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A Deterministic Algorithm for the Deployment of Wireless Sensor Networks

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***Abstract*:** Wireless sensor networks are made up by communicating sensor nodes that gather and elaborate information from real world in a distributed and coordinated way in order to deliver an intelligent support to human activities. They are used in many fields such as national security, surveillance, health care, biological detection, and environmental monitoring. However, sensor nodes are characterized by limited wireless communication and computing capabilities as well as reduced on-board battery power. Therefore, they have to be carefully deployed in order to cover the areas to be monitored without impairing network lifetime. This paper presents a new deterministic algorithm to solve the coverage problem of well-known areas by means of wireless sensor networks. The proposed algorithm depends on a small set of parameters and can control sensor deployment within areas even in the presence of obstacles. Moreover, the algorithm makes it possible to control the redundancy degree that can be obtained in covering a region of interest so as to achieve a network deployment characterized by a minimum number of wireless sensor nodes.

***Keywords*:** wireless sensor networks, sensor deployment.

1. Introduction

The advances in micro-electronics and wireless communication technologies make it possible to employ thousands of communicating sensor nodes for gathering and elaborating information from real world in a distributed and coordinated way in order to deliver an intelligent support to human activities [25]. Sensor nodes are embedded in the surrounding physical environment and accomplish their tasks through a continuous and timely access to information made possible by their capability of autonomously operating on the real world. Such nodes, which are characterized by limited wireless communication and computing capabilities as well as reduced on-board battery power, effectively implement the so-called Wireless Sensor Networks (WSNs) [3, 16, 19, 28].

WSNs can be used in many fields such as national security, surveillance, health care, biological detection, and environmental monitoring [4, 6, 9, 15]. However, they are affected by a number of problems and limitations such as, for example, energy consumption and coverage of the areas to be monitored. The former affects application lifetime, and requires a design of the WSN that carefully schedules sensor activity [5]. The latter requires that each location in the physical space of interest is in the sensing range of at least one sensor [13, 21, 22, 30]. In fact, both the problems are logically linked, since a relevant goal of the coverage problem is just to prolong WSNs lifetime [27]. However, the coverage problem can be considered as basic with respect to the problem of energy consumption, since any WSN application becomes useless without a correct coverage of the area to be monitored.

The coverage problem presents many variants mainly depending on the specific constraints that can characterize a sensor network or on objects to be covered. In particular, the most relevant constraints that algorithms solving the coverage problem have to consider are: connectivity, bandwidth limitation, fault tolerance, and network lifetime [14, 29].

Connectivity requires that the sensors of a WSN can send the sensed data to a base station. Bandwidth limitation requires that sensors are arranged into a number of subsets each one characterized by a sufficient number of available communication channels in order to enable the active sensors to communicate. Otherwise, some sensors could not send data back to base stations. Fault tolerance ensures that the regions of interest can be monitored all the time even when some sensors fail. Network lifetime requires that only an optimal number of sensors are active in a region of interest so as to reduce the amount of energy consumed by a WSN while maintaining sensing coverage.

The algorithms that solve the coverage problem under the constraints reported above are mainly based on multiobjective optimization approaches [1, 2, 11, 17]. In fact, such algorithms can achieve optimal solutions to coverage problems, even though they often demand substantial computing and communication resources or do not address the problem concerning the coverage of areas in the presence of obstacles or require that each node deployed in a sensor network knows its own location or runs a heavy code. Furthermore, although the constraints reported above may affect the solutions to coverage problems, they are usually considered only after the sensor node positions have been determined in a WSN [2].

As for the objects to be covered in a region of interest, they can be of two main types: areas or targets. However, a problem of target coverage can be transformed to a problem of area coverage. As a consequence, a coverage problem can be always characterized as a problem of area coverage. In this regard, it is worth noting that problems of area coverage can be easily solved by deploying a number of sensors in the areas of interest much higher than optimum, and such a solution is required particularly when the interest regions are inaccessible and a precise sensor placement cannot be obtained. However, a redundant deployment cannot be considered as a valid solution to the coverage problem when the interest area is well-known and a coverage study can be conducted in order to optimize the number of sensors to be employed.

This paper presents a new deterministic algorithm to solve the coverage problem of well-known areas by means of WSNs. The algorithm has been designed so as to depend on a small set of parameters, and can control sensor deployment within areas even in the presence of obstacles without requiring that each node of the deployed network knows its own location. In particular, the algorithm firstly computes the coverage of the internal edges of the area to be monitored. Then, it computes the coverage of the remaining parts of the area. In fact, the whole coverage is computed depending on the "coverage range" of sensors, which is a specific parameter computed taking into account both the sensing and communication range of sensors. Moreover, the algorithm makes it possible to control the redundancy degree that can be obtained in covering a region of interest so as to achieve a network deployment characterized by a minimum number of wireless sensor nodes without having to perform complex computations.

The paper is organized as follows. Section 2 presents some relevant deployment algorithms existing in literature. Section 3 describes the proposed deployment algorithm. Section 4 describes how it is possible to cover a well-known area by applying the proposed algorithm. In Section 5, the main results of the coverage tests conducted by exploiting the proposed algorithm are reported. Section 6 reports concluding remarks.

2. Related Work

The coverage problem of well-known areas has been studied by many researchers during last years.

In [8] two mesh-based sensor deployment algorithms are proposed. The algorithms try to optimize the number of sensors needed to cover an area and to determine their placement. The algorithms exploit a probabilistic optimization framework in order to obtain an average coverage of an area as well as to model the coverage of specific, vulnerable points existing within the monitored area. In particular, the algorithms can model the specific issue of preferential coverage of grid points on the basis of their relative measures of security and tactical importance.

In [18] an unreliable wireless sensor grid-network with nodes placed in a square of unit area is considered. The main focus is both on the coverage of the region and on the connectivity of the network. To this end, necessary and sufficient conditions for the random grid network to cover the unit square region as well as ensure that the active nodes are connected are derived and studied. Such conditions are deepened in [24], in which they are applied to arbitrary-shaped regions with obstacles. Then, they are further developed to take into account arbitrary relationships between the communication range and sensing range, thus eliminating the constraints of existing results.

A different approach to cover an area is adopted in [26]. The proposed approach is centralized and deterministic, and tries to maximize the coverage of a given sensing area with obstacles. It firstly uses a contour-based deployment to eliminate the coverage holes near the boundary of the sensing area and obstacles. Then, a deployment method based on the Delaunay Triangulation is applied for the uncovered regions. In particular, before deploying a sensor, each candidate position generated from the current sensor configuration is scored by a probabilistic sensor detection model. This enables a new sensor to be placed to the position with the most coverage gains.

Reference [9] presents a distributed and scalable potential-field-based approach to the deployment of a mobile sensor network in an unknown environment. The proposed approach is based on fields that are constructed in such a way that each node is repelled both by obstacles and by other nodes, thus forcing the network to spread itself throughout the environment.

In [27] new protocols able to dynamically configure a sensor network to achieve guaranteed degrees of coverage and connectivity are designed and analysed. The protocols can provide different degrees of coverage in order to support different applications and environments with diverse requirements. The coverage is obtained without compromising connectivity, on the basis of both a geometric analysis and a probabilistic model, which can treat coverage and connectivity within a unified framework.

Reference [10] presents polynomial-time algorithms which can treat the coverage problem as a decision problem whose main goal is to determine whether every point in the service area of the sensor network is covered by at least k sensors, where k is a predefined value. In this regard, the sensing ranges of sensors can be unit disks or non-unit disks. In fact, the characteristics of the described algorithms make them particularly suited to situations which require stronger environmental monitoring capability or scenarios which impose more stringent fault-tolerant capability.

In [20] the concept of Voronoi diagram together with direction-adjustable directional sensors are exploited to propose a distributed greedy algorithm able to improve the effective field coverage of directional sensor networks. To this end, the sensor field is divided into Voronoi cells, and the sensor working direction is evaluated based on Voronoi vertices. Considering the coverage contribution of convex polygonal cell of sensors and the coverage overlap of direction select between neighbour sensors, the working direction is adjusted and controlled, so as to improve the overall sensing field coverage ratio in the sensor network environment without global information.

Reference [30] presents the popular "open geographic density control" coverage algorithm. In this approach, by controlling the density of the active sensors, the energy consumption can be reduced. In particular, the proposed algorithm is fully localized and can maintain coverage as well as connectivity regardless of the relationship between the radio range and the sensing range. However, the algorithm requires that each node knows its own location.

In [2] the authors present a deterministic static sensor node placement algorithm that utilizes a new biologically inspired optimization algorithm, called "territorial predator scent marking algorithm", which imitates the behaviour of territorial predators in marking their territories with their odours. In fact, the algorithm can achieve maximum coverage and minimum energy consumption with guaranteed connectivity.

In [23] the author proposes a new technique to model the area coverage in WSNs based on a degree-constrained minimum-weight extension of the well-known connected dominating set problem. Furthermore, the author proposes an approach based on learning automata to find a near-optimal solution able to both balance the network load on the active sensors and improve the network coverage and lifetime.

In [11] the authors propose a multiobjective optimization approach to optimize the area coverage, network lifetime, network connectivity, transmission range adjustment of nodes, and balanced energy consumption simultaneously in WSN without any sensing range or transmission range restriction. In particular, the coverage algorithm is based on a multiobjective genetic algorithm, called "nondominated sorting genetic algorithm-II", which is exploited to optimize a number of parameters such as coverage, number of active nodes, and balanced energy consumption while maintaining the connectivity in a WSN.

3. Algorithm

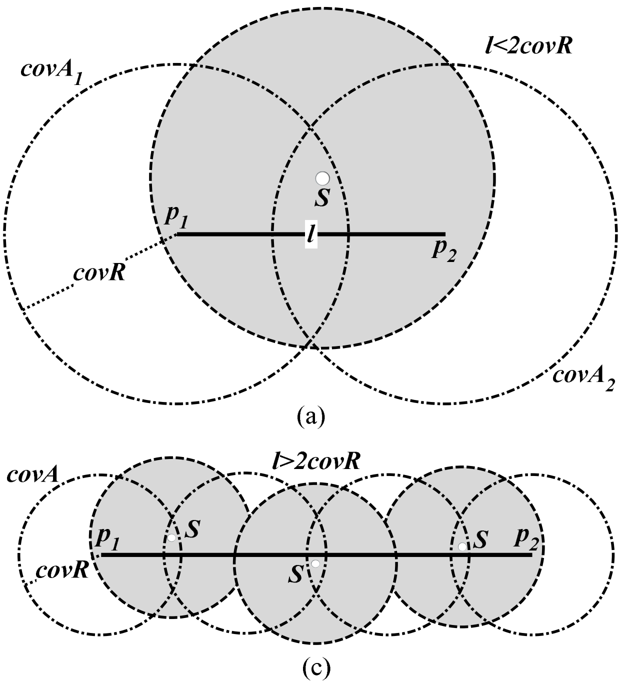
The proposed algorithm makes it possible to compute the positions of the sensors to be deployed to monitor a well-known area.

Each sensor S is characterized by a sensing range and a communication range denoted as *sDisk* and *cDisk* respectively. Both *sDisk* and *cDisk* are disks centered at sensor S with radius denoted as *sR* and *cR* respectively.

that controls the extension of the sensor coverage area. Therefore, the actual coverage radius, denoted as *covR*, corresponding to the coverage area *covA*, is given by the product $covR=\delta\cdot R$. If sensors are deployed in a regular area that does not include obstacles, then δ can be assumed as equal to 1. Otherwise, δ can be proportionally reduced.

A point p is considered as "covered" if there exists a sensor S in the covered area *covA* centered at p. Likewise, two sensors can cover an area only if all the points in the area are in the coverage range of one of the two sensors and the distance between the two sensors is less or equal to $2\cdot covR$. This implies that a point p is covered by a WSN if it is in the coverage range of one sensor and all the sensors of the WSN can communicate with each other. Communication between any two sensors can take place either directly, if their distance is less or equal $2\cdot covR$, or indirectly, if there exists a communication path involving a set of sensors that can directly communicate.

Consider a segment, denoted as *sg*, whose length is l (see Figure 1). If $l<2\cdot covR$, then the segment *sg* can be covered by one sensor. More precisely, let p_1 and p_2 denote the two ends of *sg*. Two coverage areas $covA_1$ and $covA_2$ centered at p_1 and p_2 respectively define an overlapping area where a sensor S can be positioned to cover *sg* (Figure 1a). If $l==2\cdot covR$, the



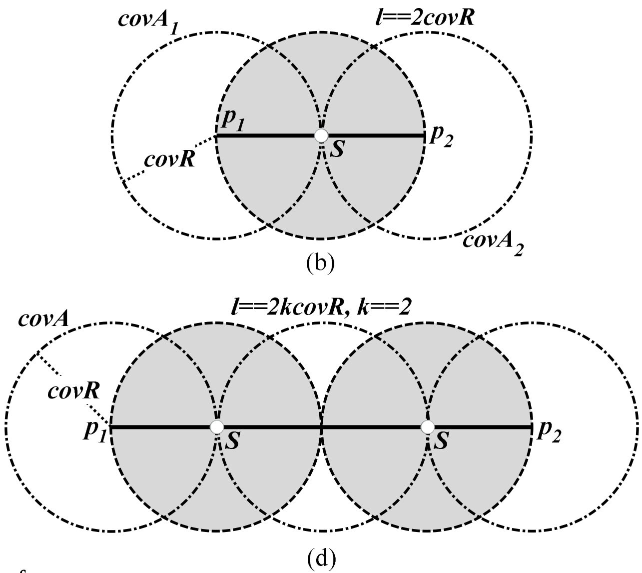


Figure 1. Coverage of a segment.

A sensor S can extend its sensing area to all the points in the sensing disk *sDisk*, and can communicate with the sensors in the communication disk *cDisk*. Therefore, a sensor S "covers" a point p if and only if the euclidean distance between S and p is less or equal to the minimum between *sR* and *cR*, denoted as R.

$R=min\{sR,cR\}$ denotes the "coverage" radius which identifies the coverage area of a sensor, denoted as *covA*. In this regard, in order to simplify the proposed algorithm, all the sensors are assumed to be characterized by a same sensing and communication range. This implies that the coverage radius R is the same for all the sensors of a WSN. However, such a radius can considerably vary depending on the peculiarities of the monitored environments and on the opacity of obstacles existing in such environments. As a consequence, the proposed algorithm adopts the parameter δ to take into account such possible variations. δ is assumed in the range]0,1] and has to be used as the multiplicative factor

overlapping area determined by $covA_1$ and $covA_2$ turns out to be the midpoint of *sg*, where the sensor S has to be positioned (Figure 1b). On the contrary, if $l>2\cdot covR$, then *sg* can be covered by considering $n+1$ coverage areas, with $n=\lceil l/(2\cdot covR)\rceil$. These areas can be centered along the segment, from p_1 to p_2 at regular intervals, and define n overlapping areas where sensors can be positioned to cover *sg*, one for each interval (Figure 1c). As a particular case, if $l==2\cdot k\cdot covR$, with k being an integer greater than 1, then n becomes just equal to k, and the overlapping areas determined by the $k+1$ coverage areas turn out to be k equidistant points on *sg* (Figure 1d).

Consider the coverage of an area adjacent to one side of a segment *sg* (see Figure 2). In this case, sensors have not to be centered on the segment, otherwise a part of their coverage capacity will be wasted. On the contrary, sensors have to be positioned in the area adjacent to the side to be monitored of the segment. Therefore, a possible coverage can be obtained by applying the scheme reported above. In particular, if *sg* is characterized by a length *l* greater than 2·*covR*, *n*+1 coverage areas can be defined and centered along the segment. Then, *n* sensors can be positioned at the points where the perimeters of the *n*+1 coverage areas intersect on the side to be monitored of the segment. If *l*≤2·*covR*, then the coverage of the area adjacent to one side of *sg* matches that one obtained by directly covering *sg*, according to the scheme reported in Figure 1a and 1d.

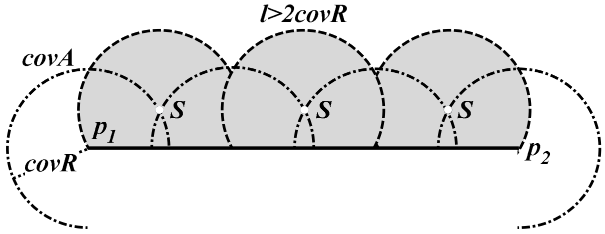


Figure 2. Coverage of an area adjacent to one side of a segment.

Consider the coverage of an area adjacent to one side of the intersection *p* of two segments sg_1 and sg_2 (see Figure 3a). In this case, the coverage can be conducted by covering both the segments, one after the other, according to what is reported above. However, a redundant coverage could result around the intersection. To limit such redundancy, it is possible to consider the bisector of the angle between sg_1 and sg_2 and to center a sensor where the perimeter of the coverage area centered at *p* intersects the bisector. The coverage area of the sensor centered at *p* intersects sg_1 and sg_2 in the points p_1 and p_2 respectively. In fact, these points have to be considered the new ends of the segments sg_1 and sg_2 from which to calculate their coverage.

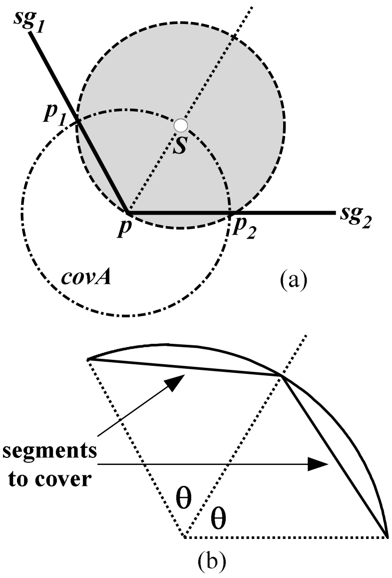


Figure 3. Coverage of an intersection and of a circle arc.

Likewise, the coverage of an area adjacent to one side of a circle arc can be conducted by approximating the arc with a sequence of line segments, each representing a chord corresponding to an internal angle Θ (see Figure 3b). Θ is assumed as an input parameter of the proposed algorithm, and controls the approximation level achieved by the algorithm in covering areas adjacent to arcs.

The steps reported above make it possible to cover areas adjacent to the edges that can be represented as a sequence of segments and/or arcs. However, the coverage of such areas can be redundant if the distance between two edges to be monitored is less or equal to 2·*covR* and the coverage is accomplished according to what is reported above. For example, consider the coverage of an area like that one shown in Figure 4. If the segments sg_1 and sg_2 are independently covered according to what is reported above, the positions of the sensors become p_1, p_2, p_3, p_4, p_5, and p_6, and their number is greater than the one really necessary (see Figure 4a).

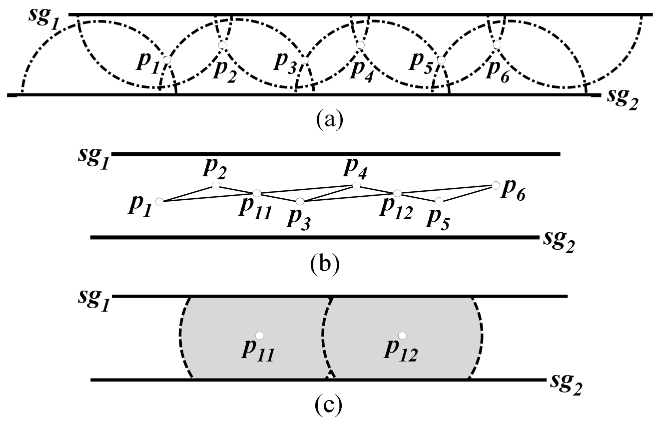


Figure 4. Coverage of near segments.

To solve such problem, it is possible to consider the points p_{11} and p_{12}, which can be obtained by intersecting the segment p_1p_4 with the segment p_2p_3 and the segment p_4p_5 with the segment p_3p_6, respectively (see Figure 4b). In fact, the points p_{11} and p_{12} represent the new positions of the sensors that can cover the considered area without incurring in a redundant coverage (see Figure 4c).

The procedure reported above to cover areas adjacent to sequences of linear segments and arcs represents the basic mechanism to cover any area. In fact, the coverage of an area can be performed by firstly covering the areas adjacent to its perimeter. Then, once covered such areas, the remaining area can be covered by determining its new perimeter and by covering the areas adjacent to it. These steps have to be recursively repeated while there are still areas to be covered. Furthermore, if the area is characterized by the presence of obstacles, the coverage algorithm can be anyway applied by considering the perimeters of such obstacles and covering the areas adjacent to them.

4. Deployment

The algorithm described in Section 3 makes it possible to cover well-known areas by means of WSNs. In particular, the algorithm deploys a minimum number of sensors to cover each point in the area of interest. In fact, once Θ has been set and *covR* has been calculated depending on *sR*, *cR* and δ, the algorithm guarantees that each point belonging to an area of interest is covered by not less than one sensor. However, if the algorithm is run assuming *covR*=*covR*/2, the coverage mechanism adopted by the proposed algorithm enables each point of the area of interest to be covered by not less than two sensors. Likewise, assuming a coverage radius equal to *covR*=*covR*/*k*, the algorithm can cover each point of a region of interest with not less than *k* sensors. This also means that the algorithm makes it possible to control the redundancy degree *k* that can be obtained in covering a region of interest by simply dividing the initial value of *covR* by *k*.

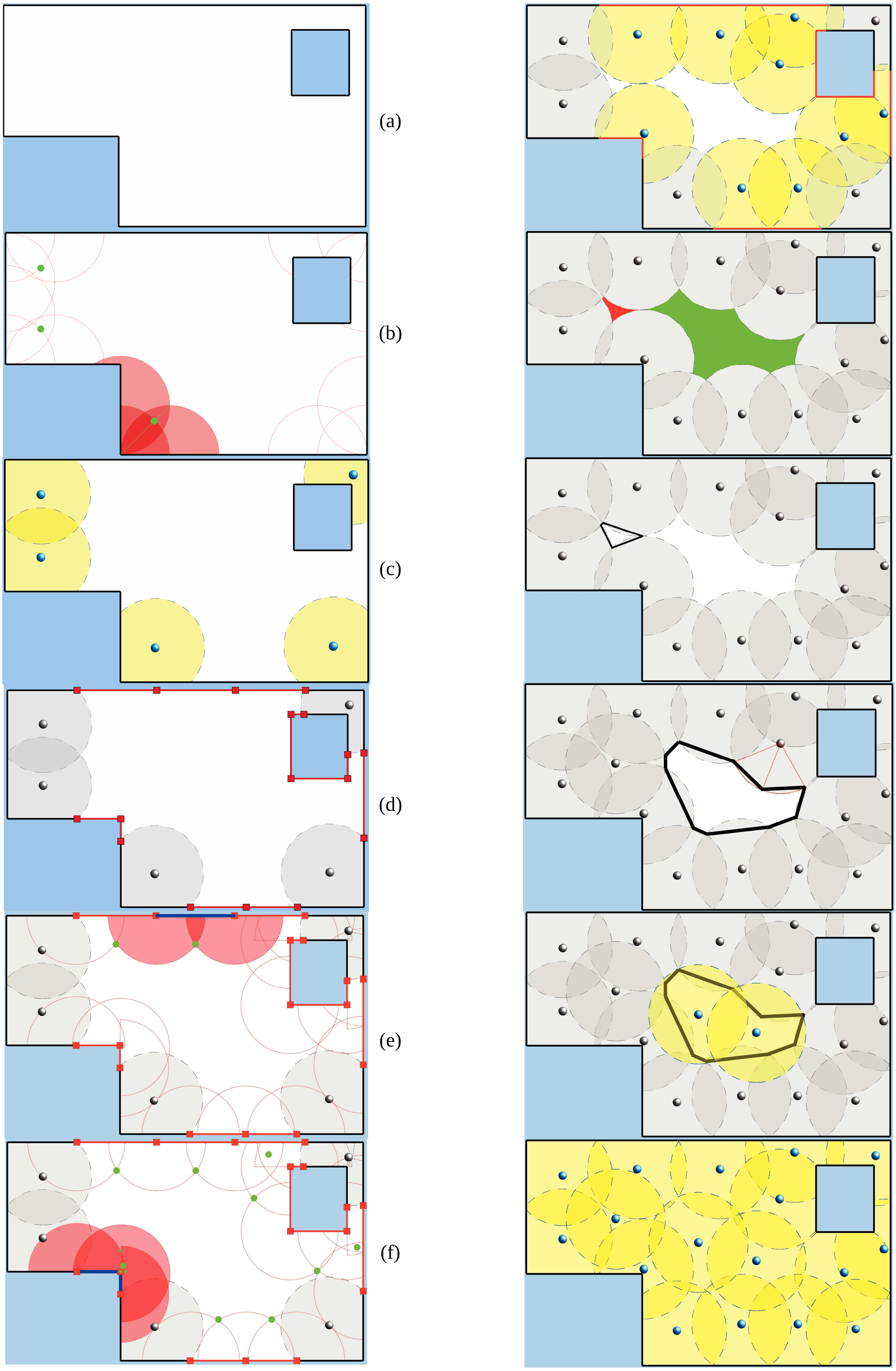
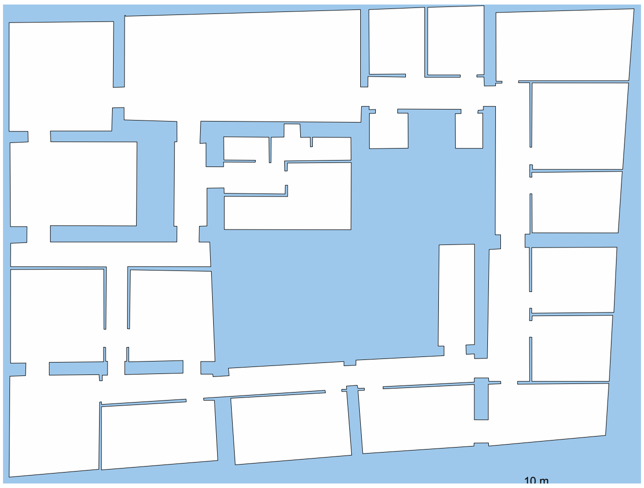


Figure 5. Coverage of an area.

To better understand how the proposed algorithm behaves, let Figure 5a be considered. It shows an area to be covered by a WSN. Once *covR* and Θ have been calculated, the first areas to be covered are adjacent to the intersections of the segments composing the perimeter of the area (see Figure 5b). The result of this first phase is the deployment of the sensors needed to cover the angles existing in the area (see Figure 5c).

(a)



(b)

Figure 6. Coverage of two different areas.

The second phase of the algorithm concerns with the coverage of the areas adjacent to the segments of the perimeter which are not covered by the deployed sensors (see Figure 5d). The coverage is obtained by applying the main schemes reported in Figure 2 and in Figure 3. However, this phase also implies that the scheme shown in Figure 4 is repeatedly applied to avoid a redundant coverage (see Figure 5e and Figure 5f). The result of this second phase is the deployment of further sensors able to cover all the areas adjacent to the linear segments of the perimeter (see Figure 5g).

The remaining parts of the area which are not covered by any sensor can be now delimited by a set of arcs (see Figure 5h). Arcs can be then approximated by a sequence of line segments, each representing a chord corresponding to the internal angle Θ (see Figure 5i and Figure 5l). The areas delimited by the segments can be covered by re-applying the algorithm reported in Section 3 and by covering the areas adjacent to these new segments (see Figure 5l and Figure 5m). The final result is thus reported in Figure 5n, which shows the deployment of the WSN covering the area of Figure 5a.

5. Experimental Section

To test the proposed algorithm, three different areas have been covered: a regular square region, a town square (see Figure 6a) and a floor of a historic building (see Figure 6b). Each area has been covered by varying the coverage range of the sensors (that is the parameter *covR* for the proposed algorithm) and reporting both the number of sensors needed to cover the area and the percentage of the connected sensors. More precisely, once the coverage range has been set and all the sensors have been deployed, the actual radio coverage of the sensor network has been evaluated by testing if all the sensors could directly or indirectly communicate with the base station of the network. Then, the percentage of the actually connected sensors has been computed. Moreover, for each area, the proposed deployment algorithm has been initially compared with three other basic algorithms well-known in literature: a mesh based algorithm [8], a pattern based algorithm [13], and a Delaunay Triangulation (DT) based algorithm [26].

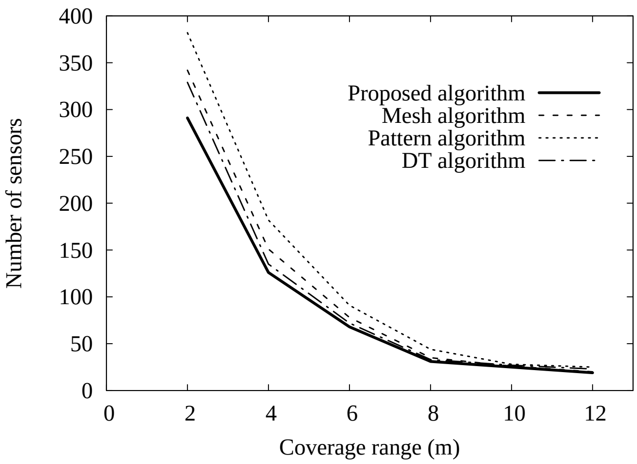


Figure 7. Comparison among different algorithms in covering a regular square area.

The square region taken into account has an area of 50m×50m and has been covered by varying the coverage range of sensors from 2m to 12m. Figure 7 shows the results obtained by running the algorithms reported above. As shown by the graph, the proposed algorithm achieves results similar to those ones obtained by the other algorithms. However, it can outperform the other algorithms particularly under low values of the coverage range. Furthermore, the figure showing the percentage of the connected sensors has not been reported since all the deployed sensors could always communicate with each other independently of the deployment algorithm.

In the second case, the area to cover is shown by a satellite image (see Figure 8a). The image has been properly modified in order to better show the perimeter of the area, which is needed to apply the proposed algorithm (see Figure 8b). In more detail, a first deployment of sensor nodes is shown in Figure 9a and is obtained by setting the coverage range to 5m. Then, Figures 9b, 9c, and 9d show the deployments obtained by setting the coverage range to 10m, 15m, and 20m respectively. The number of sensors needed for each coverage is reported in Figure 10a, which compares the behaviour of the proposed algorithm with the behaviour of the other algorithms reported above. As shown in the figure, the proposed algorithm achieves results similar to those obtained by the mesh based and pattern based algorithms, while it outperforms the DT based algorithm particularly for low values of the coverage range.

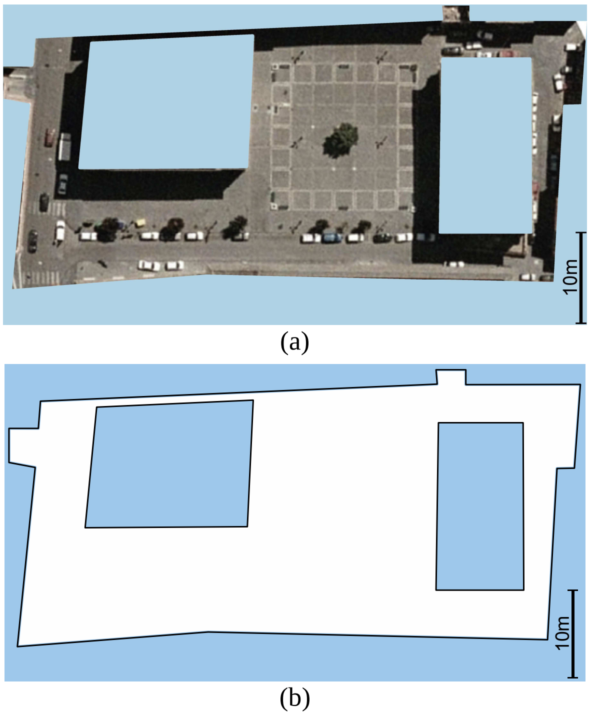


Figure 8. The area to cover for the town square shown in Figure 6a.

Moreover, the proposed algorithm deploys sensors in such a way that they can be always connected (see Figure 10b), whereas the other deployment algorithms show lower performances. In particular, the mesh and pattern based algorithms deploy sensors according to a scheme that manages the presence of obstacles with difficulty. As a consequence, a percentage of sensor nodes represents isolated nodes, and this prevents the algorithms from ensuring a total radio coverage. On the contrary, the DT based algorithm behaves as the proposed algorithm, but only under coverage ranges less than 30m. In fact, when the coverage range is set to values greater or equal to 30m, the DT algorithm cannot calculate a valid deployment for the considered area, which is characterized by the presence of obstacles.

In Figure 11 different coverages of a floor of the historical building shown in Figure 6b are reported. In particular, the coverages have been obtained under different values of the coverage range varying from 2m to 12m, even though only the coverages for 2m, 4m, 6m, and 10m are shown in Figure 11. Similarly to the coverages reported in the above figures, the results achieved in this case can be considered good and better than those obtained by the DT based algorithm, which cannot calculate a valid deployment under values of the coverage range greater than 8m (see Figure 12a). On the contrary, both mesh based algorithm and pattern based algorithm tend to achieve better results than the proposed algorithm particularly under high values of the coverage range. However, such results are not supported by good values of the connection percentage, since both the mesh based algorithm and the pattern based algorithm cannot guarantee a high connectivity degree for sensor networks in the case of complex environments characterized by a high number of obstacles (see Figure 12b).

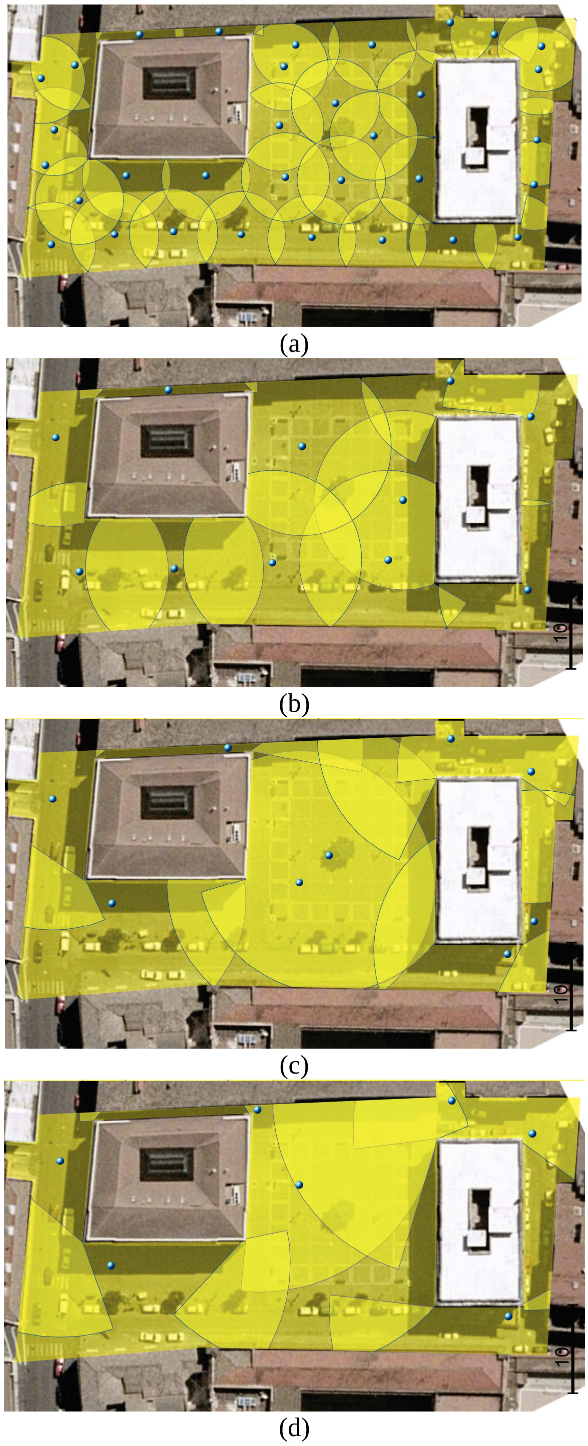
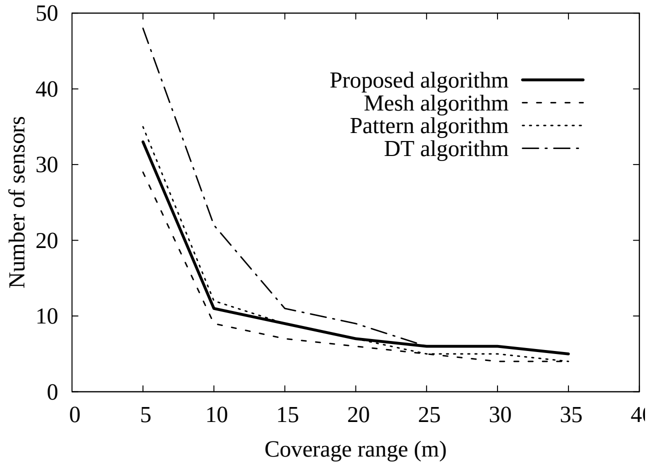


Figure 9. Coverage of the town square shown in Figure 8.

To support the results of the real tests reported above, further simulations have been conducted. In particular, the proposed algorithm has been compared with four more complex algorithms: the "Territorial Predator Scent Marking Algorithm" (TPSMA) documented in [2], the "Integer Linear Programming" (ILP) algorithm proposed in [7], the biological inspired genetic algorithm (GA) described in [12, 31], and the multiobjective optimization algorithm (TASCC) proposed in [10]. The simulations have been conducted by using the well-known Network Simulator 2 to obtain the coverage of a square region of 60m×60m with sensors whose coverage range has been varied from 5m to 15m. In fact, the choice of simulating a simple coverage scenario, such as a square region, has been mainly motivated by the documented difficulties of some of the algorithms reported above in covering regions in the presence of obstacles or characterized by complex boundaries, such as, for example, the region shown in Figure 6b.



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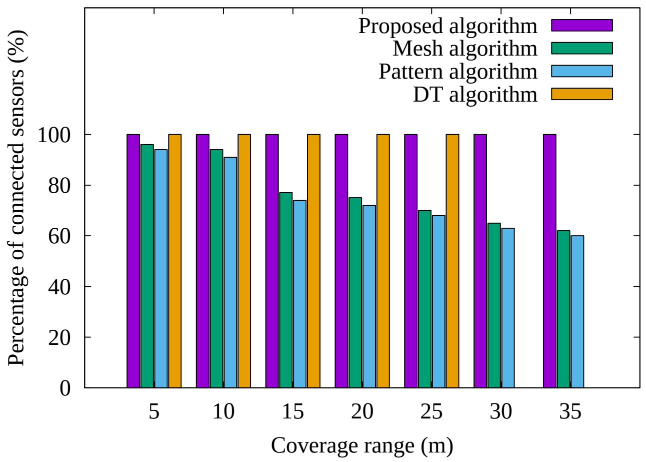


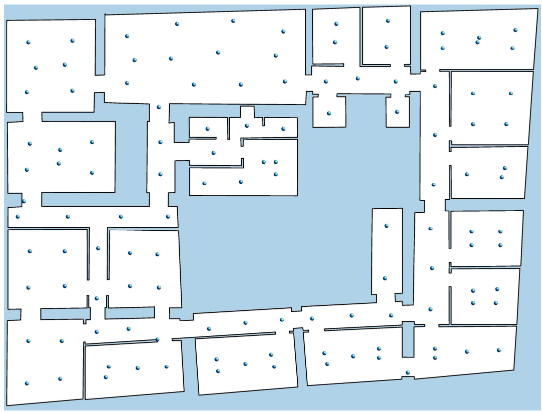
(b)

Figure 10. Comparison among different algorithms in covering the town square shown in Figure 8.

Figure 13 shows the results of the conducted simulations. In fact, the proposed algorithm is characterized by a behaviour similar to the one exhibited by TPSMA, which is an algorithm whose main task is to provide the highest coverage ratio with fewer sensor nodes compared to the other examined algorithms [2]. Moreover, the performance of the proposed algorithm is also similar to the one achieved by the TASCC algorithm, even though this algorithm can carry out multiobjective optimizations, thus maximizing the covered area without compromising energy consumption and connectivity of the deployed WSN. Finally, the figure showing the percentage of the connected sensors has not been reported since all the examined algorithms can guarantee deployments where sensors can always communicate with each other.

6. Conclusions

In this paper a new deterministic algorithm for the deployment of WSNs is presented. The algorithm has been designed to purposely solve the coverage problem of well-known areas. It is simple, depends on a small set of parameters, and can control sensor deployment within areas even in the presence of obstacles.



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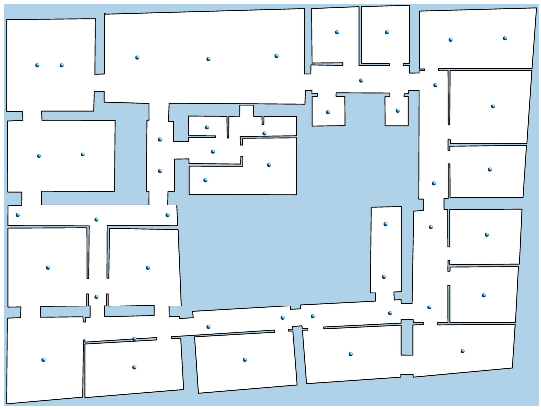

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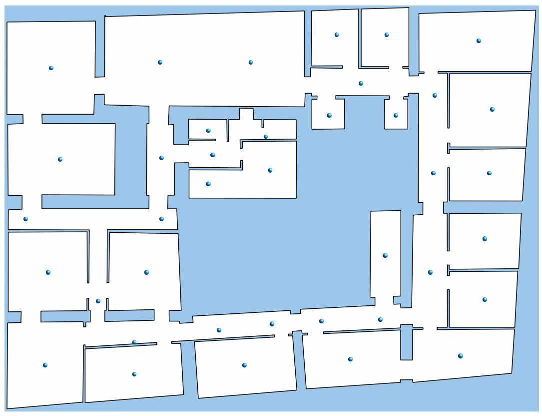

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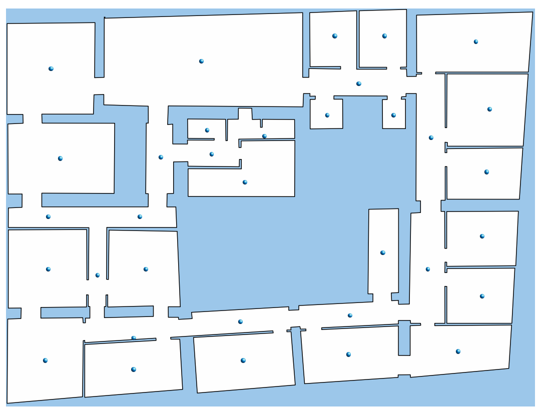

(d)

Figure 11. Coverage of the floor of the historic building shown in Figure 6b.

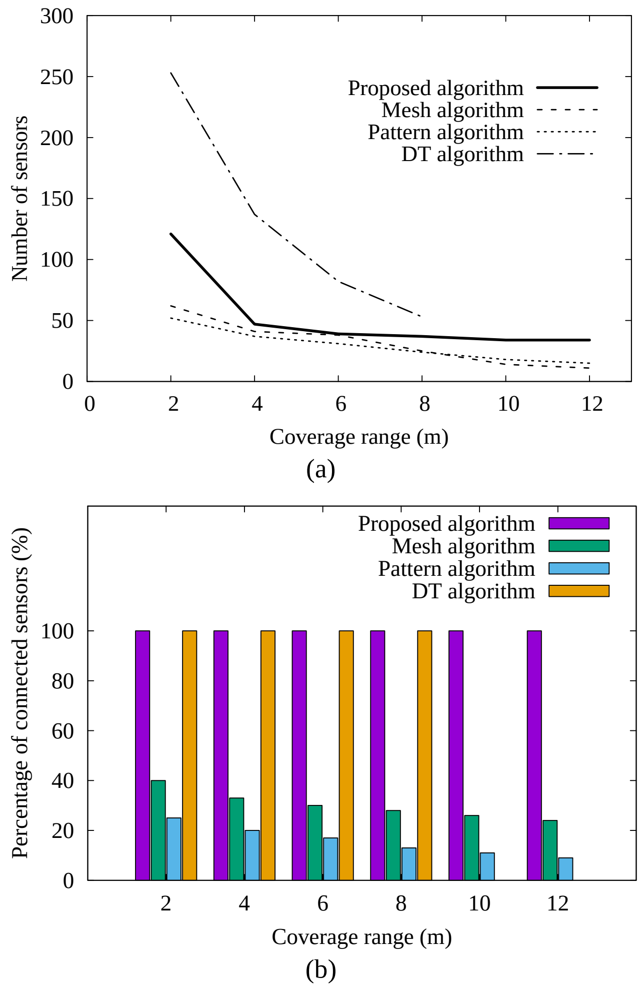

Figure 12. Comparison among different algorithms in covering the floor of the historic building shown in Figure 6b.

In this regard, the conducted tests show that the proposed algorithm can achieve better performances in covering complex areas than those shown by other algorithms well-documented in literature, such as mesh based or pattern based or Delaunay Triangulation based algorithms. Such behaviour is also confirmed by further simulations, which show that the proposed algorithm can achieve results similar to those ones exhibited by complex algorithms, such as the TASCC algorithm or the TPSMA.

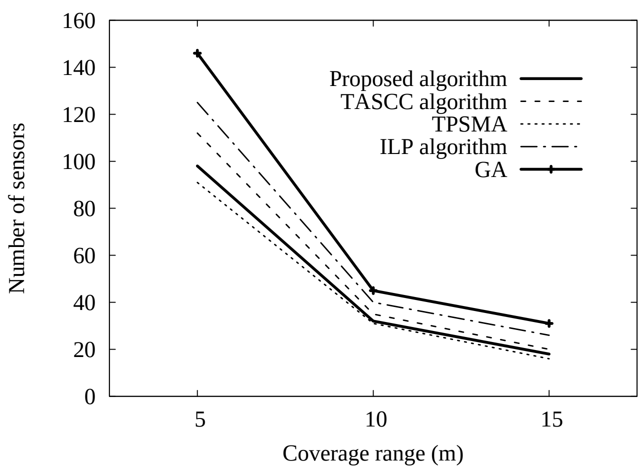

Figure 13. Comparison among different algorithms in simulating a coverage of a regular square area.

Furthermore, the proposed algorithm can deploy sensor nodes so as to guarantee the whole radio coverage of the areas to monitor even when the coverage range is increased and the areas are characterized by the presence of obstacles. In fact, in the same areas, the other algorithms either need a higher number of sensors to guarantee the area coverage, either cannot deploy sensors so as to guarantee the whole radio coverage, either cannot calculate a valid deployment in the presence of a high number of obstacles.

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