An approach for energy optimization in wireless sensor networks

G. Hristov, P. Zahariev, T. Iliev, M. Iliev
Department of Communication systems and technology
University of Ruse
Studentska Street 8, Ruse, 7013, Bulgaria
Phone: (359) 82 888 663  Fax: (359) 82 888 841  E-mail: ghristov@ru.acad.bg

Abstract - Wireless sensor networks (WSN) are lately an object of significant attention due to their unlimited potential and many areas of implementation. Many sensor network applications require prolonged network lifetime, scalability, and load balancing. Organizing sensor nodes in clusters is an effective technique for satisfying these goals. In this paper we present a study on the optimal number of cluster and the effective radius of the clusters in wireless sensor networks (WSN). Based on the results we investigate the energy dissipation in a single node and the whole network, and propose a scheme, which extends the network lifetime, due its lightweight architecture.

I. INTRODUCTION

Recent technological developments in embedded systems have led to the emergence of a new class of networks - Wireless Sensor Networks (WSNs). Their main purpose is the wireless cooperation between individual nodes with the goal of sensing and interacting with the surrounding environment. The challenges in designing WSNs are a consequence of two major factors. The first is their unique characteristics like limited power resources and restricted computation and communication capabilities of the nodes. The other factor is the increasing requirement toward those networks in terms of scalability and support of diverse applications. We examine the characteristics of the typical sensor networks as well as the different types of communications that are used. We compare different data delivery models and evaluate their energy efficiency. We believe that this study will aid the process of making better decisions regarding the organization of the network, the network protocols and information dissemination models. Furthermore, it will aid the developing of realistic sensor network models for use in future research.

The remainder of this paper is organized as follows. Section II presents some basic definitions and an overview of the characteristics of sensor networks. Section III presents results from the conducted simulations using different cluster shapes and data delivery models. Section IV presents the synthesized approach for energy optimization in wireless sensor networks, followed by the conclusions, acknowledgment and references sections of the paper.

II. CHARACTERISTICS OF A SENSOR NETWORK AND PERFORMANCE MEASURES

Sensor networks use the wireless medium for communication purposes and thereby share many of the challenges of traditional wireless networks like bandwidth-limited and error-prone channels. However, communication in sensor networks differs from communication in other types of networks in that it is typically not end-to-end.

In this paper, we use the terminology, as presented by [1]:

- **Sensor**: The device that implements the physical sensing of environmental phenomena and reporting of measurements.
- **Observer**: The end user interested in obtaining information disseminated by the sensor network about the phenomenon.
- **Phenomenon**: The entity of interest to the observer that is being sensed and potentially analyzed by the sensor network.

In a typical sensor network, the individual sensors perform measurements and transmit the information to other sensors and to the observer. These measurements are discrete samples of the physical phenomenon and are subject to individual sensor measurement accuracy and location. More specifically the sensors form a network, responsible for the delivery of information to the observer. Furthermore, energy is limited in sensor networks because of the nature of the sensors and the unavailability to recharge their batteries. Studies in numerous materials [1, 2] show that energy cost for communication exceeds many times any other sources of energy consumption. This indicates the need for reduction of the communication without decreasing the performance in terms of information delivery and delay. An approach that has proven to be successful in solving the problem, stated above, is the organization of the nodes into clusters. Since WSN are application specific the energy dissipation in the network is influenced by several parameters:

- \( N_c \) – the number of clusters in the sensor field;
- \( D \) – the density of the nodes, or the ratio between the number of nodes and a square meter of the surface;
- \( d_0 \) – the distance to the sink.

Besides the parameters listed above other crucial factors that influence the energy dissipation in the wireless sensor networks are the shape of the clusters, the distribution of the nodes and the data delivery model. To evaluate the impact of those factors we have conducted simulations with various cluster shapes and two of the most used data delivery models – single-hop (Fig. 1.) and multi-hop (Fig. 2.) [3].
When all of the nodes are organized into clusters, they transmit their information to the cluster heads. The cluster head aggregates the information and forwards it to the observer. Reclustering the network on a given period can cause the selection of nodes with higher residual energy to act as cluster heads [4]. Using this approach the energy dissipation is minimized through the decrease of the number of nodes contending for channel access, the aggregation of network information and updates, and routing among cluster heads.

III. STUDY OF THE PARAMETERS IMPACTING ON THE ENERGY DISSIPATION IN WSN

In order to study the parameters, that have impact on the network we assume a simple radio hardware energy dissipation model. According to it the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy only to run the radio electronics. The energy required for the transmission of a packet with size of $L$ bits over any given distance is given by:

$$E_{TX} = L\left(E_e + d_0 E_a^k\right),$$  

where $E_e$ is the amount of energy spent in the radio electronics, while $d_0 E_a^k$ is the amount of energy spent in the radio amplifiers. $E_a$ takes into account the antenna gains of the transmitter and the receiver and the constant factor in the propagation loss term. $d_0$ is considered to be the distance to the sink and $k$ is the propagation loss exponent and depends on the characteristics of the sensor field area. In obstacle free environment, the value of $k$ is considered to be 2. In building environments and regions with dense vegetation, the value is between 3 and 5. On the receiver side only the receiver electronics are participating in the process of receiving the packet. The energy spent on this process is:

$$E_{RX} = LE_e$$

Due to the fact, that we are going to study also and the multi-hop data delivery model, where the packets are retransmitted between the cluster heads towards the base station, the energy dissipated for the retransmission of a packet with size of $L$ bits can be given by:

$$E_{reTX} = L\left(2E_e + d_0 E_a^k\right)$$

For our study we assume that $E_e = 50\, \text{nJ/bit}$ and $L = 300\, \text{bit}$. The value for $E_a$ can be selected using:

$$E_a = \begin{cases} 
50\, \text{pJ/bit/m}^2 & \text{if } k = 2 \\
10\, \text{pJ/bit/m}^3 & \text{if } k \in [3, 5]
\end{cases}$$

Additionally we also assume that the nodes are homogenous in their initial amount of energy and that they are randomly distributed in the field.

A. Impact brought by the number of sensors

On Fig. 3 we can see the total energy dissipation in the network per round. It is noticeable that for small number of nodes ($N < 140$) the single-hop data delivery model performs better than the multi-hop data delivery model. The number of nodes does not have a direct impact on the energy dissipation. This is done because they participate in the process of determining the optimal number of clusters, which is actually one of the parameters that has impact on the energy dissipation.
between any two nodes and the base station is the same, which means that the base station is far away from the sensor field, the optimal number of clusters can be given by:

\[ \text{Opt}(N_c) = \frac{n}{\sqrt{6} d^2 \sqrt{f(E_a)}} \], \hspace{1cm} (5)

where \( n \) is the number of sensors in the network, \( d \) is the distance to the base station, \( M \) is the surface of the sensor field and \( f(E_a) \) is a function, equal to the ratio of \( E_a \) when \( k=2 \) and \( k=3 \) [5, 6].

Knowing the optimal number of clusters their radius can be determined by:

\[ R_c = \frac{M}{\sqrt{\pi \text{Opt}(N_c)}} \], \hspace{1cm} (6)

\[ R_{sq} = \frac{M}{\sqrt{4 \text{Opt}(N_c)}} \], \hspace{1cm} (7)

\[ R_{hex} = \frac{4}{27} \frac{M}{\sqrt{\text{Opt}(N_c)}} \], \hspace{1cm} (8)

where \( R_c, R_{sq} \) and \( R_{hex} \) are the radiuses for circle, encircled square and encircled hexagonal cluster respectively. The difference between the cluster radiuses is shown on Fig. 4.

Figure 5 is presenting the relations between the distance to the sink, the optimal number of nodes and the energy dissipation per round for both single-hop and multi-hop data delivery models. As already seen in Fig. 3, the energy dissipated in the single-hop scenario, before a given number of nodes, is lower than the energy used in the multi-hop scenario. Analogically the energy dissipated using the single-hop data delivery model is lower than the energy dissipated in the multi-hop model for a given distance. After that threshold it is more appropriate to use multi-hop data transmissions. In our previous papers [5, 6] we have studied the impact of the distance to the base station in more details, and due to space limitations we will not discuss it further here.

C. Impact brought by the surface of the area and the density of the nodes

The density of the nodes is closely related with the surface of the sensor field as shown in Fig. 6. It is easy to notice that the single-hop data delivery model totally underperforms, in terms of energy dissipation, the multi-hop data delivery model.

B. Impact brought by the distance to the sink

The distance to the sink, is probably the most crucial factor, which has impact on the energy dissipation. This is because the energy for transmission is directly related with distance, as it can be seen by (1). So while using single-hop (Fig. 1), the larger the distance to the sink, the more energy dissipated (Fig. 5). This is one of the reasons for the use of the multi-hop data delivery model (Fig. 2).
IV. AN APPROACH FOR ENERGY OPTIMISATION IN WSN

Based on the analysis of the parameters from the previous section we can propose a new approach for energy optimization, shown on Fig. 7.

Initially it is assumed that the values of \( M \) and \( d_0 \) are known. Since a node can be cluster head only once per epoch, we believe it is more suitable to implement the new algorithm at the beginning of every epoch. The epoch starts with the process for resynchronization of all nodes and is followed by the algorithm for estimation of the number of nodes alive. The implementation continues with the calculation of the optimal number of clusters using the values for all three parameters required to do this (Fig. 8 – Phase 1). Next, the algorithm uses the information for the number of nodes alive and the distance to the base station to select the better data delivery model. Once this phase is completed the systems start performing the operations per round. Those operations begin with the election of cluster heads, based on the value for optimal number of clusters (Fig. 8 – Phase 2), the formation of the clusters and the actual data transmissions (Fig. 8 – Phase 3).

VI. CONCLUSION

In this paper we propose an approach for energy optimization, based on the parameters, which have impact on the energy dissipation. A series of simulations have been conducted in order to point out those parameters and the relations between them. Our future work will focus on the development of simulation models for studying the model and its practical realization in a wireless sensor network.

VII. ACKNOWLEDGMENT

This work is a part of the projects: BG051PO001/07/3.3-02/8–“MEQSIS”, funded by scheme “Support of the development of PhD students, postdoctoral, post-graduate and young scientists” from the program “Development of human resources” of the “European social fund”; DMU-02/13-2009 “Design and performance study of an energy-aware multipath routing algorithm for wireless sensor networks” of the Bulgarian Science Fund at the Ministry of Education, Youth and Science.

REFERENCES