CrossMark

Minimum Perimeter Coverage Set Based on Points of Tangency and Strong Barrier for an Extended WSN Lifetime

Wahiba Larbi-Mezeghrane[1] ⬤ · **Louiza Bouallouche-Medjkoune**[1] ·
Ali Larbi[1]

Abstract The random deployment of sensors in the area of interest triggers several research issues. Among them, we can cite connectivity, localization and coverage. In this paper, we focus on the latter one. Our objective is to monitor the perimeter of a region of interest with circular shape from intrusions. We propose a new approach to define the minimum coverage set based on points of tangency and strong barrier coverage. Furthermore, in order to exploit the redundancy of information due to the random deployment of nodes, we also suggest a new approach to generate the scheduling sets, which consists on the creation of multiple virtual perimeters around the area of interest, upon which the minimum coverage sets is constructed. In other words, the objective is to minimize the number of nodes in coverage set and to maximize the number of coverage sets for scheduling. These disjoint sets of sensors can be activated one after the other to further extend the network lifetime or multiple sets at time and reach *k-barrier* coverage for strong surveillance applications. Simulation results show that to generate the minimum coverage set, our approach gives better results compared to those proposed in the literature. Moreover, the approach of constructing the scheduling sets significantly increases the network lifetime.

✉ Wahiba Larbi-Mezeghrane
w.mezeghrane@gmail.com

Louiza Bouallouche-Medjkoune
Louiza_medjkoune@yahoo.fr

Ali Larbi
larbiali2@gmail.com

[1] Research Unit LaMOS, "Modeling and Optimization of Systems", Bejaia University, Targa Ouzemmour, 06000 Bejaia, Algeria

1 Introduction

The last decades have seen rapid advancements in wireless communication and smart sensing technology. A sensor is a sophisticate device that is able to capture and process external data and to communicate information with others micro-sensors. When several sensors communicate with each other via radio links (Ad Hoc) for specific treatment they form a Wireless Sensor Network (WSN) [1, 2]. A crucial feature of a WSN is its coverage. Perfect coverage area of interest is considered as the first challenge in WSN [3]; it represents an important functional metric [4]. Each sensor of WSN is deployed to sense a portion of an area of interest. In the literature, we distinguish three types of coverage: (i) area coverage, (ii) point coverage and (iii) barrier coverage [5–9]. The first one refers to the coverage of a specific area. In this case, the deployed nodes of WSN should be able to signal any changes within this area, so that a suitable action can be made on time. Every point within this area must be in the sensor range of at least one sensor, if it is covered by at least k sensors, we speak about *k-coverage* . In the second type of coverage, one or more target objects are covered by sensors, within certain area instead of the whole of this area. The classical example cited for this type is in art gallery [10], where some priceless arts are keeping watched by sensors in place of the whole gallery. The goal of the third type of coverage is to efficiently detect activities on boundary of the region of interest. A number of sensors are connected to build a chain across the boundary of area of interest. This chain is referred as "barrier". Every object crossing the zone from one side to another is detected by the sensors on the barrier. It can be categorized as either strong barrier coverage or weak barrier coverage. The strong barrier consists in detecting intrusions with arbitrary moving paths, whereas the weak barrier consists in detecting intrusions with only congruent crossing paths. When intrusions are detected by k sensors, the coverage is called *k-barrier* coverage. Many authors [7, 11–19] have taken an interest in the determination of minimal coverage set for a given area, i.e. they try to find an efficient coverage algorithm to get a set of sensors that monitor an area of interest with minimum number of sensors. The first contribution of this work is to establish a new approach for minimal coverage set based on the concept of strong barrier and point of tangency. This set of sensors covers whole perimeter of the region of interest and can detect all attempted intrusions. The second contribution is based on the exploitation of redundancy (nodes that cover the same area) by constructing scheduling sets. An effective scheduling is a promising approach and a key factor for increasing the network lifetime [20]. Our approach consists of the creation of multiple virtual perimeters, with different radii concentric to the region of interest, upon which the minimum coverage sets is constructed. Associating these two contributions allows us to construct a maximum number of scheduling sets, thus increasing the network lifetime when these disjoint sets (barriers) are activated one after other. Furthermore, it can strengthen perimeter surveillance by activating many sets at the same time, the coverage extended to become *k-barrier* coverage (where k is the number of barriers activated at the same time). The rest of this paper is organized as follows: next section gives an overview of works related to perimeter coverage and intrusion detection. Problem statement and related concepts are presented in Sect. 3. Section 4 describes in detail our two contributions: the proposed algorithm for minimum coverage set and the scheduling scheme, the proof of its correctness is given in Sect. 5. Finally, in Sect. 6, we compare its efficiency to other existing algorithms using simulation.

2 Related Research

Perimeter coverage topic has interested many authors; we can cite the work of Hung and Lui [7], which is considered as a progress of their precedent proposition. They proposed a distributed algorithm to monitor the perimeter of a big target object with circle shape, where many nodes are necessary to ensure the coverage of the entire object. The problem was equated to the circle-cover problem in a circular-arc graph, which cannot be directly applied to WSN scenario. The authors solved the problem with few numbers of messages and minimal coverage set, they formally proved the correctness of their algorithm. Two performance metrics were studied, namely: the total number of messages generated by the algorithm and the average time taken by the algorithm to define the selection state of network nodes. In [21], Kordari and Blankenship studied the issue and conducted an analytical study, on the relationship between the different metrics of the sensor network, in a probabilistic context, such as network density, the sensing radius, coverage capability, energy efficiency, etc. Their purpose is to monitor the boundary of a circular region, i.e. to report intruders moving into or out of a field of interest and not the entire field; the authors developed a network to achieve the desired objectives with high probability by introducing detection percentage and relating it to the more commonly used measures of WSN cited above. Each relation was determined by a theorem with an associate proof. The minimum sensor density to achieve a desired average coverage is also determined. Huan et al [16], attempted to define a strong barrier with minimal active sensors, for a region of interest with rectangular shape, under probabilistic sensing model. The barrier should identify any target trying to traverse the rectangle along any moving path. The authors have based on graph theory, using Dijkstra algorithm to find the shortest path. The generated set MCSD (Minimal Coverage Set Detecting) forms a strong intrusion detection barrier with minimal active sensors; it has reliable detection performance with low computing complexity. The proposed strategy increases the network lifetime. In [17], the authors proposed two approaches to find the minimum perimeter coverage of a circular area of interest. The basic principle is to find the intersection points of the coverage area of each sensor and the perimeter of queried region. Those points are considered as reference to select the next node (a coverage neighbor) composing the minimal coverage set. This set contains the sufficient number of nodes to cover the perimeter of the zone of interest, and insure the monitoring of this perimeter. The two approaches differ in decision making. So, in the first approach, a coordinator node in the center of the region is responsible for the execution of the algorithm, whereas, in the second one, which is completely decentralized, the decision making is managed by the nodes based on the information gathered from the neighbors. The two approaches enhanced the energy and the network lifetime over existing algorithm. In experimental study conducted in intrusion detection and border surveillance using WSN, the author in [22] noticed that very few attempts have been realized. We can quote the work cited in [23], where authors developed a Wall-Mounted Wireless Fencing System (WMWFS). It is an intrusion detection system based on infrared sensors, microwave and wireless camera. The authors studied how these different entities could be collaborated and how the data gathered from them could be treated. The collected information is sent to the control center wirelessly at real time, via multiple routers, where the data are analyzed with

the help of the Intrusion software. Various levels of alert were generated (buzzer, sms, email, lighting of intrusion area . . .). For sensors deployment, the authors have opted for a deterministic one, by dividing the perimeter of the area of interest into multiple segments along the boundary. Each segment includes a plurality of sensors of different types mentioned above, for more reliable intrusion detection. In [24], the authors conducted experimental study on a dense, distributed and *2-dimensional* wireless sensor network, with 90 multi-modal sensors (magnetometer and micro-power impulse radar sensors) for intrusion detection, classification and tracking moving object (vehicles, person, soldiers), based on the concept of "influence field", which represents the number of sensors that intercept an object. The security system is called "A line in the sand"?, it allows sensor nodes to realize localized treatment, filtering, and triggering functions, taking into account the environmental perturbations during intrusions. The authors were implemented over a thousand tests on dozens of sites. A performance estimator has been developed and tested; it varies depending on the class of the target and the level of network reliability. System scalability is also considered, at the time of testing. In [25], the authors proposed a solution for marine intrusion detection on a harbor area. They used three-axis accelerometer sensors deployed on buoys on the sea surface, synchronized before deployment. These sensors are used to measure buoys movements during the waves and to detect the passage of ships and their speed. The solution was based on the use of the V-shaped wave generated by the movement of the ship on the surface of the water, using signal processing techniques and cooperative signal processing, they distinguished between the ship-generated waves and the ocean waves. To permit more efficient and reliable detection, authors exploited spatial and temporal correlations of an intrusion. The evaluation of the detection system was based on the real data collected, in terms of successful detection ratio and detection latency.

3 Problem Formulation

The fundamental problem of coverage is to use the least amount of sensors to cater for application's requirements [26]. Our work consists firstly to find the minimum coverage set based on the concept of strong barrier [13, 14] and point of tangency. This set (called barrier) contains the minimum number of sensors whilst ensuring the effective coverage and the monitoring of whole perimeter of region of interest. The second contribution consists on proposing a new approach to generate scheduling sets, we try to construct as maximum as possible number of barriers by exploiting node redundancy. This approach consists on defining multiple virtual perimeters with different radii concentric to the region of interest, upon which the minimum coverage sets is constructed (more details are given in Sect. 4.1). To extend network lifetime, only one of these scheduling sets monitors the boundary of area of interest at time, whereas the others sleep. In order to insure strong surveillance, multiple sets can be activated at the same time; the coverage is extended to be *k-barrier* coverage. In this section, we first present the basic model and assumptions that have been adopted; this is followed by definitions related to our algorithm (border node, start angle, end angle and barrier). A figure gathering the used terms is presented as well as the steps used to calculate start angle and end angle. Finally, list of used abbreviations is given before presented our algorithm.

3.1 Basic Model and Assumptions

Our approach relies on the following assumptions:

3.1.1 Area of Interest

we are interested in monitoring the perimeter P of region with circular shape of radius R.

3.1.2 Deployment

Let *Depl_Ring* be the ring width of deployment zone, thus, all sensors are deployed randomly around perimeter P, over a range of $[R - Depl\_Ring/2, R + Depl\_Ring/2]$ meters. In fact, we believe that it is not necessary to deploy nodes around the center of the region, since our objective is the perimeter monitoring.

3.1.3 Hardware Capacity

Each sensor has a detection module, a communication module and a processing module. We assume that sensors are heterogeneous, i.e. the radius of coverage and communication differ from one sensor to another. Within the same sensor, the communication radius is assumed always exceed the coverage radius, to make sure that two coverage's neighbors can establish communication, and focus only on the coverage issue.

3.1.4 Localization

The position of each sensor is known in a global coordinate system. Each sensor knows its position in terms of an (x, y) coordinates.

3.1.5 Mobility

Once the sensors are deployed, they are supposed to be static.

3.1.6 Communication Protocol

A protocol that supports all necessary information for a communication within the network is assumed to be present.

3.2 Definitions

The relevant definitions are given as follows.

3.2.1 Definition 1

We call a *BorderNode* for the perimeter p, any node whose coverage area intersects p. A *BorderNode* can intersect over a perimeter, but can only belong to one Barrier.

3.2.2 Definition 2

Each node is identified by (α_i, β_i), representing respectively (the start and the end angles) formed with the two tangents lines to its coverage area and passing through the center of the region of interest.

3.2.3 Definition 3

Minimum coverage set (A barrier) for the perimeter p, denoted $MinCov_{pq}$ is a qth set of *BorderNode* for p, such that there is no subset belonging to $MinCov_{pq}$ ensuring coverage of p. The intersection set of all barriers formed after implementation of the algorithm is empty.

3.3 Illustration of the Area of Interest with Terms Used in Our Model

Area of interest, deployed zone as well as virtual perimeters created around the zone of interest are shown in Fig. 1, where perimeter P is the basic boundary that must be monitored by deployed sensors. Figure 1 has also shown a border node S_i, which has an
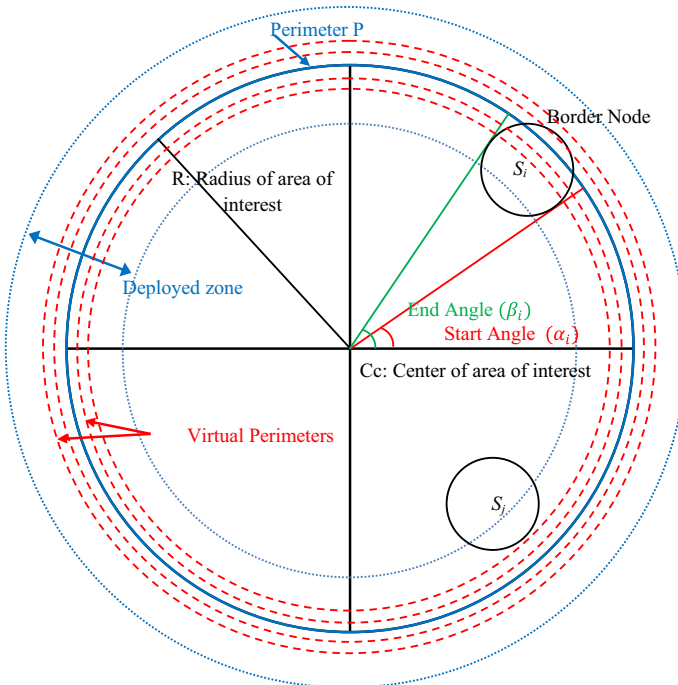

Fig. 1 Illustration of terms used in our model

Table 1 List of the used abbreviations

Abbreviations	Significations
α_i	Start angle of node S_i
β_i	End angle of node S_i
NofNode	Number of deployed nodes
R	The radius of the region of interest
Cc	The center of the region of interest
P	The basic perimeter to be covered
Depl_Ring	The ring width of deployment zone
NbPer	The number of perimeters to be covered
Step	The distance between two consecutive perimeters
NbBar	The number of barriers generated for the perimeter p
Cov_p	The set of border nodes for the perimeter p
$MinCov_{pq}$	The qth minimal coverage set generated for the perimeter p
S_{dom}	Dominant node (which covers the greater part of perimeter p)
Cov_portion	Portion of perimeter p covered by sensors

intersection with a perimeter P. However, S_j is not a border node for perimeter P (it does not intersect P). StartAngle and EndAngle for S_i are also illustrated.

3.4 List of the Used Abbreviations

The list of abbreviations used in this paper is detailed in Table 1.

4 Minimum Coverage Sets Algorithm

The first step of the algorithm consist in calculating start angle α_i and end angle β_i, based on points of tangency (the mathematical solution is detailed in Sect. 4.2). Lines 3–5 of the algorithm set nodes status to Not Selected (given that initially all nodes are not belonging to any barrier). When a node is selected in the construction of even barrier, its status becomes Selected (to make sure that all barriers are pairwise disjoint); this node can never be select by any other barrier. Lines 7–8 aim to build Cov_p , for each virtual perimeter p.

Algorithm 1 Find the minimum coverage sets

Input: $Cc, R, NbPer, Step, NofNode$
Output: $MinCov_{pq}$ with $p = \overline{1..NbPer}$ and $q = \overline{1..NbBar}$
 1: **Initially:** Sink has the positions of all nodes and theirs sensing range
 2: Compute (α_i, β_i) for each node S_i of the network
 3: **for all** nodes S_i **do**
 4:     $Selected(S_i) = False$
 5: **end for**
 6: **for all** perimeter p **do**
 7:     Construct Cov_p **such as**
 8:     $Cov_p = \{$ All nodes overlapping perimeter p, with $p = \overline{1..NbPer}$ $\}$
 9:     $CurrentBar = True$
10:     $Find = False$
11:     **while** $CurrentBar$ **do**
12:         Choose S_{dom} from Cov_p **Such as**
13:         $\begin{cases} (Selected(S_{dom}) = False) \\ \wedge \\ (|\beta_{dom} - \alpha_{dom}| = max(|\beta_i - \alpha_i|), \forall\, S_i \in Cov_p) \end{cases}$
14:         $CurrentNode \leftarrow S_{dom}$
15:         $MinCov_{pq} \leftarrow S_{dom}$
16:         $Selected(S_{dom}) = True$
17:         **while** $NotFind$ **do**
18:             Choose S_j from Cov_p **Such as**
19:             $\begin{cases} Selected(S_j) = False \\ \wedge \\ Sensing\ zone\ of\ S_j\ overlap\ the\ sensing\ zone\ of\ CurrentNode \\ \wedge \\ \beta_j = max(\beta_i), \forall\, S_i \in Cov_p \end{cases}$
20:             **if** S_j is finded **then**
21:                 $CurrentNode \leftarrow S_j$
22:                 $MinCov_{pq} \leftarrow MinCov_{pq} \bigcup S_j$
23:                 $Selected(S_j) = True$
24:                 **if** Sensing zone of S_j overlap the sensing zone of S_{dom} **then**
25:                     $Find = True$
26:                     $CurrentBar = True$
27:                 **end if**
28:             **else**
29:                 $Find = False$
30:                 $CurrentBar = False$
31:                 $\forall\, S_j \in MinCov_{pq},\ Selected(S_j) = False$
32:             **end if**
33:         **end while**
34:     **end while**
35: **end for**

In order to build minimal coverage sets *MinCov_{pq}*, we begin by selecting the dominate node S_{dom} i.e. node that cover the biggest portion of perimeter p (lines 12–13). The selection conditions of a next node are defined in lines 18–19 and correspondent formulas (11 and 12) are given in Sect. 5, the detailed process is explain in Sect. 4.3. This process is repeated (The innermost loop: lines 17–33) until the sensing zone of the next node overlap with that of dominate node (lines 24–27). If this condition is satisfied, the barrier is built. Then we try to find all possible *MinCov_{pq}* for the same perimeter p (The middle loop: lines

11–34). When a next node is didn't found, i.e. the barrier cannot be built; all nodes selected in this $MinCov_{pq}$ are deselected, to allow their selection by other barriers. Then, we sweep to the next virtual perimeter $(p + 1)$, and repeat the same process, namely, build all possible barriers for all virtual perimeter (The outermost loop: 6–35).

4.1 Scheduling Sets and Lifetime Extension

The dense deployment of sensors triggers redundancy of information transmitted to base station. In order to take advantage of this redundancy, i.e. using nodes that monitor the same zone, an efficient solution consist on dividing network into multiple scheduling sets. Defining scheduling sets for the initial perimeter P only, let a very great number of sensors very close to this perimeter unused and excluded from coverage. Consequently, we have proposed a new approach for the generation of scheduling sets by creating multiple virtual perimeters very close together that formed concentric circles around the area of interest. Let *step* be the distance between two consecutive virtual perimeters, thus, the radii of these perimeters are obtained as follows $R \pm j \times step$, with $j = \overline{1 .. NbPer/2}$ (refer to Table 1). Over each virtual perimeter, we try to define multiple barriers based on our minimum coverage set approach. At the end of execution of our algorithm, the network is divided into maximum disjoint subsets (or barriers, denoted by *MinCov* in our algorithm); each subset covers totally the zone of interest with strong barrier coverage. Only one barrier is activated at a given time, while all the others stay in sleep mode, to reduce power consumption and extend the network lifetime. More there are barriers; longer will be the lifetime of the network. When the energy of a node belonging to an active barrier reaches a critical level, this one warns the base station to activate another barrier, thus, the surveillance is not compromised. The monitoring could be strengthened by the activation of several barriers at a time, and reach *k-barrier* coverage, where k is equal to number of activated barriers at time.

4.2 Determination of the Angles Formed by the Two Points of Tangency

4.2.1 Determining the Coordinates of the Two Points of Tangency

We assume that a sensor S_1 is deployed at point (x_1, y_1), with r_1 its coverage radius. To find the points of tangency, the following equations are used. Equation (1) defines the Euclidean distance between S_1 and the center of the region of interest denoted Cc. (Refer to Fig. 2)

$$d_1 = \sqrt{x_1^2 + y_1^2} \tag{1}$$
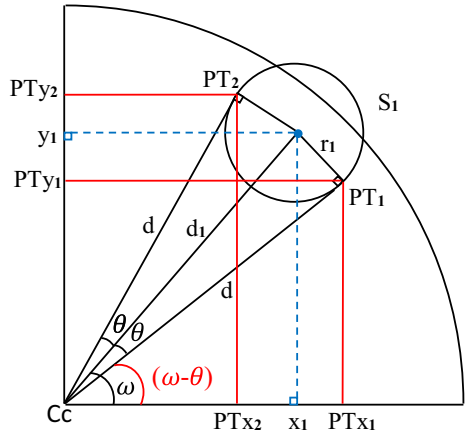
The following trigonometric formulas are used:

$$\theta = \arcsin(r_1/d_1) \tag{2}$$

$$d = d_1 * \cos(\theta) \tag{3}$$

$$\omega = \arccos(x_1/d_1) \tag{4}$$

The coordinates of the first point of tangency (PT1) are respectively:

Fig. 2 The coordinates of the
two points of tangency

The coordinates of the second point of tangency (PT2) are respectively:

$$PTx_1 = d * \cos(\omega - \theta) \tag{5}$$

$$PTy_1 = d * \sin(\omega - \theta) \tag{6}$$

The coordinates of the second point of tangency (PT2) are respectively:

$$PTx_2 = d * \cos(\omega + \theta) \tag{7}$$

$$PTy_2 = d * \sin(\omega + \theta) \tag{8}$$

4.2.2 Uniformization of the Two Angles Formed by Points of Tangency

Once the points of tangency were found, the angles formed by those points will be uniformized in order to have all angles between 0 and 2π, by using formulas (9) and (10).

$$\alpha_1 = mod(\arctan((PTy_1 - Ccy), (PTx_1 - Ccx)) + 2\pi, 2\pi) \tag{9}$$

$$\beta_1 = mod(\arctan((PTy_2 - Ccy), (PTx_2 - Ccx)) + 2\pi, 2\pi) \tag{10}$$

Except nodes whose monitor angle 0, α_1 is always smaller than β_1.

4.3 Selection Process of a Next Node

Let S_i be the dominant node, which covers the greater part of the perimeter P, it is the first node selected to built the barrier; we considerate it as *CurrentNode*. To find the second node of the barrier (or next node in general cases) refer to Fig. 3, S_j is eliminated for two reasons, firstly, it is not a *BorderNode* for P (it does not intersect P); secondly, it is not a neighbor of S_i. So we have to choose between S_k and S_l, both satisfy the two requirements listed above. However, $\beta_l > \beta_k$, consequently S_l is selected as next node. S_l becomes in turn the *CurrentNode*; the research of the next node that satisfies the three conditions cited above is repeated, until a full covering of the perimeter, i.e. finding the dominant node as the neighbor of *CurrentNode*.

Fig. 3 Selection of the next node
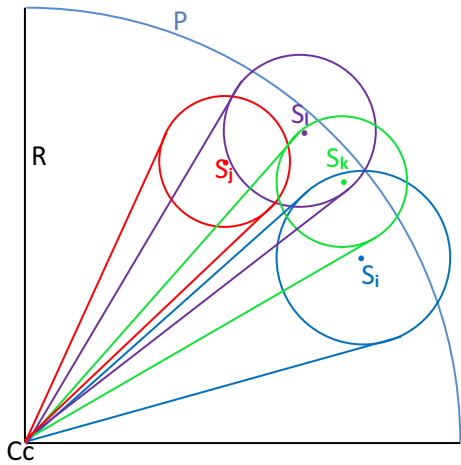

5 Correctness

In this section, we try to justify that our approach correctly identifies the minimum coverage set for a perimeter P, by using the Points of Tangency (PT) and strong barrier coverage, compared with that based on the Intersection Points (IP) reported in [17].

Considering an homogenous network, the sensing range of each node is r; we consider also the following notations for sensor S_i:

- α_i, β_i: the start angle and the end angle of S_i respectively, formed by the tangent to disc coverage of S_i, from a point Cc (center of area of interest).
- α'_i, β'_i: the start angle and the end angle of S_i, formed by the intersection points between disc coverage of S_i and a perimeter P, from a point Cc (refer to Fig. 4).

To choose the next node (S_{i+1}), its angles must satisfy inequalities (11) and (12):

Fig. 4 Illustration of PT and IP
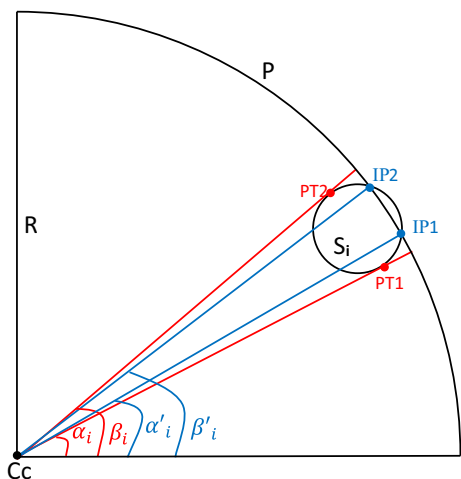
$$\alpha_i < \alpha_{i+1} < \beta_i < \beta_{i+1} \tag{11}$$

$$\beta_{i+1} > \beta_j, \quad \forall \; S_j \in \{set \; of \; neighbors \; of \; S_j\} \tag{12}$$

Inequality (11) ensures to always choose the neighbor, their cover ranges overlap (to don't let a gap between nodes), at the same time, to don't choose node that monitors the same zone; it is proved in [17].

Inequality (12) ensures to always choose the node that monitor the biggest part of the perimeter P which is not covered yet, and move with a biggest step (angle) to reach 2π faster.

From the properties of tangent and secant of a circle, the following equations are resulted:

$$\begin{cases} \alpha_i = \alpha'_i \; and \; \beta_i = \beta'_i, \; if \; PT \; and \; IP \; coincide \; (Very \; infrequently) \\ \alpha_i < \alpha'_i \; and \; \beta_i > \beta'_i \;, \; otherwise \end{cases} \tag{13}$$

Let S_i be the first node selected to cover the perimeter P, thus:
After the first selection:

Based on points of tangency (PT): $Cov\_Portion = \beta_1 - \alpha_1$ (with $\alpha_1 = 0$)
Based on points of tangency (PT): $Cov\_Portion' = \beta'_1 - \alpha'_1$ (with $\alpha'_1 = 0$)

$Cov\_Portion \geq Cov\_Portion'$ (from (13))

After the second selection:

$Cov\_Portion = Cov\_Portion + (\beta_2 - \alpha_2) - (\beta_1 - \alpha_2)$
$Cov\_Portion' = Cov\_Portion' + (\beta'_2 - \alpha'_2) - (\beta'_1 - \alpha'_2)$

$Cov\_Portion \geq Cov\_Portion'$ (By applying properties of inequalities to (13))
After the jth selection:

$Cov\_Portion = \sum_{i=1}^{j}(\beta_i - \alpha_i) - \sum_{i=2}^{j}(\beta_{i-1} - \alpha_i)$
$Cov\_Portion' = \sum_{i=1}^{j}(\beta'_i - \alpha'_i) - \sum_{i=2}^{j}(\beta'_{i-1} - \alpha'_i)$
$Cov\_Portion \geq Cov\_Portion'$ (By applying properties of inequalities to (13))

At the end, when the two approaches reach the angle 2π:

$Cov\_Portion = \sum_{i=1}^{n}(\beta_n - \alpha_n) - \sum_{i=2}^{n}(\beta_{n-1} - \alpha_n)$
$Cov\_Portion' = \sum_{i=1}^{n'}(\beta'_{n'} - \alpha'_{n'}) - \sum_{i=2}^{n'}(\beta'_{n'-1} - \alpha'_{n'})$

where n and n' are the numbers of nodes used by PT and IP respectively.
Let's prove that $n \leq n'$.

The worst scenario is to select at each step the same node by the two approaches, this lead to $n = n'$. Otherwise, based on our approach, the optimal node is always selected at each step. The difference $\beta_i - \beta'_i$ noted $\phi = 2 * \arcsin(r/R)$ (deducted by using trigonometric formulas, where R is the radius of area of interest) grows at each step, when the difference is bigger than the maximum angle could be formed by a node, the approach reported in [17] needs at least $n' = n + 1$ nodes to cover the gap. So, to cover the sector formed by $\beta_n - \beta'_{n'}$ (where $\beta_n \simeq 2\pi$), we need at least $quotient((\beta_n - \beta'_{n'})/\phi) + 1$ nodes, where $quotient(a/b)$ is a function that returns the integer part of the division of any real number a with b, thus $n' = n + quotient((\beta_n - \beta'_{n'})/\phi) + 1$. This leads to the inequality

$n < n'$ i.e. the number of nodes used by our approach for finding minimal coverage set is less then that proposed in [17].
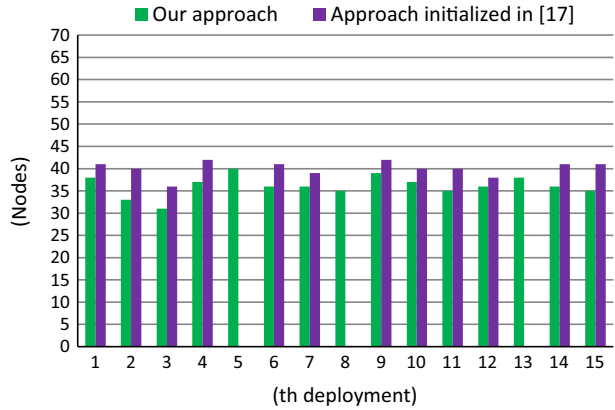
6 Simulation Results

To evaluate the performance of our proposed approach, the simulation has been implemented using Matlab. For comparison, we have implemented the algorithm described in [17]. In this algorithm, the authors defined a minimal coverage set for an area of interest with circle shape, based on the intersection points between coverage area of sensors and the area of interest. In the precedent section we proved that the use of points of tangency identifies the minimum set of sensors than the use of the intersection points, the simulation is conducted to support our proposal. In order to compare the two approaches, we have used the same parameters as those reported in [17], namely: (i) the sensors are deployed randomly with uniform distribution, (ii) the region size is $500 * 500$ m^2, (iii) the radius of monitoring perimeter is 125 m with the center coordinates at locations ($Ccx = 250$) and ($Ccy = 250$), (iv) the number of sensors are varied between ($NofNode = 1000$) and ($NofNode = 3000$), (v) the sensors are heterogeneous, their coverage radii are selected in a random manner between 20 meters and 60 meters ($Rmin = 20$) and ($Rmax = 60$). The detailed experimental parameters are set as Table 2 shows.

As can be seen, Fig. 5 shows the number of nodes used by the two approaches to cover the perimeter P, by performing 15 independent deployments. These deployments have been done in a sparse and broad network by modifying the value of two parameters as follows: $NofNode = 500$ nodes and $R = 500$ m. The figure shows that for each deployment, the number of nodes used by our approach (green color) is less than that reported in [17]. Moreover, in some deployment (5th, 8th and 13th), our algorithm covers P successfully, otherwise the algorithm used in [17] could not cover P, this may be explained by the

Table 2 Setting of simulation parameters

Parameters	Values
Ccx (X coordinate of center of region)	250 (m)
Ccy (Y coordinate of center of region)	250 (m)
R	125 (m)
$Depl\_Ring$	50 (m)
Number of base stations	4
Base station location	(375, 250), (250, 375), (125, 250), (250, 125)
$NbPer$	5
$Step$	5 (m)
$NofNode$	$1000 - 3000$
$Rmin$ (Minimum coverage radius)	20 (m)
$Rmax$ (Maximum coverage radius)	60 (m)
E_0 (Initial energy of each sensor)	0.5 (J)
$PacketLength$ (Size of packet data)	6400 (bit)
$CtrPacketLength$ (Size of packet control)	200 (bit)
E_{elec} (Electrical energy)	50 (nJ/bit)
E_{amp} (Transmit amplifier)	0. 001 (pJ/bit/m^2)

Figure 6 shows the number of nodes that cover the perimeter P. One can notice that before running the coverage approach, the number of redundant nodes is very important. This leads to waste a lot of energy by multiple active nodes. After running the coverage algorithms, all redundant nodes are deactivated, resulting in energy efficient. Moreover, it also shows that our approach reduced more the number of node covered P; this is regardless of the number of deployed nodes

In order to compare the number of scheduling-sets (or barriers) generated by the two approaches; we have implemented our scheduling-sets creation process for the approach reported in [17]. As can be seen in Fig. 7, the number of barriers generated by our approach, on the first deploy, is greater than the number of barriers generated by approach reported in [17]. As can clearly be seen from the two curves, the number of barriers
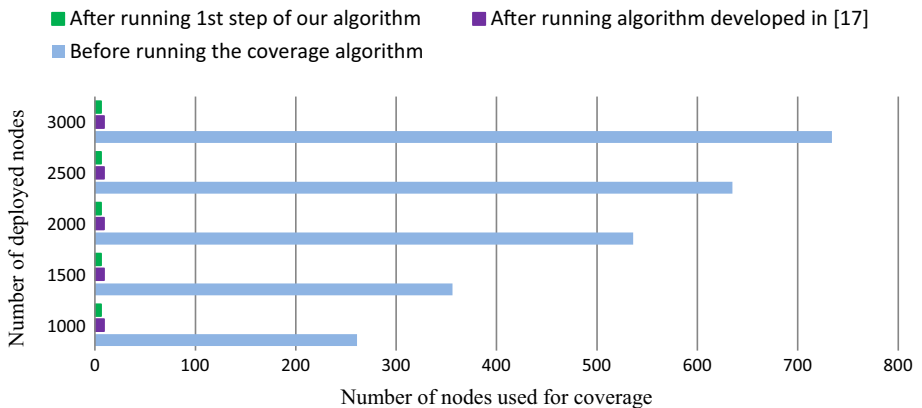

use of the point of tangency combined with strong barrier coverage to construct the minimum coverage set. More specifically, points of tangency contribute to reduce to the fullest the overlapping area between sensing area of neighboring sensors constituting the barrier.The strong barrier, on the other hand, allowed us to construct a ring around P, in such a way that all sensors constituting the barrier overlap a part of perimeter P, without covering all smallest sectors of P, As a consequence, the number of sensors required to browse the perimeter P and constituting the barrier is also reduced.

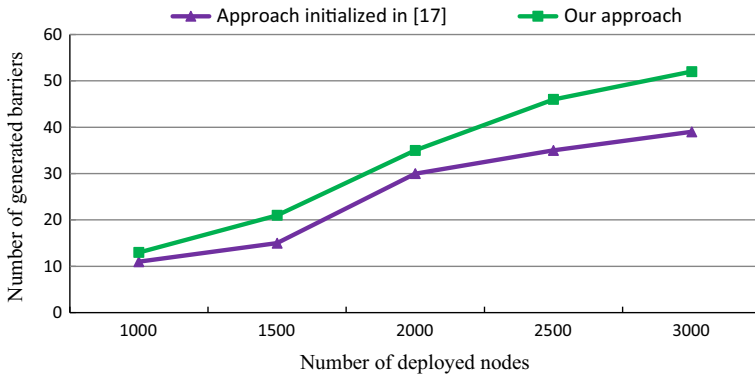**Fig. 6** Number of nodes covered the perimeter P

Fig. 7 Comparing the number of barriers generated by the two approaches

generated by our developed approach, on the first deploy, is greater than that generated by approach reported in [17]. This difference increases by deploying 1000, 1500, 2000, 2500, 3000 nodes, which could be explained by the fact that our algorithm reduces the number of nodes in minimum coverage set (or barrier), which leads to construct a greater number of barriers with less number of nodes.

Figure 8 shows the percentage of nodes participating in monitoring after running our algorithm. When the number of nodes participating in monitoring is compared with the number of deployed nodes (curve with triangles), we have used 13.1% by deploying 1000 nodes, this number grows with the growth of number of deployed nodes (we have used 22.23% by deploying 3000 nodes). It may be seen as a small percentage, due to the random deployment of sensors in all area of interest. But when we compare our simulation results with redundant nodes (curve with squares), one can notice that 90.87% are reached by deploying 3000 nodes, i.e. we have used an important number of nodes that are potential candidates in coverage. This may be explained by the creation of multiples virtual perimeters with differents radii around of P, theses virtual perimeters are separated with each other with small distance, each one is treated in the same way as the basic perimeter P. The scheduling sets are constructed based on all these perimeters.

In our study, we opted to use a target deploy to run our algorithm; we believe that is not very interesting to deploy nodes in the center of area, when the object is to monitor the perimeter. Thus, we deploy nodes randomly in strip around P, with radius $R \pm Depl\_Ring/2$, which is very realizable in practice. The virtual perimeters defined are separated from each
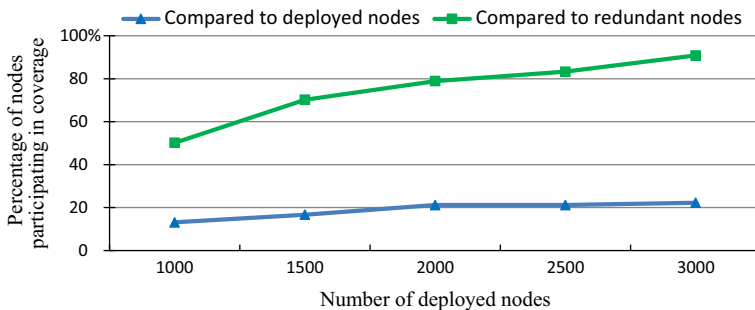

Fig. 8 Percentage of nodes that participate in monitoring versus number of deployed nodes

other by a step, with a maximum value of $Depl\_Ring/(NbPer + 1)$, where $Depl\_Ring$ and $NbPer$ are defined in Table 1.

Figure 9 shows the growth of sensor number participating in monitoring in different cases. We notice that in the first minimum coverage set (curve with circle), this number is very small regardless of the number of deploy nodes, it increases by generating scheduling sets for the basic perimeter only (curve with triangle), and still increases with the growth of deploy nodes. After running the whole proposed scheduling set with all virtual perimeters (curve with diamond), the number of nodes participating in monitoring becomes more important at each deployment. The best result is obtained by using the target deployment (curve with square), which optimizes maximally the number of nodes participating in coverage and monitoring.

In order to evaluate the energy consumption, we used the Heinzelman's model presented in [27]. According to this radio model, to transmit a *k-bit* message for distance *d*, the radio expends:

$$E_{TX}(k, d) = E_{elec} * k + E_{amp} * k * d^2 \qquad (14)$$

To receive this message, the radio consumes

$$E_{RX}(k) = E_{elec} * k \qquad (15)$$

The proposed scheme for energy balanced is as follow: we are putting on place four base stations, in the four quarts of the monitoring zone, with the *BS*1 at location (375, 250), the *BS*2 at location (250, 375), the *BS*3 at location (125, 250) and finally, the *BS*4 at location (250, 125), the whole thing could be seen as only one base station. The purpose is to reduce the number of hops necessary to attempt the base station when an intrusion has been detected. In the same way, the proposed scheme contributes to reduce the charge on the central point. If the area of interest is composed of only one base station situated in the center, in that case, nodes around the center drain quickly their batteries and become useless, the network is fragmented, in spite of the coverage is stay insured. In other word, an intrusion could be detected but never transmitted to the base station and the network is considered die. These are the reasons that induce us to choose the proposed scheme associated with the target deployment previously mentioned in Sect. 3.1. Notice that these proposed schemes are implemented for the two approaches to perform our simulation. In
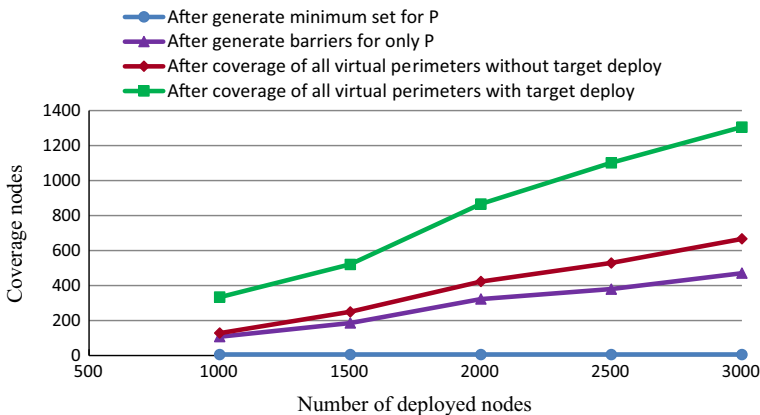

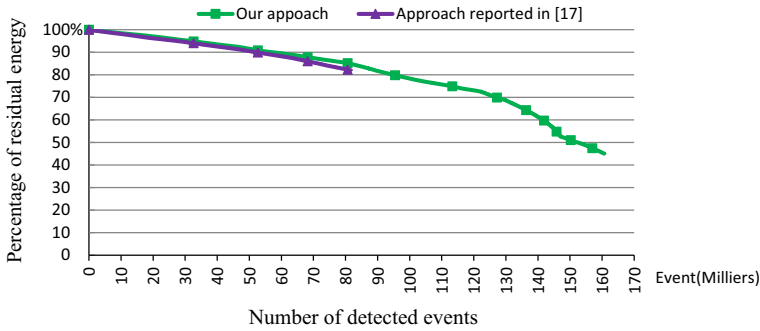**Fig. 9** Variation of number of coverage nodes in different cases

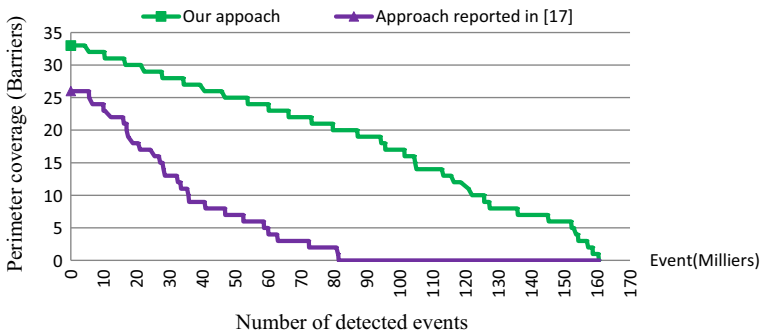**Fig. 10** Variation of energy consuming by the two approaches

Fig. 11 The relation between the perimeter coverage and the network lifetime

other hand, to route information to base station, the communication protocol that we have used favors nodes that are not participating in coverage to being 'relay node' (node used to forward messages until the base station).

Figure 10 illustrates the energy consuming by our approach and that reported in [17] by deploying 1000 nodes. Initially, the total energy of nodes composed the network drains in the same manner by the two approaches. After 81470 detected events, the network of approach reported in [17] is considered as died (ie. either all barriers are died, or a detected event cannot be routed to the base station), although the total remaining energy is greater than 80%. However, using our approach, we notice a better use of the total energy of the network, by exploiting 54,98%.

Figure 11 shows the network lifetime, which is represented by the number of events or intrusions detected versus the number of barriers generated for coverage (if we consider an average detection of an event per day, the x-axis represents days). We can clearly observe that our approach extends the network lifetime comparatively to that reported in [17]. 160, 600 events were detected using our approach, whereas only 81, 470 events were detected elsewhere. This may be explained by the fact that our approach generates more barriers than that reported in [17], which was in turn engendered by the reduction of number of nodes making up a barrier. This proposition associated with scheduling approach and routing protocol cited above, contributes to extend considerably the network life time.

7 Conclusion

In this paper, we have studied the problem of covering the perimeter with WSN; we have proposed an approach that enhances effectively the network lifetime without reducing the detection reliability. The proposed algorithm began with reducing considerably the number of active sensors needed for covering the perimeter, which in turn, contributes to increase the number of scheduling subsets generated on the multiple virtual perimeters with different radii, defined around the initial perimeter. A proof is established, to demonstrate that a concept of strong barrier associated with the points of tangency uses a minimum number of nodes for perimeter coverage than the approach based on intersection point. Simulation results support our theoretical study. In the present work, the position of nodes is supposed known but in the future work; we intend to investigate coverage and localization integrated together.

References

1. Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer Networks*, *38*(4), 393–422.
2. Ilyas, M., Mahgoub, I., & Kelly, L. (2004). *Handbook of sensor networks: Compact wireless and wired sensing systems*. Boca Raton: CRC Press Inc.
3. Zhu, C., Zheng, C., Shu, L., & Han, G. (2012). A survey on coverage and connectivity issues in wireless sensor networks. *Journal of Network and Computer Applications*, *35*(2), 619–632. Simulation and Testbeds.
4. Machado, R., Zhang, W., Wang, G., & Tekinay, S. (2010). Coverage properties of clustered wireless sensor networks. *ACM Transactions on Sensor Networks*, *7*(2), 13:1–13:21.
5. Zhao, Q., & Gurusamy, M. (2008). Lifetime maximization for connected target coverage in wireless sensor networks. *IEEE/ACM Transactions on Networking*, *16*(6), 1378–1391.
6. Wang, B. (2011). Coverage problems in sensor networks: A survey. *ACM Computing Surveys*, *43*(4), 32:1–32:53.
7. Hung, K. S., & Lui, K. S. (2010). On perimeter coverage in wireless sensor networks. *IEEE Transactions on Wireless Communications*, *9*(7), 2156–2164.
8. Tao, D., & Wu, T. Y. (2015). A survey on barrier coverage problem in directional sensor networks. *IEEE Sensors Journal*, *15*(2), 876–885.
9. S. Kumar, T.H. Lai, & A. Arora (2005). Barrier coverage with wireless sensors. In *Proceedings of the 11th Annual International Conference on Mobile Computing and Networking*, MobiCom '05 (pp 284–298). New York, NY, USA: ACM.
10. O'Rourke, J. (1987). *Art gallery theorems and algorithms*. New York: Oxford University Press.
11. Watfa, M. K., & Commuri, S. (2007). Boundary coverage and coverage boundary problems in wireless sensor networks. *International Journal of Sensor Networks*, *2*(3/4), 273–283.
12. Zorbas, D., Glynos, D., Kotzanikolaou, P., & Douligeris, C. (2010). Solving coverage problems in wireless sensor networks using cover sets. *Ad Hoc Networks*, *8*(4), 400–415.
13. Fu, D., Yang, Z., Han, L., & Jhang, S. T. (2015). An algorithm on constructing routing-based multiple cdss to prolong lifetime of wsn. In *Proceedings of the 2015 Conference on Research in Adaptive and Convergent Systems, RACS* (pp. 251–255). New York, NY, USA: ACM.
14. Mostafaei, H., Chowdhury, M. U., Islam, R., & Gholizadeh, H. (2015). Connected p-percent coverage in wireless sensor networks based on degree constraint dominating set approach. In *Proceedings of the 18th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, MSWiM '15 (pp. 157–160). New York, NY, USA: ACM.
15. Sun, S., Sun, L., & Chen, S. (2016). Research on the target coverage algorithms for 3d curved surface. *Chaos, Solitons and Fractals*, *89*, 397–404. Nonlinear Dynamics and Complexity.
16. Huan, X., Lin, K., Chaowei, W., Xiuhua, L., & Yinghai, Z. (2014) Minimal coverage set detecting algorithm for barrier coverage in wireless sensor networks. In *2014 4th IEEE International Conference on Network Infrastructure and Digital Content*, pp. 278–282.

17. Khedr, A. M., & Osamy, W. (2011). Minimum perimeter coverage of query regions in a heterogeneous wireless sensor network. *Information Sciences*, *181*(15), 3130–3142.
18. Siqueira, I. G., Ruiz, L. B., Loureiro, A. A. F., & Nogueira, J. M. (2007). Coverage area management for wireless sensor networks. *International Journal of Network Management*, *17*(1), 17–31.
19. Pazand, B., & Datta, A. (2009). An energy-efficient node-scheduling scheme for wireless sensor networks based on minimum dominating sets. *International Journal of Network Management*, *19*(2), 75–99.
20. Le, N. T., & Jang, Y. M. (2015). Energy-efficient coverage guarantees scheduling and routing strategy for wireless sensor networks. *International Journal of Distributed Sensor Networks*, *2015*, 10:10.
21. Kordari, K., & Blankenship, G. L. (2008). Perimeter coverage with wireless sensor networks. In *MILCOM 2008-2008 IEEE Military Communications Conference*, pp. 1–6.
22. Felemban, E. (2013). Advanced border intrusion detection and surveillance using wireless sensor network technology. *International Journal of Communications, Network and System Sciences*, *6*(5), 251.
23. Ghatak, S., Bose, S., & Roy, S. (2014). Intelligent wall mounted wireless fencing system using wireless sensor actuator network. In *2014 International Conference on Computer Communication and Informatics*, pp. 1–5.
24. Arora, A., Dutta, P., Bapat, S., Kulathumani, V., Zhang, H., Naik, V., et al. (2004). A line in the sand: A wireless sensor network for target detection, classification, and tracking. *Comput. Netw.*, *46*(5), 605–634.
25. Luo, H., Wu, K., Guo, Z., Gu, L., & Ni, L. M. (2012). Ship detection with wireless sensor networks. *IEEE Transactions on Parallel and Distributed Systems*, *23*(7), 1336–1343.
26. Kong, L., Zhao, M., Liu, X. Y., Lu, J., Liu, Y., Wu, M. Y., et al. (2014). Surface coverage in sensor networks. *IEEE Transactions on Parallel and Distributed Systems*, *25*(1), 234–243.
27. Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on Wireless Communications*, *1*(4), 660–670.

Wahiba Larbi-Mezeghrane received the engineer degree in Computer Science from University of Tizi-Ouzou (Algeria) in 2006, the Magister degree from USTHB University of Algiers (Algeria) in 2010. Currently, she is Ph.D student at University of Bejaia. She works as a teacher at the department of Technology of University of Béjaïa and as a researcher at LaMOS Research Unit (Modeling and Optimization of Systems) of University of Béjaïa. Her research interests include sensors networks, their architecture, application and resource management.

Louiza Bouallouche-Medjkoune received the engineer degree in Computer Science from University of Setif (Algeria), the Magister degree in Applied Mathematics from University of Béjaïa (Algeria); the Doctorate degree in Computer Science from University of Setif in 2006 and the HDR from the University of Constantine in 2009. She works as a teacher at the department of Computer Science of University of Béjaïa and as a researcher at LaMOS Research Unit of University of Béjaïa. Bouallouche-Medjkoune is head of the computer science teaching staff since 2008, and head of the research team EPSIRT since 2005. She is also head of department of Operational Research since January 2010 to July 2015. Her publications have appeared in various publishers: Taylor & Francis, Springer, AMS, BCS. Her research Interests are: Performance Evaluation of Computer Systems and telecommunication networks, Stability of Systems, Markov Chains, Queueing theory, Computer Networks (ad hoc networks, sensors networks…), Quality of Service…

Ali Larbi received the engineer degree from University of Tizi-Ouzou (Algeria) in 2006 and the magister degree from University of Bejaia (Algeria) in 2009. Currently, he is Ph.D student at University of Bejaia, Member of LaMOS Research Unit (Modeling and Optimization of Systems). His research interests include mobile networks (Ad Hoc networks, sensors networks…), their architecture, application and resource management.