

An Efficient Multi-Parameter Group Leader Selection Scheme for Wireless Sensor Networks

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Abstract—Future Wireless Sensor Networks (WSNs) are predicted to use thousands of sensor nodes. Moreover due to the limited resources of sensor nodes a core challenge is how to prolong WSN lifetime. Group-based or cluster-based approaches are well known methods used to enhance the lifetime and performance of such large scale networks. For these approaches each group leader in a group of nodes plays an important role in gathering data from member nodes, aggregating it and sending the information to the sink. These activities reduce the amount of data transmitted between source and destination nodes, thereby conserving energy. A major challenge in group-based WSNs is to select an appropriate new group leader in an efficient manner after failure or resource depletion of the existing group leader node. In this paper we propose a novel group leader selection scheme for WSNs which is based on four different selection parameters: available energy, number of neighbouring sensor nodes, distance from the current group leader and level of trust. We also analysed and found that the positioning of the group leader had a significant effect on the amount of energy consumed by the group overall. Simulation results demonstrate that our proposed scheme is effective in prolonging the lifetime of a WSN as compared to existing schemes.

I. INTRODUCTION

Generally WSNs are assumed to contain hundreds or thousands of sensor nodes. To manage a large scale network researchers generally recommend splitting the network into groups, clusters or domains, and also distributing the workload in an equitable way across these groups. In each group one special sensor node acts as a group leader which receives and aggregate data from all member sensor nodes within that group, and transmits aggregated results toward the sink. The advantage of data aggregation in WSNs is to reduce the amount of data to be transmitted between source and destination. Furthermore, in case a group leader or a cluster head sensor node fails due to resource depletion it will no longer be operational and all group member sensor nodes belonging to that group may lose communication ability with the rest of the WSN as a result. The increasing number of inoperative group leaders becomes the bottleneck of the whole WSN and shortens the network lifetime. Clearly group leaders play an important role in a WSN. Thus an efficient process for the election or selection of a new aggregator or group leader node is essential.

Many group leader selection/election solutions have been proposed to increase WSN lifetime. However the majority of these schemes have been evaluated only using a specific one hop network model (where all sensor nodes are directly connected with the cluster head) [1, 6]. Their performance reduces dramatically when using multi-hop communication between member sensor nodes and the group leader node. The performance is also affected adversely as communication

packet sizes increase in large scale WSNs and as the group size increases. Furthermore most of these current schemes involve all sensor nodes in the selection/election process, increasing the communication and computational overhead, especially in larger groups.

To maximize WSN lifetime and handle the issues presented above, we propose a novel energy efficient multiple parameter group leader selection scheme. This scheme allows a new group leader to be selected using four different weighting factors: available energy at each sensor node, number of neighbouring sensor nodes, a node's distance from the current group leader and its level of trust. Sensor nodes with the highest weighted and combined factor value will be selected as the new group leader node. Moreover, the scheme only involves a few sensor nodes in the new group leader selection process, which helps to reduce the overall cost. Simulation results have shown that our scheme increases group lifetime and performs well in multi-hop network models and smaller/larger groups. The proposed scheme can be applied across various application domains such as those mentioned by Sklavos *et al.* [3].

The rest of the paper is organized as follows. In Section II related work will be briefly discussed. In Section III we present the effect of group leader position on the performance of the entire group using experimental results. Section IV elaborates our proposed group leader selection scheme. In Section V we evaluate our scheme by comparison with existing schemes. Finally in Section VI we summarize our paper and discuss future research.

II. RELATED WORK

In this section we give an overview of various different proposed solutions for group leader election/selection in WSNs. These schemes use a variety of different selection/election factors. In LEACH [1], cluster head election decisions are based on the suggested percentage of cluster heads for the WSN (determined *a priori*) and the number of times the sensor node has been a cluster head previously. In general sensor nodes with more energy have more chance of being elected as cluster heads. In some cases LEACH becomes inefficient when cluster heads are very close to each other or located at the edge of the WSN. In contrast CHEF [6] uses the remaining available energy and distance as selection factors, applying fuzzy logic to the election of new cluster heads. In CHEF the cluster head election is localized and based on a network model similar to LEACH, but they don't consider the number of times the sensor node has been a cluster head previously in order to balance energy. The LEACH and CHEF schemes are based on a specific one hop network model and produce dramatic communication overhead in multiple hop network models. Wen *et al.* [2] have considered

multi-hop network models. They define two different methods: centralized and distributed methods for cluster head election. In the centralized method, the current cluster head determines a new cluster head by aggregating energy and neighbouring sensor node information from its cluster members. In the distributed method, once the energy in the current cluster head is below a given threshold, it transmits a message to start the reselection process. Each cluster member then checks its energy constraints. As long as the cluster member satisfies these constraints, it generates a random waiting time which depends on the number of neighbouring cluster members and the remaining energy level.

Although the above schemes provide effective methods in specific cases, by only considering certain parameters and certain network models, they suffer from limited applicability. For example, the group leader position has a surprising impact on group efficiency as we will show in the next section.

II. IMPORTANCE OF GROUP LEADER POSITION

In this section we present one of the research findings that have been identified during our investigation: the importance of the position of a new group leader on the overall cost of the group. This is one of the selection parameters in our group leader selection scheme that we will describe in the next section. The analysis/simulation process outlined below has assumed a simple scenario as shown in Figure 1. In this we select a group of 25 sensor nodes in a grid topology. Each sensor node is equipped with one Joule of energy, and a packet size of 48 bits is used. Through repeated iterations of the simulation we place the group leader sensor node at each of the possible positions in the group. For this evaluation process all sensor nodes sense and route data towards the group leader using an adaptive routing algorithm [4]. The group leader receives data from 24 nodes and aggregates all of the data before finally routing it towards the sink. This entire process is considered to be one cycle. After running 100 cycles for each group leader we then calculate the energy consumption of the entire group, the results of which are shown in Figure 2. The energy model used is described in detail in Section IV, and is the same as that used by LEACH and CHEF. This experiment provides us with some relevant insights. In particular the sensor at position (2, 2) is the most efficient, consuming 0.310 Joules in comparison to the least efficient sensor node at position (0, 0), consuming 0.504 Joules.

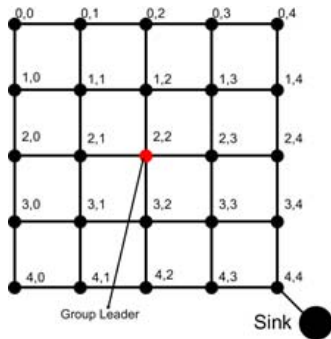


Fig. 1 Group leader positions and communications toward the sink.

As shown in Figure 2, a central group leader position helps to reduce energy consumption significantly. These results clearly indicate that the position of the group leader has a direct impact

on the performance of the entire group.

Conclusions: The outcome and results from our experiments show the importance of the group leader's position and its effect on the WSN performance. This importance will increase further as the size of the group increases, or as the packet size increases. With large group or packet sizes, the inappropriate selection of a new group leader can result in a large energy overhead.

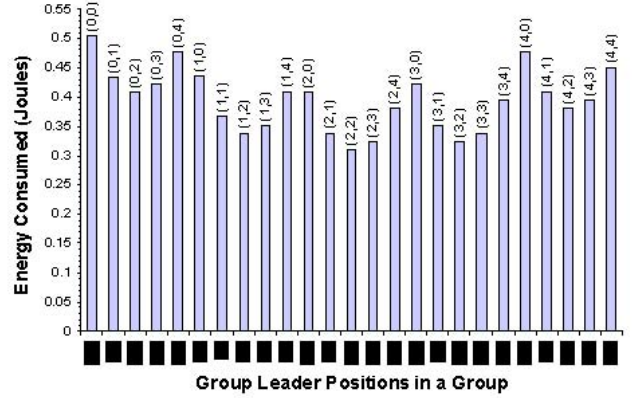


Fig. 2 Energy consumption of group with different group leader positions.

III. PROPOSED SCHEME

In this section we propose a formula for new group leader selection. In this formula we consider four important factors in the selection process. These factors include available energy, number of neighbouring nodes, position of a new group leader node and trust level. Before going into further discussion, we present the notation that will be used in our proposed formula.

- S_l Space between source sensor node l and the group leader.
- d_l Distance between sensor node l and the group leader.
- h_l Number of hops between sensor node l and group leader.
- δ Energy threshold level.
- α Trust threshold level.
- w_e Weighting factor for energy.
- w_{sl} Weighting factor for the space between sensor node l and the group leader node. This value can be one of w_{dl} or w_{hl} , depending on whether the weighting factor relates to geographical distance d_l or network distance h_l respectively.
- w_t Weighting factor for trust.
- E_l Available energy of sensor node l .
- T_l Trust level of sensor node l .
- N_l Number of neighbouring sensor nodes.
- V_l Selection value of sensor node l in the process of new group leader selection.
- W_l Final weighting factor value of sensor node l .

In the new group leader selection process, the current group leader will send a selection process packet to specific nodes that are to participate in the selection process. All participant nodes will calculate their selection value V_l using equation (1) shown

below, and send it to the current group leader.

$$V_l = (E_l \times w_e) + (N_l \times w_n) + \left(\frac{1}{S_l} + w_{sl} \right). \quad (1)$$

For this equation we apply threshold values, requiring that $E_l > \delta$, $N_l > 0$ and $S_l > 0$, where $S_l = d_l$ or h_l . Otherwise we set $V_l = 0$. The group leader will receive V_l and calculate a weighting factor W_l as follows.

$$W_l = V_l + (T_l \times w_t). \quad (2)$$

Again we apply threshold values, so that we must have $V_l > 0$ and $T_l > \alpha$. Otherwise we set $W_l = 0$.

In equation (1) we multiply the available energy E_l with the weighting factor w_e , N_l with its weighting factor w_n and S_l with its weighting factor w_{sl} . We then sum them to calculate V_l . Furthermore in equation (2) we add V_l with $(T_l \times w_t)$ where T_l is the trust value of sensor node l and w_t is a trust weighting factor (the group leader will determine the trust values for nodes participating in the selection process). The weighting factors in equations (1) and (2) help us during the simulation to evaluate the effect of each parameter during the selection process. Any node with $W_l = 0$ will not be selected as a new group leader. In order to participate in the group leader selection, a sensor node's available energy E_l , trust level T_l and number of neighbouring sensor nodes N_l must be greater than the thresholds δ , α and zero respectively. Note that $1/S_l$ gives a higher value when a sensor node is closer to the current group leader.

The group leader sensor node will determine the highest value of W_l in order to select a new group leader sensor node. The current group leader will then broadcast a message containing the new group leader ID to all its group member sensor nodes. Furthermore if the current group leader holds any secure key or keys shared with other groups these will also be sent to the new group leader or recalculate new keys. For future communication all data should then be routed towards the new group leader sensor node.

In the given formula we calculate the selection value W_l using four different factors by adding the values of the *energy* factor, *number of neighbouring nodes* factor, *distance between group leader and node* factor and *trust* factor. If node l has the highest energy above the threshold δ , has more than one neighbouring node ($N_l > 0$) and is close to the current group leader (S_l) but its trust level T_l is less than the threshold α , then the node will have $W_l = 0$ and be automatically ruled out as a future group leader. Similarly the other factors will play roles in much the same way. According to the results described earlier in Section II, we don't involve all group member sensor nodes in the selection process. As nodes closer to the current group leader are more likely to be more appropriate for performing the role of the new group leader as compared to sensor nodes that are further away.

Therefore we only involve the limited number of sensor nodes around the current group leader in the selection process. This helps to reduce the energy cost incurred during the selection process. This is in contrast with many existing proposed solutions, which involve all group members in their election or selection process, thereby consuming extra energy as a result. This constitutes an additional advantage of our proposed scheme. The formula above can be coded into all group member nodes. Whenever a group leader requests a member node's selection value, the node will calculate it using this formula and send it to the group leader.

Our proposed scheme can also be used for different applications with respect to different communication behaviour of the sensor nodes. For example, in some applications sensors might use different radio ranges with respect to distances between different sensor nodes. In this case we can measure the space S_l between a source node and a group leader in order to establish a distance metric d_l . However in applications where a fixed radio range is used for communication between sensor nodes this may not be possible. In such cases we measure the space S_l between a source sensor node and a group leader using hop count h_l . Figure 3 demonstrates an example of this. In case 1 of Figure 3, we have a fixed radio range meaning that every hop is considered to be of the same distance, whereas in case 2 every sensor node has a different radio range, and different hops between sensor nodes can have different distances.

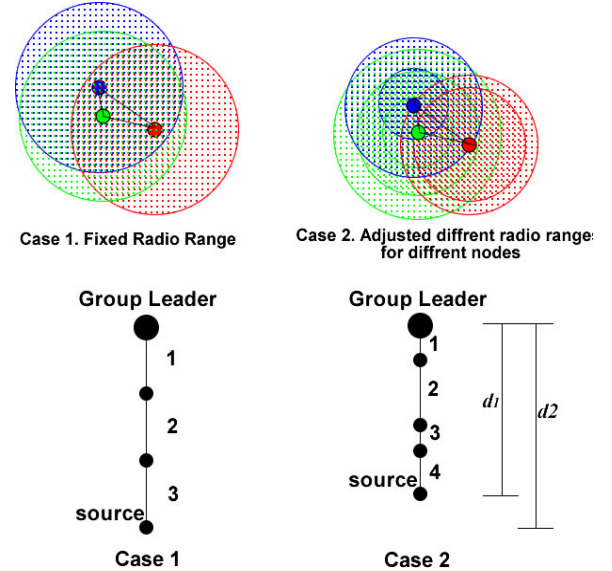


Fig. 3. Distance or number of hops from a source to its group leader.

The distinction is highlighted by the fact that in the diagram $d1$ has four hops, $d2$ has three hops, but the distance $d2$ is greater than $d1$. In our proposed group leader selection process we have considered both of these cases. Furthermore our proposed group leader selection scheme can also be used in heterogeneous WSN applications where different types of sensor nodes are used and have differing energy requirements. However, existing solutions for group leader selection/election have only considered energy or the number of neighbouring sensor nodes and distance as their main election criteria [1, 2, 6]. Our current solution is also scalable. The number of participant

nodes can be increased by sending participation packets to more nodes during the new group leader selection process. For example, the current group leader can restrict participation packets to n -hop neighbours, where n is determined by the size of the group.

In our present solution we do not consider issues related to member nodes sending false information (energy, number of neighbouring nodes, trust etc.), nor do we consider the exact details of the trust mechanism. These are areas of ongoing research where existing work may be applied depending on application, and that we hope to tackle in future work.

IV. EVALUATION

In this section we discuss our implementation and performance evaluations of our group leader selection scheme and compare it to existing schemes. We have used a grid topology with a fixed distance of 20 metres between nodes for all experiments. The packet size used during our implementation is 48 bytes, which includes 36 bytes of data, 12 bytes for a node ID and a time stamp. We have used the same adaptive routing algorithm as in previous work [4]. We use the same radio model (first order radio model) as LEACH and CHEF for our communication model, which is widely used (this is the same radio model as used for the experimentation in Section II). In this model the radio dissipates $E_{elec} = 50$ nJ/bit to run the transmitter or receiver circuitry and $E_{amp} = 100$ pJ/bit/m² for the transmit amplifier to achieve an acceptable E_b/N_o .

During our analysis we have assumed that the first group leader will be at the ideal position within the group. Although we include trust in the calculation, we are not proposing any scheme to calculate trust values for sensor nodes. Therefore during the evaluation we use constant trust values for every sensor node and assume all nodes are trusted. Any solution for finding the trust values of sensor nodes can be easily integrated into the formula [5]. For the group leader selection formula we evaluated various cases, as detailed below.

Case 1: In this case we have considered a group of 25 sensor nodes. The initial energy of all sensor nodes is set to one Joule. Consequently the total initial energy of each group is 25 Joules. In our group leader selection scheme we only involve the neighbouring sensor nodes of the current (outgoing) group leader in the selection process. To make an appropriate comparison, we have also considered a similar process involving all sensor nodes in the selection process. During this experiment the group leader selection process is undertaken ten times, each of which happens after a fixed number of cycles. One cycle constitutes all sensor nodes in a group sending one packet to the group leader. When one cycle completes the group leader will have received 24 packets from all member sensor nodes plus one packet from the group leader sensor node itself; it then sends the aggregated data towards the sink. We consider LEACH, CHEF and Wen *et al.*'s schemes for comparison since all are well established and widely known protocols for group leader selection in WSNs. The results of this comparison are shown in Figure 5. In this figure *Our Scheme All* refers to our proposed scheme with all sensor nodes participating in the selection process and *Our Scheme* refers to our scheme with only neighbouring sensor nodes participating in the selection process.

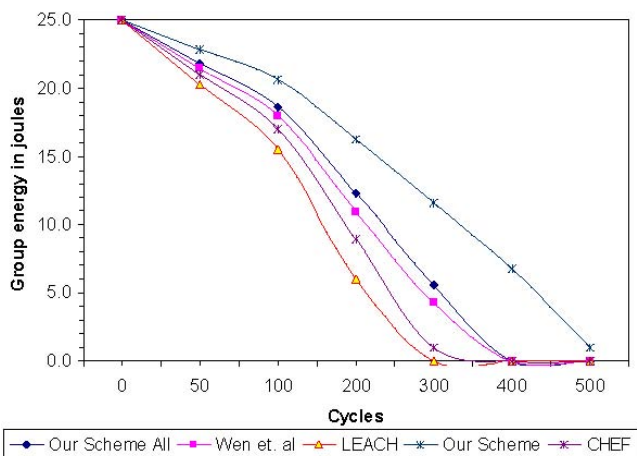


Fig. 5 Group energy consumption with 25 sensor nodes for n cycles.

In the first set of experiments we have evaluated all five methods for group leader selection over 50 cycles. After 50 cycles a new group leader is selected and this process is repeated ten times. In other words, once the group leader receives 1250 packets (25×50) it will initiate a new group leader selection process. Furthermore, ten group leader selection processes will run where each selection starts after fifty cycles.

In the second set of experiments we have considered 100 cycles. In this case the new group leader selection process will start after 100 cycles ($100 \times 25 = 2500$ packets received by the current group leader). Furthermore the group leader selection process will run ten times, where each selection is initiated after 100 cycles of the simulation. During all of these experiments we have considered the energy cost of the group leader selection. There are a certain number of communication steps that happen during the group leader selection process, as described below.

- The group Leader sends a *selection process* packet to all/neighbouring sensor nodes.
- All/neighbouring sensor nodes receive the *selection process* messages.
- All/neighbouring sensor nodes send their weighting factors to the current group leader.
- The group leader receives all weighting factors and trust levels from all/neighbouring sensor nodes.
- The group leader sends the selected new group leader ID to all member sensor nodes.
- The current group leader will send information (secure key and keys shared with other groups or renegotiate such keys) to the new group leader.
- All sensor nodes receive the new group leader ID.

All of these steps remain the same in all cases. In Figure 5 we can see that *Our Scheme* consumes less energy as compared to all of the other schemes tested. One of the main reasons for this reduced energy consumption is due to the fact that fewer sensor nodes need to participate in the selection process. As pointed out in Section II, packet and group sizes have a direct impact on the energy consumption for the group leader selection process. This is further supported by the following case with increased group size.

Case 2: In this case we have considered a group of 100 sensor nodes. The initial energy of each sensor node is one Joule. Consequently the total initial energy of the group is 100 Joules.

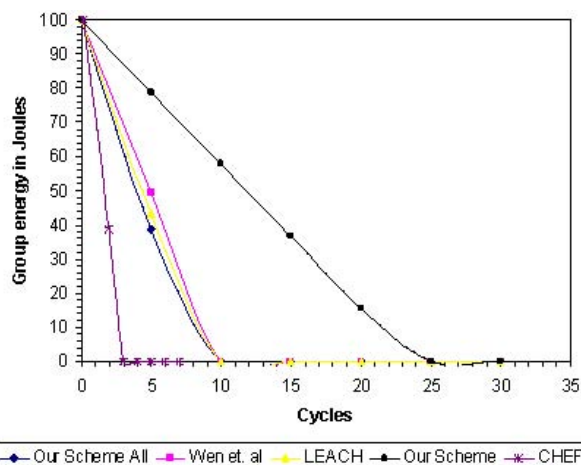


Fig. 6 Group energy consumption with 100 sensor nodes for various schemes.

During the experiments of Case 2 the group leader selection process will take place 50 times after a fixed number of cycles. In this case one cycle means all sensor nodes in the group will send one packet to the group leader sensor node. When one cycle completes the group leader will have received 99 packets from its member sensor nodes plus one packet from the group leader itself for data aggregation.

In the first set of experiments we have evaluated the five methods for group leader selection using 5 cycles. This means that after every 5 cycles a new group leader sensor node will be selected. Once the group leader sensor node has received 500 packets (100×5) it will initiate the new group leader selection process. In the second set of experiments we have considered 10 cycles, so that the new group leader selection process starts after each 10 cycles ($10 \times 100 = 1000$ packets received by the current group leader). This experiment was run until 50 rounds of new group leader selection had occurred.

In Figure 6, we can clearly see the effect of the larger group on the group leader selection. Using, *Our Scheme*, *Our Scheme All*, LEACH, CHEF and Wen *et al.*'s methods, the entire group energy was consumed after just 15 cycles. The reason for this higher energy consumption is that 50 rounds of new group leader selection are applied, in addition to the larger group size. Most of the energy was consumed during the selection process. This underscores the need to be particularly careful about how to operate the selection process for large groups. From Figure 6, it is clear that *Our Scheme* is more energy-efficient than the comparable schemes. Another finding from the experiments is that we need to find a careful balance between the number of group leader selection rounds and cycles. It would be unwise to start a new group leader selection process after just a few cycles, as the group leader selection process costs significantly in terms of energy. Therefore we should find optimum values, which will be different for different group sizes.

Case 3: In this case, we have used the same setting as in case 2. During the experiment we alter the number of group leader selections in a 60 cycle period to increase the group life time. The results are shown in Figure 7. From these we can identify the optimum values for group leader selection and cycles for a

group of 100 sensor nodes. For example after running 31 cycles and 30 group leader selections, the final group energy remaining was 38.75 Joules and the total packets sent was 93000. By contrast after 26 cycles and 35 selections the final energy was 38.92 Joules and the total packets sent was 91000.

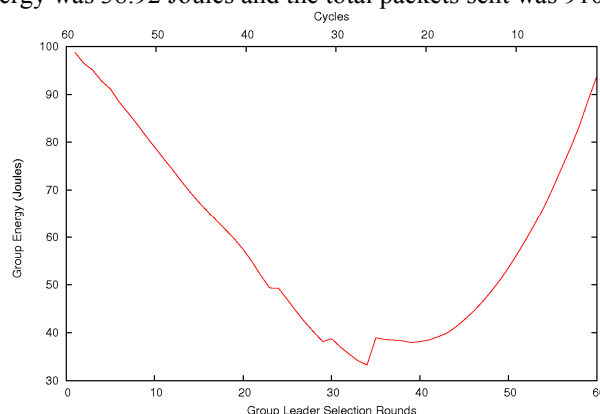


Fig. 7 Energy consumption for numbers of group leader selections versus numbers of cycles.

We can therefore establish that the highest performance value for a 100 sensor node group is with 31 rounds and 30 cycles. The motivation to balance cycles against frequency of group leader selection is to increase overall availability. Running many cycles on a group leader node can increase the chance of it dying, potentially leading the entire group to the point where sensor nodes are unable to communicate with the rest of the sensor network even though active sensor nodes remain.

IV. CONCLUSION AND FUTURE WORK

In this paper, we propose an efficient group leader selection scheme to prolong WSN lifetime. Four selection factors are considered: energy, number of neighbouring sensor nodes, position of sensor nodes and their trust level. The simulation results demonstrate that our proposed group leader selection scheme can enhance WSN lifetime markedly, improving efficiency in large and small groups compared to existing schemes. In future work we intend to simulate our scheme on a larger scale and for irregular networks, and to evaluate sensor nodes with random trust levels and with other selection factors.

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