IMPROVING ENERGY CONSUMPTION IN LARGE SCALE WIRELESS SENSOR NETWORKS WITH MULTIPLE MOBILE SINKS DEPLOYMENT

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Abstract: In this paper, we consider the multiple sinks placement problem in energy constrained large-scale Wireless Sensor Networks (WSN). First, some fundamental design parameters in WSNs such as nodes deployment, the network architecture, sink velocity and transmission range, are investigated. Each of these parameters is analysed and discussed according to its influence on the energy consumption in a WSN. Second, a simple and efficient approach for the placement of multiple sinks within large-scale WSNs is proposed. The objective is to determine optimal sinks' positions that maximize the network lifetime by reducing energy consumption related to data transmissions from sensor nodes to different sinks. Balanced graph partitioning techniques are used to split the entire WSN into connected sub-networks. Smaller sub-networks are created, having similar characteristics and where energy consumption can be optimized independently but in the same way. Therefore, different approaches and mechanisms that enhance the network lifetime in small-size WSN can be deployed inside each sub-network. Performance results show that the proposed technique significantly enhances the network lifetime.

1 INTRODUCTION

A stationary sensor network is a static ad hoc network composed of hundreds or thousands of sensor nodes. Each sensor node is equipped with a sensing device, a low computational capacity processor, a short-range wireless transmitter-receiver and a limited battery-supplied energy. Sensors monitor some surrounding environmental phenomenon, process the sensed data and forward it towards a "close" a sink. This latter collects the data from the different sensor nodes and transmits this data to some remote control station where the data will be exploited at the application level.

Achieving maximum lifetime in stationary WSNs by optimally using the energy within sensor nodes has been the subject of significant researches in the last recent years. In this field, radio transmission and reception operations are being identified as the most energy consuming features.

On the other hand, the development of large-scale sensor networks has drawn a lot of attention. One of the main challenges is to set up new architectures and mechanisms that can efficiently scale up with the growing number of nodes that may be required to ensure adequate coverage of large areas of interest. At the same time, these new architectures and mechanisms should maintain low energy consumption per node so as to get by with energy guaranty acceptable network lifetime.

Most of known existing protocols and mechanisms are not scalable. They are mostly conceived and adapted to relatively small networks (i.e. reduced number of nodes) and/or when the amount of data being gathered and transmitted is small. In particular, centralised approaches, where data from each sensor is sent to a central base station, are not efficient and can not scale for large wireless sensor networks.

The use of multiple mobile base stations is one possible solution for large-scale WSNs. The idea is to shorten the path (distance) between each sensor node and the nearest base station, leading to save energy consumption for transmission operations. To achieve this efficiency, the multiple base stations should be optimally placed within the sensed area.

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Our contributions in this paper include:

1. We present an interesting analysis of the fundamental design parameters in large scale WSNs with multiple, mobile sinks. A brief related work of the existing techniques of multiple sinks deployment in WSNs is also provided.

2. We propose to use graph theory techniques and in particular graph partitioning in order to determine a balanced partition of large-scale WSNs and then to optimize the placement of the different sinks over the obtained smaller sub-networks to minimize the energy consumed for data transmissions.

The remaining of this paper is organized as follows:

After discussing the design parameters analysis and related work in section 2, the proposed scheme is described and explained in section 3. Simulations, performance results and analysis are presented and discussed in section 4. Finally, concluding remarks are given in section 5.

2 DESIGN PARAMETERS IN ENERGY CONSTRAINED WSNS: DESCRIPTION AND RELATED WORK

In the following, we propose to discuss and analyse some fundamental techniques and parameters that should be seriously taken into account when designing WSNs. We show through the analysis presented below how important is their impact and influence on the performance of such networks and the way they should be investigated to face the energy consumption challenge in WSNs.

2.1 Network Architecture for WSNs

Scalability of methods, algorithms and protocols used in WSNs mostly depends on the interconnection topologies of sensor nodes. Two main architectures are proposed and studied in the literature: Hierarchical and Flat topologies.

Hierarchical topologies allow easier scalable mechanisms. A hierarchical (multi-tiered) architecture comprising multiple tiers is depicted in fig.1:

- The lowest tier: represented by a dense deployment of low cost and low power static sensor devices. Each sensor is equipped with a micro controller, a flash memory and a radio. Their main task is to collect information about specific phenomena and send it to a higher tier.
- The middle tier: formed by mobile sinks which have significant computation, memory and storage resources and no power constraints. These mobile sinks act as relays for information gathering.
- The highest tier: it is the application which queries the sensor network through a query interface and the final information fusion point that provides to the manager the data in interest.

Another example of hierarchical topologies is the clustered two tier architecture where a single cluster head handles several member nodes in its neighbourhood (i.e. its cluster). The cluster heads form a separate top layer communication structure. Network protocols designed for these architectures are highly scalable. However, they require the definition of specific roles and mechanisms for cluster heads as well as specific signalling mechanisms.

As opposed to these hierarchical topologies, flat distributed topologies are easier to deploy but more difficult to scale. Here, nodes are connected in a complete ad-hoc fashion. All sensing nodes have equivalent roles with no specific hierarchy between them. The main advantages of flat topologies are their easy deployment and reduced cost. However, such a topology are difficult to scale up since communications between thousands or perhaps millions of nodes in a ad hoc fashion lead to degraded performances and hence higher energy consumption. For instance, routing protocols are a prominent factor of the scalability of sensor networks. In recent researches, the proposed routing protocols require that some of the sensors have knowledge of the topology of the entire network at every point in time. This requires a lot of signalling and do not scale well with a high number of nodes. Different solutions are proposed in the literature to overcome these weaknesses. For instance, a distributed protocol for large-scale WSNs is proposed in (Tilak, 2003). It is based on localized interactions and does not require global knowledge such as the current network topology. In (Grossglauser, 2001), authors proposed to use specific mobility patterns in order to achieve higher capacity in large scale WSNs.

In these studies, the evaluation of the scalability of the proposed protocols is mainly based on a well known metric for WSNs which is the network lifetime. The objective is to avoid significant degradations of the network lifetime when the number of nodes composing the WSN increases.

Through the analysis of the above sited studies, it appears that no single architecture can be adopted to face the scalability issues. Different solutions should be envisaged since the performances of the WSN may also depend on the type of applications for which they have been conceived.

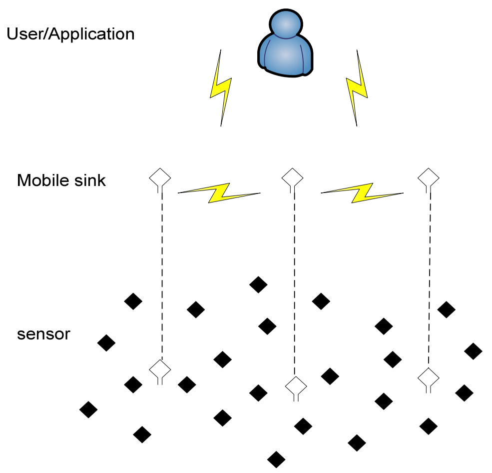

Figure 1: Architecture of a multi-tiered wireless sensor network.

2.2 Nodes Deployment

It is important to consider the distribution of the sensors within the phenomena area according to the needs of the application. We can distinguish three deployment strategies. The self organization feature of sensors makes possible to deploy them randomly over the observed area. In such a case, sensors might be distributed in a random uniform way, like dropped from an aircraft. The sensors can also be regularly deployed in the field as placed on a predetermined geometric grid. Finally, they can be placed in a planned manner in order to provide higher sensor density in a region where the phenomenon is concentrated.

Random deployment is usually preferred because more realistic but regular deployment can offer in some specific cases some advantages. In fact, many applications require sensors location information to achieve the desired functionality and since using a GPS system is not a feasible solution, we choose to place the sensors over a grid points to have a prior knowledge of sensors location information. In some other researches, location estimation techniques are proposed to get over the problem (Bulusu, 2000), (Doherty, 2001), (Savvides, 2002), (Nasipuri, 2002).

2.3 Energy Model

Energy consumption in a sensor node has in general the following components:

a) Sensing energy:

It represents the energy consumed when activating the sensing circuitry and collecting data from the environment. The amount of this energy depends on the task that is assigned to the sensor.

b) Transmission energy:

It represents the energy consumed by the transmitter and the receiver circuitry of the sensor.

The energy consumption due to transmissions between node i and node j can be modelled as

$$E_t(i,j) = \alpha \quad . \quad r_{i,j}$$
$$E_r(j,i) = \beta \quad . \quad r_{i,j}$$

Where:

- $E_t(i,j)$ is the energy consumed at node i when transmitting to node j with a bit rate equal to $r_{i,j}$.
- $E_r(j,i)$ is the energy consumed at node j when receiving from node i with a bit rate equal to $r_{i,j}$.
- $d_{i,j}$ is the distance between node i and node j.
- $\alpha = a + b.d_{i,j}{}^2$
- $\beta = a$

c) Computation energy

It represents the energy consumed to activate the sensor's processing unit in order to operate the transmitter and receiver circuitry.

Compared to the transmissions energy, the sensing and computing energies are relatively low.

2.4 Single Hop vs. Multi Hop

When the sensor nodes use single hop communication, each node sends its data directly to the sink. In such case, the sensor nodes located farthest from the sink have to spend the maximum amount of energy and hence are the first to be dead whereas in multi-hop communication, the nodes located closest from the sink are the first to be dead because they have to relay the farther nodes data.

Moreover, since the communication is directly between the sensor nodes and the sink, only one node transmits at the same time and then a contention less MAC is used.

Multi-hop communication has been vastly favoured over long-range single-hop links to provide a large coverage area. The use of multi-hop is essentially to combat the rapid decay of the received signal strength as communication distance increases. However, multi-hop transmission is not always better than single-hop transmission in perspective of energy conservation. In fact, we knew from previous works that it depends on the distance between the sensor and the sink node, the number of hop and each hop distance. A careful investigation ((Chen, 2006), (Bhardwaj, 2001), (Mhatre, 2004)) has proved that the energy consumption rate is minimized only when using an optimal hop number N_{opt} of identical hop distances named characteristic distance $d_{char} = \sqrt{2a/b}$. We can write $N_{opt} = D / d_{char}$ (D the distance between the source and the sink node). Consequently, the most energy efficient scheme is to use single hop if the distance between the sensor and the sink is no greater than d_{char} , else multi-hop with hop distance of d_{char}.

2.5 Multiple Mobile Sinks

2.5.1 Why Multiple Sinks?

In recent researches, energy efficient usages of multiple and/or mobile sinks to increase the network lifetime were proposed (Gandham, 2003), (Kim, 2005), (Oyman, 2004), (Vincze, 2006). The idea behind this is to decrease the distance between each sensor node and the *nearest* sink. In fact, when a higher number of sinks are distributed within the WSN, the path lengths from any sensor node to its *nearest* sink is decreased leading to lower energy consumption and therefore to higher network lifetime.

However the cost of a sink is more expensive than the sensor and then the number of sink nodes is financially constrained. In (Oyman, 2004), the authors proposed to find the minimum number of sinks while maximizing the network lifetime by connecting the budget reserved for the sink nodes with the lifetime of the sensor nodes.

2.5.2 Why Moving Sink?

In a wireless sensor network where a multi-hop communication is used, the nodes which are one hop from the sink drain their energy faster than other nodes because they have to relay messages originating from many other nodes in addition to delivering their own messages. In the case of one-hop communication, the nodes send directly their messages to the sink and the nodes farthest from the sink are the first to drain their energy. In doing so and in the both cases, many sensor nodes will become quickly unable to communicate with the base station and the network becomes inoperational.

Several researches have then demonstrated analytically and with experimental results that using multiple mobile sinks increases the network lifetime (Vincze, 2006), (Luo, 2005).

We note that the sink trajectory can be rather controlled by the application; it can be mounted on a remote controlled robot and can be moved from one point to an other like in (Gandham, 2003). Else, it can follow a specific mobility model in which case an estimation of its position can be computed like in (Chen, 2006).

2.5.3 Existing Approaches

Deploying multiple mobile base stations in WSNs has been investigated in a dynamically growing number of papers. We mention hereafter some of the most relevant.

In (Luo, 2005), the authors have developed an analytical model that describes the communication load distribution in WSNs and proved that base station mobility is a strategy that deserves to be considered when optimizing the network lifetime. They have further shown that the optimum movement strategy for a mobile base station is to follow the periphery when the deployment area is circular.

Network lifetime elongation using mobile base station has also been investigated in (Wang, 2005). The author gave a novel linear programming formulation for the joint problem of determining the movement of the sink and the sojourn time at different points in the network. The simulations have shown that lifetime maximizing solutions are achieved by nonuniform sojourn time distributions among grid points depending on the shape of the deployment area.

In (Gandham, 2003), authors propose to divide time into rounds and to dynamically relocate multiple sinks, at different positions along the periphery of the sensed field, at the beginning of each of these rounds. An integer linear program is used to determine the new locations of the different base stations. Results have shown that the energy consumption of individual sensors is better balanced and the overall energy consumption of all sensors is minimized. In (Kim, 2005), authors propose another approach to find the optimal locations of multiple stationary sink nodes. The proposed scheme allows sensor nodes to communicate with one or multiple sinks through multiple paths in order to improve the network lifetime. In (Oyman, 2004), authors claim that finding the optimal placement for a given number of sinks is equivalent to the clustering problem and should be solved using a clustering algorithm. Another approach to solve the problem of multiple mobile base station placements is proposed in (Vincze, 2006). An electrostatic model is applied to determine sinks' locations and to coordinates the movements of these sinks considering the network state.

Unfortunately, most of the above strategies are proposed and evaluated over small to medium size wireless sensor networks (typically less than 100 nodes). For large scale wireless sensor networks, where hundreds or thousands of nodes can be deployed, the placement of multiple sinks still requires advanced studies. For instance, and as illustrated on Fig. 2, if we consider the case where the sinks are located along the periphery as stated in (Gandham, 2003), the paths between each node and its nearest sink is relatively short when the number of nodes is limited. However, the more the area size increases and/or the number of nodes within it increases, the longer this path is and the shorter the sensor nodes lifetime will be.

2.5.4 Sink Velocity Influence

A mobile sink can move in two different regimes (Luo, 2006), a fast mobility regime and a slow mobility regime. In the fast mobility regime, the sink moves in a continuous form with a velocity v along the time without any stop or pause in a particular position. In the slow mobility regime, the sink moves in a discrete form and the sink's trajectory is a sequence of anchor points between which the sink moves with a velocity v and at which it pauses during a period of time (epoch). The slow mobility regime is considered more realistic and is adopted in a big number of researches.

However, it is very important to carefully choose the value of the sink velocity. In fact, when the mobile sink velocity is high, the sink will more frequently change its position and visit more the different regions over the area in interest during the network lifetime. Therefore, the energy consumption is efficiently distributed over the sensors and the network lifetime extended. This can be much more efficient in the particular case where the sensors buffer the data sensed and wait until sink approaches to deliver it (Chen, 2006) which reduces unnecessarily packet forwarding actions since sensors are sure of sink arrival before loosing the data (because of buffer size limitation or packet deadline expiration). Besides, the high speed moving sink produces a tolerable data delivery delay especially in the case of fast mobility regime, which can be very important for some specific applications. However, the mobile sink high velocity can have negative effects. In fact, it can make the session interval too short to successfully exchange a long data packet and hence the packet loss rate will increase. In slow mobility regime, it is preferred that the epoch be long enough to guaranty long messages exchange.

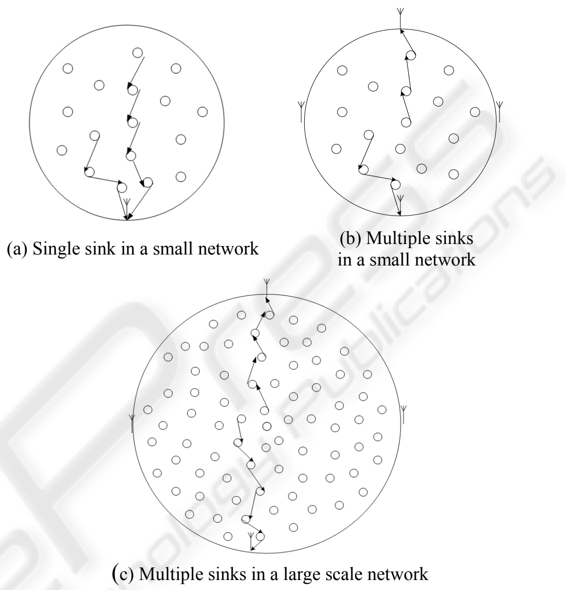

Figure 2: Multiple sink placement.

2.6 Overhead Problem

Using a moving sink to collect the information in a static wireless sensor network is a strategy that has been adopted by several researchers because of its efficiency in increasing the network lifetime. However, it seems obvious that the mobility of the sink will inevitably incur additional overhead in data exchanges since the nodes will continuously need to be informed of the sink location. This can be much more dramatic when the number of sensors is very large. In (Luo, 2006), the authors evaluated the performances of MobiRoute, a routing protocol that supports sink mobility. They proved that when using a slow mobility regime with an epoch much longer than the sink moving time, the overhead introduced by the mobility of the sink became negligible because amortized across a long epoch. Hence, to avoid that the overhead offsets the benefits brought by sink mobility, such a scenario should be adopted.

2.7 Buffering Data

In a static wireless sensor network where the sink is mobile, the sensors can send the sensed data immediately to the sink by direct transmission if the sink is in the transmission range of the sensor or by multi-hop communication over the different relay sensors. In some proposals like (Chen, 2006), (Chakrabarti, 2003) and (Rahul, 2003), the sensors hold the data they sense in their buffer until they encounter the mobile sink. The authors proved that it represents the most economic way in terms of energy. However, if the time between two successive sensor-sink meetings is too long, packets loss is expected because of the buffer size limitation or packet deadline expiration as well as an intolerable delay of data delivery. Hence, an optimal choice of the value for these parameters is very important to guaranty the best results in terms of network lifetime.

2.8 Transmission Range Influence

In wireless sensor networks with moving sinks, the transmission range is one of the fundamental design parameter. In fact, depending on if it increases or decreases, the network topology changes since the number of one hop neighbours of a sensor as well as the path length from a sensor to the sink varies (Youssef, 2002). Besides, when the transmission range increases, the connectivity of the network increases and hence the network lifetime is improved. However, there is a threshold of the transmission range value over which the connectivity of the network is no more influenced whereas the energy consumption becomes dominant resulting in the network lifetime degradation (Gandham, 2003). This threshold obviously depends on the other parameters of the network (number of sinks, size of the network, transmission energy model, the initial energy of each sensor…). Analytical studies in (Chen, 2006) have also shown that the transmission range can also influence the data delivery delay, the sensor-sink meeting delay and the outage or unsuccessful packet transmission probability. The lager it is, the lower they are.

Through the analysis presented above, it is obvious that deploying multiple, mobile sinks in WSNs efficiently reduces the energy consumption level and further lengthens the network lifetime. However, as stated before, most of the existing solutions are appropriate and efficient over small to medium size wireless sensor networks (typically less than 100 nodes). Therefore, further investigations should be conducted in order to optimize multiple mobile sink placement in large scale wireless sensor networks, where hundreds or thousands of nodes can be deployed. Moreover, the fundamental design parameters discussed previously and which have a serious influence on the energy consumption should be carefully chosen in order to let them contribute in optimizing the network behaviour and extending its lifetime duration.

3 MULTIPLE SINKS LACEMENT IN LARGE SCALE WSNS: PROPOSED APPROACH

We propose in this work to enhance sink placement in large scale WSNs. An intuitively appropriate solution is to decompose the underlying sensor network and then optimize energy usage in each of the sub-networks independently. The objective is to take advantage of the powerful and efficient sink placement techniques proposed for small scale WSNs. In order to apply these techniques over large scale WSNs, we propose to first divide the network into sub-networks according to specific criteria. An adequate sink placement technique can then be applied independently within each of the defined sub-networks.

Graph partitioning is a promising approach to split a large sensor network into balanced sub-networks. In practice, different criteria can be considered in order to partition a large scale wireless sensor network. One simple objective is to create balanced sub-networks (in terms of number of sensors) that group the sensors according to their neighbourhood. This allows creating smaller sub-networks with similar characteristics that can be easily optimized, independently but in the same way.

In graph theory related literature, different approaches and techniques are proposed for balanced graph partitioning.

3.1 Existing Graph Partitioning Techniques

In (Even, 1997), a fast approximate graph partitioning algorithm is proposed. The authors unified the problems of b-balanced cuts and k-multiway separators using a new approach called minimum capacity ρ-separators. They studied the graph partitioning problems on graphs with edge capacities and vertex weights and described a simple approximation algorithm for minimum capacity ρ-separators leading to a fast approximation algorithm both for b-balanced cuts and k-multiway separators. They define a ρ-separator as a sub-set of edges whose removal partitions the vertex set into connected components such that the sum of the vertex weights in each component is at most ρ times the weight of the graph. In (Ito, 2006), authors considered three problems to find an (l, u)-partition of a given graph. They proposed to partition a graph G into connected components by deleting some edges from G making the total weight of each component equal at least to l and at most to u. The minimum partition problem is to find an (l, u)-partition with the minimum number of components, the maximum partition problem is defined in the same way and the p-partition problem is to find an (l, u)-partition with a fixed number p of components. Authors proved that the three problems are NP-complete or NP-hard. In (Chlebikova, 1996), authors studied the approximation of the Maximally Balanced Connected Partition problem (MBCP). They first presented the optimization problem that finds the maximally balanced connected partition for a graph G. It results in a partition (V_1, V_2) of V composed of disjoint sets V_1 and V_2 such that both sub-graphs of G induced by V_1 and V_2 are connected, and maximize an objective function "balance", $B^w (V_1, V_2) = \min(w(V_1), w(V_2))$. Authors proved that the problem is NP-hard.

In this work, this last approach will be adapted and applied to large scale Wireless Sensor Networks. Our choice is mainly motivated by the practical approach provided in (Chlebikova, 1996) and based on the use of a polynomial-time algorithm that gives an approximate solution.

In the following the Maximally Balanced Connected Partition (MBCP) technique (Chlebikova, 1996) is adapted and formulated for partitioning a large WSN. A corresponding approximate resolution algorithm is then presented.

3.2 Model Formulation

Assume that G = (V, E) is a connected graph where V is a set of nodes and E is the set of all links connecting two nodes of V.

In our case, V represents the set of sensors and E represents the set of all links connecting two sensors belonging to V.

The objective is to partition G into connected balanced sub-graphs (in terms of number of nodes). We assume that all sensors have the same initial energy.

To achieve this objective, let w be a non-negative vertex-weight function representing the balancing criteria. In this case, w will reflect the number of nodes. Hence $w(V') = |V'|$.

This MBCP problem can then be formulated as follow:

Maximize $B^w (V_1, V_2) = \min (w(V_1), w(V_2))$

Subject to

1. (V_1, V_2) is a partition of V into nonempty disjoints sets V_1 and V_2 such that sub-graphs of G induced by V_1 and V_2 are connected.
2. $w(V') = \sum_{v \in V'} w(v) \quad \forall \quad V' \subseteq V$

The resolution of this model will result into two balanced sub-networks. Each of them can be partitioned again using the same process.

This partitioning technique should be applied as much as required according to the targeted size for the sub-networks and taking into account the number of available sinks to be placed. The final result should be 2^n equivalent smaller sub-networks where n is the number of partitioning iterations.

3.3 Problem Resolution

To solve this model, we used the polynomial approximation algorithm presented in (Chlebikova, 1996) that finds an approximate solution for the MBCP problem.

In order to select neighbouring sensors within the same sub-networks, we adapted the algorithm by sorting the list of candidates for each partition according to their distance (vicinity).

The algorithm can be written as follow:

```
Input: G = (V, E).
V= {v1, v2, v3… vN}  where  N=|V|.
0. Initialize V1={v1}, V2= V\V2 such v1 a
node near the periphery.
1. If | V1| >= 1/2 | V| then Step 3
else Step 2.
2 .Let V0 = {u Є V / (V1 U {u}, V2 \{u})
is a connected partition of G}.
Choose u of V0 such that u the closest
element to V1.
If |u| < |V| - 2|V1|
     then V1 := V1 U {u}, V2 := V2 \ {u},
    Step 1
     else Step 3
3. Return (V1, V2).
```

4 SIMULATION RESULTS AND ANALYSIS

The effect of the proposed partitioning technique on the WSN lifetime is investigated using numerical simulations over Matlab environment. A circular large scale wireless sensor network, with a radius R = 500m is considered. 1000 nodes are randomly (uniformly) deployed over the network area. Sensors are similar with a communication range r= 80m and an initial energy of 1000J unit. The cost of sending and receiving operations is 1mJ per packet. Sinks are assumed to have no energy constraints because they have larger batteries or their batteries are rechargeable. Sensors communicate with the sinks in a multi-hop manner. We assumed that the shortest path routing algorithm is used to find the shortest route to the sink. The network lifetime is defined as the moment at which the first sensor runs out of energy. Time is divided into rounds. Each round is composed of T=100 timeframes. Each sensor node generates one data packet every timeframe.

To evaluate the efficiency of the proposed graph partitioning technique in elongating the network lifetime, the following scenario is considered:

Comparative Scenario:

Case 1: The entire network is considered. N sinks are deployed randomly on the periphery of the network. Then, the sinks start to move along the periphery. In one round each sink moved 60 m.

Case 2: The graph partitioning algorithm is used to define N smaller sub-networks. One single sink is randomly deployed on the periphery of each sub network. Then each sink moves 60m each round on the periphery.

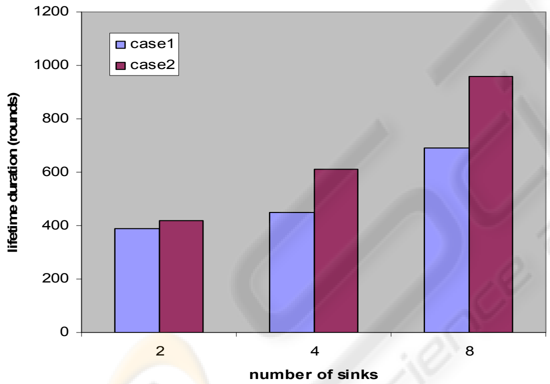

Figure 3: The network lifetime in the comparative scenario.

Several simulations are then run to compare the network lifetime in the two different cases of described scenario.

Simulation results are presented in figure 3. First, let's notice that the simple use of multiple sinks enhances the network lifetime (with and without partitioning). Indeed, the network lifetime increases proportionally to the number of sinks because the distance between the sensors and their correspondent sinks decreases.

Second, enhancements of the network lifetime can be observed in the case of partitioned large-scale WSNs compared to non partitioned ones. This was expected as when one sink is moving along the periphery of each sub-network, the energy consumption is obviously much more distributed over the sensors than when all the sinks are moving along the periphery of the whole network. The nodes that are the closest to the sinks are logically the ones who die first because they not only send their own data but also relay the data of all the nodes in the network. In this scenario, the nodes who die first in the case of non partitioned network are the nodes situated all along the periphery whereas in the case of partitioned network, they are the ones situated along the peripheries of the different sub-networks. Then, using the graph partitioning technique to deploy the sinks distributes the load relay and decreases the average distance between the sensors and the sinks. Indeed, the improvement of the network lifetime of the partitioned network is much more important when the number of sinks (or sub-networks) increases.

For interested readers, other comparative scenarios are investigated and provided with all details in (Slama, 2008).

5 CONCLUSIONS AND FUTURE WORK

The use of multiple sinks in large scale wireless sensor networks is necessary in order to cover large areas and to minimize energy consumption for data transmission operations. In this paper, we discussed the fundamental design parameters considered in WSNs with multiple sinks and which have a considerable influence on the energy consumption. We have shown that they should be carefully chosen in order to let them contribute in optimizing the network behaviour and extending its lifetime duration. We also proposed the use of graph partitioning techniques to obtain smaller and balanced sub-networks over which existing sink placement techniques that are optimized for small to medium scale WSNs can be used.

Performance results show that the proposed technique considerably enhances the network lifetime particularly when the sinks are moving along the periphery.

This first step using graph partitioning approach to improve energy consumption in large-scale WSNs is promising. We will focus in complementary and future work on more elaborated approaches for optimal multiple sinks placement and WSN partitioning. In addition, efficient tools should be proposed to determine the optimal number of partitions and sinks to be used according to the WSN characteristics, applications' requirements and financial costs.

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