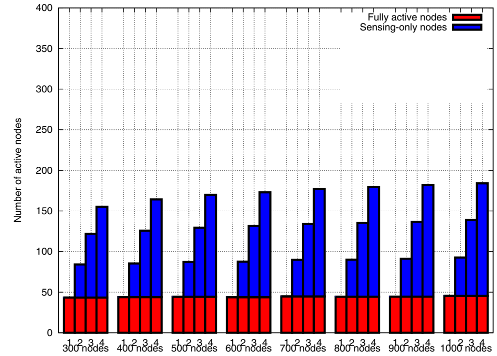


Figure 5: Fully active and `Sensing-Only` nodes resulting from Positive-Retreat mechanism alone.

30%. It is also worth noting that on both figure, the number of nodes in each layer are roughly the same for both schemes which shows the efficiency of the k-coverage provided by our algorithm. Similar simulations have also been performed with non-uniform node distributions and the results are of the same order and show that our scheme is insensitive to the initial node distribution.

4.2.2 With gradient use

This subsection presents the same results when a gradient is applied at layer 1 and the subset of non-relaying nodes are set to `Sensing-Only` state. Figure 6 and Figure 7 show the results for different node density and different number of layers.

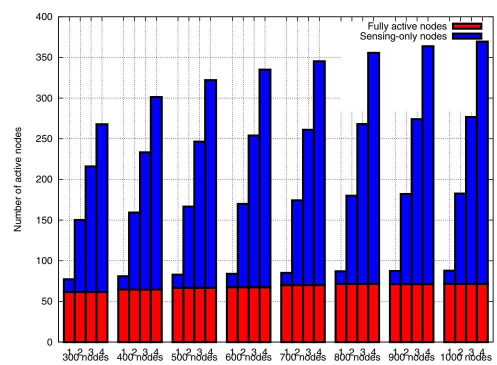
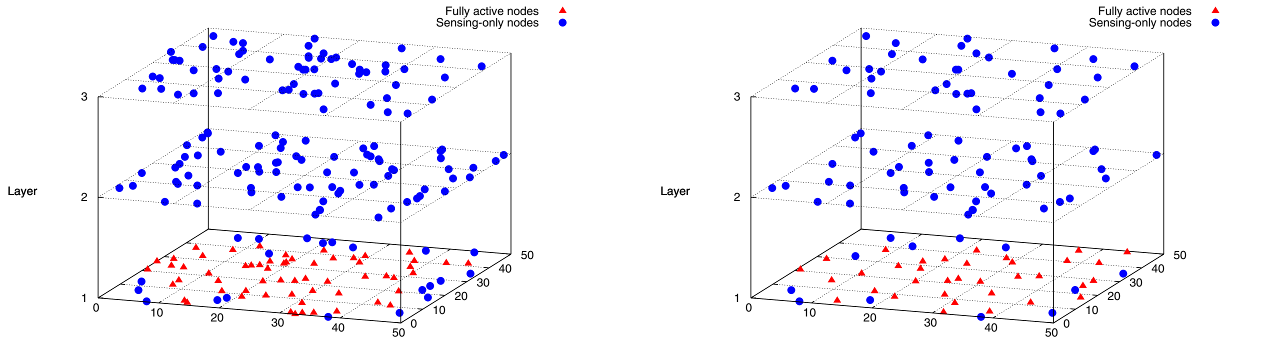


Figure 6: Fully active and `Sensing-Only` nodes resulting from Positive-only and gradient mechanisms.

We can see from these figure that unlike the results presented in Section 4.2.1 some node can be set to `Sensing-Only` state even when we consider 1-coverage. By applying this simple gradient procedure to increase the number of `Sensing-Only` nodes the number of active nodes is reduces by 10% with PO, and up to 20% with PR.

Finally, Fig. 8 shows an example of a resulting topology using Positive-Only or Positive retreat, both with our gradient mechanism. Note that all layers are only virtual, and that all nodes in the network topology belong to the same 2D plane. As the sink station was placed at the center of the zone, we can observe that PO combined with routing information allowed several sensors to turn into `Sensing-Only` state, all of them being logically located next to the borders



(a) Positive-only mechanism with layered k-coverage benefits from `Sensing-Only` nodes (blues points) at first layer.

(b) Largely reduced proportion of fully active nodes (red triangles) using our positive and retreat mechanism.

Figure 8: 300 node topologies targeting 3-coverage using gradient information to allow some nodes of first layer to be in `Sensing-Only` mode.

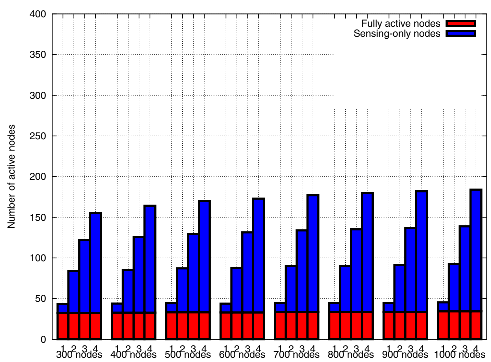


Figure 7: Fully active and `Sensing-Only` nodes resulting from Positive-Retreat and gradient mechanisms.

of the target area (see Fig. 8(a). Fig. 8(b) shows how much energy savings our positive and retreat scheme can provide as the obtained 3-covering topology is much sparser than the one of Fig. 8(a).

5. CONCLUSION

In this paper we introduce a new node states for wireless sensor network deployment. This state called "`Sensing-Only`" is used to reduce the energy consumptions of the network. Indeed, in wireless sensor networks some nodes may not be useful for the data routing process and therefore can turn their radio off for reception. The `Sensing-Only` mode, is a state where nodes use their transceiver only to send messages, in order to save energy.

This paper shows a new algorithm that combines a k-coverage scheme and a gradient field. During the localized k-coverage construction, all nodes that are not on layer $k = 1$ are set to `Sensing-Only` state. This first elimination scheme can reduce the number of active nodes by $\sim 70\%$ for a network with initially 300 nodes that provides a 4-coverage. The second elimination scheme is based on a gradient field where nodes that are not useful for relaying messages from the sensors to the sink go to the `Sensing-Only` state. This gradient elimination can help reducing the number of active nodes at layer 1 by $\sim 30\%$. Therefore by applying both schemes, $\sim 80\%$ of useful nodes are in `Sensing-Only` state.

In this paper, we apply a simple gradient scheme to reduce the number of active node a layer 1. Our short-term investigations will focus on several other methods to determine a set of `Sensing-Only` nodes in layer 1. Our goal is to increase the number of `Sensing-Only` nodes while maintaining a low message overhead. We are now testing the implementation of our solutions combined with techniques such as k-Local Minimum Spanning Tree (LMST). We will lead our further investigations to the construction of a local approximation of Maximum Leaf Spanning Tree (MLST) in order to maximize the number of `Sensing-Only` nodes.

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