Zone and Block Cluster Wireless Sensor Network Routing Protocols

by

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B.Eng., Mehran UET Jamshoro, 2011

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Supervisory Committee

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Supervisory Committee

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Abstract

A Wireless Sensor Network (WSN) supports a wide range of applications, but there are many challenging problems which need to be addressed. The energy consumption of nodes, in terms of extending the network lifetime and the network throughput, are key challenges. In this project, block cluster based routing protocols are implemented and the performance evaluated using MATLAB. The three implemented protocols are Low Energy Adaptive Clustering Hierarchy (LEACH), Stable Election Protocol (SEP), and Zone and Energy Threshold (ZET). ZET is a recently proposed block clustering based sensor network routing protocol. This algorithm divides the network area into a number of zones and each zone is called a cluster. After dividing the nodes into zones, ZET calculates the energy efficiency of each node in a zone and selects the cluster head as the node with the highest energy efficiency. Results are presented which show that ZET provides a better network lifetime, network stability, and throughput compared to the LEACH and SEP routing protocols.

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Dedication

This work is dedicated to my Parents!

Chapter 1 Introduction

A Wireless Sensor Network (WSN) consists of a large number of sensor nodes which communicate wirelessly. Sensor nodes are small, battery operated computing devices equipped with sensors which are able to observe the environment. Each sensor node consists of a radio transceiver, a small microcontroller, and a battery [3]. The sensor nodes are inexpensive, so they can be easily produced and deployed in large numbers [4]. Due to their physical form, resources such as memory, energy and bandwidth are severely constrained [2].

Sensor networks have a variety of applications such as environmental monitoring, which can involve monitoring air, soil, and water. Sensor networks are also deployed for surveillance, inventory tracking, and habitat monitoring. Sensor networks gather information by sensing temperature, pressure, sound, and vibrations in environments such as buildings, industrial areas, homes, ships, and transportation systems [6].

Sensor networks were first developed for military surveillance applications where a large number of nodes were deployed in hostile environments in order to provide information about opponents [3]. Later, sensor networks became a common tool for environmental monitoring.

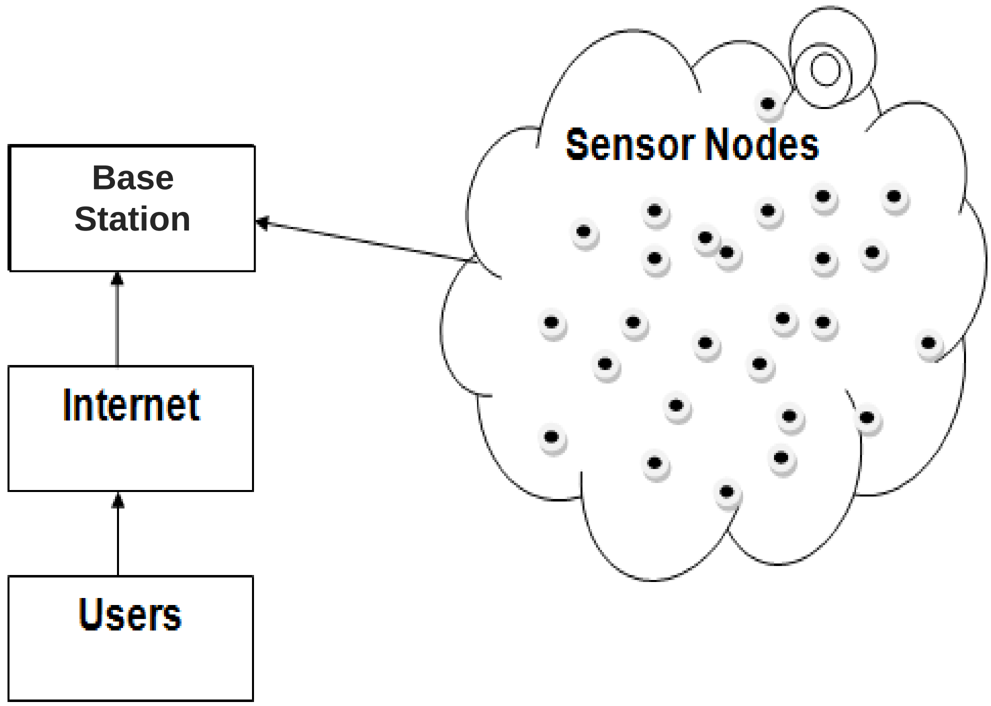


Figure 1: The wireless sensor network model [12].

Figure 1 shows a sensor network deployment and operation. The cloud shows the sensor field with the sensor nodes. The Base Station (BS) connects the sensor network to the internet, through which users receive information from the WSN [12].

1.1 Wireless Sensor Network Applications

Military and Surveillance

Sensor networks have become an essential part of military command and control systems [3]. Sensors are deployed in a battlefield to monitor the presence of enemy forces in order to track their movements, which enables close surveillance of opposing forces.

Industrial Plant Maintenance and Control

In industry, sensor networks are used for monitoring manufacturing processes and the condition of manufacturing equipment [6]. Chemical plants and oil refineries use sensors to monitor production. These sensors are also used to alert if any plant, machinery, or process failures have occurred [6].

Remote Billing

Wireless sensors are used to remotely read utility meters in homes, such as water, gas, or electricity, and then send the readings to a remote center through wireless channels [3].

Health Care

Wireless sensor networks can be used for health care monitoring, which can relieve the shortage of health care personnel and reduce health care expenditures [3,6]. Sensors can be deployed on a patient to monitor their condition, and sensors can alert doctors when the patient requires medical attention [6].

Infrastructure Maintenance and Monitoring

Sensors can be used to monitor infrastructure such as bridges and flyovers [6]. The deployment of sensor networks for structural monitoring enables assets to be remotely observed without the need for site visits. Sensor networks provide an immense advantage over personnel site visits for infrastructure maintenance in terms of reliability and data collection frequency [6].

Environment Monitoring

Sensor networks are deployed to monitor environmental conditions affecting livestock or crops [2]. Sensor networks are also used to observe the temperature for heating or cooling systems in offices and buildings [6].

Chapter 2 Block Clustering Based Routing Protocols

Sensor network routing protocols are developed on the basis of the application and architecture of the network. There are several factors that should be taken into consideration when developing a routing protocol for wireless sensor networks. Energy efficiency is considered the most important criteria, as it affects the lifetime of the network [2, 5].

Clustering is the process of partitioning a network into small groups of sensor nodes which are referred to as blocks or clusters [2]. Each cluster has some sensor nodes and one or more cluster heads depending on the routing algorithm [3]. The cluster head gathers data from sensor nodes in the cluster and routes this data to the Base Station (BS) [2]. The BS is a fixed node in the network, and generally it is capable of transmitting and receiving data throughout the entire network [3]. Cluster based routing provides energy efficiency [3]. The node with the highest energy efficiency in a cluster is typically selected as the Cluster Head (CH) [1]. Nodes with lower energy efficiency are used for sensing and sending data to their CH [1].

The network stability is the interval of time from the start of the network to the death of the first sensor node. Throughput is defined as the data sent from nodes to cluster heads plus the data sent from cluster heads to the BS or sink. Network lifetime is the time from the start of the network to the death of the last alive node.

Figure 2 shows the list of block cluster based routing protocols.

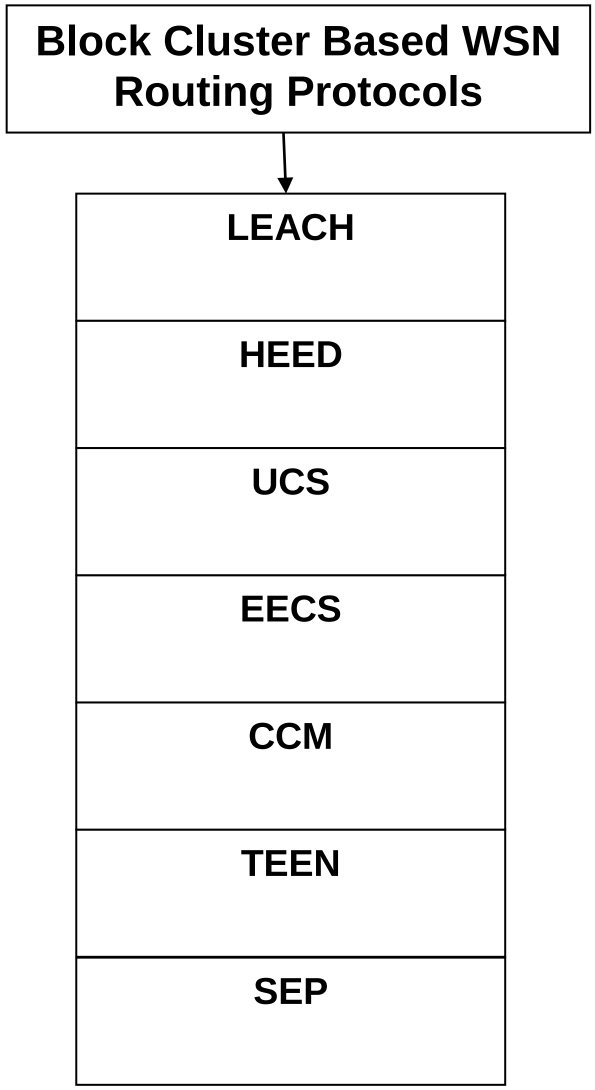


Figure 2: List of block cluster based WSN routing protocols [2].

The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol provides effective routing in sensor networks to reduce the energy consumption [2]. The LEACH protocol makes use of single hop routing wherein each sensor node transfers information directly to the CH or the BS [1,4,8]. LEACH is not recommended for large scale networks because it is a single hop communication algorithm [4].

The Hybrid Energy Efficient Distributed (HEED) protocol is a fully distributed routing scheme [3]. The HEED algorithm provides load balancing and uniform cluster head distributions [2]. However it is complex because of the periodic cluster head election and repeated iterations for rebuilding the clusters which needs extra energy [2].

Unequal Clustering Size (UCS) is a protocol in which cluster heads are assumed to be in a circle around the BS [2]. Cluster heads are predetermined and the residual energy of the nodes is not considered to determine cluster heads [2].

Chain Cluster Mixed (CCM) is a routing algorithm that organizes the sensor nodes as a set of horizontal chains and a vertical cluster with only chain heads [4]. CCM combines the advantages of the Power-Efficient Gathering in Sensor Information Systems (PEGASIS) algorithm and LEACH [4]. CCM is considered a complex algorithm due to the chain-head selection criterion [2].

The Threshold sensitive Energy Efficient sensor Network (TEEN) protocol is a hierarchical WSN routing protocol. In TEEN, cluster heads broadcast two thresholds to sensor nodes which are a soft threshold and a hard threshold. When the sensed value exceeds the hard threshold, the sensor node enters the transmission mode. The soft threshold is a small change in the sensed value which makes the sensor node send sensed data to the cluster head [14]. The TEEN algorithm becomes less effective in applications where a continuous data update is required because if the thresholds are not reached, the nodes will never communicate to the cluster heads [2, 14].

The Stable Election Protocol (SEP) is a hierarchical sensor network protocol. The SEP algorithm has been implemented with some of the sensor nodes in the network equipped with higher energy levels [9]. Higher energy level nodes are called advanced nodes in SEP [1]. SEP provides stability in a network, but the network lifetime decreases rapidly after the death of the first sensor node.

In a small network, LEACH provides network stability, but SEP gives better performance than LEACH [1]. In order to overcome the limitations of the LEACH and SEP routing protocols for small scale networks, Zone and Energy Threshold (ZET) routing was proposed [1]. ZET is a block clustering based routing algorithm. The sensing area is divided into multiple zones and each zone has its own central reference point [1].

In this report, the performance of ZET is compared with the LEACH and SEP routing protocols. Simulations are carried out using MATLAB, and the results show that ZET has better network stability, network lifetime and throughput than the LEACH and SEP routing protocols.

Chapter 3 ZET Routing Protocol

ZET has been proposed for effective energy management in small scale block cluster based wireless sensor networks. The network model for ZET is different from previously proposed block cluster based sensor network routing protocols. ZET divides the sensing area into an equal number of logical zones and each zone represents a cluster [1]. Dividing the total deployed area into equal logical zones helps to balance the network traffic [1]. Figure 3 shows the random deployment of nodes in a ZET sensor network with 9 zones. The reference point is in the center of each zone and the network area is 100 m x 100 m.

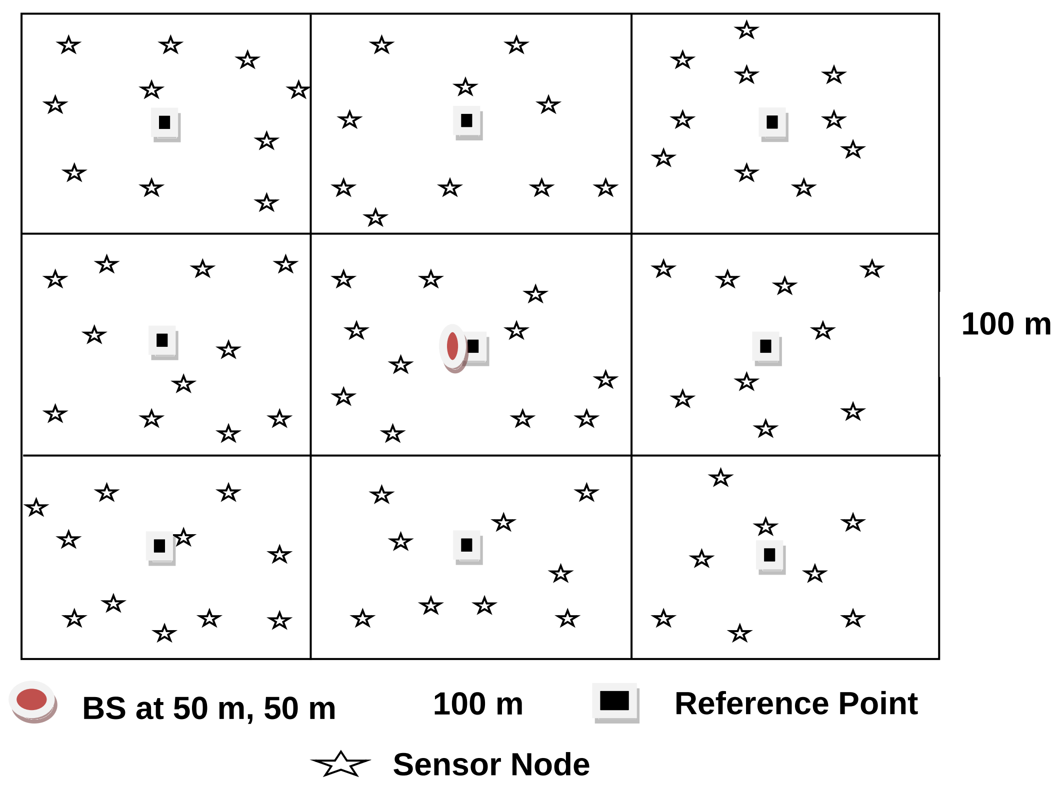


Figure 3: Zonal deployment with the ZET routing protocol [1].

The ZET algorithm is divided into two operational phases, network initialization and network transmission. During network initialization, cluster heads are selected and clusters are formed. Data communication occurs during network transmission [1]. A cycle is known as a round, and in one round there is a network initialization and multiple data transmissions to the BS [1]. In each round one node in a zone is selected as the cluster head. Slection of the cluster head in a zone depends upon the residual energy of a node and the distance of a node from the reference point and the BS, which is defined as [1]

$$\boldsymbol{E_{eff}} = \frac{\boldsymbol{Er}}{\boldsymbol{Min}(\boldsymbol{D_{toRP}})} \times \frac{\mathbf{1}}{\boldsymbol{Min}(\boldsymbol{D_{toBS}})} \qquad \mathbf{(3.1)}$$

where, $\boldsymbol{Er}$ is the residual energy of the node. $\boldsymbol{Min}(\boldsymbol{D_{toRP}})$ is the distance from the node to the reference point and $\boldsymbol{Min}(\boldsymbol{D_{toBS}})$ is the distance from the node to the BS. The probability of a node becoming a cluster head in a zone in a round is defined as [1]

$$\boldsymbol{P} = \frac{\boldsymbol{z}}{\boldsymbol{n}} \qquad \mathbf{(3.2)}$$

where $\boldsymbol{z}$ is the number of zones and $\boldsymbol{n}$ is the number of nodes in a zone. The number of cluster heads in the entire network is [1]

$$CH = n \times P \qquad (3.3)$$

where n is the number of sensor nodes.

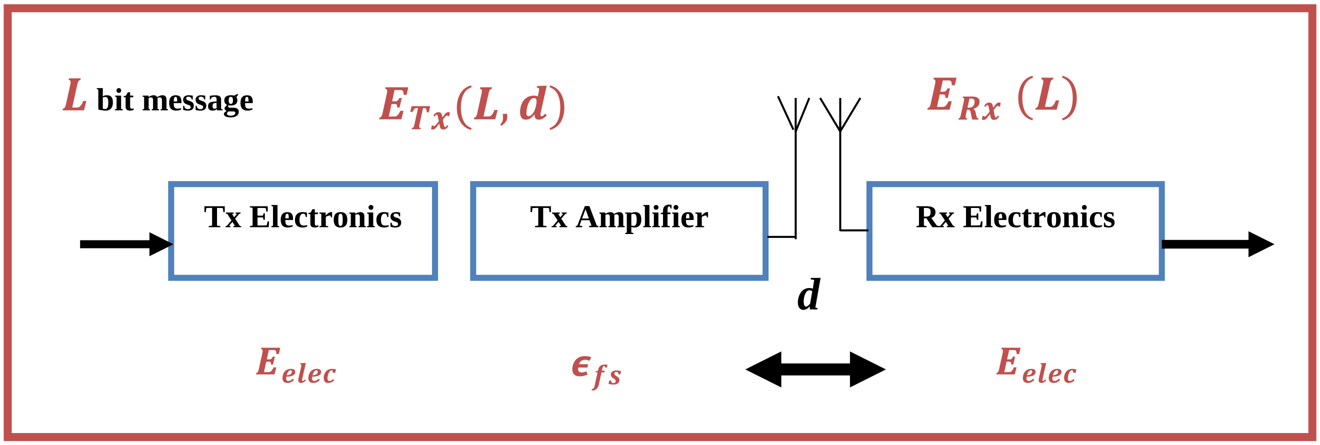


Figure 4: Radio model used in the ZET implementation [1, 8].

Figure 4 shows the radio model used in the implementation of ZET. $E_{Tx}(L, d)$ is the energy required to transmit an L bit message over a distance d, E_{elec} is the energy dissipated in the node per bit, ϵ_{fs} is the transmit amplifier energy to transmit an L bit message over a distance d, and $E_{Rx}(L)$ is the energy required to receive an L bit message.

To transmit an L bit message over a distance d, the energy required is [1]

$$E_{Tx}(L, d) = E_{elec}L + L\epsilon_{fs}d^2 \qquad (3.4)$$

The d^2 power loss model has been implemented as the network area is considered free space, where sensor nodes are in line of sight to each other.

To receive an L bit message, the energy required is [1]

$$E_{Rx}(L) = E_{elec}L \qquad \textbf{(3.5)}$$

With a random deployment of sensor nodes, and the BS at the center of the network, the energy dissipation of a cluster head is defined as [1]

$$E_{CH} = \left(\frac{n}{z} - 1\right) L_c\, E_{Rx}(L) + \frac{n}{z}\, L_c E_A + L_A E_{Rx}(L) + L_A \epsilon_{fs} d_{toBS}^2 \qquad \textbf{(3.6)}$$

where n is the number of nodes, z is the number of zones, and E_A is the data aggregation energy per bit. Data aggregation is the process of combining the data packets of several nodes to reduce the data transmission. L_c is the number of bits received from the nodes within a zone, L_A is the number of aggregated data bits, and d_{toBS} is the average distance between the cluster head and the base station defined as [1, 10]

$$d_{toBS} = \alpha \times \frac{m}{2} \qquad \textbf{(3.7)}$$

where α is constant set to 0.765 and m is the area of the network.

The energy dissipation of a node in a zone is [1]

$$E_{node} = L_c\, E_{Rx}\,(L) + L_c \epsilon_{fs} d_{toCH}^2 \qquad \textbf{(3.8)}$$

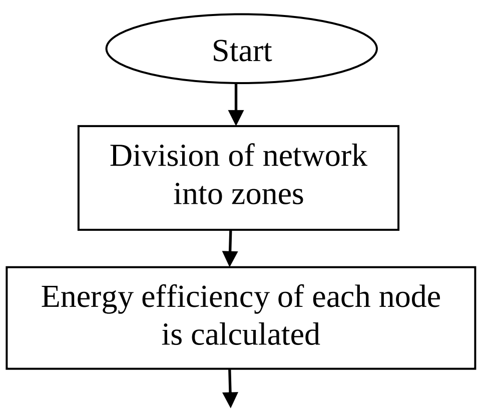
where d_{toCH} is the distance between the cluster head and the node. The total energy dissipated in each zone E_{zone} in a round is [1]

$$E_{zone} = E_{CH} + \frac{n}{z}\, E_{node} \qquad \textbf{(3.9)}$$

The total energy dissipated in a network for a round can then be calculated as [1]

$$E_{tot} = z \times E_{zone} \qquad \textbf{(3.10)}$$

Figures 5 and 6 illustrate the network initialization and network transmission.



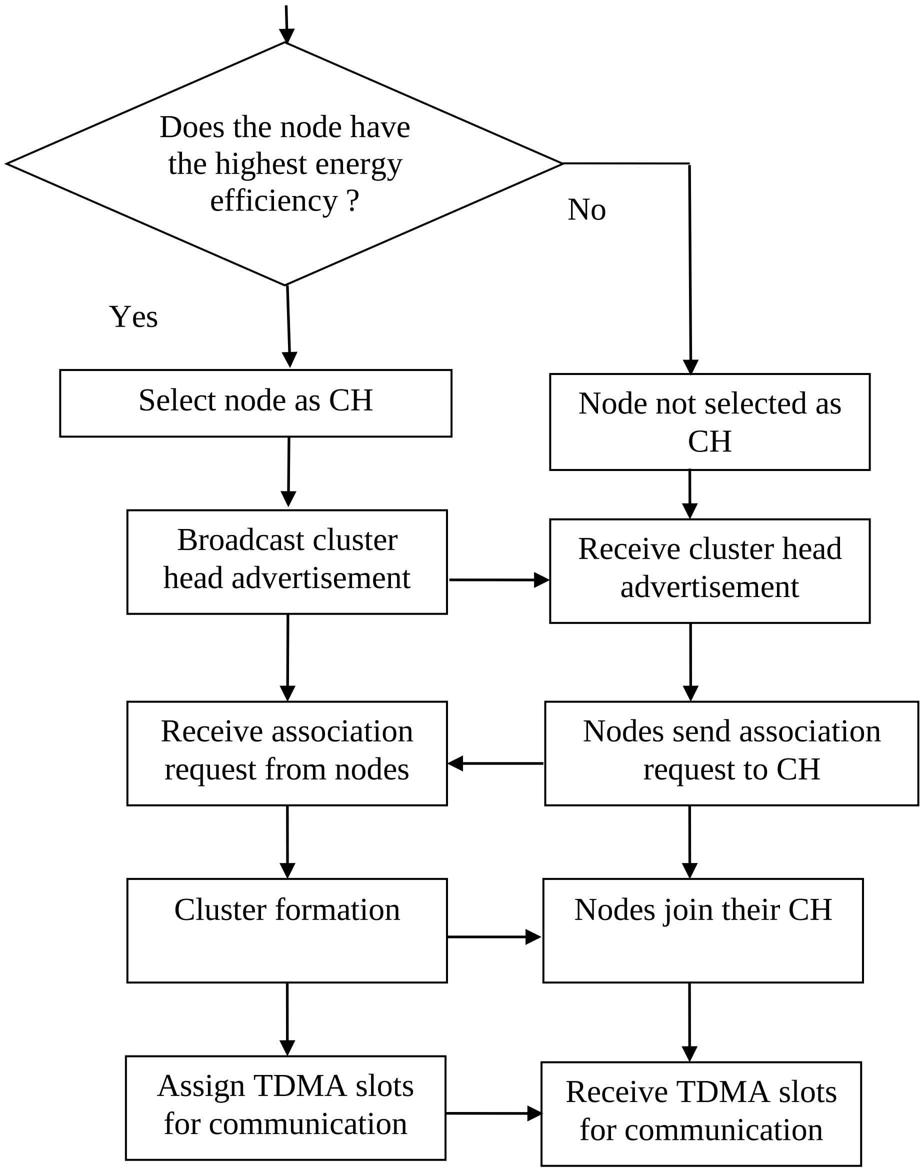


Figure 5: Network initialization flowchart [1].

Figure 5 shows the network initialization flowchart. This begins with dividing the sensors into equal area zones. After the zones are formed, the residual energy and distances of each node to the reference point and the base station are calculated. The node with the highest energy efficiency is elected as the cluster head and all other nodes in the zone are considered as zone members for that cluster.

Once a node is elected as the cluster head, it broadcasts the cluster head advertisement, which is acknowledged by zone members, and they send an association request to the cluster head to join the cluster. This is how a cluster is formed. For efficient communication between a cluster head and zone members, Time Division Multiple Access (TDMA) is used. TDMA allows nodes to communicate in their own time slot without any interference from other nodes while sharing the same channel for communication with the cluster head [13].

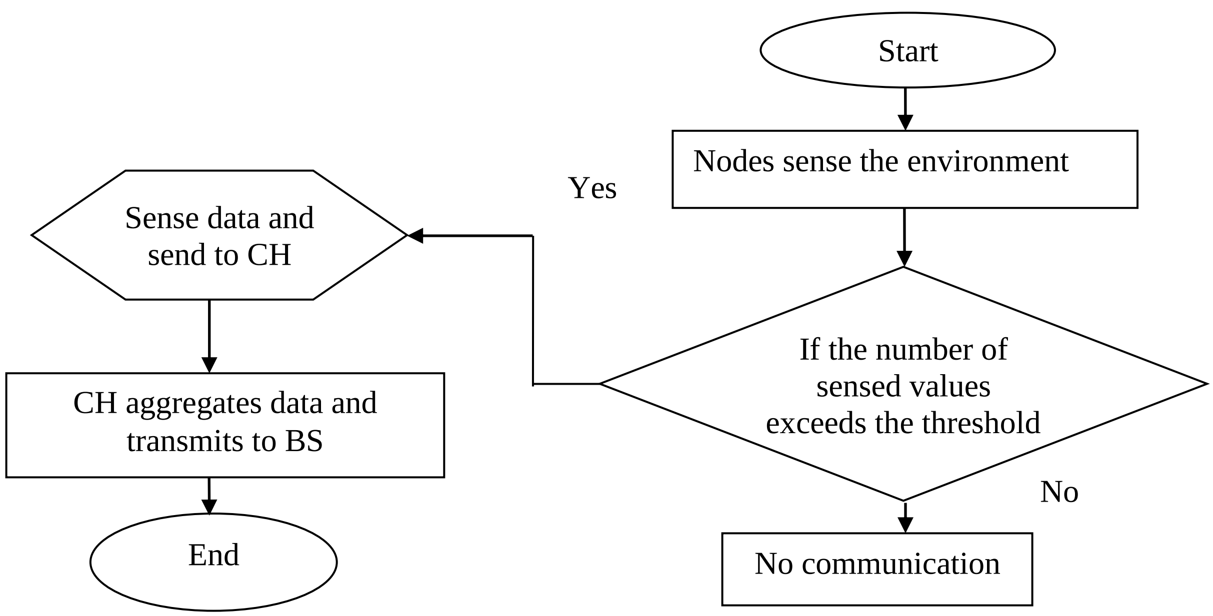


Figure 6: Network transmission flowchart [1].

Figure 6 shows the network transmission flowchart. In the ZET protocol, sensor nodes do not send their information until the number of sensed values exceeds the threshold [1]. The threshold is taken as 180 [1]. When the CH receives data from all the nodes in a cluster, CH aggregates it and transmits to BS.

Chapter 4 Results and Discussion

The nodes are randomly deployed in areas of 100 m x 100 m, 150 m x 150 m, and 200 m x 200 m. The base station is located at the center of each network. The numbers of nodes used in the simulations are 100, 150, and 200 nodes. The network simulation and radio parameters are given in Table 1.

Parameter	**Value**
Number of nodes ($\boldsymbol{n}$)	100, 150 and 200
Network size	100 m x 100 m, 150 m x 150 m and 200 m x 200 m
Base station location	(50 m, 50 m), (75 m, 75 m) and (100 m, 100 m)
Data packet size	4000 bits
Initial energy ($\boldsymbol{E_o}$)	0.5 J
Data aggregation energy ($\boldsymbol{L_A}$)	50 pJ/bit
Transmit energy ($\boldsymbol{E_{elec}}$)	50 nJ/bit
Receive energy ($\boldsymbol{E_{Rx}}$ ($\boldsymbol{L}$))	50 nJ/bit
Transmit amplifier energy ($\boldsymbol{\epsilon_{fs}}$)	100 pJ/bit/m^2

Table 1: The simulation parameters [1].

The performance with the ZET protocol is compared with that of the well known WSN protocols LEACH and SEP. MATLAB is used to perform the simulations. In order to provide a comprehensive evaluation of the techniques, simulations results for different parameters are provided. The parameters are given in Table 2.

Network Area	**Number of Nodes**	**BS Location**
100 m x 100 m	100	50 m, 50 m
150 m x 150 m	100	75 m, 75 m
150 m x 150 m	150	75 m, 75 m
150 m x 150 m	200	75 m, 75 m
200 m x 200 m	200	100 m, 100 m

Table 2: Distribution of nodes in the network areas.

4.1 Network Lifetime

The overall network lifetime depends on the lifetime of each sensor node. Network instability occurs as soon as the first node dies in the network. The lifetime of network is the number of rounds, as shown in Figures 7 to 11.

A round is one complete network initialization process and one transmission from each of the cluster heads. It ends when there is no communication between nodes and the cluster heads for a time slot defined in algorithm.

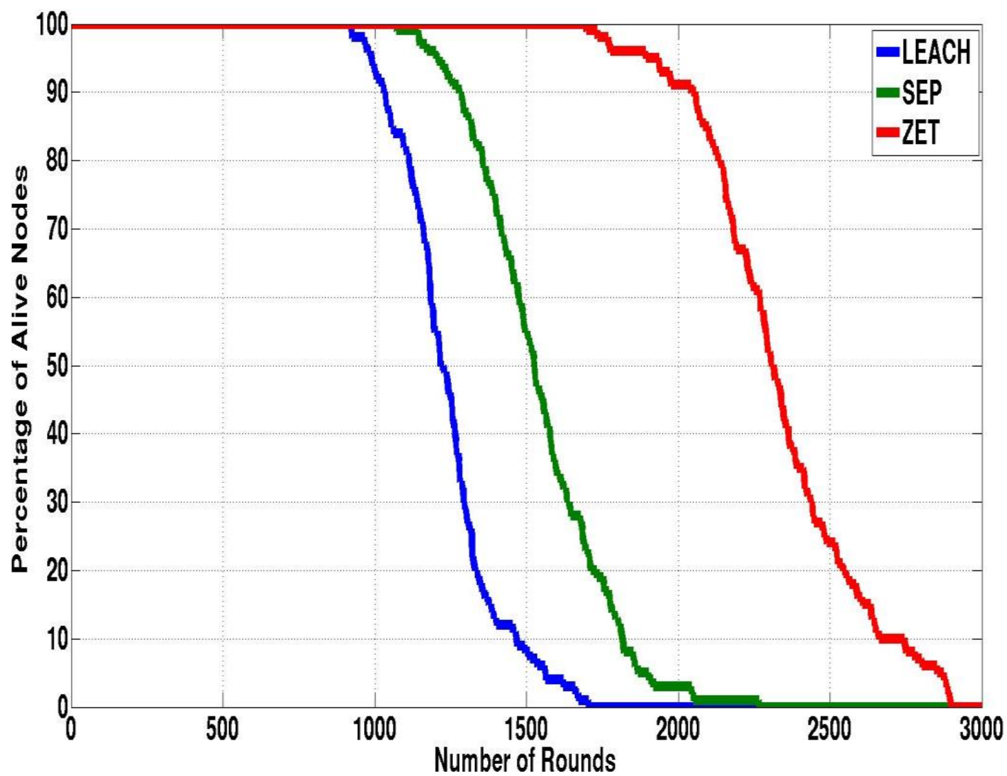


Figure 7: Percentage of alive nodes in a 100 m x 100 m network with 100 nodes.

Figure 7 shows the percentage of alive nodes in the network for the LEACH, SEP, and ZET protocols. The network consists of 100 nodes and the network area is 100 m x 100 m. These results clearly show that SEP has better network stability and network lifetime, but ZET has even better performance than SEP with the same network parameters.

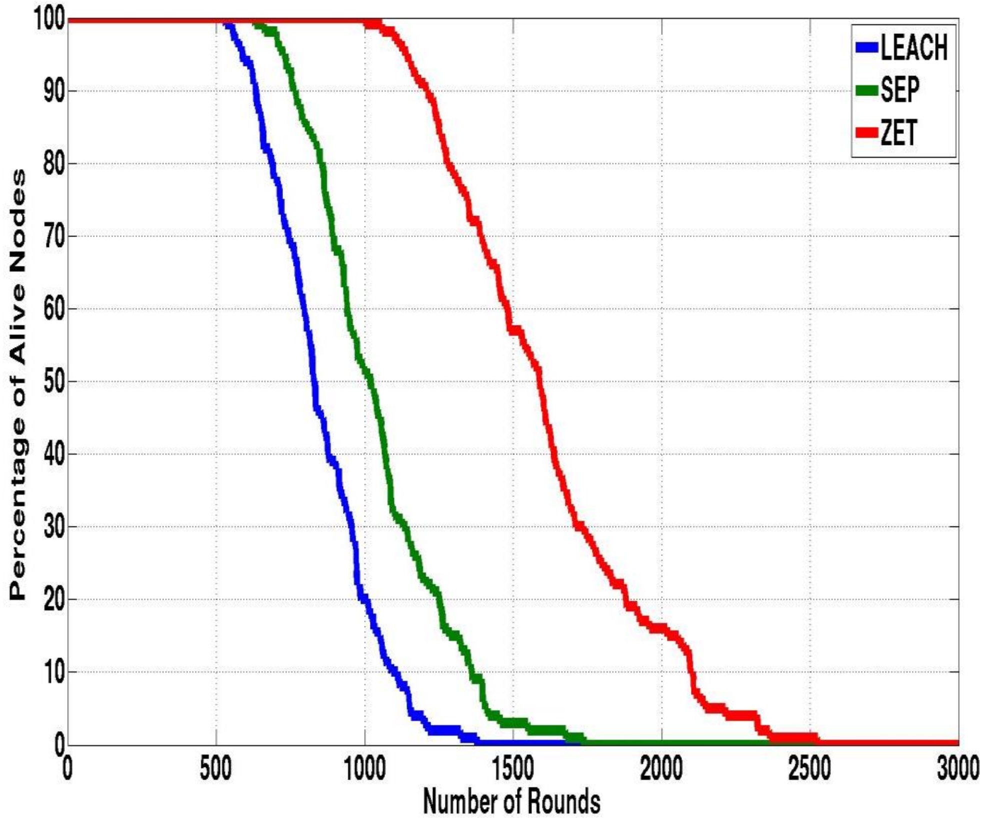


Figure 8: Percentage of alive nodes in a 150 m x 150 m network with 100 nodes.

Figure 8 shows the percentage of alive nodes in the network for the LEACH, SEP, and ZET protocols. The network consists of 100 nodes and the network area is 150 m x 150 m. When the area of the network is increased while keeping the number of nodes at 100, the network lifetime is slightly decreased. This is because with an increase in the network area, path losses increases and nodes need more transmission energy in order to communicate with the cluster heads. This causes network instability and the network lifetime decreases when compared to Figure 7.

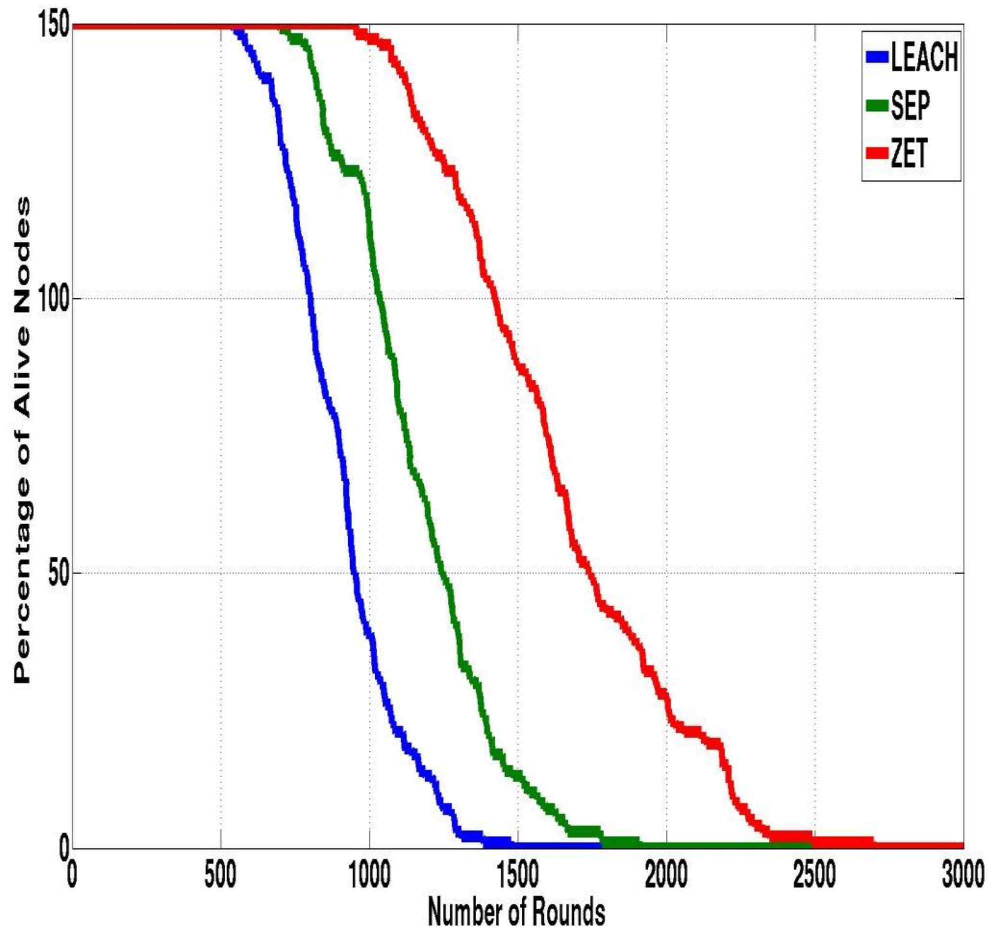


Figure 9: Percentage of alive nodes in a 150 m x 150 m network with 150 nodes.

Figure 9 shows the percentage of alive nodes in the network for the LEACH, SEP, and ZET protocols. The network consists of 150 nodes and the network area is 150 m x 150 m. Compared to Figure 8, this network provides better network stability and lifetime because the number of nodes has been increased in the network. This reduces the path losses and nodes in the network can communicate longer to the cluster heads, having spent less energy on transmission.

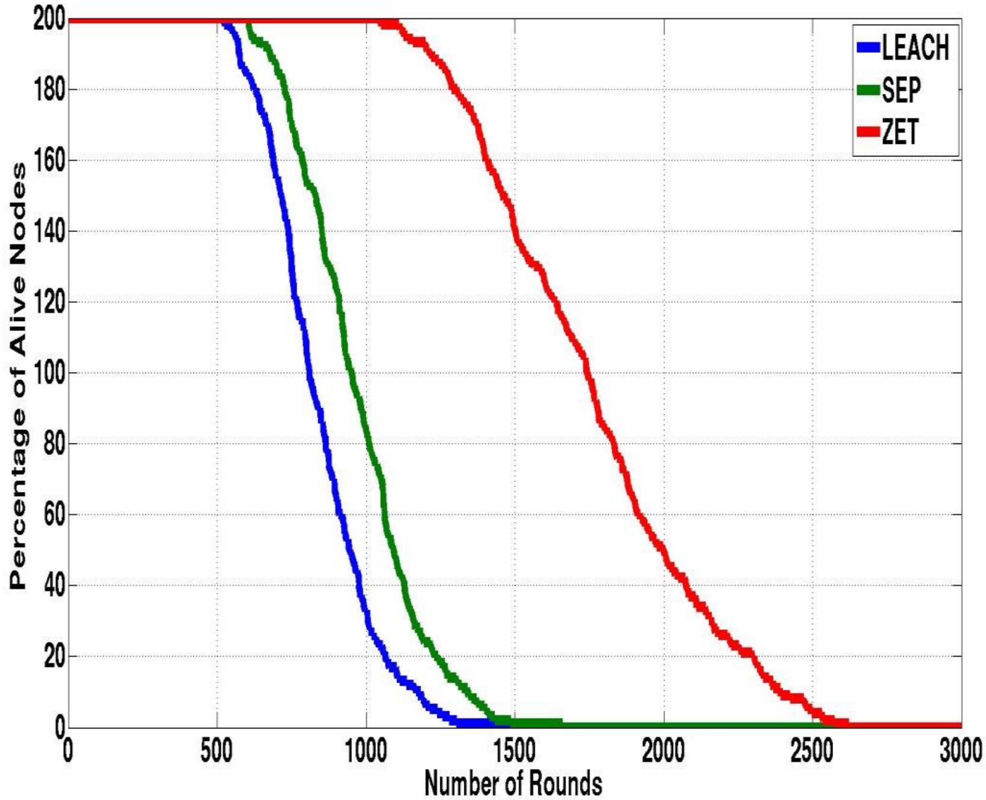


Figure 10: Percentage of alive nodes in a 150 m x 150 m network with 200 nodes.

Figure 10 shows the percentage of alive nodes in the network for the LEACH, SEP, and ZET protocols. The network consists of 200 nodes and the network area is 150 m x 150 m. It can be seen in Figure 8 that if the number of nodes in a network are reduced the lifetime decreases due to an increase in the path losses. In Figure 10, the number of nodes has been increased to 200, which causes increased network instability and decreases the overall network lifetime, compared to Figure 9.

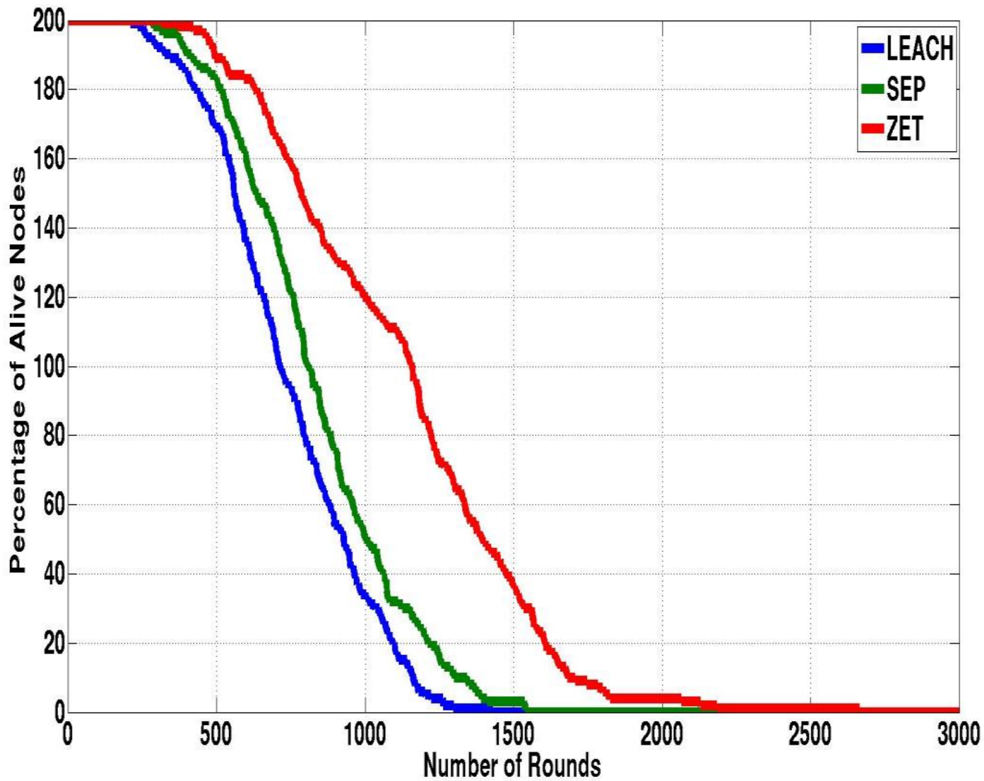


Figure 11: Percentage of alive nodes in a 200 m x 200 m network with 200 nodes.

Figure 11 shows the percentage of alive nodes in the network for the LEACH, SEP, and ZET protocols. The network consists of 200 nodes and the network area is 200 m x 200 m. As the LEACH, SEP, and ZET protocols were proposed for small scale networks. It can be seen in Figure 11 that overall network stability and lifetime is decreasing with an increasing network area, compared to Figures 7 to 10.

4.2 Throughput

The throughput for the LEACH, SEP and ZET routing protocols was simulated using MATLAB. The results presented show the number of packets sent to the cluster heads from nodes and from the cluster heads to the BS.

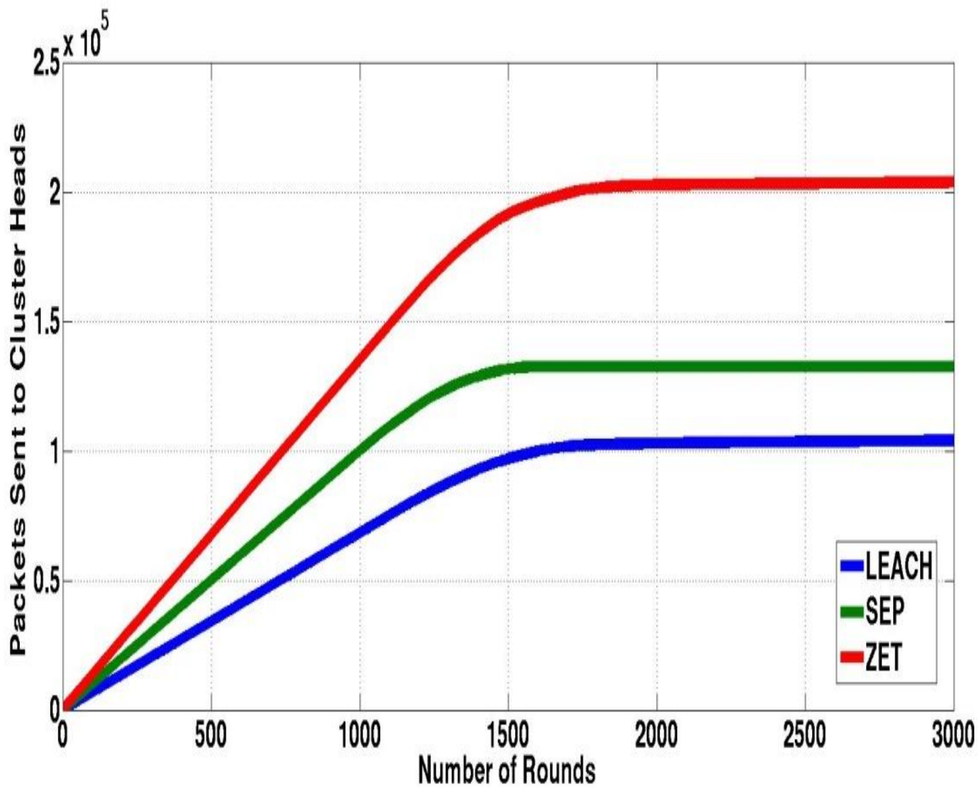


Figure 12: Packets sent to the cluster heads with 100 nodes in a 100 m x 100 m network.

Figure 12 shows the number of packets sent to the cluster heads from the nodes. These results are for 100 sensor nodes in a network area of 100 m x 100 m. This shows that the throughput of ZET is higher than with the LEACH and SEP protocols.

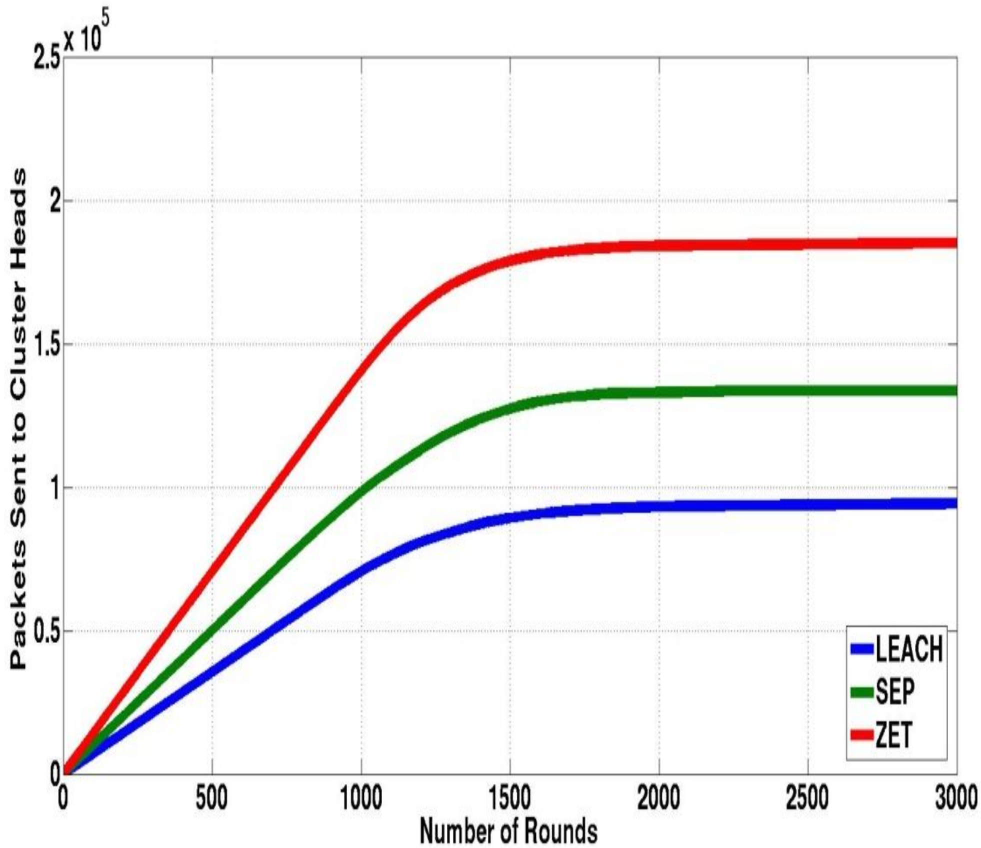


Figure 13: Packets sent to the cluster heads with 100 nodes in a 150 m x 150 m network.

Figure 13 shows the number of packets sent to the cluster heads from the nodes. These results are for 100 sensor nodes in a network area of 150 m x 150 m. This shows that the throughput of ZET is higher than with the LEACH and SEP protocols.

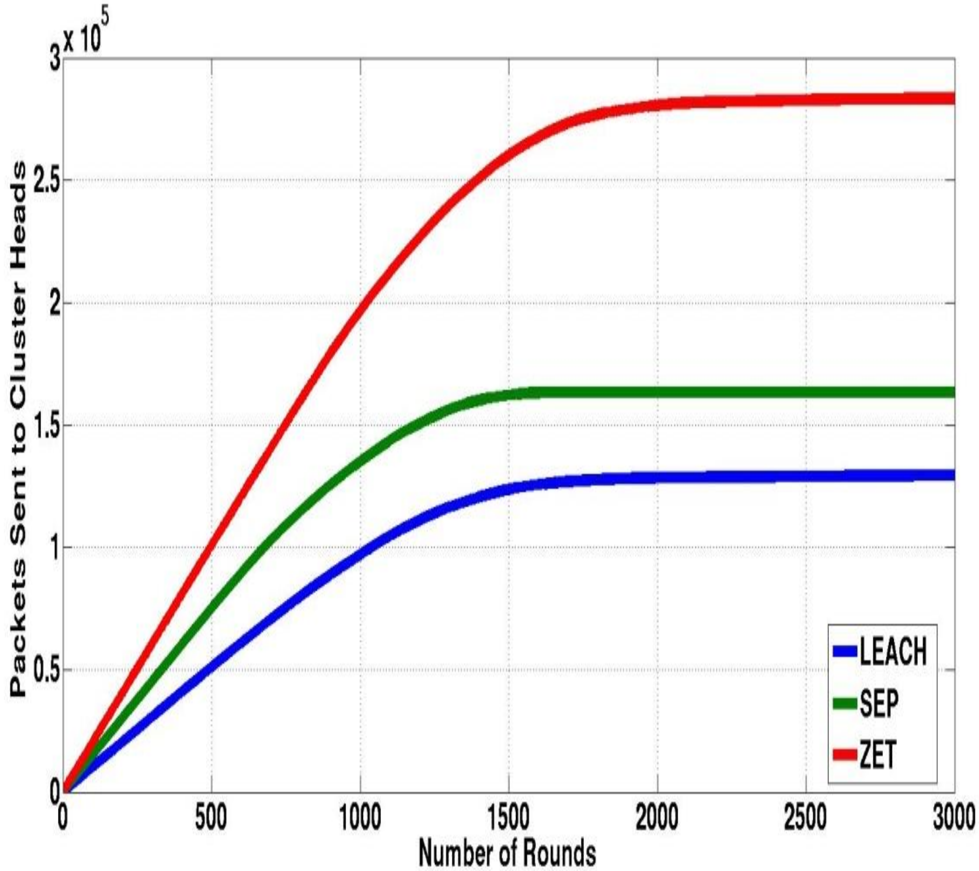


Figure 14: Packets sent to the cluster heads with 150 nodes in a 150 m x 150 m network.

Figure 14 shows the number of packets sent to the cluster heads from the nodes. These results are for 150 sensor nodes in a network area of 150 m x 150 m. Figure 14 shows that the throughput of ZET is higher than with the LEACH and SEP protocols. The throughput in Figure 14 has been increased by approximately 32% for ZET, 25% for SEP, and 21% for the LEACH protocol, compared to Figure 13.

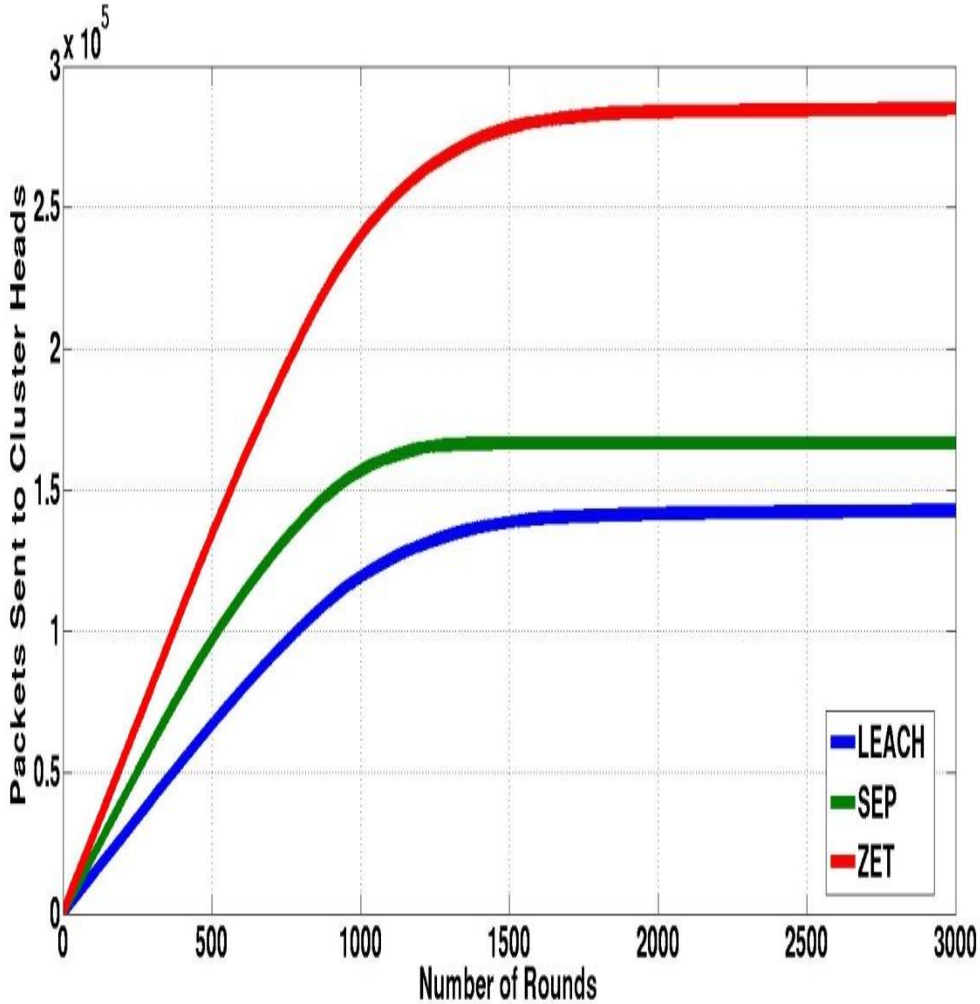


Figure 15: Packets sent to the cluster heads with 200 nodes in a 150 m x 150 m network.

Figure 15 shows the number of packets sent to the cluster heads from the nodes. This shows that the throughput of ZET is higher than with the LEACH and SEP protocols. Figures 14 and 15 show almost identical results even though the number of nodes is increased to 200 in Figure 15. If the number of nodes in a network area is increased, the network lifetime decreases, therefore there is not any notable improvement in network throughput compared to Figure 14.

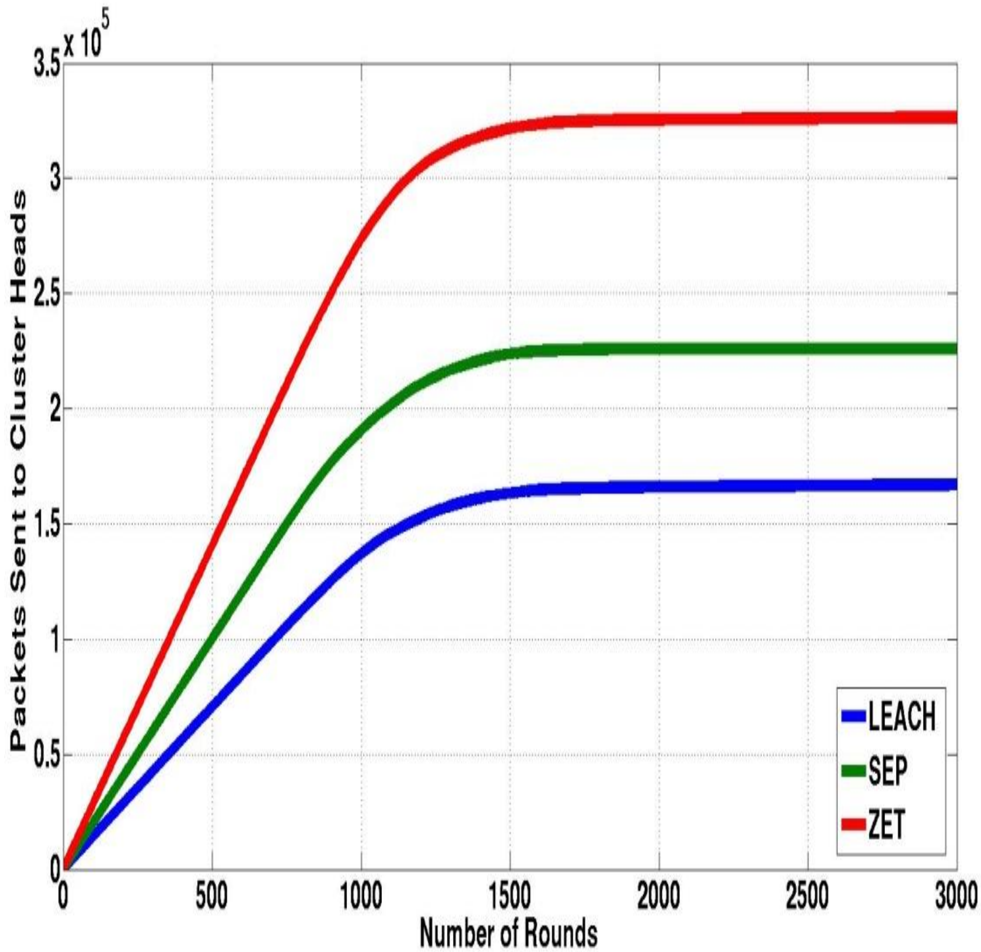


Figure 16: Packets sent to the cluster heads with 200 nodes in a 200 m x 200 m network.

Figure 16 shows the number of packets sent to the cluster heads from the nodes. These results are for 200 sensor nodes in a network area of 200 m x 200 m. Figure 16 shows that the throughput of ZET is higher than with the LEACH and SEP protocols. The network throughput in Figure 16 increases by approximately 17% for the LEACH, 26% for SEP, and 16% for ZET protocol, compared to Figure 15.

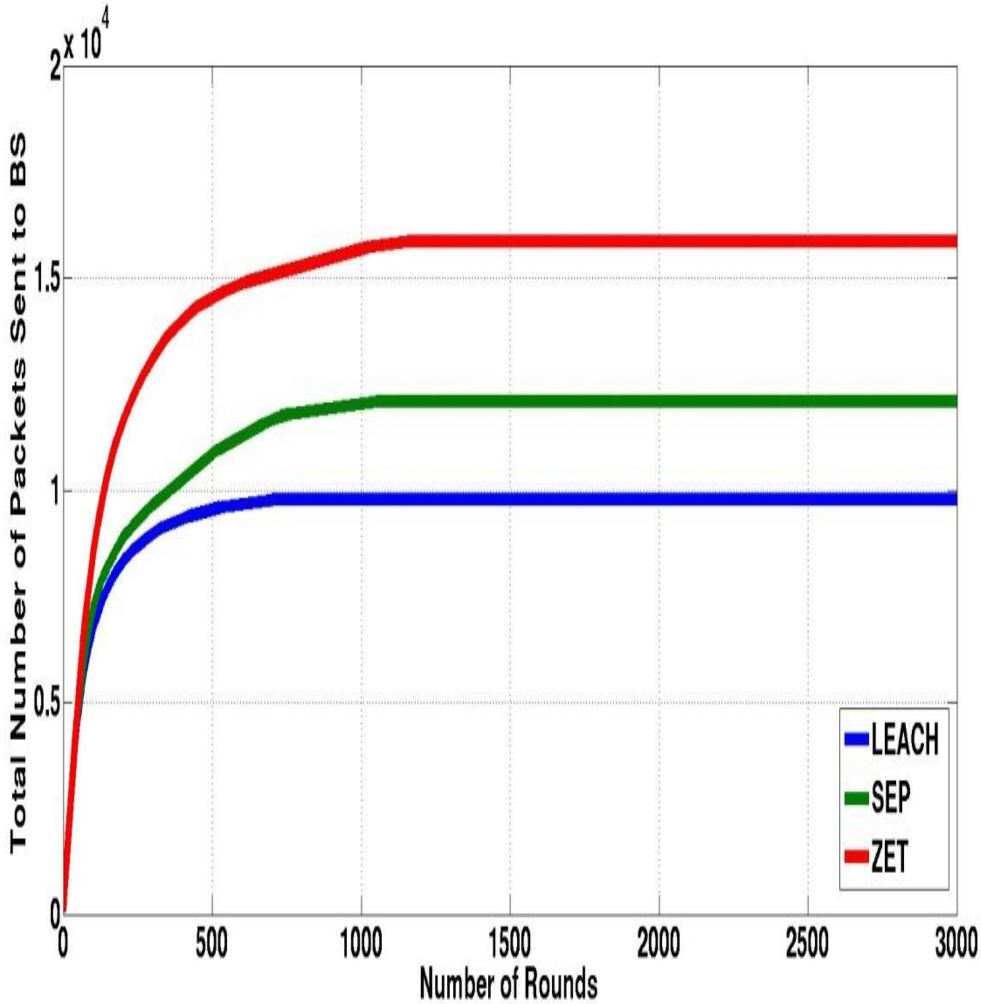


Figure 17: Packets sent to the BS with 100 nodes in a 100 m x 100 m network.

Figure 17 shows the number of packets sent to the BS from the cluster heads. These results are for 100 sensor nodes in a network area of 100 m x 100 m. This shows that the throughput of ZET is higher than with the LEACH and SEP protocols.

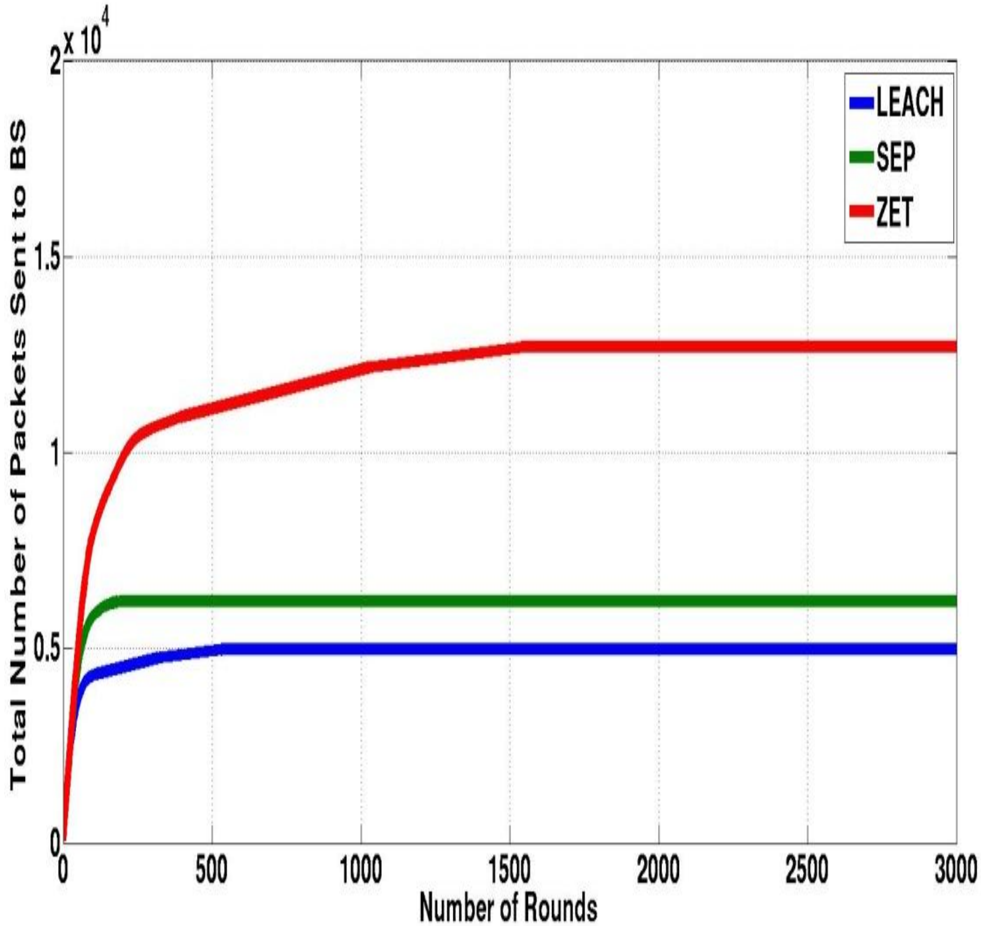


Figure 18: Packets sent to the BS with 100 nodes in a 150 m x 150 m network.

Figure 18 shows that the packets sent to the BS from the cluster heads. This shows that the throughput of ZET is higher than with the LEACH and SEP protocols. For the LEACH protocol, the network lifetime and throughput significantly decrease with an increase in path losses, compared to Figure 17.

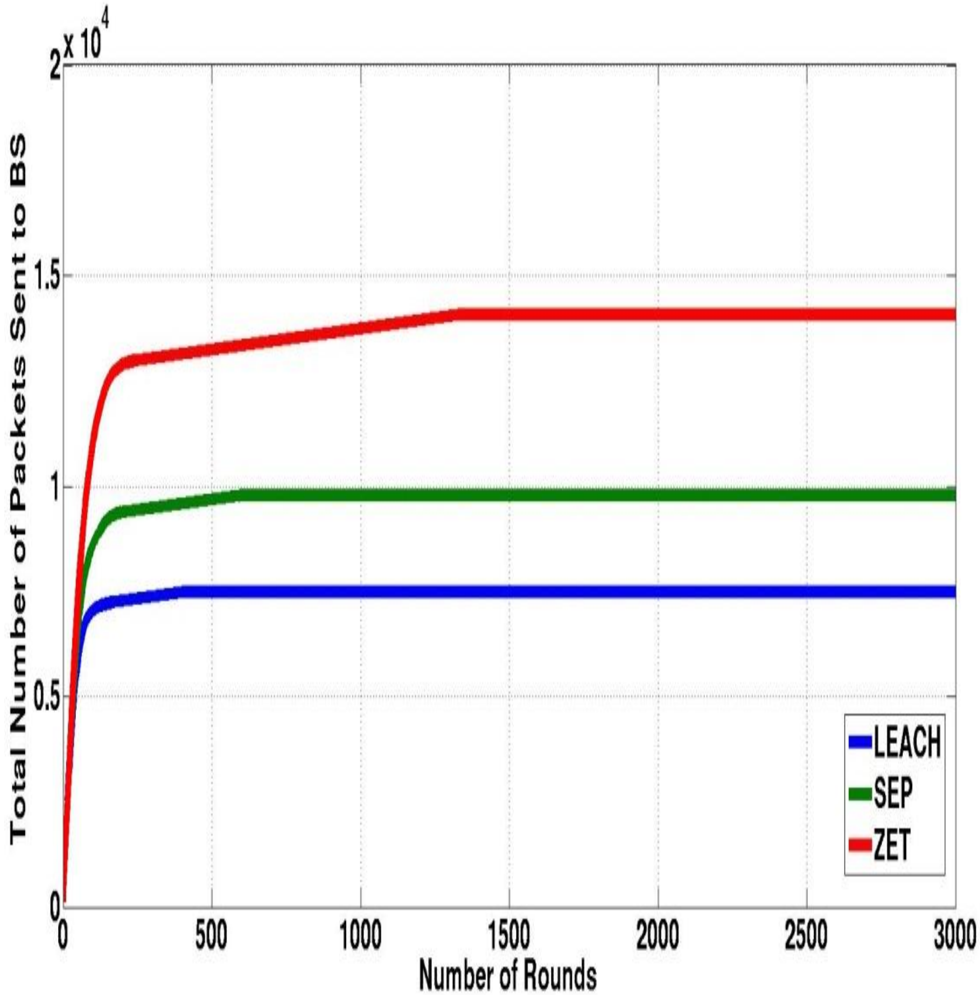


Figure 19: Packets to the BS with 150 nodes in a 150 m x 150 m network.

Figure 19 shows the number of packets sent to the BS from the cluster heads. These results are for 150 sensor nodes in a network area of 150 m x 150 m. This shows that the throughput of ZET is higher than with the LEACH and SEP protocols.

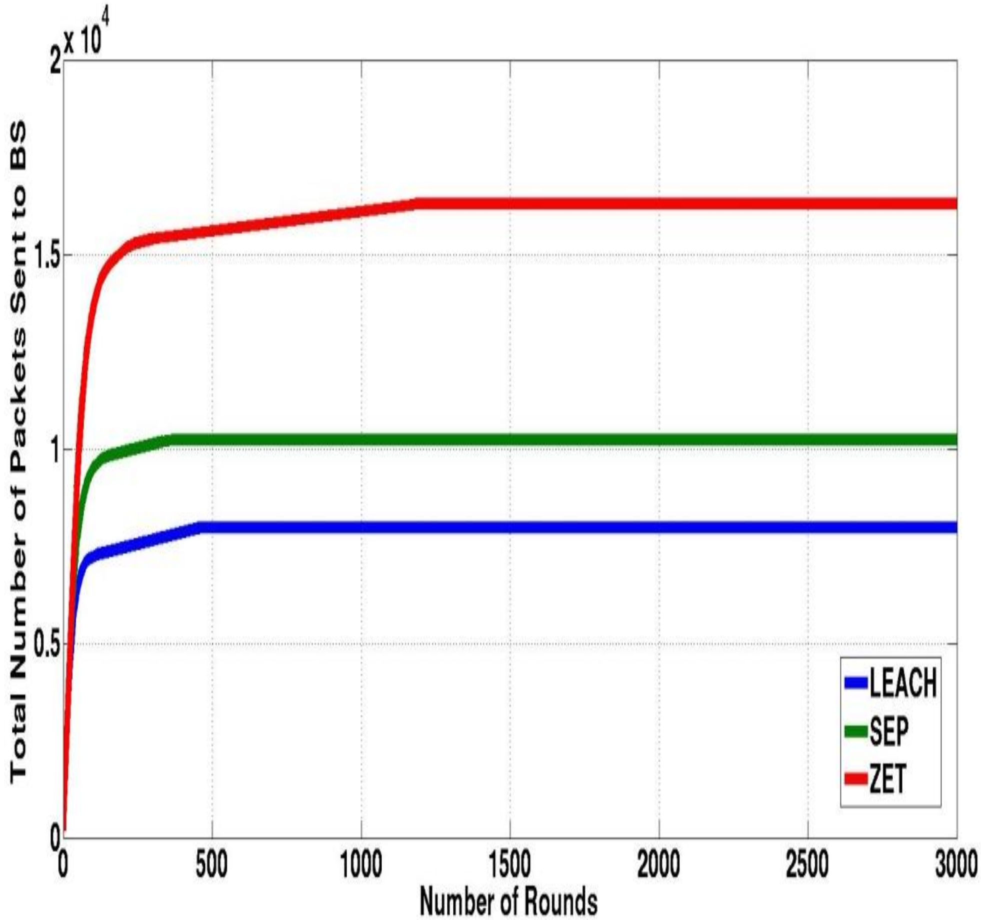


Figure 20: Packets sent to the BS with 200 nodes in a 150 m x 150 m network.

Figure 20 shows the number of packets sent to the BS from the cluster heads. The number of sensor nodes has been increased to 200 in a network area of 150 m x 150 m.

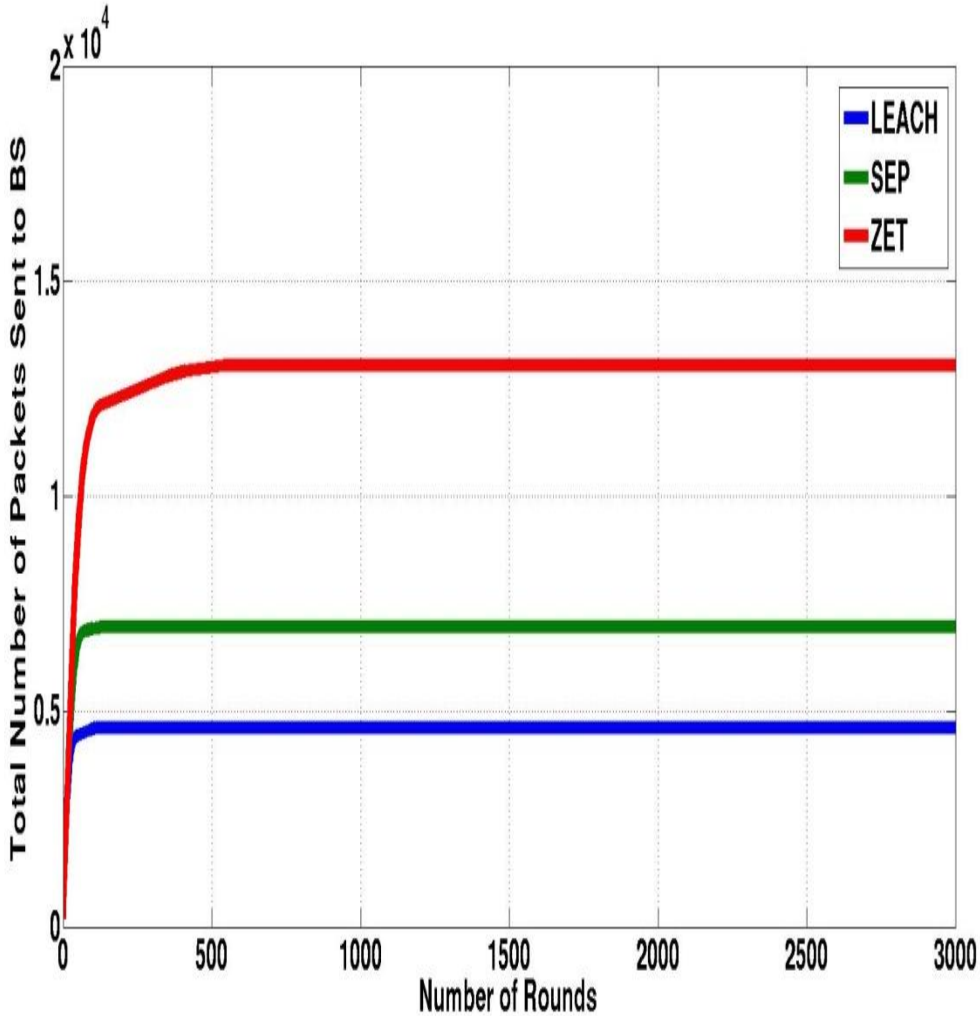


Figure 21: Packets to the BS with 200 nodes in a 200 m x 200 m network.

Figure 21 shows the total number of packets sent to the BS from the cluster heads. These results are for 200 sensor nodes in a network area of 200 m x 200 m. The total number of packets sent to the BS is decreasing for all protocols as the number of nodes and area of the network is increased. Still the throughput of ZET is higher when compared to the LEACH and SEP protocols, as shown in Figures 17 to 21.

4.3 Discussion

Figures 7 to 11 show the network lifetime and the network stability. It can be observed from Figure 7 that ZET has a better network stability and network lifetime than with LEACH and SEP. When the area of the network is increased as shown in Figure 8, the network lifetime for LEACH decreases by 12.5%, SEP by 26%, and ZET by 9.5% compared to Figure 7. It can be observed that the overall performance of the routing protocol decreases but still ZET performs better than LEACH and SEP. This is also true for a network area of 200 m x 200 m with 200 nodes, as the network stability decreases gradually for LEACH and SEP, but still ZET performs better. Figure 22 summarises the network lifetime for the LEACH, SEP, and ZET routing protocol in terms of the number of rounds.

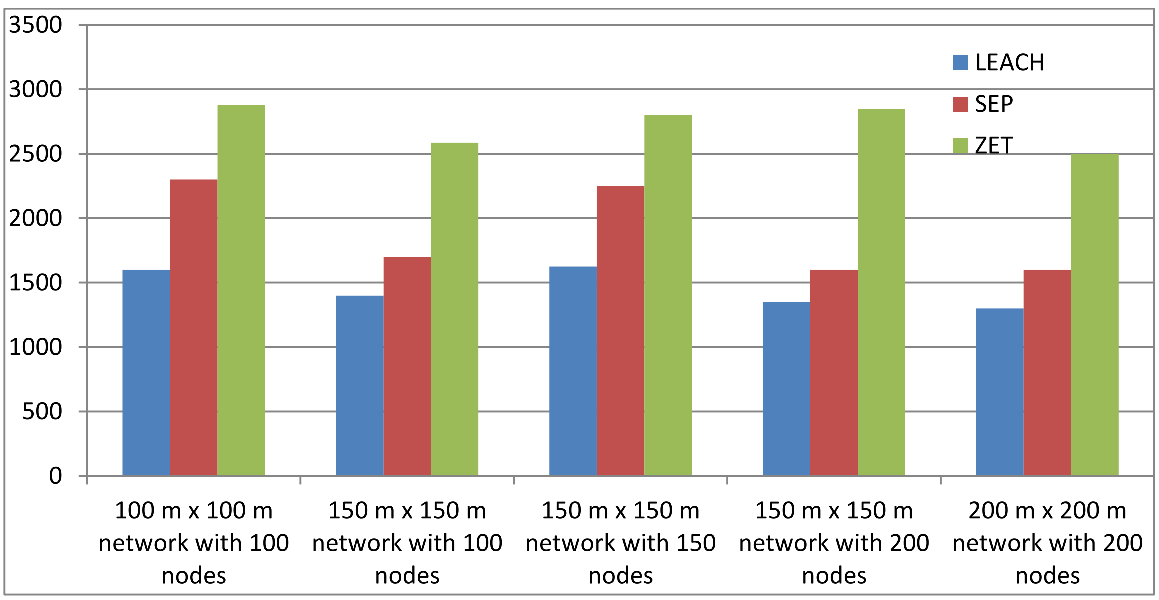


Figure 22: The network lifetime in terms of rounds for the LEACH, SEP, and ZET routing protocols.

Figures 12 to16 show the total number of packets sent to the cluster heads from the nodes for the LEACH, SEP, and ZET protocols. These results show that ZET has a higher throughput than the LEACH and SEP protocols. Furthermore, the number of packets sent to the cluster heads from nodes increases with an increase in the number of nodes in the network, but it gradually decreases the network lifetime. When the area of the network is increased to 150 m x 150 m with 150 nodes, the number of packets sent to the cluster heads from nodes is increased by approximately 25% for the LEACH, 20% for SEP, and 28% for ZET protocol. If the area of the network is increased to 200 m x 200 m with 200 nodes, the number of packets sent to the cluster heads from the nodes is increased by approximately 31% for the LEACH, 35% for SEP, and 40% for ZET. Figure 23 summarises the total number of packets sent to the cluster heads from the nodes for the LEACH, SEP, and ZET routing protocols.

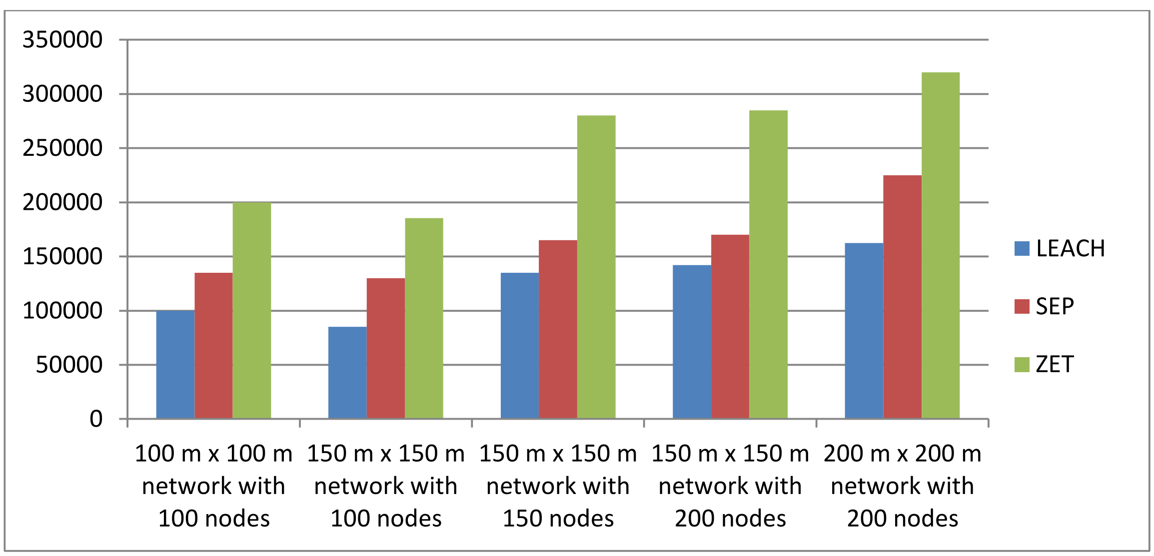


Figure 23: Number of packets sent to the cluster heads with the LEACH, SEP, and ZET protocols.

Figures 17 to 21 show the total number of packets sent to the BS from the cluster heads for the LEACH, SEP, and ZET protocols. These results show that with the ZET protocol the cluster heads send more packets to the BS than the LEACH and SEP protocols. ZET achieves these results because of the prolonged network lifetime, as seen in Figures 7 to 11. It can be observed from the results for the number of packets sent to the BS from the cluster heads that the throughput of LEACH and SEP significantly decreases with an increase in the network area and the number of nodes in the network. This is because of the reduction in network lifetime. As the network area increases the performance of the protocols decreases, but still ZET has better network stability, network lifetime, and throughput than the LEACH and SEP routing protocols. Figure 24 summarises the total packets sent from the CHs to the BS.

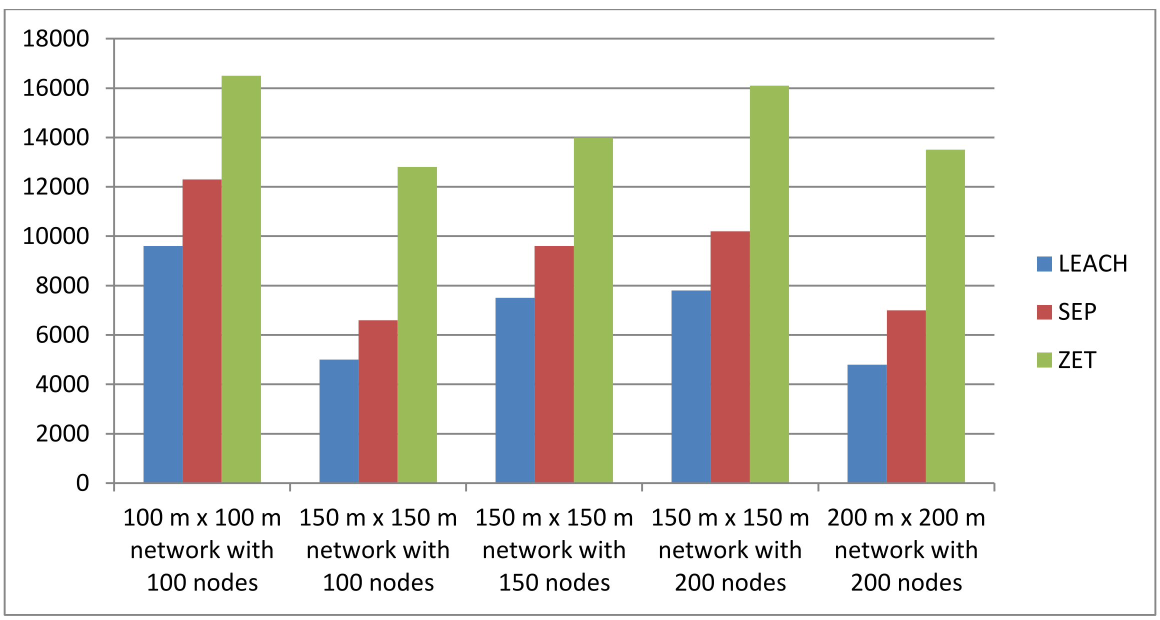


Figure 24: Number of packets sent to the BS with the LEACH, SEP, and ZET protocols.

Chapter 5 Conclusion

In this project, three block cluster based wireless sensor network routing protocols have been implemented, namely LEACH, SEP, and ZET. The ZET routing algorithm provides an improvement of approximately 60% over LEACH and 40% over SEP for the network lifetime, and ZET also improves the network stability over LEACH and SEP. The throughput also significantly increases with the ZET algorithm. It can be concluded that the ZET WSN routing protocol is better than the LEACH and SEP protocols in terms of the network lifetime and throughput. ZET outperforms the LEACH and SEP routing protocols because of the cluster formation process, as in ZET clusters are formed even before the cluster heads are selected. This significantly reduces the complexity of the ZET algorithm. The performance of the ZET protocol decreases with an increasing number of the nodes and area of the network.

References

[1] Z. Jaffri and Y. Cai, "ZET: Zone and energy threshold based clustering routing protocol for wireless sensor networks", *Proc. Computer Commun. and Networks*, pp. 1 - 6, 2014.

[2] S. Singh and S. Sharma, "A survey on cluster based routing protocols in wireless sensor networks", *Proc. Comp. Sci.*, vol. 45, pp. 687-695, 2015.

[3] N. Pantazis, S. Nikolidakis and D. Vergados, "Energy-efficient routing protocols in wireless sensor networks: A survey", *IEEE Commun. Surveys & Tutorials*, vol. 15, no. 2, pp. 551-591, 2013.

[4] R. Soua and P. Minet, "A survey on energy efficient techniques in wireless sensor networks", *Proc. Wireless and Mobile Networking*, pp. 1-9, 2011.

[5] N. A. Pantazis and D. D. Vergados, "A survey on power control issues in wireless sensor networks", *IEEE Commun. Surveys & Tutorials*, vol. 9, no. 4, pp. 86-107, Fourth Quarter 2007.

[6] S. Prasanna and S. Rao, "An overview of wireless sensor networks applications and security", *Int. J. Soft Computing and Eng.*, pp. 2231-2307, 2012.

[7] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks", *IEEE Trans. Wireless Commun.*, vol. 1, no. 4, pp. 660-670, 2002.

[8] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks", *IEEE Proc. Hawaii Int',l. Conf. Sys. Sci.*, pp. 1-10, Jan. 2000.

[9] G. Smaragdakis, I. Matta, and A. Bestavros, "SEP: A stable election protocol for clustered heterogeneous wireless sensor networks", *Proc. Sensor and Actor Network Protocols and Applications,* 2004.

[10] M. Ye, C. Li, G. Chen and J. Wu, "EECS: An energy efficient clustering scheme in wireless sensor networks", *Proc. IEEE Int. Performance, Computing, and Commun. Conf.,* pp. 535-540, 2005.

[11] T. Murata and H. Ishibuchi, "Performance evaluation of genetic algorithms for flowshop scheduling problems", *Proc. IEEE Evolutionary Computation,* pp. 812-817, 1994.

[12] S.S. Panda, "Heterogeneous wireless sensor network", *www.slideshare.net/chinmayjena/hetrogenous-wireless-sensor-network*.

[13] S. V. Krishnamurthy, A. S. Acampora and M. Zorzi, "On the radio capacity of TDMA and CDMA for broadband wireless packet communications", *IEEE Trans. Veh. Technol.*, vol. 52, no. 1, pp. 60-70, 2003.

[14] K. Akkaya and M. Younis, "A survey of routing protocols in wireless sensor networks", *Ad hoc Network J.,* vol. 3, no. 3 pp. 325-349, 2005.