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A Survey of Four Routing Protocols for Wireless Sensor Networks

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ABSTRACT

Routing protocols are the most important aspect in Wireless Sensor Networks, since they have a direct effect on the overall network performance like throughput, power consumption, packet loss, and end-to-end delay. Despite the introduction of a wide variety of routing protocols in the literature, this area of research is still active and faces new challenges due to the growth of WSNs applications and sizes. In this paper, we perform a survey of four well-known Wireless Sensor Networks protocols and compare their performance; They are: LEACH, DEEC, M-GEAR and EESAA. In our study, we tracked four performance parameters: node lifetime, message delivery throughput, cluster head formation stability, and traffic imposed on the cluster heads. We performed a MATLAB simulation to create six different scenarios in a controlled environment by varying the grid area, the number of nodes in the grid, and the placement of the main Base Station (middle location vs. border location). We present our findings and classify these four protocols according to our evaluation criteria. At the end, we give recommendations concerning their potential usage in different environments and real-life scenarios.

KEYWORDS

Wireless Sensor Networks (WSNs), routing protocols, LEACH, DEEC, M-GEAR, EESAA, MATLAB, Simulation, network performance, efficiency.

1 INTRODUCTION

Over the last decade, research in Wireless Sensor Networks (WSNs) had grown rapidly and received an increasing interest by many researchers worldwide [1]. We believe this is due to two reasons: (1) the increasing number of applications of these networks, like military operations, health monitoring, process

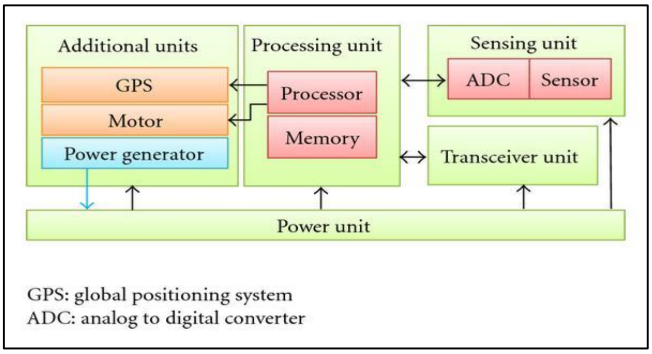

Figure 1. An Architecture of a wireless sensor node [4].

control (SCADA systems), infrastructure protection, surveillance systems, Intelligent Transport Systems (ITSs), etc. [2, 3], and (2) the advancement of technologies in wireless networks, embedded systems, and electronic components. For example, nowadays, we can easily find inexpensive and tiny microprocessors with wireless connectivity capabilities.

A WSN typically consists of a large number of inexpensive, limited energy, and multifunctional sensor nodes that communicate over short distances via wireless medium. These nodes usually collaborate to accomplish a common task that involves tracking, monitoring and controlling potential applications.

Sensor nodes can perform some processing, gathering sensory information from unattended locations, communicating with other nodes in the network, and transmitting the gathered data to a particular user or a Base Station (BS). These sensor nodes have some constraints due to their limited energy, storage capacity, and computing power. Figure 1 illustrates the basic components of a sensor node, namely: a *sensing unit*, a *processing unit*, a *transceiver unit* and a *power unit*. The sensor node works as follows: (1) it senses the physical environment being measured and converts the captured data into an electrical signal that feeds to an Analog-to-Digital (A/D) converter with the aim of converting it into a suitable form to be used by the microprocessor, (2) the microprocessor converts the signal into digital data depending on how it is programmed, and finally (3) it sends the information to the network by using a transceiver. This information is shared between other sensor nodes and used as input for a distributed management system.

Recent developments in WSNs have focused on several Quality of Service (QoS) parameters such as energy, scalability, reliability, accuracy, adaptability, fault tolerance, and security. Routing in WSN is considered as one of the most important challenges that highly affects these parameters. This is due to the fact that several network constraints might exist; these constrains stem from the nature of the application, network architecture, and route establishment. Usually, WSNs aim at minimizing the overall power consumption by employing the appropriate routing protocol to meet these constrains. In this paper, we provide a performance comparative study of four well-known routing protocols developed for WSNs, and analyze the simulation results according to several QoS metrics.

The rest of the paper is structured as follows. First, we provide a review of related works in Section 2. In Section 3 we give an overview of the four protocols that are the subject of this paper. In Section 4 we present the simulation testbed and the common parameters, and in Section 5 we summarize the simulation results and make a comparison based on several QoS metrics. Finally, in Section 6 we provide some conclusions and shed the light on some insights about future works.

2 RELATED WORK

As noted in the introduction section, in recent years many routing protocols have been proposed by researchers worldwide to improve the performance of WSNs. Despite the availability of large proposals, routing in WSN is still a big challenge since WSNs are designed for specific applications, and every application has its own constraints that must be considered when designing efficient routing protocols. Several comparative studies have been carried out by many researchers in order to analyze the performance of the current WSN routing protocols. In this section, we summarize the most relevant studies in this domain outlining their main findings.

Recently, Sabor et *al.* [5] made a comprehensive state-of-the-art of the hierarchical-based routing protocols for Mobile Wireless Sensor Networks (MWSNs). In this study, they classified the protocols into two categories: classical-based routing and optimized-based routing, and analyzed each group separately based on different metrics such as control manner, network architecture, mobile element, mobility pattern, and applications, among others. They also evaluated and compared the considered protocols using three more parameters they are delay, network size, and energy efficiency. They argued that, the comprehensive study of this set of protocols can be helpful for designers of MWSNs in selecting appropriate hierarchical routing protocols for a specific application. The same work was done in [6], but here the authors adopted another taxonomy: flat and hierarchical based routing protocols. They compared them based on network structure, state of information, energy-efficiency, and mobility. Finally, they gave recommendation about their usages and some insights into the enhancements that can be done to improve some of them.

Al-Karaki et *al.* [7] classified routing protocols for WSNs into three categories based on the underlying network structure: flat, hierarchical, and location-based routing. They went further and classified them into multipath-based, query-based, negotiation-based, QoS-based, and coherent-based. They highlighted the advantages and some performance issues of each routing protocol. While, in [8], the routing protocols discussed are classified into seven categories they are: Data centric routing, Hierarchical routing, Location based routing, Negotiation based routing, Multipath based routing, Quality of Service (QoS) routing and Mobility based routing, and compared them based on several parameters such as power consumption, scalability, mobility, optimal routing and data aggregation. Jain et *al*. [9] surveyed the existing cluster-based protocols for both static and mobile WSNs, and made a comparative study among them based on several features such as basic assumptions, working environment, advantages, limitations, and working style. Location-based routing protocols that support the sink mobility were revised in [10]. The authors of this paper classified this category of protocols into backbone-based and rendezvous-based approaches according to their network structures, and discussed the advantages and disadvantages of each one of them.

Daesung *et al.* [11] performed a performance study for three different types of routing protocols: LEACH, PEGASIS, and VGA using `Sensoria Simulator` [12]. Power consumption and overall network performance were used as the QoS metrics. Based on the simulation results, the authors argued that PEGASIS outperforms the two others, then LEACH and finally VGA which has the worst power consumption when the sensing range is limited, and the best when the sensing range is increased. Bansal *et al.* [13] analyzed only LEACH and PEGASIS based on total energy consumption, overheads, and sensors lifetime. They argued that PEGASIS outperforms LEACH in terms of network lifetime, communication overhead and the percentage of node deaths. In addition, it offers an extended lifetime of the network due to its energy efficiency. For large networks, the early death of nodes reduces the network stability in LEACH as compared to PEGASIS.

Latif *et al.* [14] analyzed the performance of four routing protocols: LEACH, TEEN, SEP and DEEC based on a proposed mathematical model they developed. For validation purposes, they performed analytical simulations in `MATLAB` by choosing a number of performance metrics: number of alive nodes, number of dead nodes, number of packets delivered, and number of cluster heads. The simulation results showed that DEEC outperforms the others by providing feasible optimal results against a set of constraints of their suggested mathematical model. Guangjie *et al.* [15] conducted different set of experiments in `MATLAB` to analyze the performance of five routing protocols: EDFCM, MCR, EEPCA, LEACH, and SEP. The simulation results showed that the first three protocols are better in terms of the time of the first node's death and the total number of packets successfully delivered to the BS.

The research presented in this paper differs from these works in two main aspects: (1) we have selected to analyze a different set of protocols, namely: LEACH, DEEC, M-GEAR, and EESAA, because we felt they have comparable features plus they represent a long time span that covers a wide spectrum of protocols, (2) we implement the four routing protocols using `MATLAB` simulation platform, but also we create six different scenarios in a controlled environment by varying three parameters: the grid area (50m x 50m & 100m x 100m), the number of nodes in the grid (sparse grid: 70 in the small grid vs. condensed grid: 1000 nodes in the big grid), and the placement of the main BS (in the middle of the grid vs. on the border of the grid). The aim of this study is to test the behavior of these routing protocols when applied to different scenarios resulted from varying these parameters.

3 THE EVALUATED ROUTING PROTOCOLS

In this section, we give a brief overview of the four WSN protocols analyzed in this work, namely LEACH, DEEC, M-GEAR and EESAA. For more information, please refer to the original papers.

3.1 LEACH Protocol

The Low Energy Adaptive Cluster Hierarchy (LEACH) is the most popular WSNs routing protocol, which was proposed by Heinzelman *et al.* [16] many years ago, with the overall aim of reducing power consumption. LEACH works in a completely distributed way, and does not need to acquire global knowledge of the network. The main functions of LEACH can be grouped into two phases: (1) in the setup phase several tasks are performed related to the organizing of the network into clusters, *i.e.*, LEACH is based on the concept of a hierarchical clustering, it divides the entire network into several clusters and assigns one node for each to be the Cluster Head (CH), CH advertisement, and creating transmission schedule for the entire network, and (2) a steady-state phase that consists of data aggregation (or fusion), compression, and transmission to the BS. LEACH reduces energy consumption by (1) minimizing the communication cost between sensor nodes and their CHs, and (2) shutting down non-CH nodes as much as possible. A CH is responsible for data collection from the entire sensor nodes belonging to the cluster under its control, and then it makes the necessary processing tasks on the data before sending it to the BS. LEACH uses a single-hop routing where each node can directly transmit to the CH and the BS. Therefore, it is not efficient in large networks. Furthermore, the concept of assigning clustering dynamically brings additional overhead such as CH changes and advertisements, which can minimize the gain in energy consumption. While LEACH helps the sensor nodes within their clusters to diminish their energy slowly, the CHs consume a larger amount of energy when they are located at the farthest point from the BS. Also, LEACH clustering terminates in a finite number of iterations, but does not guarantee a good CH distribution and assumes uniform energy consumption for CHs, *i.e.,* it adapts a randomized rotating mechanism of high-energy CH position rather than making a selection in a static manner, to give an equal chance to all sensor nodes to become CHs.

3.2 DEEC Protocol

Distributed Energy-Efficient Clustering (DEEC) protocol [17], is an adaptive clustering protocol used in heterogeneous wireless sensor networks. It assumes that in a WSN there are several types of nodes of different initial energy levels, *e.g.,* a WSN with three types of nodes of initial energy levels is a three-level heterogeneous network. In DEEC, every sensor node independently elects itself as a CH, and the probability for a node to be a CH is calculated based on two parameters: (1) the ratio between the residual energy of the node, and (2) the average energy of the entire network. Therefore, a node with high initial energy and residual energy acquires more chances to become a CH. To control the energy consumption of sensor nodes by means of adaptive approach, DEEC uses the average energy of the network as the reference energy. Thus, DEEC does not require any global knowledge of energy at every election round. Unlike LEACH, DEEC can perform better in multi-level heterogeneous WSNs.

3.3 M-GEAR Protocol

Gateway-Based Energy-Aware Multi-Hop routing protocol for WSNs (M-GEAR) [18] uses a BS and a gateway node. It divides the nodes into four regions. The operation of the protocol consists of five phases, in its initial phase the BS broadcast a HELLO packet, and all nodes in the network replay indicating their locations. Then, the BS can build the node’s data table by saving each node’s id, location, distance from the BS and gateway node and residual node energy. In the second phase (setup), the protocol divides the network into four regions, the first one for nodes near the BS (nodes in this region can send data directly to the BS), the second region for nodes near the gateway node (nodes in this region can send their data to the gateway node which in turn aggregates the data and forwards it to the BS). The rest of the nodes in the network are grouped into two regions and nodes within each region are further grouped into clusters. The first two regions are referred to as non-clustered regions, while the last two regions are referred to as clustered regions. In the third phase (CH selection) cluster heads are selected in the two clustered regions, for that purpose, the protocol uses the LEACH cluster head selection approach. After the selection of CHs, each CH creates a TDMA-based time-slots for its member nodes, so that each node can transmit its data in its time-slot and switch to an idle mode for the rest of the time, this phase is called (scheduling phase). The final phase of the protocol is operation (the steady-state phase), in which all sensor nodes transmit their sensed data to its cluster heads, which in turn receive and aggregate the data of all its member nodes and send it to the gateway node. After collecting the data from all CHs, the gateway node aggregates the data and sends it to the BS.

3.4 EESAA Protocol

Energy Efficient Sleep Awake Aware intelligent sensor network routing protocol (EESAA) [19] uses the concept of pairing and equipping the nodes with Global Positioning System (GPS) capabilities. In addition to the enhanced cluster head selection technique, the protocol was designed to improve network stability period and prolong the network lifetime.

Sensor nodes use their GPS to calculate their own locations and send them to the BS, where in the first round; cluster head selection takes place using LEACH CH selection technique. When BS receives the nodes’ location information, it groups the nodes into pairs (create couples) based on the minimum distance from each other in their intra-cluster transmission range, and also they should belong to the same application type. Then it broadcasts this “pairing” information to all nodes in the network for each node to become aware its coupled node. During a single communication interval, paired nodes switch between awake and sleep modes. In any given pair, at first the node closer to the BS switch into awake mode (active mode) and is responsible to collect data from its surroundings and send it to the CH, while its coupled node remains in sleep mode during this period. In the next round, nodes in active mode switch into sleep mode while its couple becomes awake, and so forth.

Unpaired nodes remain in active mode in all the rounds until they die.

The selection of CHs after the first round depends on remaining energy of active nodes only, so in the start of each round nodes transmit information about their energy to CH, which in turn calculates the energy of every node in its cluster and distance from each node and select CH for the next round. In this regard, the selected CH broadcast an advertisement message that can be heard by every awake node to select their CH according to the received signal strength indication of those advertisements. Finally, nodes in active mode are the only nodes allowed to transmit their sensed data during their TDMA-slots while nodes in sleep mode turn their transceivers off to save energy.

4 SIMULATION TESTBED

As mentioned earlier, we have used MATLAB to run our simulations. MATLAB is an ideal choice for WSN simulations since it gives accurate results and includes built-in capabilities. For each simulation scenario, we designed a network with a predefined area and then distributed a given number of nodes randomly within that area. Each one of the four protocols has been simulated with 6 different scenarios (as shown in Table 2), but in all of these scenarios we used common fixed radio parameters. Also, each node was considered dead when its internal energy approaches zero. To simulate message exchanges between nodes we used a fixed message size of 4000 bit, and finally, it is worth mentioning that we assumed the network to be free of collisions. Table 1 lists the network parameters used in the testbed scenarios.

The four WSN routing protocols surveyed in this study are already built-in MATLAB, which we believe is a very good thing since it enables us to get reliable and consistent results. We designed the testbed to simulate six scenarios for of each one of the four protocol to study the impact of changing the sink node position, the impact of having different network sizes and densities, and the number of nodes and their distributions. In the following subsections, a summary about the setup variables on each scenario will be listed, then we provide the main differences between the four protocols LEACH, DEEC, M-GEAR and EESAA using four parameters: (i) the number of the dead nodes per round, (ii) the number of packets successfully received by the BS, (iii) the number of cluster heads per round, and finally (iv) the number of packets that went through the cluster heads. Next, we make a comparative study of their performance in six scenarios in order to study the impact of changing the position of the sink node, network size, and nodes distributions.

Table 1. Network simulation parameters.

Parameter	*Value*	*Description*
E_{elec}	50 nj/bits	power needed to run the transmitter or receiver circuitry
E_{fs}	10 pj/bit/m^2	% Transmit Amplifier type
EDA	50 nj/bit/packet	Data Aggregation Energy
E_0	0.5 J	Initial Energy
Number of rounds	5000	--
Emp	0.013pj/bit/m^4	% Another Transmit Amplifier type

5 SIMULATION RESULTS AND DISCUSSION

As previously mentioned, in the first two scenarios we built a small-area scattered network of 70 nodes dispersed randomly in 50m * 50m simulation area with a BS located at the center and the border respectively. In the third and fourth scenarios, we built a dense network of 500 nodes distributed randomly in 100m * 100m area with BS located at the center and the border of the area respectively, and finally in the fifth and sixth scenarios, we built a highly- dense network of 1000 nodes distributed randomly in 100m * 100m area with BS located at the center and the border of the area respectively. Table 2 summarizes the characteristics of these six simulation scenarios.

Table 2. The six simulated scenarios.

Scenario	**Num. of nodes**	**Area**	**BS location**	**Property**
S1	70	50m x 50m	Center	Sparse
S2	70	50m x 50m	Border	Sparse
S3	500	100m x 100m	Center	Dense
S4	500	100m x 100m	Border	Dense
S5	1000	100m x 100m	Center	Hi-Dense
S6	1000	100m x 100m	Border	Hi-Dense

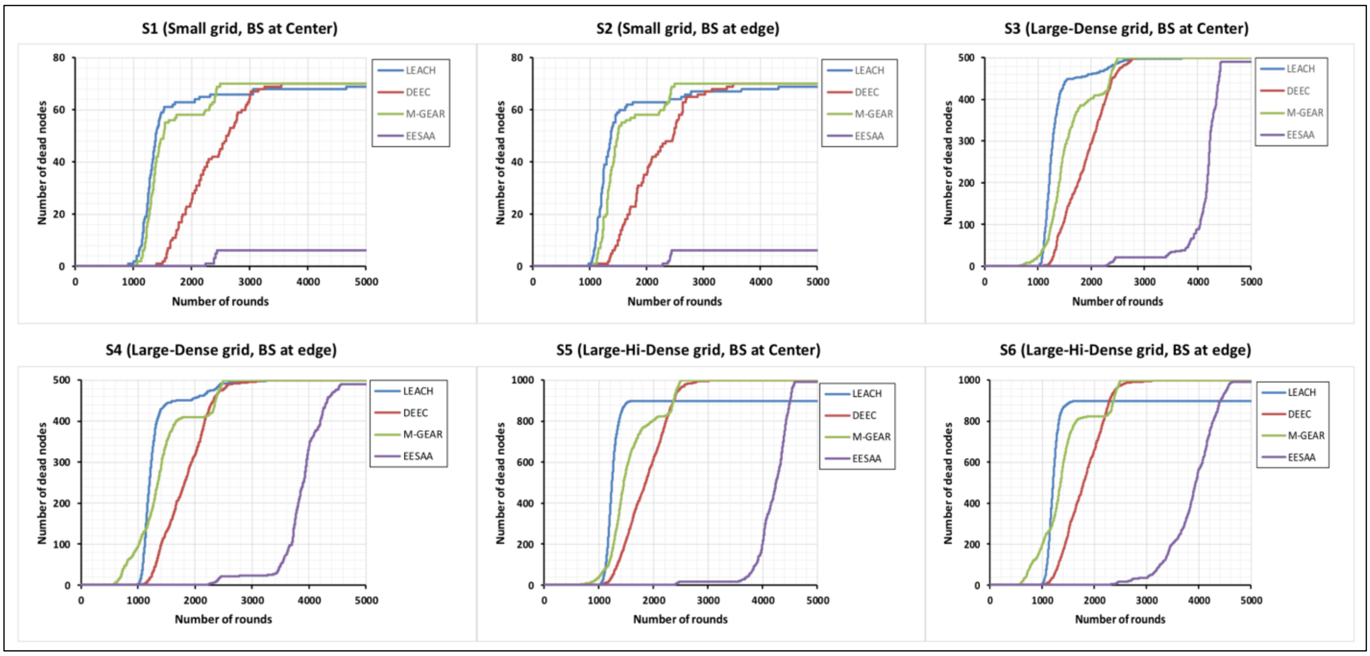

Figure 2. Number of dead nodes per round.

5.1 Number of Dead Nodes per Round

The first metric analyzed in this study is the number of dead nodes. It is considered as one of the mostly relevant metrics used by researchers to evaluate the performance of a given routing protocol, because it affects other important metrics, specifically network lifetime and network stability period. Network lifetime is defined as the time duration between the network process initialization and the expiry of the last alive node in the network, while the stability period can be defined as the time duration between the starting of the network process and the expiry of the very first node in the network (i.e. the time when the first node dies).

Figure 2 shows the simulation results of the number of dead nodes vs. the number of rounds of the six scenarios. It is worth mentioning here that we put the simulation results of the six scenarios in one big plot to facilitate the comparative process as we forward from Scenario 1 to Scenario 6. From the figure, we derive the following findings: (1) for all scenarios, it is clearly observable that LEACH gives the minimum stability period then comes M-GEAR, DEEC, and finally EESAA which has the best stability measure among the others; (2) Also, EESSA protocol has the maximum network lifetime, and gives incredible results compared to others, which almost have the same value with some variants, especially for DEEC; (3) We observe that changing the location of the BS has significant effects on the performance of some protocols, mainly M-GEAR, DEEC, and EESAA. In M-GEAR, the number of dead nodes is almost the same when applied in low dense networks (S1 and S2), but it behaves badly in the case of bigger networks (S3 to S6), therefore when using M-GEAR, it is better to locate the BS at the center of the network to get the maximum performance in terms of network stability and lifetime. The same finding is almost valid for the EESAA protocol. Here, EESAA gives best performance measure when the BS is located at the center of network in large networks, this is contrary to the M-GEAR which is slightly better small networks when locating the BS at the network borders. Finally, in DEEC locating the BS at the center of the network area gives higher instability period compared to the BS located at the borders regardless of the network size. It is worth mentioning that the performance results of the four protocols in this plot seem to be consistent between the large grid-dense cases (S3 & S4) and the large grid-very dense cases (S5 & S6), which is basically an indication that even if we double the number of nodes in the large grid (100m x 100m), we still get very similar results. Table 3 shows the round’s number of the first dead node. Here, the numbers emphasize our findings obtained from Figure 2. The numbers show that ASSEE outperforms all other routing protocols with about 100% stability period and network lifetime in all scenarios; here we can clearly see that all numbers in the ASSEE column are larger than 2170 with case S6 being the worst with 2171 which is way

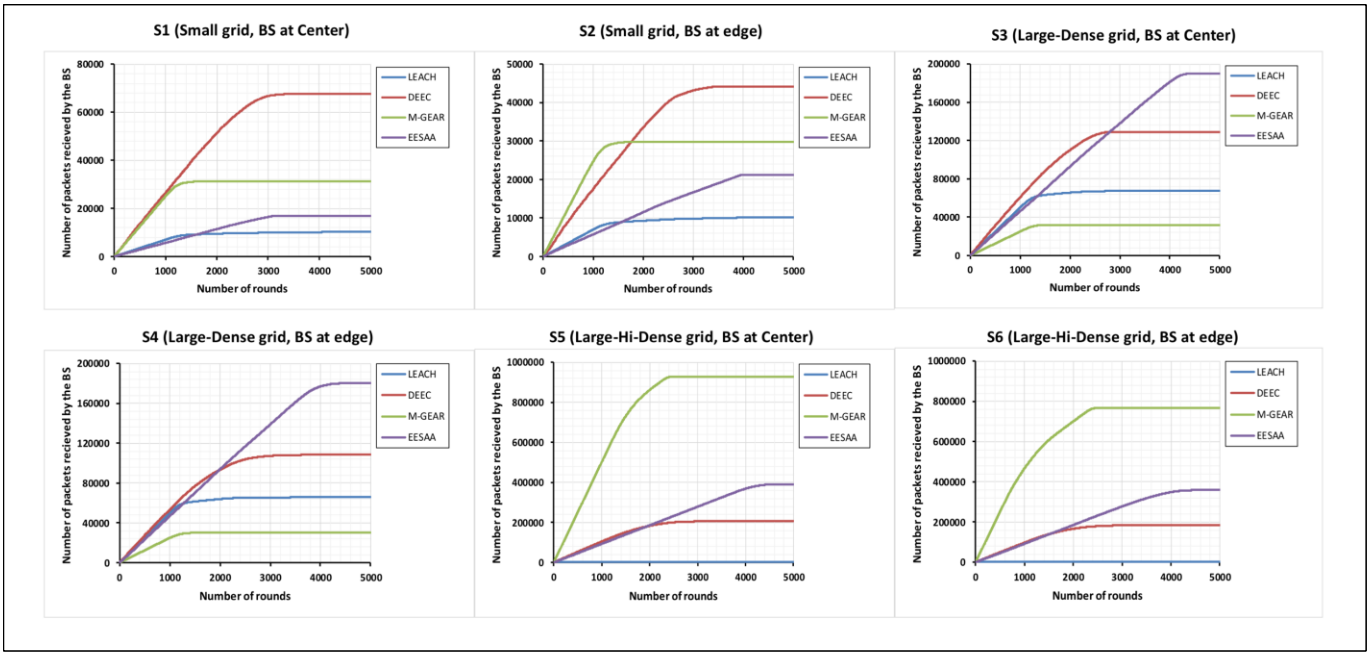

Figure 3. Number of packets received by the BS.

better than the other three. Then comes DEEC, LEACH, and M-GEAR, and in that order; DEEC in the range 930 (worst performance in S4) and 1390 (best performance in S1), LEACH in the range 892 (worst performance in S6) and 984 (best performance in S3 & S4), and finally M-GEAR in the range 521 (worst performance in S6) and 1070 (best performance in S1). This is evidence that DEEC and M-GEAR are badly affected by the number of nodes in the grid. Furthermore, M-GEAR has almost the same performance measure as DEEC for the first two scenarios, while it gives the minimum performance results in the large and dense grids.

Table 3. Round's number of the first dead node**.**

Scenario	LEACH	DEEC	M-GEAR	EESAA
S1	912	1391	1070	2236
S2	978	1113	1053	2283
S3	984	994	630	2233
S4	983	934	526	2182
S5	966	1042	597	2336
S6	892	1018	521	2171

5.2 Packets to the Base Station

In this section, we study another performance metric which is the number of data packets successfully received by the BS. This metric gives good measures about the reliability of the network, *i.e.*, it presents a good indicator whether the routing protocol is doing its job properly or not. Figure 3 shows the simulation results of the six scenarios. Several findings are extracted as follows: (1) in the first two scenarios (S1, S2), DEEC outperforms the others in the number of packets successfully delivered to the BS, then comes M-GEAR, EESAA, and finally the LEACH which has the minimum number of packets received by the BS. Whereas, in scenarios S3 and S4, EESAA outperforms all of them, while M-GEAR gives the minimum number. Both DEEC and LEACH are located at the middle; (2) regarding the effect of the location of the BS, we find that in LEACH the number of packets delivered to the BS is almost the same whether the BS is located at the center or at the borders of the network, with a slightly higher number in the former case. DEEC gives the best results of packet delivery ratio, mainly when the BS is located at the center. Like DEEC, M-GEAR does the best job when the BS is located at the center. Finally, there is a significant effect of the location of the BS on the functioning of EESSA. Here, we observe that EESAA gives better results when the BS is located at the center when deployed in large networks (S3 and S4), whereas in the case of small networks (S1 and S2) its highly recommended to put the BS at the borders to get the maximum benefits of this protocol.

5.3 Cluster Heads Formation

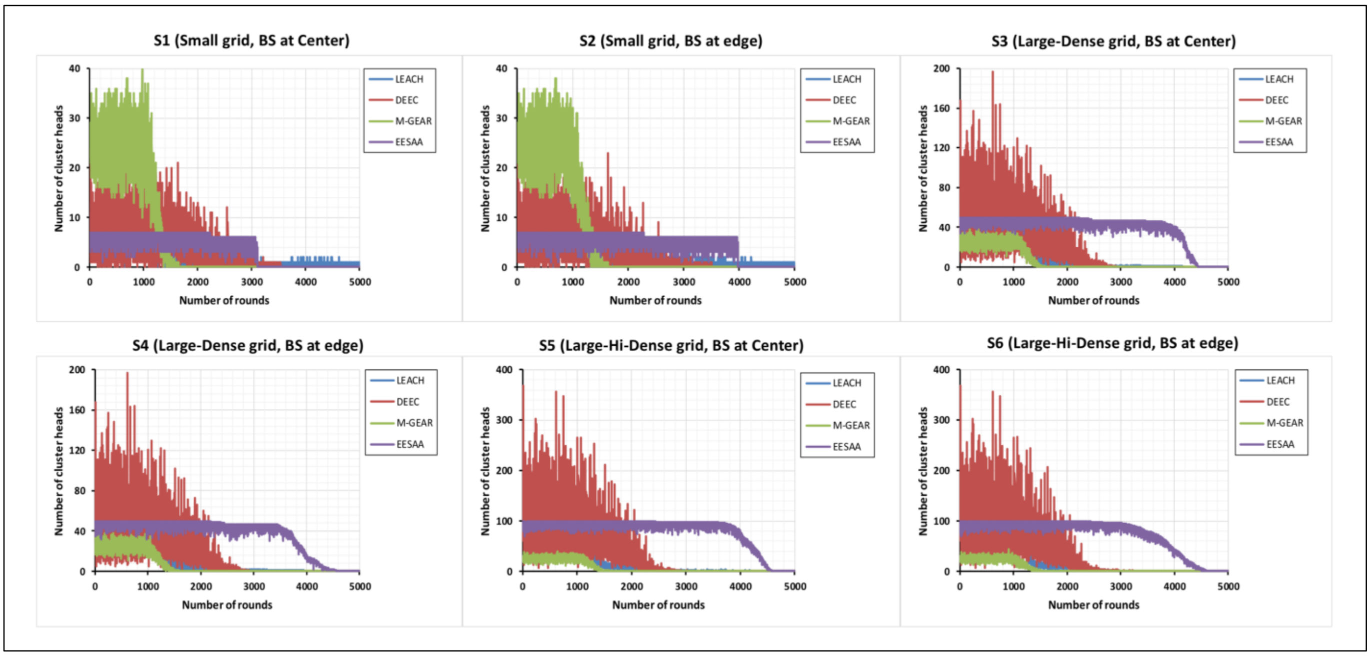

Figure 4. Number of cluster heads.

The third performance metric considered in this study is the stability of the cluster heads formation process. This process plays an important role in the stability of the whole network.

Unlike the aforementioned performance metrics, a protocol having a large number of cluster heads per round does not mean that the protocol behaves better than of those having small ones. Here, we perform the analytical study considering that the cluster heads per round for a particular protocol is much closer to the optimal situation when this number follows a uniform distribution within the network lifetime. Based on this definition, Figure 4 shows the simulation results of the four protocols. Here, we extract the following findings: (1) in all scenarios, it's obvious that EESAA has the highest stability in cluster head formation process as the number of cluster heads created is uniformly distributed within the whole network lifetime with an average of 4 cluster heads/round. DEEC has low cluster formation stability in all scenarios; in small grid networks LEACH shows low cluster formation stability, but in large grid networks it shows moderate stability level. M-GEAR also has a moderate level of cluster stability for all scenarios. (2) contrary to what is expected, M-GEAR creates a small number of cluster heads per round as the network becomes larger (S3 to S6). This is due to some design issues behind this protocol. In the setup phase of the operation of this protocol, it divides the network into four regions; the first one consists of nodes which are located near the BS. Nodes in this region can send data directly to the BS; The second region encompasses a set of nodes that are close to the gateway node. Nodes in this region send their data to the gateway node, which in turn aggregates the data and forward it to the BS; the remaining nodes are grouped into two regions, and nodes belonging to a group are further split into more clusters. The first two regions are referred to as non-clustered regions, while the last two are referred to as clustered regions. This process explains the behavior of M-GEAR protocol in creating fewer cluster heads in the large grids compared to the small ones.

5.4 Number of Packets at Cluster Heads

As the fourth and last performance metric in our study, we will study the impact of the total number of packets that went through the cluster heads on the network. We can consider this parameter as an approximation of the centralized nature of the protocol and the overhead traffic imposed by the protocol on the cluster-heads. Figure 5 presents the simulation results of the four protocols. Here, we can extract the following findings: (1) in the small/sparse grid (S1 & S2), all protocols are generating big and noisy traffic at the cluster heads, while they perform better when the grid is big and dense where we can see smoother and smaller plots, (2) it seems that the BS location being at the center or at the edge does not really affect this parameter.

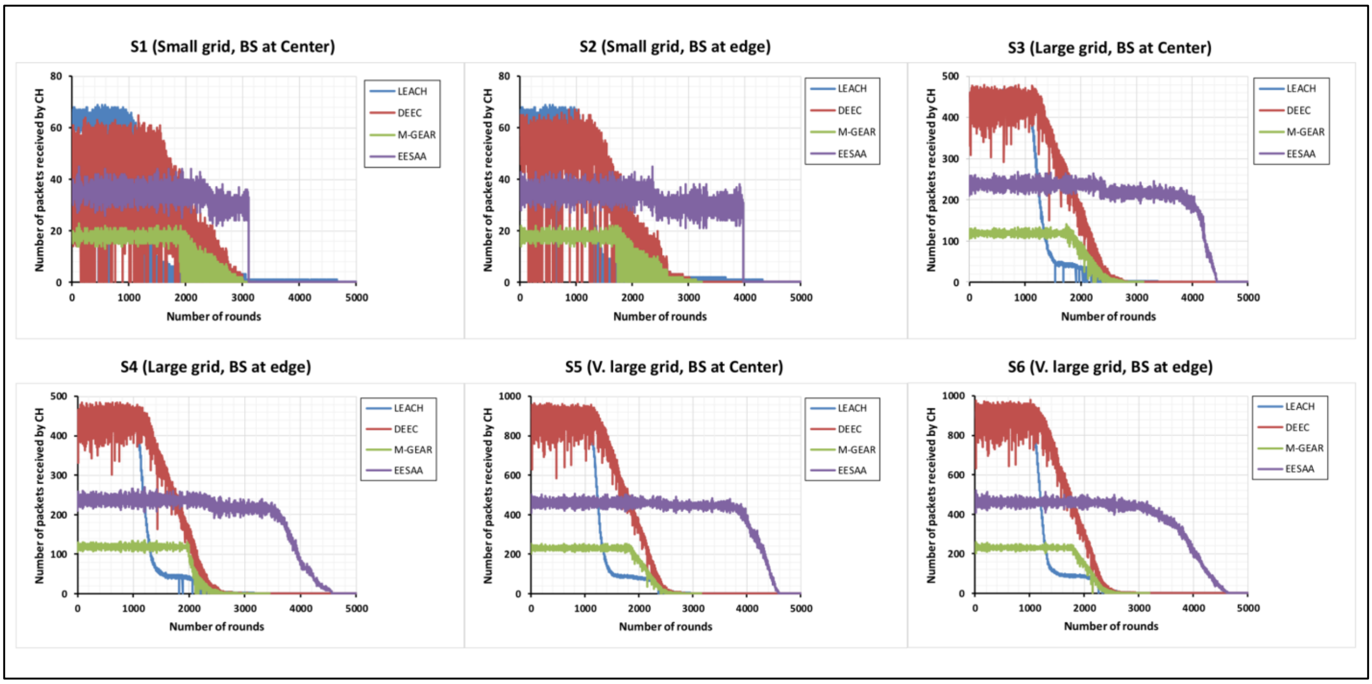

Figure 5. Number of packets received by cluster heads.

In this plot, we can see that (S3 & S4) are almost identical and the same can be observed for (S5 & S6), (3) we can see that the M-GEAR is giving best performance here with minimum overhead, followed by EESAA and last come LEACH and DEEC. We can attribute this good performance of M-GEAR to its smart multi-hop hierarchy such that in level zero nodes can send to the BS directly, and in level 1 nodes can send to the gateway then to BS, and only in the outer regions cluster heads are involved. The EESAA gives good performance here due to its smart pairing mechanism which also reduces this kind of overhead, (4) the last observation on this plot is the shape of the curve (especially in the big grid cases); it starts semi-linear and then a sharp drop happens in the middle when the nodes start to lose their energy and die. Here we can see that EESAA gave the longest survival time among the other which all dropped to zero between rounds 2500 to 3000.

In summary, Table 4 presents all these findings in a more readable way. In this table, we use keywords to evaluate these protocols targeted at the three previously discussed metrics. These keywords are *High*, *Moderate* and *Low*. *High* means highest performance, while *Low* refers to the lowest performance. If we take the average of all six scenarios and all four parameters (total 24 entries in the table for each protocol), it is obvious that EESAA is the winner with best performance in all categories, next come M-GEAR and DEEC, with M-GEAR performing better in columns 3 and 4, while DEEC performing better in columns 1 and 2 and high-order grids. LEACH took the last place with Weak to Moderate performance in all scenarios.

6 CONCLUSION AND FUTURE WORK

In this paper, we surveyed and compared the performance of four well-known routing protocols which were mainly developed for WSNs, namely LEACH, DEEC, M-GEAR, and EESAA. The performance of the four protocols was tested and evaluated in four performance metrics and under six different scenarios. The empirical results have shown that the performance of the protocols differs as we go from small grid and sparse networks to larger grid dense networks. Some protocols gave best performance when applied at small grid networks, and moderate or even low performance when applied at large grid networks and vice versa. Furthermore, we have found that the location of the BS can have a significant effect on networks' stability. Some protocols provide high stability and long network lifetime when the BS is located at the center of the network, and others perform better when the BS is located at the borders of the network. As illustrated in Table 3, EESAA has the highest performance measures in all scenarios. DEEC and M-GEAR come next with a moderate to high levels, with one outperforms the other in some cases, and finally comes the LEACH which has the lowest performance measures.

Table 4. Summary results.

Protocol	Scenario	Network Stability	Packets Transfer Rate	Cluster Formation Stability	Packets to CH Overhead
LEACH	S1	Moderate	Low	Low	Low
	S2	Moderate	Low	Low	Low
	S3	Moderate	Moderate	Moderate	Low
	S4	Moderate	Moderate	Moderate	Low
	S5	Low	Low	Low	Low
	S6	Low	Low	Low	Low
DEEC	S1	Moderate	High	Moderate	Moderate
	S2	Moderate	High	Moderate	Moderate
	S3	Moderate	High	Low	Low
	S4	Moderate	Moderate	Low	Low
	S5	Moderate	Moderate	Low	Low
	S6	Moderate	Moderate	Low	Low
M-GEAR	S1	Moderate	Moderate	High	High
	S2	Moderate	High	Moderate	High
	S3	Low	Low	Moderate	High
	S4	Low	Low	Moderate	High
	S5	Moderate	High	Moderate	High
	S6	Moderate	High	Moderate	High
EESAA	S1	High	Low	High	High
	S2	High	Moderate	High	High
	S3	High	High	High	High
	S4	High	High	High	High
	S5	High	Moderate	High	High
	S6	High	Moderate	High	High

Based on these findings, we will continue to investigate the performance of these routing protocols in more complicated scenarios and will try to combine the best features in them (which led to their good performance) specially EESAA and DEEC, to design a new (hybrid) routing protocol and test it as well.

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