A COMPARATIVE STUDY OF ENERGY SAVING ROUTING PROTOCOLS FOR WIRELESS SENSOR NETWORKS[1]

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Abstract: Routing protocols play a vital role in wireless sensor networks because of its dynamic topology and its nodes limited battery lifetime. In wireless sensor context, saving consumed energy is a crucial task that affects the overall network performance. Researchers exert great efforts to develop energy saving protocols that protract the network lifetime. As such, analyzing routing protocols with respect to total energy dissipation, network lifetime is strongly required. This paper provides a comparative study to extract the key features of various energy aware routing protocols. Two of these protocols are implemented to draw an efficient evaluation procedure to design energy saving routing protocols.

Key words: Wireless Sensor Networks, energy saving, routing protocols, Ant colony, clustering techniques.

1. INTRODUCTION

Wireless Sensor Network (WSN) is composed of hundreds or thousands of sensor nodes that are deployed throughout the sensing field. Each sensor node can collect, process and route data to Base Station (BS) using a multi-hop fashion [1].

Although, many protocols and algorithms have been proposed for traditional ad hoc networks, but they are not suitable for WSNs [2], due to the unique characteristics of WSNs. WSNs share many commonalities with ad hoc networks. However, there are

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fundamental differences between them such as dynamic topology change, limited power nodes, nodes computational capacity, failure exposure and scalability. Therefore, there are different challenges and research issues that should be taken into consideration when designing protocols for WSNs. One of the most significant challenges and research issues of WSNs is saving energy of the nodes because of their limited power batteries [3]. Moreover, recharging or replacing batteries is so hard and costs a lot of money.

In general, Energy is consumed in the three components of the sensor node: sensing, processing and communication [1]. Various factors affect the energy dissipation like idle listing, redundant data transmission, direct transmission etc. In large networks, multi-hop routing consumes less energy than direct routing and therefore routing protocols should be able to discover energy efficient paths to minimize the energy consumed by the nodes and prolong the Network lifetime.

The purpose of this paper is to study and compare the performance of different energy conserving routing protocol for WSNs that affect the network lifetime. To efficiently draw an evaluation method for assessing these protocols, two protocols [4] and [5] are implemented. The evaluation method explores the ability of these two algorithms to:

1- Choose a path that has higher residual energy and less distance to BS.
2- Extend the network life time by finding a new alternative path when the sensor node dies or blocked.
3- Locate CHs in an appropriate location to reduce the energy consumption in intra-cluster communications and prolong the stability period.

The rest of this paper is organized as follows: Section 2 surveys two categories of energy aware routing protocols; cluster and swarm intelligence-based routing protocols. Section 3 explores the two investigated routing protocols. Section 4 illustrates the simulation results of implementing the investigated two protocols. Finally, Section 5 concludes this paper.

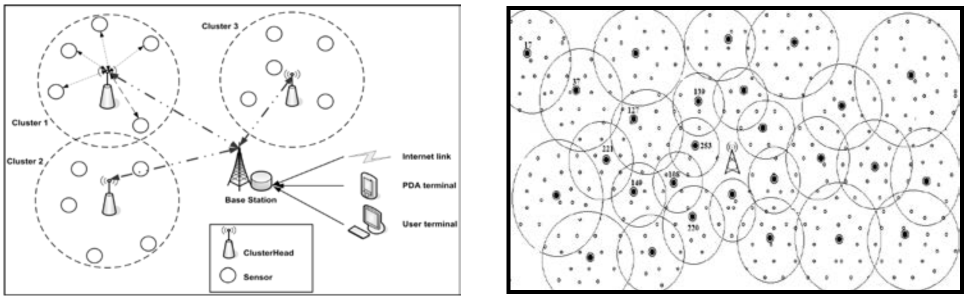
2. RELATED WORK

Energy consumption level of the WSN is one important factor that affect its performance. Energy consumption is occurred by these operations: sensing, communication, and data processing [1]. Energy consumption can be classified either as useful or wasteful. Useful energy consumption arises from transmitting or receiving data from neighbors, processing data or query requests, and forwarding data packet [6]. On the other hand, the wasteful energy consumption sources are: idle listening “when the node waiting and listening for information from other nodes”, retransmission “due to collision of packets”, receiving packet that are not belonging to the node, and generating or handling control packets [7]. There are different ways to minimize the amount of consumed energy in WSNs: 1) applying efficient data compression techniques to compress the data before transmission it [8]. 2) blocking redundant data transmission, when multiple nodes sense the same event. 3) Turning off the transceiver when it is not required.

2.1. Cluster Based Routing Protocols

Cluster based routing protocols mostly take into consideration several issues. 1) Load balancing that is achieved by rotating the CH role among various sensor nodes. 2) Compressing the data locally before sending it to the BS to reduce the global communication cost. 3) Tolerating fault to allow the system to recover from a CH failure. 4) Ensuring connectivity between CHs is an important factor in some applications because it ensures a connected path from the CH node to the BS. 5) Reducing data delay, by determining the maximum number of hops in the path. 6) Clustering approach that aims to minimize energy consumption by the network [9].

Clustering algorithms are classified as centralized, distributed or hybrid [10]. In centralized clustering, each cluster has a fixed cluster head, while the other nodes are member nodes. In distributed clustering, the cluster head role rotates between nodes based on some parameters. Hybrid clustering combines features of centralized and distributed clustering. Distributed clustering algorithms are divided into two types, equal or unequal clustering algorithms. In equal clustering algorithms, the sensor network is divided into equal-sized clusters as shown in Fig.1a. Whereas in the unequal cluster sizes (Fig.1b) algorithms, the sensor network is divided into clusters with different sizes. Cluster size increases as the CH node is far away from the BS and decreases as the CH is closer to the BS.



(a) (b)

Fig. 1. (a) Equal cluster sizes [9]; (b) Unequal cluster sizes

These algorithms use the distance to the BS and the nodes residual energy to select the CH. A benefit of this approach is to avoid the hot spots problem. Clusters closer to the BS forward larger amount of packet to the BS and typically die early [10]. Many unequal clustering algorithms are proposed in [11-16].

In the clustering-based approaches, CH nodes are responsible for data aggregation and forwarding data packets [9]. CH selection process varies from protocol to the other. It could be selected randomly, based on its residual energy level or its distance from the BS. Energy consumption could be distributed among all the nodes by rotating the cluster head role in a periodic way. The number of clusters either increase or decrease the global energy cost in the network [17].

Several routing protocols have been proposed around clustering technique, most of them differ in the way of selecting the CH nodes. Low Energy Adaptive Clustering Hierarchy (LEACH) [18] is a popular homogenous distributed clustering protocol. It aims to minimize energy consumption and extend network lifetime by rotating CH role randomly among the various sensor nodes to balance the energy of the network. Also, it compresses the data locally before sending it to BS to reduce global communication. In addition, each non-cluster head node can turn the transceiver off when it is not required. Initially, CHs are selected, and the nodes are organized into clusters. After that, the nodes send the data during their transmission time to the CH, then the CHs compresses the data and send it to the BS using single hop routing. After a period, the setup phase is restarted, and a new CHs are selected. Although this algorithm improves the energy efficiency of the network it has some limitations. First, it assumes nodes consume the same level of energy which is not practical. Second, it is a single hop routing protocol. Third, CHs are randomly selected and not based on the node's residual energy. Finally, when the first node die, all remaining nodes die within a small number of rounds because all nodes have same probability to become a CH.

Sharma et al. [19] tried to overcome some of the limitations of LEACH protocol such as: CHs are elected randomly and do not depend on the residual energy, by proposing new protocol that is heterogeneous in terms of the energy consumption of the nodes. Their new protocol LEACH-heterogeneous is a clustering protocol that aims to save the energy and extend the network lifetime. It contains two type of nodes Normal Nodes and Advanced Nodes, where the advanced nodes are the nodes that have more energy than normal nodes, and the number of advanced nodes depend on the application. The CH selection process in their protocol depends on the node with higher residual energy and avoid the node with little residual energy. The authors of [19] compared their protocol with only the homogeneous LEACH protocol but they did not compare their results with any heterogeneous protocols. Moreover, the authors of [19] did not discuss the transmission process, as it may be known as one of the limitations of the LEACH protocol is its direct communication with the BS, which consumes much more energy when the CH nodes are far from BS.

Ma et al. [20] tried to improve the LEACH protocol. They followed the same idea of CH selection depending on higher residual energy presented in [19]. But, their proposed protocol differs in transmission process, as they used two kinds of transmission: one hop transmission as in LEACH and multi-hop transmission. Depending on the distance between CH nodes and the BS, the CH nodes decide either to transmit their messages using the one hop or multi-hop transmission method. N. Javaid et al. [21] proposed a Hybrid Energy Efficient Reactive Protocol (HEER) which is based on the combination between two protocols TEEN and DEEC. HEER is a clustering-based protocol that selects CH node based on its initial and residual energy. After cluster formation is done, the CH node transmits two values Hard Threshold (HT) and Soft Threshold (SH) to its members. The node sends its data to CH node when the Current Value (CV) of the node reaches to HT. The node stores CV on which first transmission occurs in a Sensed Value (SV). After that, the node can transmit again when the condition "CV– SV >= ST " is true. HEER like TEEN in HT and ST values, and like DEEC in CH selection. HEER saves nodes energy by turning the transceiver off when it is not used.

To achieve balance between the approaches mentioned above, the EAICR (Energy Aware Intra Cluster) is introduced by A. Akhtar et al. [22]. The idea of this work depends on combination between one hop and Multi hop model to overcome the limitations of each one. In large size direct hop network models, nodes far from BS consume more energy to send their data. While in multi hop model, nodes closer to BS consume more energy because they send their own data and data received from other nodes. EAICR perform direct routing for nodes closer close to BS and perform multi hop routing far nodes. This protocol starts where each node sends its energy level to BS which in turn assign the CH role to the node with highest residual energy. After Clusters are constructed, each CH node use the most suitable routing models according to its location. The limitation of this algorithm is; it is only applied on small network sizes and its performance is only compared with other multi hop protocols not with other single hop protocols.

2.2. Energy Aware Routing Protocols

In this section, we survey recent swarm intelligence-based routing protocols for wireless sensor networks.

In [17] authors introduced an Artificial Bee Colony algorithm (ABCACO) routing protocol. It is a clustering technique that increase network lifetime by adopting Artificial Bee Colony algorithm ABC and Ant Colony Optimization algorithm ACO. ACO is used to choose optimal path from source node to BS, while ABC is used to select CH and second CH (SCH) nodes. In ABCACO nodes are classified into, CH, SCH and member node. It works in two phases, set-up phase and steady state phase. In the set-up phase, each node calculates the distance to BS and other nodes using Euclidian distance formula. Then it transmits its information (energy, calculated distance) to BS. Based on this information, BS calculates average energy of nodes and selects CH nodes for each cluster. Then, BS computes the optimal number of sub clusters in each cluster and assign a SCH per sub cluster. Now, ACO is used to selects the optimal path from all CH nodes to BS. ACO, apply forward and backward ant paths. In the forward path, the probability of selecting the nodes considers its energy and its distance to BS. In the backward path, the same path is used to update pheromone value of each node in the path. In The steady state phase, ready data packets are sent to SCH nodes which in turn send them to CH node. CH aggregate received data and forward it to BS in multipath fashion. SCH is promoted to replace CH nodes with low energy. The shortcomings of this algorithm are the additional traffic of messages due to the forward and backward ants and the large packet sizes.

Yang et al. proposed an O_ARA [23] routing protocol for WSN based on ant colony algorithm. The algorithm improved the selective probability model to avoid the shortcomings of ordinary ACO algorithm. The algorithm considers the energy consumption for transmission and residual energy of nodes to select optimal path. The algorithm divided network into populations, each population has the same number of ants and same pheromone value. Initially, ants are placed in source nodes, then, nodes with higher probability is next selected. The Ants update pheromone value moving ants store information about the source node ID and intermediate nodes, average and minimum of residual energy of intermediate nodes, and distance between intermediate nodes. These steps are repeated until the ants reach the BS. Then the ants store the information in memories of BS, select optimal path, send back ants to source nodes through optimal path and update pheromone values. The limitation of this algorithm is the additional traffic generated in the forward and the backward ants' paths. Also, no data aggregation is applied. Moreover, the large size of the transmitted packets since all visited nodes information are stored.

Sanjoy Mondal et al. [24] proposed an ACOHC hierarchical routing protocol for WSN, which combined the advantages of Cluster based and Chain based approaches. This algorithm enhances network lifetime by equally distributing the energy consumption between all the network nodes. The BS divides network into optimal number of clusters which remain fixed until the first node dies. In each cluster, a chain of nodes is created similar to the TSP problem using ACO algorithm. Ant moves through the cluster nodes according to the probability formula of ACO algorithm. After visiting all nodes in that cluster each ant goes back to its source node. In each cluster, node with maximum residual energy is elected as a Chain Leader (CL). After that, the algorithm forms a chain between all CLs and of them is elected as a Super Leader (SL) based on its residual energy and its distance to the BS. SL node is responsible for transmitting aggregated data to the BS. Source nodes transmit packets along the chain to The CL nodes. CL nodes in turn aggregate and transmit date to the SL node. The SL node send the aggregated data to the BS node. The main limitations of the ACOHC is its high Latency because of the single chain between source and destination node.

MRP [25] is an energy efficient routing protocol for reactive WSNs, it aimed to reduce energy consumption using improved ACO algorithm to deliver data packets from source nodes to the BS via multiple paths. It also exploited the advantages of a clustering technique to reduce size of the transmitted data. This protocol is divided into three phases: cluster formation phase, constructing multipath phase and data transmission phase. Initially, each node constructed its neighbor information table by transmitting ADV message to its neighbors. When events occurred in a specific area, each node decides whether it is in an event area or not based on received signal strength RSS, the node with stronger RSS and higher residual energy has higher chance to be elected as a CH node. When CH node needs to transmit data packets to the BS, it uses improved ACO algorithm to search for multiple path from CH node to BS. CH node creates search ants "SANT" that travel from node to node based on probability formula to collect information about multiple paths. In this algorithm, the memory of visited nodes is kept in the node instead of carrying by ant to reduce size of ant packets. When SANT reaches the BS, the BS creates backward ant "BANT" that is responsible for transition from BS to source CH node through the same path of SANT. Finally, when BANT reaches source CH node, the CH node transmits data packets to BS through the selected path. Although this algorithm has reduced the size of ant packets and consequently the energy consumption, but it still generates additional traffic to find optimal paths from source node to BS because it uses forward and backward ants. also, the number of transmitted messages for constructing neighbor information tables consume much energy that can be saved.

The energy-efficient ant-based routing for WSN (EEABR), is proposed by Camilo et al [26]. The algorithm reduces the communication load during the process of finding the optimal path. It considered the energy level of the nodes in the discovered path beside the number of intermediates nodes. In this algorithm a new formula is designed for updating pheromone value to find the shortest and energy-efficient path. To reduce the size of ant memory, each ant carries only the ID of last two visited nodes, and each node save the ID of ant that is recently passed over "previous nod". At a regular interval, each node created forward ant to search for optimal path toward BS, forward ant moves from node to node based on the probability formula. When forward ant reaches next hop node, the node searches in its table for ant ID, if it does not exist, the node record the information of ant in its table. And so on until the forward ant reaches the BS, then it is converted to a backward ant and moves in the same path of forward ant but in opposite direction. Moreover, it updates pheromone value of each node according to proposed formula. The protocol lacks data aggregation and scalability.

3. THE INVESTIGATED ROUTING PROTOCOLS

In this section we present the fundamental information about two routing protocols that are mainly used to improve the energy consumption efficiency and performance of WSN. The first is Trail-using-ants [4] a swarm intelligence-based routing protocol. Its operation is based on the use of ACO algorithm. The second protocol is presented in [5] and it employs clustering and tree approaches to give better results than the LEACH, LEACH-C and TL-LEACH.

3.1. Trail-using-ants routing protocols

This protocol is proposed by Jung et al. [4] in 2016. It is a recent energy-efficient routing protocol for WSNs based on ACO algorithm. The objective of this algorithm is to reduce the additional traffic that is generated by forward and backward ants and increase network lifetime. The protocol uses multi-path fashion to forward data packet from nodes to BS. Types of node in this protocol are: 1) Ordinary node that is responsible for sensing an environment and transmits data to Relay node. 2) Relay node that is responsible for sensing an environment and receiving data packet from ordinary nodes then forwarding it to BS. Initially, BS broadcasts ESTA packets which contain hop number and ID of node to its neighbors. Each node receives ESTA packet from BS, set itself as candidate relay node and sets waiting time. If time is ended, the node selects itself as Relay node, sets pheromone, and transmits new ESTA packet to its neighbors. When receiving ESTA packet from Relay node, there are different reaction to each node based on its type: 1. Ordinary nodes: record the information of relay node in its routing table, 2. Candidate relay node: cancel its timer if it is outside zones of two or more relay nodes, select itself as ordinary node, and 3. Never received any ESTA packet: set itself as candidate relay node and sets waiting time. These steps repeated until every node declares its type. The relay node periodically transmits a HELLO message to its neighbors. When the ordinary node has data packet, it transmits data packet to next hop relay node using probability formula of ACO algorithm (Eq.1). The probability formula of ACO algorithm depend on residual energy and distance to next relay node. Relay node receive data packet from ordinary node then forwards it to other relay nodes until reaching the BS.

$$P_{ij} = \frac{\tau_j^{\alpha} * \eta_{ij}^{\beta} * \varphi_j^{\gamma}}{\sum_{l \in R(i)} \tau_j^{\alpha} * \eta_{ij}^{\beta} * \varphi_j^{\gamma}} \qquad (1)$$

Where P_{ij} is the probability to choose which node i to forward its data packet to relay node j, (i) is a group of relay nodes with less hop distance than node i, τ_j is the pheromone value of relay node j, and η_{ij} is the normalized distance between node i and relay node j. φ_j is the residual energy of the relay node j. Although the algorithm presented above has some advantages of energy conservation, but still there is a wasted energy that can be saved because of the following reasons: 1) Idle listening to the media, when the node is waiting and listening for information from other nodes. 2) This algorithm did not apply any data aggregation to remove redundant data. 3) The relay node selection process depends only on the distance to BS and not the residual energy of the node. 4) Energy is wasted because of the periodical transmission of Hello messages.

3.2. Cluster-Tree routing protocol

In this section a tree-based clustering algorithm is presented [5]. The algorithm constructs the routing tree for better data transmission. The protocol achieves less dissipated energy by uniformly distributing them over the network.

The algorithm consists of three steps, cluster head selection, clusters establishment and routing tree construction. The algorithm runs in rounds where by the end of each round every node joins a certain cluster. In the first step, no CH exist per any cluster. A random node is selected which increment its index by 1 and check if it is even or odd. Only even values lead to select that node as a CH. Odd values will not be selected in this round of execution and waits for the next round. A threshold value set by the CH is sent to the cluster members for that round. Every node increments a counter until reach this threshold value. At that time, the process of selecting a new CH is started but with two conditions. The new CH residual energy should be greater than the average energy of all the cluster member nodes. The second condition is that, the node has not recently become a CH. The CH is responsible for aggregating and transmitting sensed data to the other cluster heads. In the second step, the cluster formation is executed. The CH determined in the previous step broadcasts messages to all other nodes. These nodes will determine the cluster to join based on the RSS (Receiver Signal Strength) where CH that needs minimum communication energy is selected. In the third step, the routing tree is constructed. All formed cluster heads send a message to the sink node to indicate its status. The sink node will start later the process of constructing the routing tree by sending messages to the CHs. CHs in turn send back to the sink node its residual energy and its location. Based on the values received from all nodes, the sink node will select a parent for the tree. The parent node sends a message to its near CHs. CHs reply to be a child for the parent. The process is repeated from the new child nodes to its near CHs.

4. RESULTS

In this section we present the simulation results of the two selected routing protocols. In addition, we discuss the results. We conducted four experiments to record the total energy consumption, network lifetime, stability period and finally the successfully received packets at the BS. All the experiments have been carried on using Castalia WSN simulator [27]. All sensor nodes are stationary. The network sensor nodes are uniformly distributed over a field area of 500 × 500 m^2 with the BS at the center. All sensor nodes have initial energy of 1J.

First, we compare the two algorithms in terms of the total energy consumption. In this experiment, we record the total energy consumption all over the network nodes. This experiment is repeated ten times with variant number of network nodes for every simulation from 100 nodes to 1000 nodes. The results show that the Cluster-Tree algorithm consumes less energy than the Trail-using-ants algorithm especially for higher number of nodes as shown in Fig. 2.

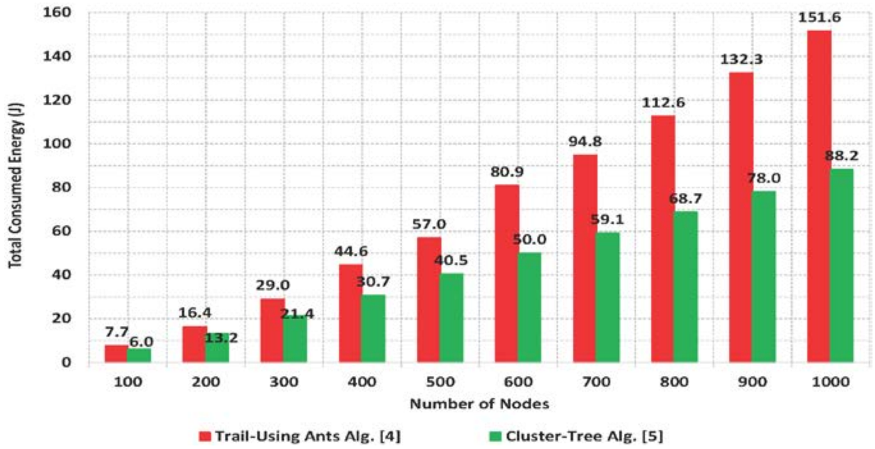


Fig. 2. Total consumed energy versus number of nodes.

Second, we compare the two algorithms in terms of the network lifetime. Although the literature provides many definitions for the network lifetime [28], we choose the following definition “the time till all nodes run out of energy” [29]. In this experiment, we record the network lifetime versus varying number of nodes from 100 to 1000 nodes. The results demonstrate that Cluster-Tree algorithm provide the network with higher lifetime compared to the Trail-using-ants algorithm as shown in Fig. 3.

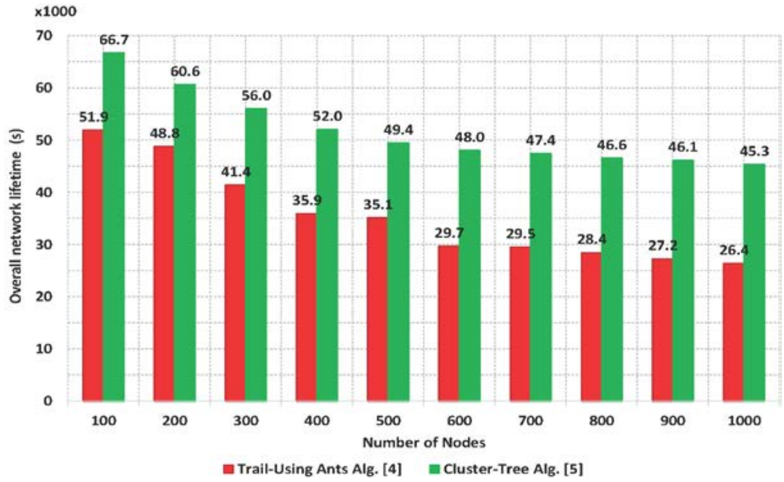


Fig. 3. Network life time versus number of nodes.

Third, we compare the two algorithms in terms of the number of successfully extradited packets to the BS. In this experiment, we record the number of successfully extradited packets to the BS versus time. The experiment illustrates which algorithm effectively distribute the energy consumption all over the nodes. Which ensures that nodes closer to the BS will not run out of energy at early time causing the BS not to receive any packets however, the network is still alive. The results show that the BS in both the two algorithms stop to receive packets after 28,000 s as shown in Fig. 4. However, in the Cluster-Tree algorithm the BS receive higher number of packets than Trail-using-ants for the same period.

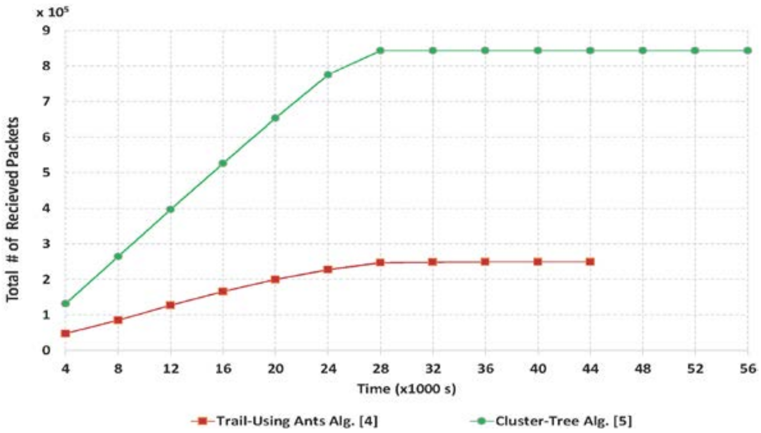


Fig. 4. Number of received packets at BS versus time.

Finally, we measure the time to first dead node for both algorithms. The results indicate that the time to the first dead node is 14,240 s and 19,903 s for Cluster-Tree, Trail-using-ants' algorithms respectively.

5. CONCLUSION

In this paper, we reviewed energy saving routing protocols for wireless sensor networks focusing on cluster-based and swarm intelligence-based protocols. In addition, we studied the performance of two routing protocols from the abovementioned categories in terms of energy consumption, network lifetime, stability period and successfully received packets at BS. The results illustrate that clustering significantly reduce the energy dissipation and consequently increase network lifetime. In the future, we intend to develop a routing protocol that considers the advantages of swarm intelligence as well as unequal clusters.

REFERENCES

[1] Yick J, Mukherjee B, Ghosal D. Wireless Sensor Network Survey. *Elsevier Journal of Computer Networks*, vol. 52, 2008, pp.2292-2330.

[2] Manjeshwar A. and Agrawal D. P. TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks. *Proceedings 15th Int. on Parallel and Distributed Processing Symposium*, vol. 3, April 2001, pp. 2009-2015.

[3] Sharma S., Bansal R. K., Bansal S. Issues and Challenges in Wireless Sensor Networks. *International Conference on Machine Intelligence and Research Advancement*, December 2013, pp. 58 – 62.

[4] Jung S-g, Kang B, Yeoum S, Choo H-. Trail-Using Ant Behavior Based Energy-Efficient Routing Protocol in Wireless Sensor Networks. *International Journal of Distributed Sensors Networks*, 2016.

[5] Malathi L., Chandrasekaran M.K., Gnanamurthy R.K. A Novel Routing Protocol with Lifetime Maximizing Clustering Algorithm for WSN. In: *Proceedings of Annual IEEE India Conference*, Kochi, 2012, pp. 925-930.

[6] Younis O., Fahmy S. HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks. *IEEE Transactions on Mobile Computing*, vol. 3, December 2004, pp. 366 – 379.

[7] Sendra S., Lloret J., García M. and Toledo J. F. Power saving and energy optimization techniques for Wireless Sensor Networks. *Journal of Communications*, vol.6, September 2011, pp. 439-459.

[8] Sazalapski T. and Madria S. Energy Efficient Real-Time Data Compression in Wireless Sensor Network. In: *Proceedings of IEEE International Conference on Mobile Data Management*, vol.1, June 2011, pp. 236 - 245.

[9] Abbasi A., Younis M. A survey on clustering algorithms for wireless sensor networks. *Journal on Computer Communications*, vol 30, 2007, pp 2826–2841.

[10] Singh J., kumar R., Mishra A.K. Clustering algorithms for wireless sensor networks: A review. In: *Proceedings of 2nd International Conference on Computing for Sustainable Global Development (INDIACom'15)*; 11-13 March 2015; New Delhi, India. New York, NY, USA: IEEE. pp. 637-642.

[11] Gunathillake A., Samarasinghe K. An Unequal Clustering Algorithm for an Emergency Response Wireless Sensor Network. In: *Proceedings of IEEE 9th Int. Conference on Mobile Ad-hoc and Sensor Networks*, 2013, pp. 383-388.

[12] Mao S., Zhao C., Zhou Z. and Ye Y. An Improved Fuzzy Unequal Clustering Algorithm for Wireless Sensor Network. *6th International ICST Conference on Communications and Networking in China*, 2011, pp. 245-250.

[13] Yu J., Qi Y., Wang G. J. An energy-driven unequal clustering protocol for heterogeneous wireless sensor Networks. *Journal of Control Theory and Applications*, vol. 9, February 2011, pp. 133–139.

[14] Dhanpal D., Joseph A., Panicker A. An Energy Efficient Unequal Cluster Based Routing Protocol for WSN with Non-Uniform Node Distribution. *International Journal of Scientific & Technology Research*, vol. 4, May 2015, p.6.

[15] Bagci H., Yazici A. An Energy Aware Fuzzy Unequal Clustering Algorithm for Wireless Sensor Networks. In: *Proceedings of International Conference on Fuzzy Systems*, July 2010, pp. 1-8.

[16] Tong W., Jiyi W., He X., Jinghua Z. and Munyabugingo C. A Cross Unequal Clustering Routing Algorithm for Sensor Network. *Journal of Measurement Science Review*, vol. 13, No. 4, August 2013, pp. 200-205.

[17] Kumar R. and Kumar D. Hybrid Swarm Intelligence Energy Efficient Clustered Routing Algorithm for Wireless Sensor Networks. *Journal of Sensors*, vol. 501, January 2016, p. 19.

[18] Heinzelman WR, Chandrakasan A, Balakrishnan H. Energy-Efficient Communication Protocol for Wireless Microsensor Networks. In: *Proceedings of 33rd Hawaii International Conference on System Sciences (HICSS'00)*; January 2000; Maui, HI, USA. NY, USA: IEEE. pp. 8020-8030

[19] Sharma N. and Verma V. Energy Efficient LEACH Protocol for Wireless Sensor Network. *International Journal of Information & Network Security (IJINS)*, vol.2, August 2013, pp. 333-338.

[20] Ma X. and Ya X. Improvement on LEACH Protocol of Wireless Sensor Network. In: *Proceedings of the 2nd International Symposium on Computer, Communication, Control and Automation (ISCCCA-13)*, Vols. 347-350, 2013, pp. 1738-1742.

[21] Javaid N. HEER: Hybrid Energy Efficient Reactive Protocol for Wireless Sensor Networks. In: *Proceedings of Electronics, Communications and Photonics Conference (ECPC)*, April 2013, pp. 1-4.

[22] Akhtar A., Minhas A. A. and Jabbar S. Energy Aware Intra Cluster Routing for Wireless Sensor Networks. *International Journal of Hybrid Information Technology*, vol.3, January 2010, pp 29-48.

[23] Yang B., Ma Q., Wang J. Study on the Routing Technology of Wireless Sensor Network Based on Ant Colony Optimization. *Journal of Sensor Technology*, vol. 6, No. 4, December 2016, pp.141-158.

[24] Mondal S., Ghosh S., Biswas U. ACOHC: Ant Colony Optimization based Hierarchical Clustering in Wireless Sensor Network. In: *Proceedings of International Conference on Emerging Technological Trends,* 2016, pp. 1-7.

[25] Yang J., Xu M., Zhao W. and Xu B. A Multipath Routing Protocol Based on Clustering and Ant Colony Optimization for Wireless Sensor Networks. *Journal of Sensors*, vol. 10, May 2010, pp. 4521-4540.

[26] Camilo T., Carreto C., Silva J. S. and Boavida F. An energy-efficient ant-based routing algorithm for wireless sensor networks. In: *Proceedings of 5th International Workshop on Ant Colony Optimization and Swarm Intelligence*, vol. 4150, 2006, pp. 49–59.

[27] Castalia Wireless Sensor Network simulator, User Manual. Available Online: http://cpham.perso.univ-pau.fr/ENSEIGNEMENT/PAUUPPA/INGRES-M1/Castalia - User Manual.pdf

[28] Dietrich I, Dressler F. On the Lifetime of Wireless Sensor Networks. *ACM Transactions on Sensor Networks*, 2009; 5:5.1-5.39.

[29] Tian D., Georganas N. D. A Coverage-preserving Node Scheduling Scheme for Large Wireless Sensor Networks. In: *1st ACM International Workshop on Wireless Sensor Networks and Applications (WSNA'02)*; 28 September 2002; Georgia, USA. New York, NY, USA: ACM. pp. 32-41.

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