Simulation Comparison of LEACH-Based Routing Protocols for Wireless Sensor Networks

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Abstract. Battery-powered nodes have limited energy reserves therefore applications and protocols used for WSNs, should be designed, concerning the optimized energy consumption in order to prolong the network lifetime. Data reception and transmission are the main energy consuming operations and they are regulated by the network layer, hence the routing protocol plays very important role in network optimization.

In this paper information concerning the LEACH routing protocol is gathered and the classification of LEACH-based modifications is presented. Furthermore this paper focuses on improvements to the LEACH protocol that address problems of the cluster head selection, load balancing and lifetime enhancement as well as presents the simulation results for the selected group of LEACH-based protocols.

Keywords: LEACH, routing, sensor network, simulation.

1 Introduction

Wireless sensor networks (WSNs) are believed to be one of the fundamental technology that will have and actually already has an enormous impact on our everyday life. The potential field of application is unlimited. WSNs play an important role in many industrial, commercial and domestic applications concerning asset tracking systems, controlling and monitoring the buildings' equipment (lighting, ventilation, security systems, fire systems), security systems, habitat monitoring, environment monitoring, vehicular tracking, medical applications, Automated Meter Reading (AMR) for water, electricity, heat and gas and many many more. This dynamic and rapid development is possible thanks to the revolution in wireless technologies as well as the introduction of smaller and more effective electronic devices.

Typical WSN consists of many sensor nodes (SN) which are usually small and inexpensive devices. Nodes may be equipped with one or more, different kinds of sensors, embedded processors, memory, radio transmitter and are normally operated with a battery. Nodes of a WSN communicate with each other by establishing multi hop, wireless network. Each SN is responsible for sensing a desired parameters, some of SNs may also perform some data preprocessing

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or data aggregation. Furthermore SNs relay data to the same location usually called the WSN sink or the Base Station (BS).

Battery-powered nodes have limited energy reserves therefore applications and protocols used for WSNs, should be designed, concerning the optimized energy consumption in order to prolong the network lifetime. Data reception and transmission are the main energy consuming operations and they are regulated by the network layer, hence the routing protocol plays very important role in network optimization. Energy efficient routing protocols may reduce the number of transmitted packets as well as optimize the selection of traces and nodes for data relaying.

Mainly because of the large number of nodes, deficiency of global addresses, scarce energy resources and synchronization problems existing routing protocols used in IP and cellular networks are not applicable in WSNs. A WSN may consist of hundreds or thousands of SNs. The deployment of nodes in WSN may be deterministic or random, dense or spacious. Data transmission to the BS may be continuous, event-driven or query-driven. Some nodes may stop working in time course, therefore the routing protocol must be able to adapt to the topology changes and always find the optimal (according to defined criteria) route.

There are three main communication schemes in WSNs: direct, flat and hierarchical. In direct scheme, each SN communicates directly with the BS. The solution is rather useless, because not every node is in the sufficient proximity. Routing protocols using the flat communication scheme treat all nodes equally and they all take part in routing. The main flaw is that nodes close to the BS more often take part in data forwarding than farther nodes. To provision the efficient energy consumption, WSNs use clustering. The network is divided into a cluster, in each cluster one node is selected as the Cluster Head (CH). Nodes within one cluster communicate with the CH and the CH communicates directly with BS. This is the hierarchical communication scheme.

One of the first and most common hierarchical routing protocol is LEACH (Low-Energy Adaptive Clustering Hierarchy) [1]. Since it was described over twelve years ago, many modifications were proposed to elevated some of its limitations. LEACH and its derivatives are described in Sect. 2

The main purpose of this paper was to gather information concerning LEACH and present classification of LEACH-based modifications. Furthermore this paper focuses on improvements to the LEACH protocol that address problems of the cluster head selection, load balancing and lifetime enhancement as well as presents the simulation results for the selected group of LEACH-based protocols.

The rest of the paper is organized as follows. As mentioned before, Sect. 2 presents the fundamentals of LEACH protocol as well as description of the newly proposed LEACH modification is covered. Related work is referenced in Sect. 3. Sections 4 and 5 contain simulation details and its results respectively. The concluding remarks and future work suggestions are provided in Sect. 6.

2 LEACH and LEACH-Based Protocols

LEACH [1] is one of the first hierarchical routing algorithms proposed for the WSNs. The routing is two hop, according to the following rules. Each node may act as a cluster head (CH) or a regular sensor node. Communication to the sink goes through the CHs. Every time interval (round), a node declares himself as a CH with the certain probability. The node selects a CH which is closest to him. The node itself makes a decision, if or not become a CH. It selects a random number between 0 and 1, if the chosen number is less than the threshold $T(n)$, the node starts being the CH. The $T(n)$ threshold is defined as follows:

$$T(n) = \begin{cases} \frac{P}{1-P(r \mod \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{if } n \notin G \end{cases} . \quad (1)$$

Where P is the desired percentage of CHs (usually 0.05), r is the number of the current round, G is the set of nodes that have not been cluster heads for the last $1/P$ rounds.

Sensors organize themselves in clusters. Every round reorganization is performed. Only the CHs can communicate with the BS, nodes use CHs as a route to pass data. The CH collects, aggregates, sometimes compresses and transmits received data. The steady state phase starts after selecting CHs. In the state phase nodes transmit data to the sink, during allocated time slots, otherwise they remain asleep.

2.1 LEACH Limitations

There are several problems with LEACH, that lead to the rapid battery drain. All nodes are assumed to have the same capabilities and the same residual energy level, which may not be correct.

The main LEACH limitations, as depicted in [2,3,4], are as follows :

- Two-hop routing – some CHs may be far from the BS, therefore transmission may use considerable amount of energy.
- Number of cluster heads is predefined, however the selected number, depends on the node distribution; the number may not be sufficient and the cluster formation may be suboptimal.
- The threshold $T(n)$, defined in Equation (1), doesn't take into account the residual energy level while selecting CHs.
- The cluster size may differ significantly every round when selected randomly.
- In each round, all nodes take part in network reconstruction, which consumes their energy.

2.2 LEACH Improvements

The modifications of LEACH protocol, concern mainly several parameters. Their categorization, presented in [4], is as follows:

- The cluster head selection;
- Multihop Data Transmission;
- Heterogeneous – support heterogeneity among the nodes;
- Chain Based – focused on the construction of chains among the nodes;
- Others: Mobility, Security, Spare Management, Application Specific, Clusters Radius Fixation.

Most modifications, introduced to the LEACH algorithm, depict how the cluster head is selected and/or add the multihop transmission.

In the original LEACH, cluster heads are selected randomly. The intuitively better methods, take into consideration, that different nodes have different energy level, especially in the time course, and use it to increase the probability of becoming a CH, basing on the energy level e.g. HEED [5], PEACH [6], PEGASIS [7] and more [8].

There is a whole group of the LEACH modifications, that change the original LEACH into the multi hop protocol [3,9,10,11,12,13,14]. The multi hop versions are usually designed with one of two assumptions: reducing power consumption [3,10,12], reducing the amount of traffic or hybrid [11].

Furthermore this paper focuses on two LEACH improvements, described further in this section, that address problem of the proper selection of the cluster heads. The advantage of the first version is the constant percentage of the cluster heads throughout the network lifetime; the second protocol considers the residual energy level for all nodes.

2.3 LEACH-Balanced

The protocol called LEACH Balanced (LEACH-B) was presented in [15]. At each round, after the selection of CHs, according to the original LEACH procedure, the second selection is performed, that leads to the fixed number of cluster heads. If too much cluster heads are selected, the ones having the lowest energy level, are eliminated from the CH list; on the other hand, if too few are selected, some additional nodes are converted into the cluster heads. The nodes with the highest energy level, have the highest probability of being selected as the additional cluster heads. The improvements provide, that the required number of CHs is always assured, moreover nodes, that have the highest energy level, are selected as the CHs in the first place.

2.4 Energy LEACH

Xiangning et al. [14] proposed two improvements to the original LEACH. The Energy-LEACH modification redefines the cluster head selection procedure. The residual energy of a node is the main indicator whether or not turn the node into the cluster head. The second modification, proposed in aforementioned paper, concerns the multihop routing and, as out of the scope of this paper, is not discussed. The Energy-LEACH although proposed in 2007, represents major trend in LEACH development, therefore is a good representative of its group.

3 Related Work

The detailed survey of then routing protocols, along with their description and discussion, is presented in [16], with their classification to three main categories: data-centric, hierarchical and location-based. The comparative analysis of LEACH and its variants, however without simulation results, is presented in [17]. Another survey is presented in [18]. Through Matlab simulation, the authors compare LEACH and few LEACH-based modifications, both centralized and distributed, multi-hop and dedicated for mobile nodes. The comprehensive survey of all main classical and swarm routing protocols in WSNs is presented in [19]. The analytical and simulation comparison of the selected algorithms is also covered.

There are many papers, that present detailed survey of the routing algorithms, however there is lack of papers, that present comparison based on simulation or emulation results. There are also few papers, that are focused on the LEACH based protocols and, according to the author's best knowledge, no simulation comparison among numerous improvements described in the literature is covered. The purposed of this paper, is to compare the LEACH-based modifications, that improve the procedure of the cluster head selection. Two base algorithms were selected, as mentioned in the previous section, which represent the main trends for LEACH development.

4 Simulation Scenario

To compare the depicted LEACH modifications, the network simulator NS-2.34 [20] was used with LEACH model developed by [21], with own modifications for the presented algorithms. The parameters were set according to the directives given in [22,21], details are presented in Table 1.

Table 1. Simulation parameters

Simulation area	100*100
Simulation time	1000 s
Number of nodes	100
Initial energy of node	2 J
Round time	20 s
Radio speed	1 Mbps
Data size	2000 B

Several simplifications were assumed, i.e. all nodes are identical, static and have the same initial energy. Nodes are displaced randomly, however they stay within transmission range. Nodes always have some data to send. All LEACH protocols were configured to select 5 % of nodes as the cluster heads. Simulation results and discussion are presented in the following section.

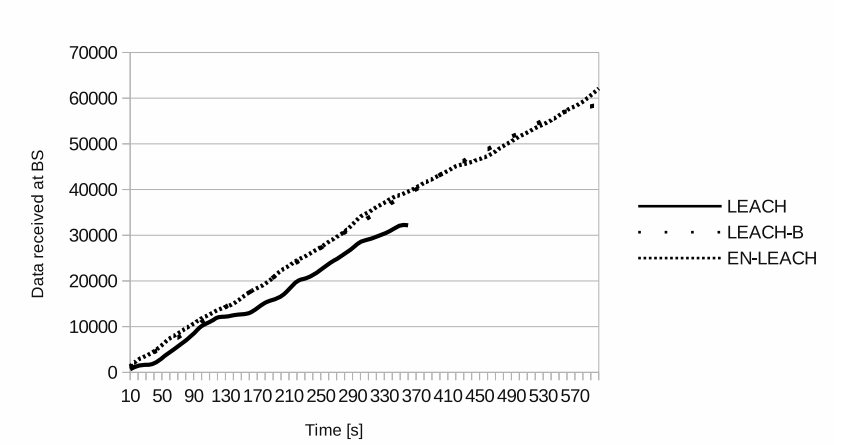

Fig. 1. Time vs no of data signals received at BS

5 Result Analysis

The network lifetime for each LEACH version is as follows:

- LEACH – 363 s,
- Balanced LEACH – 604 s,
- Energy LEACH – 3600 s.

The obtained results, depicting the number of data signals, total energy dissipation and number of nodes alive are presented in the Figs. 1, 2, 3.

From Fig. 1 it can be concluded, that LEACH-B and Energy LEACH are able to deliver more data to the BS, comparing to the original LEACH. In LEACH-B the number of the cluster heads is constant, some CHs are selected with regard

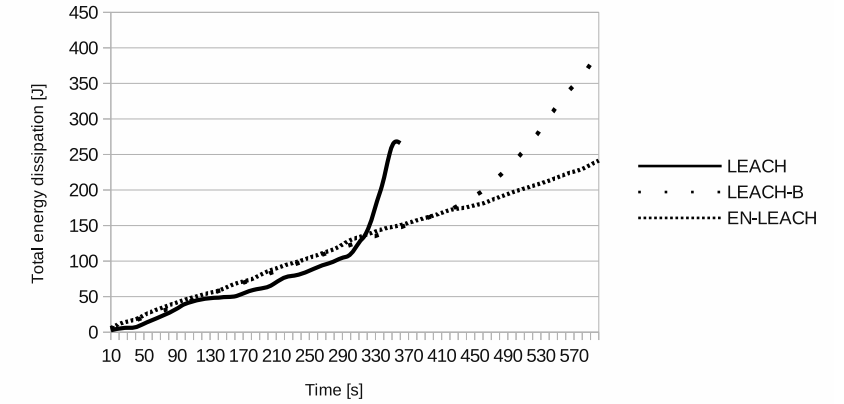

Fig. 2. Time vs total energy dissipation

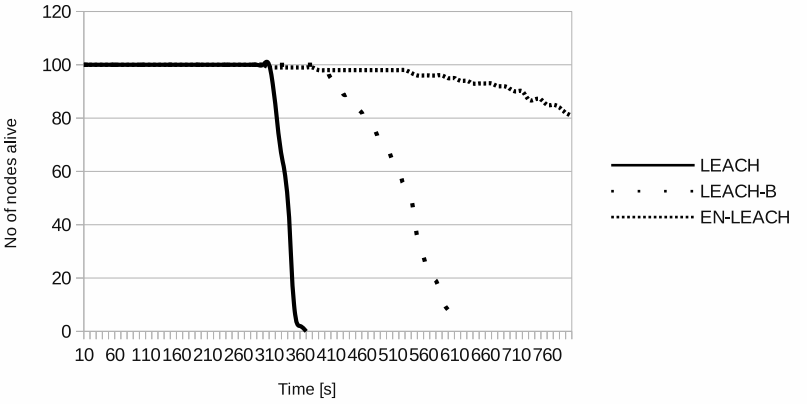

Fig. 3. Time vs no of nodes alive

to the residual energy of a node, there are no rounds with an extra number of the CHs, hence the clustering is more effective and consequently more data is delivered. Moreover, during the network lifetime, the number of data transmitted with LEACH-B is comparable with the amount delivered with Energy LEACH, which has the longest network lifetime.

Figure 2 depicts, how the energy is dissipated for the evaluated protocols. To some point, for all LEACH versions the total energy dissipation linearly increases. For LEACH-B and Energy LEACH this tendency last longer, due to the higher number of nodes alive. For original LEACH we can see, that at some point, where too much nodes are dead, the energy usage significantly increases, which leads to the network death. At the end of every WSN life, similar increase can be observed; it strictly depends on the number of nodes alive and the distance between nodes and cluster heads.

From Fig. 3 we can see, that the number of nodes alive decrease much slowly in Energy LEACH, than in any other version. Therefore the network lifetime is significantly prolonged. For pure LEACH, uneven distribution and variable number of the cluster heads, significantly reduces the number of nodes alive in short time course. The faster some of the nodes die, the shorter the remaining nodes live, due to the higher extend of network scattering, longer distances and therefore higher transmission power for each connection. From this figure, it can be observed how important balancing the energy usage is.

6 Conclusions and Future Work

The cluster head selection and the energy consumption are the most important factors when discussing the hierarchical, clustering routing algorithms for WSNs. Low Energy Adaptive Clustering Hierarchy (LEACH) is the fundamental clustering protocol for WSN and is taken as a benchmark solution – basis for the newly proposed findings. In this paper, detailed discussion, concerning ongoing

work is provided. Brief description of chosen LEACH modifications is presented, along with the classification of improvements introduced, since the original protocol has been proposed. Also simulation results and analysis of these protocols are presented.

The presented LEACH protocol improvements represent major trends in LEACH development. They are proved to overcome the shortcomings of the original protocol and significantly enhance the original protocol efficiency. Future work will cover more detailed simulation scenarios, along with additional versions of LEACH modifications, especially the newly proposed.

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