Performance Evaluation of Routing Protocols in Wireless Sensor Networks: A Comparative Study

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Abstract — **In Wireless Sensor Networks, information is routed from one sensor node to another using a variety of routing protocols, each having its own advantages and disadvantages. Despite the availability of a large number of routing protocols, it is still an active area of research, and is considered as one of the most important challenges that highly affects the Quality of Service of these networks. In this paper, we compare the performance of four well-known Wireless Sensor Networks protocols, namely: LEACH, DEEC, M-GEAR and EESAA. In this study, we tracked three performance metrics: node lifetime, message delivery throughput, and cluster head formation stability. We performed a MATLAB simulation to create four 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; node lifetime; efficiency.

I. INTRODUCTION

Over the past few years, the research in Wireless Sensor Networks (WSNs) had grown rapidly and received great attention by many researchers worldwide [1]. This is due to: (1) developing a wide range of potential applications that mainly relay on these types of networks, *e.g.,* military operations, health monitoring, process 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, *i.e.,* 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.

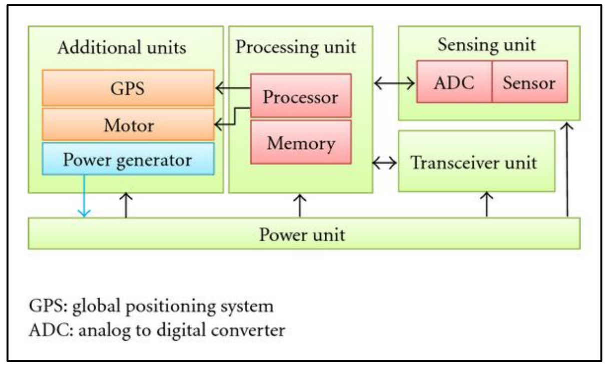

Figure 1. Architecture of a wireless sensor node [4].

Sensor nodes are capable of performing 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. Fig. 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

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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, a review of related work is presented in Section II. An overview of the four protocols is presented in Section III. Section IV presents the simulation testbed and the common parameters. Section V summarizes simulation results and makes a comparison based on several QoS metrics. Finally, Section VI provides some conclusions and sheds light to some insights about future works.

II. Related Work

As noted in the introduction section, in recent years many routing protocols have been proposed by the research community to improve the performance of WSNs. Despite the availability of large proposals, routing in WSN is still a big challenge; this is due to the fact that 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.

Daesung *et al.* [8] performed a performance study for three different types of routing protocols: LEACH, PEGASIS, and VGA using `Sensoria Simulator` [9]. 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.* [10] 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.* [11] 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.* [12] 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 timespan that covers a wide spectrum of protocols, (2) we implement the four routing protocols using `MATLAB` simulation platform, but also we create four 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: 500 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.

III. 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.

A. LEACH protocol

The Low Energy Adaptive Cluster Hierarchy (LEACH) is the most popular WSNs routing protocol, which was proposed by Heinzelman *et. al* [13] 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.

B. DEEC protocol

Distributed Energy-Efficient Clustering (DEEC) protocol [16], 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. In order 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.

C. M-GEAR protocol

Gateway-Based Energy-Aware Multi-Hop routing protocol for WSNs (M-GEAR) [14] 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.

D. EESAA protocol

Energy Efficient Sleep Awake Aware intelligent sensor network routing protocol (EESAA) [15] uses the concept of pairing and equipping the nodes with 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 in order 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.

IV. SIMMULATION TESTBED

In this section we test the four routing protocols in several network scenarios; we designed the testbed of these scenarios to study the impact of changing the sink node position, the impact of having different network size, and finally 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 three parameters that are (i) Number of the dead nodes per round, (ii) Number of packets successfully received by the BS, and (iii) Number of clusters heads per round. Next, we make a comparative study of their performance in the four scenarios in order to study the impact of changing the position of the sink node, network size, and nodes distributions.

Table 1 lists the network parameters that are common in the four scenarios.

Table 1. Network simulation parameters.

Parameter	*Value*
E_{elec}	50 nj/bits
E_{fs}	10 pj/bit/m^2
EDA	50 nj/bit/packet
E_0	0.5 J
Number of rounds	5000
Emp	0.013pj/bit/m^4

V. Simmulation Results and discussion

As previously mentioned, in the first two scenarios we built a network of 70 nodes scattered randomly in 50m * 50m simulation area with a BS located at the center and the border respectively. In the second two scenarios, we built a network of 500 nodes scattered randomly in 100m * 100m area with BS located at the center and the border of the area respectively.

A. 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 most metrics used by researchers to evaluate the performance of routing protocols, 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).

Fig. 2 shows the simulation results of the number of dead nodes vs. the number of rounds of the four scenarios. Its worth mentioning here that we put the simulation results of the four scenarios into one big plot in order to facilitate the comparative process as we forward from Scenario 1 (**S1; Small grid, BS at center**) to Scenario 4 (**S4; Large grid, BS at edge**). From the figure, we derive the following findings: (1) for all scenarios, it's 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

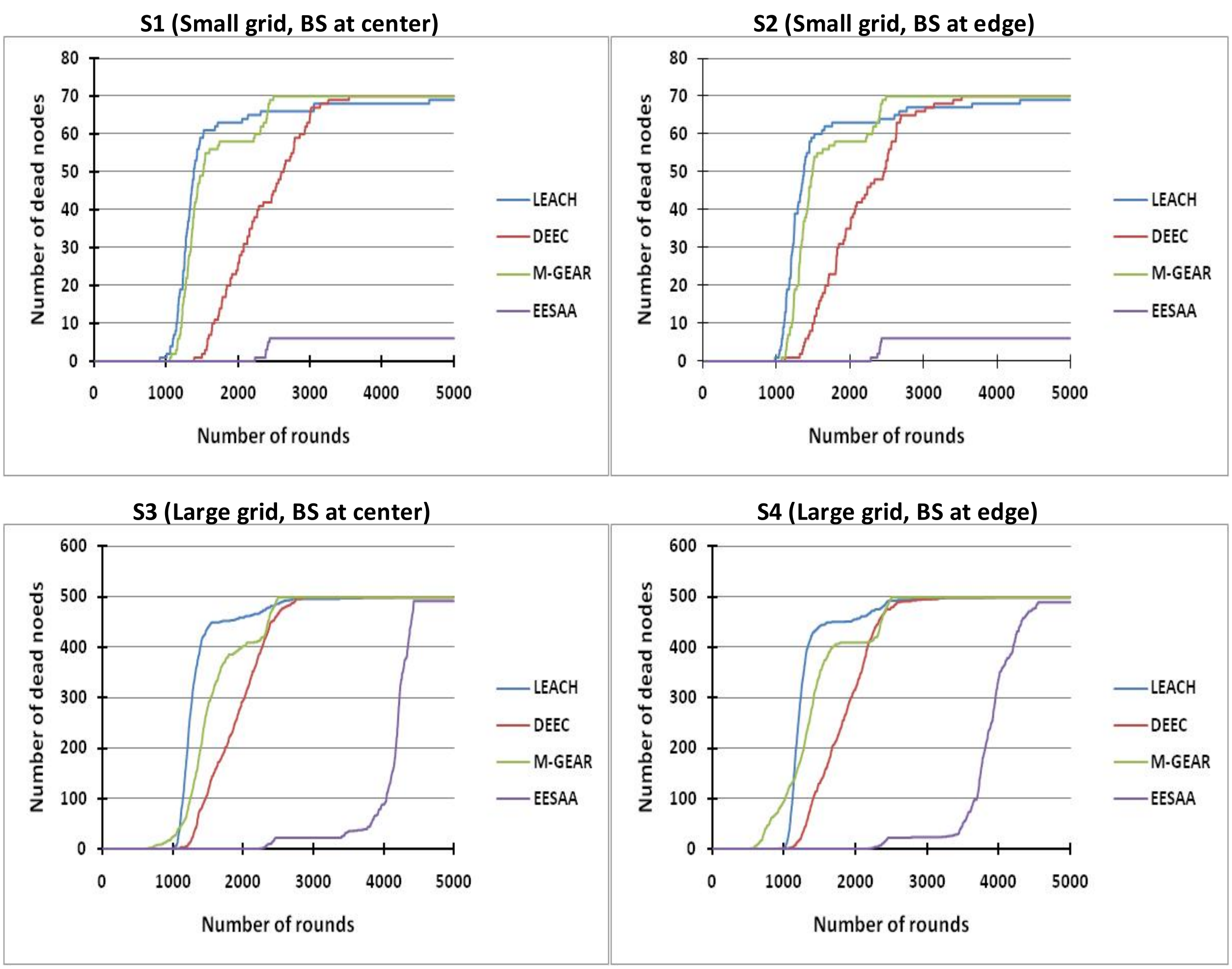

Figure 2. Number of dead nodes per round.

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, therefore when using M-GEAR, it is better to locate the BS at the center of the network in order 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.

Table 2 shows the round's number of the first dead node. Here, the numbers emphasize our findings obtained from Fig. 2. The numbers show that ASSEE outperforms all other routing protocols with about 100% stability period and network lifetime in all scenarios, then come DEEC, LEACH, M-GEAR, and in that order. 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 other two, mainly in dense networks, *i.e.,* large grid.

Table 2. Round's number of the first dead node.

Scenario	LEACH	DEEC	M-GEAR	AASEE
S1	912	1391	1070	2236
S2	978	1113	1053	2283
S3	984	994	630	2233
S4	983	934	526	2182

B. 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. Fig. 3 shows the simulation results of the four 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

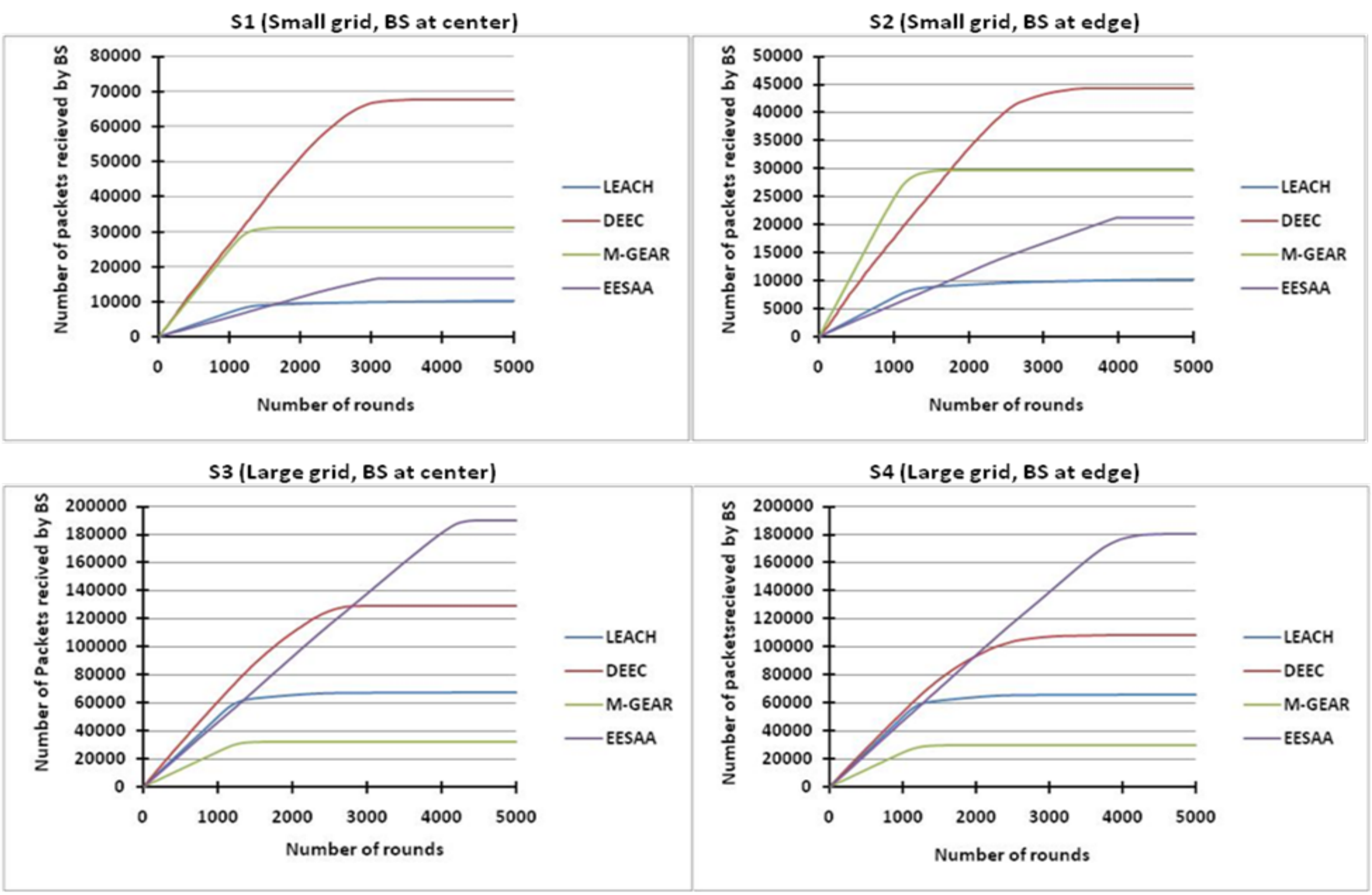

Figure 3. Number of packets successfully received by the BS

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 in order to get the maximum benefits of this protocol.

C. Cluster Heads Formation

The last 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, Fig. 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 and S4). 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

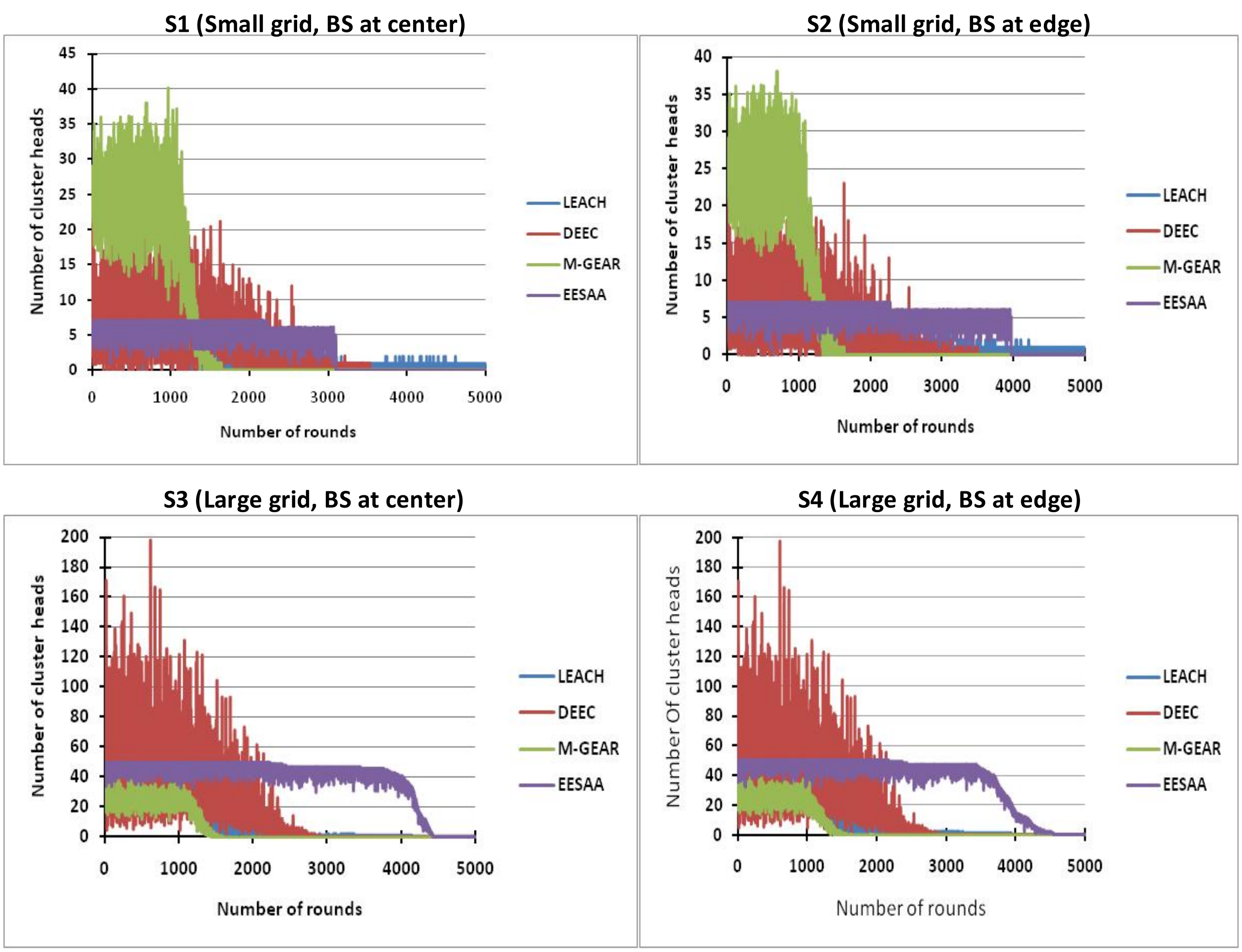

Figure 4. Number of cluster heads per round

Table 3. Summary results.

Protocol	*Scenario*	*Network stability*	*Packets transfer rate*	*Cluster formation stability*
LEACH	S1	Moderate	Low	Low
	S2	Moderate	Low	Low
	S3	Moderate	Moderate	Moderate
	S4	Moderate	Moderate	Moderate
DEEC	S1	Moderate	High	Low
	S2	Moderate	High	Low
	S3	Moderate	High	Low
	S4	Moderate	Moderate	Low
M-GEAR	S1	Moderate	Moderate	High
	S2	Moderate	High	Moderate
	S3	Low	Low	Moderate
	S4	Low	Low	Moderate
EESAA	S1	High	Low	High
	S2	High	Moderate	High
	S3	High	High	High
	S4	High	High	High

referred to as clustered regions. This process explains the behavior of M-GEAR protocol in creating fewer cluster heads in S3 and S4 compared to the others.

In summary, Table 3 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.

VI. CONCLUSION AND FUTURE WORK

In this paper, we compared four routing protocols which were mainly developed for WSNs, namely LEACH, DEEC, M-GEAR, and EESAA. The performance of the four protocols was tested under the various performance metrics evaluated from four different scenarios. The results have shown that the performance of the protocols differs as we go from small grid networks to large grid. Some protocols have high performance when applied for small grid networks, and moderate or even low performance when applied to large grid networks and vice versa. Furthermore, we have found that the location of the BS has 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 some others perform well 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.

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.

REFERENCES

[1] I. F. Akyildiz, Weilian Su, Y. Sankarasubramaniam and E. Cayirci, "A survey on sensor networks," in IEEE Communications Magazine, vol. 40, no. 8, pp. 102-114, Aug 2002. doi: 10.1109/MCOM.2002.1024422.

[2] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," Computer Networks, vol. 52, issue 12, pp. 2292-2330, August 2008, ISSN 1389-1286, http://dx.doi.org/10.1016/j.comnet.2008.04.002.

[3] D. Culler, D. Estrin, and M. Srivastava, "Overview of sensor networks," *Computer Magazine,IEEE*, vol. 37, no. 8, pp. 41-49, August 2004.

[4] C. Y. Lin, S. Zeadally, T. S. Chen, and C. Y. Chang, "Enabling cyber physical systems with wireless sensor networking technologies," International Journal of Distributed Sensor Networks, vol. 2012, Article ID 489794, 21 pages, 2012. doi:10.1155/2012/489794

[5] J. N. Al-Karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: a survey," in IEEE Wireless Communications, vol. 11, no. 6, pp. 6-28, Dec. 2004. doi: 10.1109/MWC.2004.1368893.

H. S. Bazzi, A. M. Haidar, and A. Bilal, “Classification of routing protocols in wireless sensor network,” Computer Vision and Image Analysis Applications (ICCVIA), 2015 International Conf. on, IEEE, 2015.

[6] M. Patil and R. C. Biradar, “A survey on routing protocols in wireless sensor networks,” *2012 18th IEEE International Conf. on Networks (ICON)*, Singapore, 2012, pp. 86-91. doi: 10.1109/ICON.2012.6506539.

[7] K. Daesung, K. Dongkyun, P. Hyeon, and Y. Seung-mok, “Performance evaluation of routing protocols for wireless sensor networks in military scenarios,” *2011 Third International Conf. on Ubiquitous and Future Networks (ICUFN)*, Dalian, 2011, pp. 101-106. doi: 10.1109/ICUFN.2011.5949143.

[8] J. N. Al-Karaki, and G. A. Al-Mashaqbeh, “SENSORIA: a new simulation platform for wireless sensor networks,” International Conf. on Sensor Technologies and Applications, pp: 424 - 429. 2007.

[9] B. Parul, P. Kundu, and P. Kaur, “Comparison of LEACH and PEGASIS hierarchical routing protocols in wireless sensor networks,” International Journal on Recent Trends in Engineering & Technology , 11.1 (2014): 139.

[10] K. Latif, M. Jaffar, N. Javaid, M. N. Saqib, U. Qasim, and Z. A. Khan, “Performance analysis of hierarchical routing protocols in wireless sensor networks,” In *Proceedings of the 2012 Seventh International Conf. on Broadband, Wireless Computing, Communication and Applications* (BWCCA '12). IEEE Computer Society, Washington, DC, USA, pp. 620-625. DOI=http://dx.doi.org/10.1109/BWCCA.2012.108, 2012.

[11] G. Han, X. Jiang, A. Qian, J. J. P. C. Rodrigues, and L. Cheng, “A comparative study of routing protocols of heterogeneous wireless sensor networks,” The Scientific World Journal, vol. 2014, Article ID 415415, 11 pages, 2014. doi:10.1155/2014/41541.

[12] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” *System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conf. on*, 2000, pp.10-pp, vol.2, doi: 10.1109/HICSS.2000.926982.

[13] Q. Nadeem, M. B. Rasheed, N. Javaid, Z. A. Khan, Y. Maqsood and A. Din, "M-GEAR: Gateway-Based Energy-Aware Multi-hop Routing Protocol for WSNs," Broadband and Wireless Computing, Communication and Applications (BWCCA), 2013 Eighth International Conference on, Compiegne, 2013, pp. 164-169, doi: 10.1109/BWCCA.2013.35.

[14] Shah, T., Javaid, N., and Qureshi, T. N., “Energy Efficient Sleep Awake Aware (EESAA) Intelligent Sensor Network Routing Protocol,” Nov. 2012.

[15] L. Qing, Q. Zhu, and M. Wang, “Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks,” Comput. Commun. 29, 12 (August 2006),2230-2237. DOI = http://dx.doi.org/10.1016/ j.comcom.2006.02.017.