Comparative analysis of routing approaches for wireless sensor networks

Plamen Zahariev[1], Georgi Hristov[1], Ivanka Tsvetkova[1] and Mihail Iliev[1]

Abstract – **The aim of this paper is to present a simulation study of the three most common approaches for routing of information in the wireless sensor networks (WSNs). In the introduction of the paper we shortly describe some of the characteristics of the WSNs, and then we present some of their main implementation areas. In the second section we present the theoretical aspects of the approaches for flat, directed and hierarchical routing. Later we present a comparative analysis of the three approaches and we highlight their main advantages and disadvantages. In the fourth section we present the results of the conducted simulation experiments with the three approaches and we discuss and analyse them. The paper is then completed by the conclusion section, followed by the acknowledgment and references sections.**

Keywords – **Wireless sensor networks, hierarchical, directed and flat routing.**

I. Introduction

The wireless sensor networks are combining the benefits of the modern technologies for detection and sensing with the possibility to transmit the data using the wireless medium. These networks are found suitable and are being used for numerous of different purposes including animal and insect monitoring, intelligent and autonomous housing, vehicle and people tracking, intrusion detection and prevention, military purposes and other [1]. There are many different issues currently open with these networks, and they all are a consequence of the limited resources and the small size of the sensor devices [2]. One of the biggest challenges is to present a routing approach, which is corresponding to the needs of the sensor networks and is suitable to the hardware and software capabilities of the devices [3, 4]. There are several major approaches for routing of data in wireless sensor networks – direct routing, flat routing and hierarchical routing [5]. These three approaches are used separately and interchangeably and are dependent on the architecture of the network and its purpose. The first type of architecture, which we will investigate, is characterized by the fact that all of the devices in the network (except for the base station) are performing the same tasks and functions. This means that all of the devices are able to perform sensing tasks, to receive information from other devices and to send data to the other sensor motes or to the base station. These are the necessary prerequisites to implement the direct and flat routing approaches [6]. The second type of architecture is characterized by the fact that the devices, which are forming it, are not performing the same tasks and functions. The networks, which implement this type of architecture, are formed by two types of sensors. The first class of sensor devices is capable of performing the basic sensing and communication tasks while the second class of devices is performing specialized actions and functions, like cluster formation, data aggregation and other [7].

[1]Dr. Plamen Zahariev is a principal assistant professor at the Department of Telecommunications of the University of Ruse “Angel Kanchev”, Studentska str. 8, Ruse 7013, Bulgaria, e-mail: pzahariev@uni-ruse.bg.

[1]Dr. Georgi Hristov is an associate professor and Vice Head of the Department of Telecommunications of the University of Ruse “Angel Kanchev”, Studentska str. 8, Ruse 7013, Bulgaria, e-mail: ghristov@uni-ruse.bg.

[1]Ivanka Tsvetkova is a PhD student at the Department of Telecommunications of the University of Ruse “Angel Kanchev”, Studentska str. 8, Ruse 7013, Bulgaria, e-mail: itsvetkova@uni-ruse.bg.

[1]Dr. Mihail Iliev is professor at the Department of Telecommunications and Vice Rector of the University of Ruse “Angel Kanchev”, Studentska str. 8, Ruse 7013, Bulgaria, e-mail: itsvetkova@uni-ruse.bg.

II. Direct, Flat and Hierarchical routing in the Wireless Sensor Networks

The direct routing approach (Fig. 1) is one of the oldest approaches for data transmission in the wireless sensor networks. This approach defines, that the sensor devices are to be accessed using data about their coordinates or their location [8]. By using this approach the Base Station can request information about the occurrence of an event from a given area on the sensor field instead to request the data from all of the sensor devices in the network.

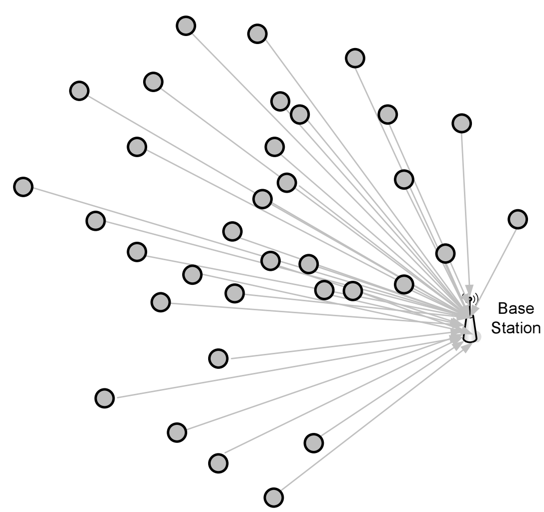

Fig.1. Example of the direct routing approach in the wireless sensor networks

The most common approach to determine the location of the sensor motes is to use the received signal strength indication (RSSI). Alternative approach for localization of the devices is the direct communication with a satellite, trough a GPS interface (if the mote has one).

The direct routing approach defines that the sensor devices should communicate direct with the data sink (either the Base Station or a neighbor sensor mote). Unlike this approach the flat routing defines that the sensor devices can communicate with the nearest device towards the sink thus reducing the communication distances and by that also decreasing the amount of energy required for the communication processes (Fig. 2). Additionally, when this approach is implemented, the intermediate devices can use the data from the transmitting device and if possible can aggregate it with the data, which it has personally collected from the sensed area. The flat routing approach, similar to the direct routing approach is ideal for implementation in information-orientated wireless sensor networks [8]. Additionally this approach is much more suitable for implementation in large scale WSNs, since due to the retransmission of the data, the sink will receive information from a smaller number of devices compared to the direct routing approach. This will provide also better quality of service and smaller delays.

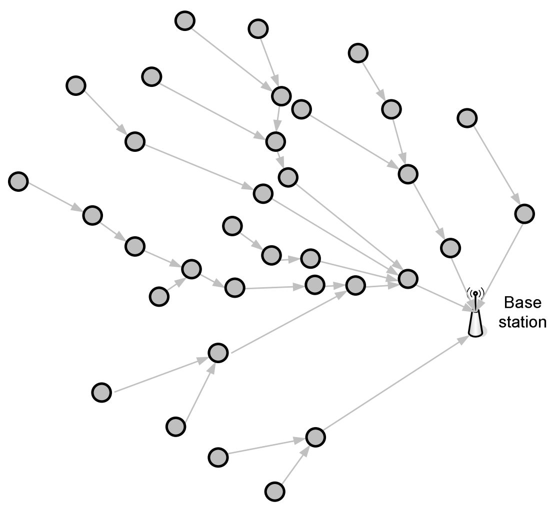

Fig.2. Example of the flat routing approach in the wireless sensor networks.

The hierarchical (also known as cluster based) routing approach (Fig.3) is initially proposed for implementation in the traditional Ethernet networks and is widely used because of its unmatched communication efficiency and because of its high level of tolerance towards network scalability [9, 10].

These are the main reasons for the exceptional results, which this approach shows in terms of effective and balanced consumption of the energy of the sensor motes. With the hierarchical architecture, the motes, which are having more energy, are used for data processing, aggregation and communication, while the sensor devices with less energy are used for low energy processes, like sensing and environmental monitoring [11, 12]. This idea is accomplished by organizing the network into clusters and by defining roles to the specific devices in the cluster. The network can be formed into several levels where the lowest level is consisting of sensor motes, which communicate with a cluster head, and the higher levels are formed by cluster heads, which are communicating either with other cluster heads or with the base station [13].

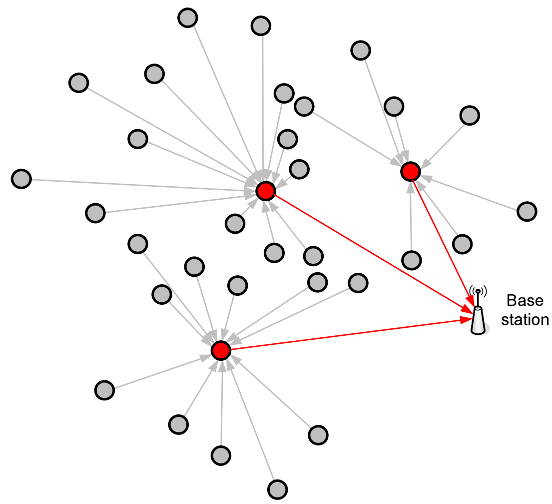

Fig.3. Example of the hierarchical routing approach in the wireless sensor networks

Typical representative of the hierarchical cluster based routing approaches is the LEACH protocol [5, 10]. The approach for hierarchical organization of the network, which is defined by this protocol, states that the first layer of the network will consist of devices, which are in communication range with the base station. The devices of every layer will be able to communicate with the sensors from the previous one, but not with the devices from the layers before that.

After the conclusion of this process the total number of the clusters N_{CL} in the system can be divided by the number of the layers N_L, and thus obtaining the average number of clusters per layer N_{CL}^{avg}. Assuming that the devices are distributed equally on the sensor field, then the average number of devices per layer n^{avg} can be calculated by dividing the total number of sensor nodes n by the number of the layers N_L:

$$n^{avg} = n / N_L \quad (1)$$

After the average number of devices is determined, they are distributed equally in the corresponding clusters for every layer.

By using these rules, the possibility for a certain module P_{ni} from a given layer to become a cluster head for the communication round t can be given by:

$$P_{n_i}(t)\begin{cases}\dfrac{N_{CL}^{avg}}{n^{avg}-N_{CL}^{avg}\left(R_e \bmod \dfrac{n^{avg}}{N_{CL}^{avg}}\right)} & when\ \ C_{n_i}(t)=1\\ 0 & when\ \ C_{n_i}(t)=0\end{cases} \quad (2)$$

In the equation above, R_e is the number of elapsed communication cycles from the start of the communication round and $C_{ni(t)}$ is a variable, which has value of 0 when the device has already been a cluster head during this communication round and 1 otherwise. After the completion of the process for organization of the hierarchical wireless sensor network, the system is divided into clusters of equal number of sensor modules.

III. Comparative Analysis of the Routing Approaches for WSN

In order perform a comparative analysis between the direct, the flat and the hierarchical routing approaches, we have decided to collect the main advantages and disadvantages of these approaches and present them using a table.

Table 1. Comparative analysis of the advantages and disadvantages of the three routing approaches for WSNs

	Advantages	Disadvantages
Direct routing approach	• Effective dissipation of the energy needed for communication, when the network is formed by small number (less than 100 nodes) of sensor devices. • Accurate estimation of the length of the communication round. • The amount of the traffic in the network is proportional to the number of the devices. • It is possible to use addressing schemes to distinguish the devices	• Requires accurate localization of the sensor devices. • Large delays during data transmission in networks, which consists of thousands of sensor devices. • Large possibilities for collisions accuracies in systems with shared transmission mediums (especially in large networks with thousands sensor motes). • Unequal energy dissipation (due to the unequal distances to the sink).
Flat routing approach	• Effective dissipation of the energy needed for communication, when the network is formed by large number (>100 nodes) of sensor devices. • Possible data aggregation, when the data is send to the base station. • Smaller amounts of network traffic (due to the data aggregation).	• Use of only information-oriented architecture. • Impossible to determine accurate the length of the communication round. • Delays in networks with large number of sensor devices (due to the larger number of intermediate hops). • Unequal energy dissipation and processing loads (due to the unequal number of hops for the devices further away from the Base Station).
Hierarchical routing approach	• Effective dissipation of the energy needed for communication, when the network is formed by large number (>100 nodes) of sensor devices. • Data aggregation in the cluster and between the clusters (higher data integrity and reliability). • The amount of the data traffic in the network depends on the amount of the cluster head devices. • Possible implementation of mechanisms for more effective and balanced energy dissipation. • Possible use of both information-oriented and addressable architectures.	• Impossible to determine accurate the length of the communication round. • Somewhat unequal energy dissipation and processing loads (due to the different roles of the devices).

IV. Simulation Experiments and Evaluation of the Routing Approaches for WSNs

In order to prove the statements from Table 1 and also to further investigate the routing approaches, we have conducted a series of simulation experiments with them. For this purpose we have developed several MatLab models for all of the approaches. We have then implemented and tested the model for a sensor network, which is deployed on a sensor field with dimensions of 100x100 meters. The network consists of 1000 random distributed nodes and a base station at x=50 m and y=50m (center of the field). In order to evaluate the approaches we use the values for the dependence between the communication rounds and the total amount of the energy in the networks. Additionally we evaluate the number of active sensor devices per communication round for the three approaches. The initial amount of energy for all sensor devices is the same and is equal to 0.1 J.

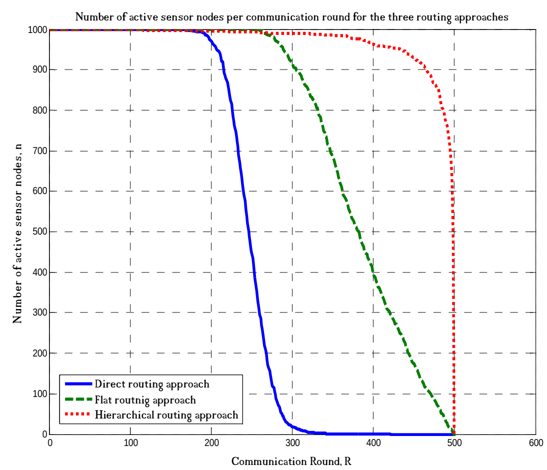

Fig.4. Number of active sensor devices per communication round

As seen on Fig. 4, in the network where the direct routing approach is used, the number of active sensor motes is starting to decrease around the 180-th communication round. This can be explained by the fact that the distance between the nodes in the sensor field and the base station is not the same, which will lead to the faster dissipation of the energy in the sensor devices farther away from the base station. The simulations with the network, where the flat routing approach is implemented, provide significantly better results, but nevertheless they show that the sensor devices start to deplete their energy around the 250-th communication round. This can be explained by the multiple retransmissions of the data towards the base station by the devices. Despite the fact that the hierarchical routing approach provides the best results, it also shows one of the largest disadvantages. This is the early dissipation of the energy by some of the devices in the network, and can be observed by the slight slope of the line towards the horizontal line. Actually during this simulation experiment the first module consumes its energy around the 104-th round. This can be explained entirely with the unequal data and processing load of the devices, which is a consequence of the different roles they have in the network.

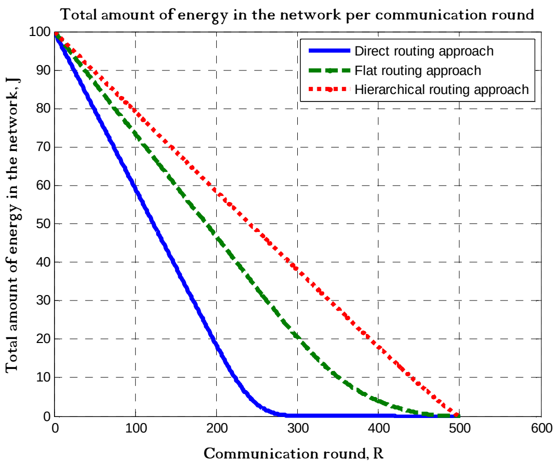

Fig.5. Energy dissipation ratio of the sensor devices per communication round

Fig. 5 presents the ratio of energy dissipation in the networks when the three routing approaches are used. It is easy noticeable that again the approach for direct routing is showing the worst results. This is again because of the much greater distances the data has to be sent, compared to the other two approaches, where the data is being retransmitted either to a closer neighbouring sensor device or to the cluster head.

V. Conclusion

As a conclusion we can state that the approach for hierarchical routing can significantly increase the efficiency of the system. The results, which are demonstrated by this approach, show that it is approximately two times more efficient compared to results from the simulations with the approach for direct routing. When comparing the flat routing approach with the hierarchical routing approach, we can notice a 25% better efficiency in terms of average lifetime of the sensor nodes and in terms of balanced energy consumption. Based on the conducted analysis, we can state, that the hierarchical routing approach is definitely the best approach among the three investigated, but it also suffers from few, but serious disadvantages. An eventual improvement of the mechanisms for effective and balanced dissipation of the energy by the sensor motes can increase significantly the effectiveness of this approach and the lifetime of the hierarchical sensor networks.

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