Stratégie de Placement des Puits Mobiles dans les Réseaux de Capteurs sans Fil pour Bâtiments

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***Abstract*—Le besoin des réseaux de capteurs sans fil croit très rapidement dans un large éventail d'applications industrielles. Parmi celles-ci se trouve l'observation, le suivi des données physiques et l'automatisation des bâtiments. Dans ces réseaux, un grand nombre de capteurs transmettent via multi sauts les données collectées vers le puits le plus proche. Les capteurs qui sont proches des puits épuisent leurs réserves d'énergie beaucoup plus rapidement que les capteurs distants car ils ont une charge de trafic très importante. Ceci est dû au fait qu'ils transmettent leurs propres données ainsi que les données des capteurs éloignés provoquant ainsi prématurément la fin de la durée de vie du réseau. Le déplacement périodique des puits permet de résoudre ce problème en distribuant la charge du trafic entre les capteurs et améliorer ainsi la durée de vie du réseau. Dans ce travail, nous proposons un nouvel algorithme qui détermine le positionnement de plusieurs puits mobiles dans un réseau large échelle afin d'augmenter la durée de vie du réseau. Son principe se base sur le déplacement régulier des puits vers les capteurs distants qui ont le plus grand nombre de sauts à faire pour atteindre le puits le plus proche. Nous avons évalué les performances de notre solution par des simulations et comparé avec d'autres stratégies. Les résultats montrent que notre solution améliore considérablement la durée de vie du réseau et équilibre notablement la consommation d'énergie entre les nœuds. Ces résultats sont très utiles pour le déploiement réel de réseaux de capteurs sans fil au sein des bâtiments.**

***Index Terms*—Réseaux de capteurs sans fil, positionnement des puits, puits mobiles, durée de vie du réseau.**

I. Introduction

Wireless Sensor Networks (WSNs) deployment inside buildings is a very challenging problem. In fact, such networks are formed by a large number of tiny battery-operated sensors which have a limited and non-renewable energy supply because it is usually impractical and even impossible to replace or recharge their batteries. The sensors near the sink are more likely to use up their energy much faster than distant nodes because they carry heavier workloads due to forwarding the data of nodes farther away as well as their own data. Therefore, they become hotspots. The hotspot problem prevents farther nodes to relay their data to the sinks. Consequently, the network lifetime ends prematurely.

More and more efforts have been done recently to improve the lifetime of WSNs. Many communications protocols have been proposed including among others topology control[1][2], routing[3][4] and clustering[5] etc. However, further improvement can be achieved if we relocate the sinks in order to change over time the nodes located close to them.

In order to solve the hotspot problem, many researchers propose to place more sensor nodes around the sink[6][7]. However, these solutions are not always feasible in practice and result in unbalanced sensing coverage over different regions of the network. Another proposed solution is to make multiple fixed sinks cooperate with each other to lighten the load and distribute it among the nodes[8][9].

Most of published works suggest to move a single sink to improve the network lifetime[10][11][12][13][14]. But, very few studies focused on the mobility of multiple sinks. Some proposed algorithms find the locations of mobile sinks by solving a mathematical model[15][16]. In [15], the algorithm minimizes the average distances between sensors and closest sinks. In [16], the algorithm selects the locations of sinks in the periphery of the network in such way the difference between the maximum and the minimum residual energy of nodes is minimized. To find the optimal placement of mobile sinks, some researches formulate the problem as an Integer Linear Program ILP[17][18][19] or Linear Program LP[20]. However, the drawback of the LP and ILP based solutions is that they are hard to compute in networks with thousands of sensors due to their high resolution complexity.

Some other works make a moving decision according to the complete knowledge of the energy distribution of the sensors. In [21], the sinks move towards the nodes that have the highest residual energy. But, this strategy requires that the sensors send periodically to the sink additional information about their energy level to allow the sink to found out the nodes which have the highest energy. By doing so, a lot of energy will be wasted.

In this work, our purpose is to determine where to place multiple sinks inside buildings, how long they have to stay in certain locations and where to move them to extend the network lifetime. To answer these questions, we propose a new scalable multi-sink heuristic algorithm (Hop) which regularly moves the sinks towards the distant nodes which have lower load contrary to nodes near the sinks. This approach scales to thousands of nodes and prevents from sending additional information about the energy level of each sensor which is what was done in previous solutions. Simulation results demonstrate that by relocating the mobile sinks according to our proposed algorithm, the energy consumption is balanced among the sensors which lead to significant increase of the network lifetime.

The rest of this paper is organized as follows. In Section 2, we describe the network model including the major assumptions. Section 3 presents our proposed multi-sink heuristic algorithm. Section 4 evaluates the performance of the proposed approach and presents the simulation results. Section 5 concludes the paper.

II. Network Model

In order to deploy sensors and sinks inside buildings, we made the following assumptions for the network model.

- We assume N sensors statically placed in a bi-dimensional grid (LxL) of same size cells constructed from the building plan as shown in the Figure 1.

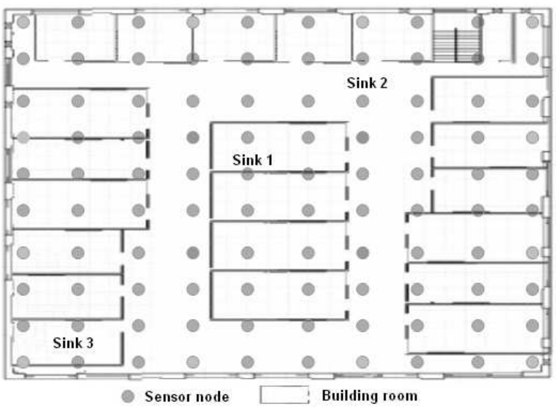


Fig. 1. 10x10 grid of cells with sensors in office building (L=10)

- All sensors have a limited initial energy e_0 (J) and a fixed transmission range r (m) equal to the distance between two nodes (i.e, cell size).
- A time-driven application is considered where each sensor regularly generates the same amount of data g_r (bit/s).
- M sinks keep moving in the grid from one node to another one until the network lifetime end.
- The network lifetime is defined as the time until the first sensor dies (i.e, it uses up its residual energy).
- The sinks should stay at a certain location for at least a duration of time T (sojourn time). At the end of this duration, they can change their locations.
- The traveling time of sinks between sensor nodes is considered negligible for analytical simplicity.
- The sensor nodes which are not co-located with any sinks inside the grid, relay their generated data via multiple hops to reach the nearest sink using the shortest path routing protocol.
- In our routing protocol, we consider only the two paths along the perimeter of the rectangle, i.e., paths 1 and 2 in Figure 2. These two routes are considered equivalent.
- An ideal MAC layer with no collisions and retransmissions is assumed.
- Only the energy consumption for communication is considered. Let e_T (J/bit) be the energy consumption coefficient for transmitting one bit and e_R (J/bit) be the energy consumption coefficient for receiving one bit.

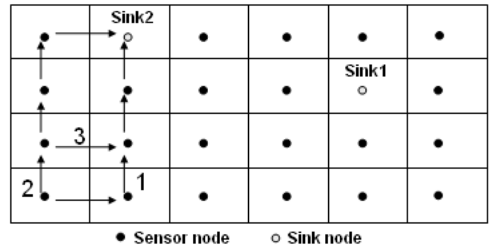


Fig. 2. Path selection

III. Multi-Sink Heuristic Algorithm (Hop)

The purpose of the multi-sink heuristic algorithm is to find the best way to move the sinks in order to improve the lifetime of large scale sensor networks. Our approach is based on number of hops and consists in relocating periodically the sinks towards the distant nodes. The difference between our strategy and what was already proposed is that there is no need for the sensors to drain their energy in sending additional information about their energy level. Each sink knows its own position, others sinks positions and the locations of all the sensors. Therefore, from the number of hops to reach the nearest sink, it is possible to guess which sensors are distant and may have more residual energy.

The algorithm begins with an initialization phase where the sinks are placed at their optimal locations in terms of hop counts. Then, for each sensor, the number of hops to reach the nearest sink is computed. Next, the nodes are sorted with decreasing number of hops in order to determine the distant nodes from the sinks. Afterwards, the first sink will be relocated at the farthest node. The second sink will be relocated at the following distant node but respecting the condition that the number of hops between the two new locations must be upper than minimum number of hops min_{hop}. The third sink is relocated with the same manner in such way the distance between the three new positions of sinks is upper than min_{hop}. The remaining sinks are relocated with the same way. All the chosen positions of sinks at each period are saved in a list. In the case that the selected positions of sinks where already chosen in previous periods, the algorithm chooses as the first sink location a node which has not been chosen before and determines the locations of the other sinks. If all sensor nodes where already visited by the sinks, the chosen list is emptied. The same operations are repeated at the beginning of each new period T.

The pseudocode of the algorithm is shown in the Figure 3.

The algorithm is implemented in a distributed manner. In the sense that it does not determine the sinks locations based on the knowledge of the global network parameters. But, each sink has to know only the initial starting locations of sensors and sinks. Throughout the network lifetime, each sink is able to compute autonomously its next position and move there.

To have a better idea about the algorithm, an example of a network with 100 sensors and 3 mobile sinks is provided. The sinks locations pattern obtained by the execution of our

Multi-Sink Heuristic Algorithm (Hop)

1: place the M sinks at optimal starting locations in LxL grid
2: add starting locations of the sinks to $chosen_{list}$
3: $min_{hop} = \begin{cases} L-1, & M=2 \\ [2(L-1)/(M-1)], & M>=3 \end{cases}$
4: **while** new period T **do**
5: **for** $i = 1$ *to* N **do**
6: $nearest_K$ = nearest sink for sensor $node_i$
7: n_{hop} = number of hops between $node_i$ and $nearest_K$
8: add $(node_i, n_{hop})$ to $node_{list}$
9: **end for**
10: sort nodes of $node_{list}$ in decreasing order of n_{hop}
11: p_1 = select first node of $node_{list}$ in the sorted order
12: add p_1 to $select_{list}$
13: **for** $i = 2$ *to* M **do**
14: p_i = select next node from $node_{list}$ having minimum number of hops with nodes in $select_{list} >= min_{hop}$
15: add p_i to $select_{list}$
16: **end for**
17: **if** nodes from $select_{list}$ not in $chosen_{list}$ **then**
18: add nodes from $select_{list}$ to $chosen_{list}$
19: **else**
20: empty $select_{list}$
21: p_1= select not chosen node from $node_{list}$
22: go to line 12
23: **end if**
24: **if** $chosen_{list}$ contains all nodes **then**
25: empty $chosen_{list}$
26: **end if**
27: **for** $i = 1$ *to* M **do**
28: move $sink_i$ to node p_i from $select_{list}$
29: **end for**
30: **end while**

Fig. 3. Hop algorithm

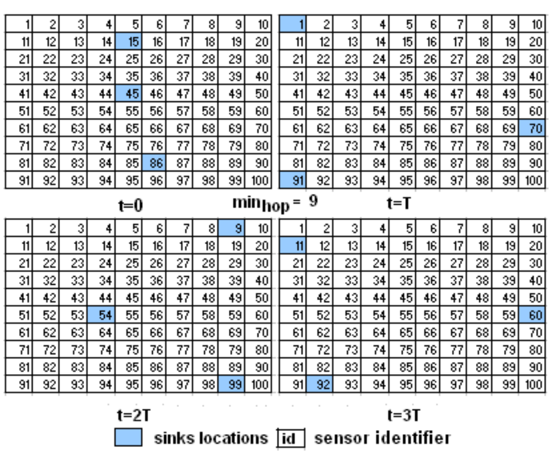


Fig. 4. The sinks locations pattern in 10x10 grid network ($L = 10$)

algorithm during the three first periods T are represented in the Figure 4. The sinks were initially placed at their optimal locations in sensor nodes 15, 45 and 86. The minimum number of hops between the locations of sinks min_{hop} was fixed to 9.

IV. Simulation results

To analyze the performances of our proposed algorithm, we built a simulator in Java environment with variable number of sensors and sinks deployed on different grid sizes.

To compute the energy consumption, we used the same model described in [19]. We chose realistic parameter assumptions for the network. The initial energy at each node is equal to energy found in two Alkaline batteries AA of 1.5V usually 2600mAh i.e., e_o= 28080 J. The energy consumption coefficient for transmitting and receiving one bit was chosen the same as vendor-specified values for the Chipcon CC2420[22] where $e_T = 0.225\ 10^{-6}$ J/bit and $e_R = 0.2625\ 10^{-6}$ J/bit. We fixed the minimum duration of sojourn time T of the sinks to 30 days because it is economically not easy for technicians to relocate sinks in buildings very often. The sensor transmission range is $r = 10$ m. The rate at which data packets are generated is g_r = 1 bit/s. Notice that real micro-controllers stop running when the battery voltage is below a given threshold. This depends on the micro-controllers and can not be taken into account here.

To show the efficiency of our proposed scheme, we evaluated its performance by making a comparative study with four other schemes.

Thus, the following schemes were implemented :

1) Static: Static sinks placed in optimal locations[19]
2) Periphery: Sinks moving in the periphery of the network
3) Random: Sinks moving randomly
4) Hop: Sinks moving according to our algorithm
5) Opt: Sinks moving according to ILP solution[19]

In the following sections, the network lifetime, the energy consumption and the residual energy at each sensor are investigated.

A. The network lifetime

We evaluated the network lifetime of the five schemes on networks of 100 sensors with increasing number of mobile sinks.

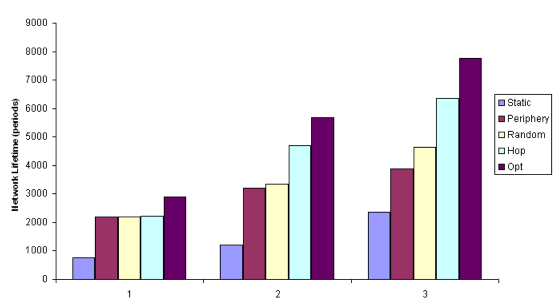


Fig. 5. Network lifetime with 100 sensors (10x10 grid)

Figure 5 shows that the Opt scheme performs better than the others schemes because it selects the optimal locations of

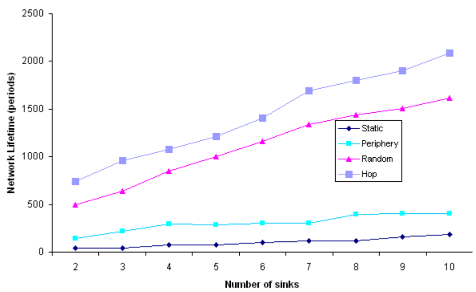


Fig. 6. Network lifetime with increasing number of sinks

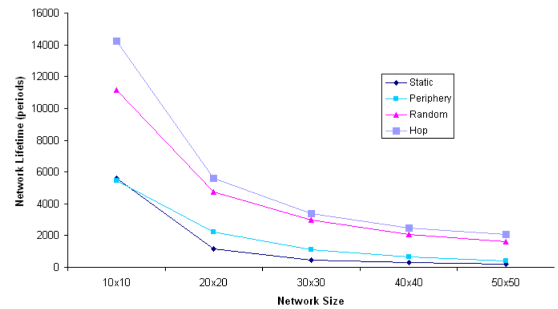


Fig. 8. Network lifetime with increasing network size

sinks and their optimal sojourn times. But, the problem with Opt is that it is based on Integer Linear Program which can handle only small scale networks. All the remaining schemes are scalable but the Hop scheme is the best of them because it achieves longer lifetime. The lifetime improvements achieved by Hop in 10x10 grid network with 3 mobile sinks are almost 38 % against Random, 64 % against Periphery and almost 170 % against Static. The gap between Hop and Opt in network lifetime is about 18 %.

We investigated the network lifetime of Static, Random, Periphery and Hop schemes in a large scale network with 2500 sensors on 50x50 grid. We varied the number of sinks from 2 to 10.

Figure 6 shows that all schemes improve the network lifetime when the number of sinks increases. Because, using more sinks reduces the average path length between the sensors and sinks and enables to achieve less traffic load to the nodes which extends the network lifetime. Nevertheless, the Hop scheme leads to longer network lifetime than all other schemes. In a network with 2500 sensors and 10 sinks, Hop achieves 29 % of lifetime improvement than when 10 sinks are moving randomly, 42 % than when 10 sinks are moving on the periphery, and 1014 % than when 10 sinks are static.

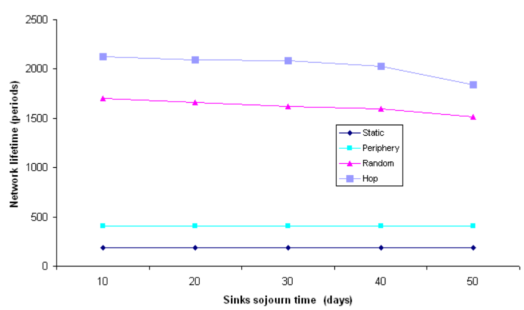


Fig. 7. Network lifetime with different sinks sojourn times

We studied the network lifetime with different sinks sojourn times (see Figure 7). The number of sinks was fixed to 10 and the number of sensors to 2500. The results indicate that when the the sinks sojourn time increases the network lifetime decreases slowly. In fact, the longer the sojourn time is, the less the sinks movements are which lead to shorter lifetime.

We varied the network size from 10x10 to 50x50 sensors. The number of sinks was fixed to 10 and the sojourn time T to 30 days. We noticed as shown in the Figure 8 that the network lifetime decreases considerably when the network size increases. In fact, the sensors near the sinks must retransmit a higher number of packets from their higher number of neighbors which leads to higher energy consumption.

B. The energy distribution

We analyzed the impact of the five schemes on the energy consumption at lifetime end in a network with 3 mobile sinks and 100 sensors. The distribution of energy consumption when the first sensor dies is depicted in Figures 9, 10, 11, 12 and 13. A light color means a higher percentage of energy consumption.

It is remarkable in all the figures that the energy consumption is highly variable and depends on the sinks locations. We notice that the nodes closest the sinks locations have relatively higher energy consumption compared to most of the others because they have to receive and relay all other neighbors data in addition to their own data. This leads them to consume more energy.

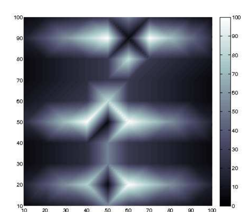


Fig. 9. Energy consumption with Static scheme

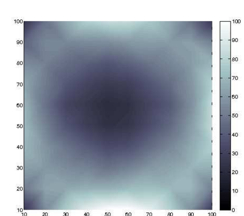


Fig. 10. Energy consumption with Periphery scheme

In Figure 9, we observe that higher percentage of energy consumption is concentrated around three nodes in the grid which are the locations of the sinks whereas the others sensors have a lower amount of energy consumption (dark color).

When the sinks move on the periphery of the network the highest energy consumption occurs in nodes closest to the boundary of the network while the others nodes specially in the center consume less energy as seen in the Figure 10.

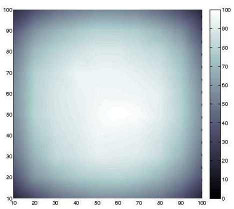


Fig. 11. Energy consumption with Random scheme

Figure 11 shows that the energy consumption of Random scheme is more balanced among the nodes than Periphery and Static schemes.

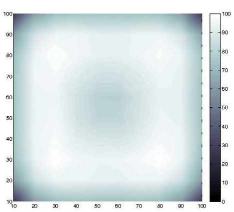


Fig. 12. Energy consumption with Hop scheme

Figure 12 shows that Hop scheme results in a better balancing of energy consumption than Periphery, Static and Random schemes. In fact, we notice a larger area with light color.

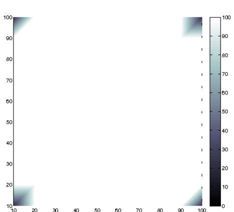


Fig. 13. Energy consumption with Opt scheme

Opt scheme balances almost perfectly the energy consumption among the nodes. In fact, the majority of the nodes deplete their energy at the same time except the four nodes in the corners as shown in the Figure 13. However, this scheme is restricted only to small scale networks.

The distribution of the residual energy at each sensor node in 10x10 grid with 3 mobile sinks was also studied (see Figures 14, 15, 16, 17 and 18).

The results show that the percentages of the residual energy that remained unused at the network lifetime end are 71 %,

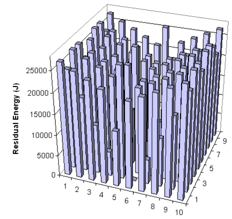


Fig. 14. Residual energy with Static scheme

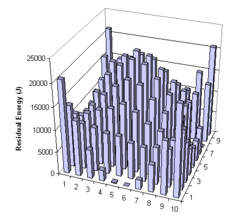


Fig. 15. Residual energy with Periphery scheme

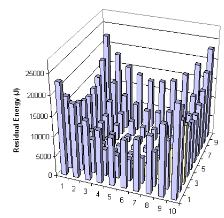


Fig. 16. Residual energy with Random scheme

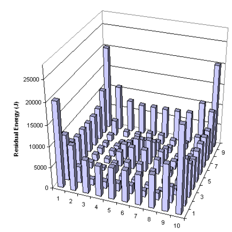


Fig. 17. Residual energy with Hop scheme

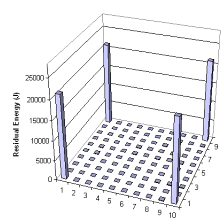
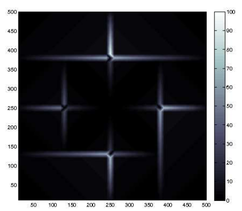


Fig. 18. Residual energy with Opt scheme

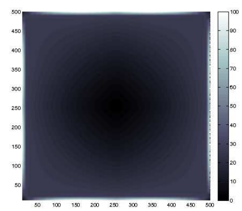
45 %, 31 %, 17 % and 3 % respectively for Static, Periphery, Random, Hop and Opt schemes. Moreover, the numbers of sensors which have more than 50 % of their initial energy at network lifetime end are 80, 36, 20, 4 and 4 respectively for Static, Periphery, Random, Hop and Opt schemes.

The two schemes Opt and Hop result in a better distribution of residual energy compared to Periphery, Random and Static. Nevertheless, Opt can be efficient only for small networks contrary of Hop which can scale to thousands of sensors.

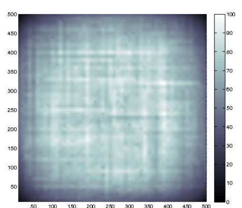
We analyzed the impact of the scalable schemes Static, Periphery, Random and Hop on the energy consumption at lifetime end in a large scale network with 4 mobile sinks and 2500 sensors. The results are similar to what was found in small network with 100 sensors. Hop balances better the energy consumption among the nodes than the other schemes because it leads to a higher number of sensors with very small amount of energy left unused (see the Figure 19).



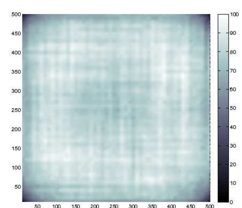
(a) Static



(b) Periphery



(c) Random



(d) Hop

Fig. 19. Energy consumption in 50x50 grid network

V. Conclusion

In this paper, we have proposed an efficient solution to extend the lifetime of large scale WSNs. The proposed heuristic algorithm regularly moves the sinks towards the distant nodes. This approach, based on number of hops, prevents from sending additional information about the energy level of each sensor. We evaluated the performance of our algorithm by simulation in a network with thousands of sensors and compared it with others schemes: Static, Periphery, Random and Opt. The results show that it extends significantly the lifetime of the network and balances notably the energy consumption among the nodes. Our solution is very simple and useful for wireless sensor network deployment inside buildings because it is scalable and achieves 1014 % lifetime improvement when we deploy 10 mobile sinks instead of 10 static ones in a network with 2500 sensors.

In our future work, we intend to study the management of multiple sinks moving according to our proposed solution in a 6lowpan-based wireless sensor networks for buildings. We would like to focus on how IPv6 mechanisms could support efficiently sinks periodic mobility.

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