

Multi-Tier Cluster Based Energy Conservative Wireless Sensor Networks

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Abstract: The Wireless Sensor Network (WSN) is made up of numerous nodes that are dispersed at random both close to and far from the base station. Forwarding data generated by remote nodes adds to the communication burdens of the nodes closer to the Base Station (BS). As a result, they lose energy quickly and pass away more quickly than remote nodes. Clustering, multi-hop routing, and two-tier networks that combine evolutionary and classical methods were proposed by several authors as ways to extend the lifetime of networks. Hence, nodes close to or distant from the BS will need to choose shorter pathways for transmission instead of their assigned ones. Thus, depending on their topologies, such as two-tier or three-tier networks, it is possible to guarantee, to some extent, minimal power consumption per bit of transmission. This article has built four-tier networks to further boost lifetime. In addition to increasing the network's lifetime, improved its stability compared to earlier networks by keeping the nodes' energy dissipation uniform. All issues considered, the simulation results show that the proposed networks are superior to the two- and three-tiered networks. Additionally, WSNs' heterogeneous networks were incorporated into this four-tiered network design.

Keywords: cluster heads, network lifetime, routing protocols, wireless sensor networks, energy efficiency, tier networks.

1. INTRODUCTION

The exponential growth of wireless sensor networks (WSNs) is at least partially attributable to the proliferation of smart sensors made feasible by developments in micro electro mechanical systems (MEMS). WSNs are utilized in a wide variety of applications, such as environmental studies, healthcare and many more [1]. The complexity, power consumption, processing speed, communication bandwidth, and storage capacity constraints of WSNs have prompted researchers to seek out alternatives [2]. One node in each cluster acts as the CH in the conventional hierarchical arrangement of sensor nodes. Once the CH has processed data from every sensor in the cluster, it will transmit the results to another hub, which is also known as the sink hub or base station (BS). The LEACH protocol is a prime example of a progressive routing strategy that is frequent in WSNs [2]. It allocates a CH to each cluster in a WSN and divides the network into them dynamically using an optimal probability calculation.

Various topologies impact various aspects of transmission, including power, co-channel interference, and coverage patterns for both transmitters and receivers [3]. The wireless communication between the sensor nodes is not predetermined and uses many hops. Over time, this ad hoc topology may change due to node relocations or modifications to transmission and reception characteristics. In the case of military applications, nodes may occasionally have mobility in intriguing locations to track intruders instead of being static [4]. Limited energy supplies are a problem with these kinds of networks. Enhancing energy efficiency in a number of ways is the goal of numerous research initiatives [5].

Energy management techniques must be applied to lower the total power consumption of all nodes in order to maximize the network's lifespan. The goal of our suggested method, location-based routing, was to find the most energy-efficient way to move

packets from the source to the destination. It is impossible to ignore the problem of excessive energy use. A trust-aware WSN e topology protocol that takes node density and residual energy into account while selecting cluster head nodes is therefore presented in this study. It is designed to be low-energy. The selection of the next hop node according to residual energy and distance to the base station topology is the next step in building these cluster head nodes, which together form a reliable, secure, and energy-efficient network [6].

Energy conservation in sensor networks is directly correlated with longevity since it determines the network's quality in terms of data transmission volume [7]. As the network's energy reserves start to dwindle, it must limit the quality of its output in order to keep the nodes from dissipating power and increase the network's lifetime. There are still a number of obstacles to overcome when designing energy-efficient routing protocols in WSNs. Because of this, it is imperative that protocols be designed with data communication and energy concerns about transmission methods and distances in mind.

II. LITERATURE REVIEW AND PROBLEM STATEMENT

There is significant energy consumption during data retrieval from the CHs and transmission to the faraway base station. Sang H. Kang suggested that the method for optimizing energy efficiency should converge fast enough so that the BS, or management center, could run the optimization algorithm in real time. Their method achieves better average node longevity and energy savings than previous non-optimized LEACH-based approaches. This method is probably going to help current cluster-based algorithms become even more energy efficient. Nevertheless, they did not employ a homogeneous distribution of clusters when choosing sensor nodes [8, 9]. As a result, the most recent proactive routing techniques' energy efficiency is examined from a number of angles. Their assistance supported efforts to move base stations in order to extend the lifespan of these networks.

The hierarchical method developed by Damien Wohwe Sambo enhances network longevity and performance [10]. A WSN's structure is made up of sub networks called clusters, each of which is headed by a cluster head. For WSNs, computational intelligence-optimized clustering techniques outperform traditional clustering algorithms and rely on contextual characteristics. Nevertheless, choosing a suitable paradigm for a clustering solution is still difficult due to the diversity of WSN applications. Several characteristics can be used to classify routing protocols, including "energy efficiency, data aggregation, location awareness, quality of service, scalability, load balancing, fault tolerance, query-based, and multipath" [10]. This sought to solve this hierarchy and improve these systems' energy efficiency by leveraging location awareness, as stated in its citations.

The LEACH technique chooses cluster leaders on a regular basis and rotates positions to distribute energy equally [10]. When choosing to take on the role of cluster leader, each node adheres to a probability distribution. Efficiency in power collection in sensor information systems allows for the placement of base stations or individual hubs along a hub chain (PEGASIS). It will be difficult to put this strategy into action without first having an in-depth understanding of the architecture of global networks. To implement HEED clustering, the nodes to serve as cluster heads are chosen at random. How much energy a node has left over determines how likely it is that it will be elected. Subjects discussed encompassed power usage, resilience, efficiency, placement of sensor nodes, methods for routing, and choice of CH [11]. Finding the best path from the transmitter to the receiving hub remains a challenge, despite the many ways in which routing protocols

have been improved. Determining which CHs to keep for each round is still the biggest obstacle.

Shukun et al. proposed a method for optimizing data transmission between sensor nodes that involves hopping between them in order to create a multi-hop network [12]. Metaheuristic approaches, on the other hand, demonstrate that CH node overburdens influence the NP-hard problem cluster optimization method performance. To make UWSNs last longer and use less energy, they proposed a clustering and routing protocol based on metaheuristic algorithms. However, existing metaheuristic-based approaches combine multi-hop routing and clustering using separate algorithms; this increases computational complexity, calls for distinct initialization, and makes hyperparameter adjustment more difficult. Their negative impacts still make it difficult to choose different multihops, and when larger networks are taken into account for the crucial applications for the suggested work, an excessive number of parameters affects performance.

Underwater wireless sensor networks, according to Mohammed, are submerged sensor networks that use sound waves to communicate with one another. The position-independent, cluster-based EECRU routing algorithm was employed in underwater wireless sensor networks [13]. The concept of special nodes acting as headers is used by the EECRU algorithm. This process uses the neighbor node technique to transfer data if no header is found. Additionally, it uses the CDMA concept to collect data from different nodes, some of which are helpful in extending network lifetime and lowering power usage. Nevertheless, the CH position is not taken into account in the work to be examined, even though the placement with particular nodes has an impact on the overall performance of energy consumption.

Asha looked into how sensor nodes' energy consumption allows WSN to run constantly [14]. "PSO-PSO-WSN, PSO-GSO-WSN, GSO-KGMO-WSN, FCM-PSO-GSO-WSN EBC-S, or RSOM-WSN" are examples of sustained energy conservation approaches that have been improved with bioinspired methodologies or neural computational systems. Additionally, a clever routing technique efficiently delivers the collected data to the base station. The performance of these methods is evaluated in terms of energy consumption, throughput, total data/packet delivered, dead nodes, and living nodes. Their approach did not emphasize the concepts of network longevity and stability.

In order to provide energy-efficient communication between sensor nodes, Prakash investigates cluster-based routing. Sensing and aggregation consume less energy than transmission and reception [15]. Energy-efficient methods are therefore essential for boosting network longevity and stability. From decision-making to node placement, a plethora of solutions have been put forth to enhance energy efficiency. In order to make these methods more precise, we supply more settings for cluster-based routing using an enhanced PSO optimizer. The optimal single or multi-hop relay CH can be selected using these four factors. Their main drawback is that because remote nodes use more energy, the relaying nature results in an uneven distribution of energy. This restricts the potential for further research on selecting CHs with uniform network division.

For WSNs, Kiani et al. created the EEAR protocol to help nodes communicate with one another while reducing power consumption [16]. Using the data-center gradient diffusion routing protocol, EEAR is able to reduce power consumption without compromising communication or sink paths. Although it does not rely on position data, EEAR is just as efficient as location-based protocols when it comes to controlling topologies, routing data, and conserving energy. It also improves packet delivery and lowers average packet latency. Nevertheless, the uniform energy distribution and network stability components don't offer a convincing idea.

In order to extend the network's lifespan, the two tiered networks allocate each node that isn't connected to the right cluster. As numerous cluster heads must be covered, it also ensures a minimum number of relay nodes with better energy provisioning. Occasionally, the nodes that the CHs formed must cover die. To handle data collection, fault-tolerant clustering, and extending the lifetime of sensor networks, three-tier networks have been proposed in recent years [11- 16]. Multiple researchers have hypothesized that taking into account the interconnections (dependencies) between the different layers of a network's protocol stack can lead to a decrease in energy consumption. Some sophisticated topologies allow for the connection of an additional relay node. By identifying minimum power pathways, it must reduce power consumption and hence extend network lifetime. Nonetheless, three-tier networks with the aforementioned top priority must minimize redundant power usage and accommodate the sensor's restricted resources. Topologies are crucial in three-tier networks. Hence, an extra layer may be required from time to time for energy balancing in these types of networks, depending on their complicated topologies. Their long transmission distance to the base station and energy dissipation can be somewhat controlled in this way. There are situations when three-tier networks don't work. In order to address all of the shortcomings of the networks previously discussed, four tiered networks are suggested in this study.

III. AN ENERGY-CONSERVING HOMOGENEOUS NETWORK MODEL BASED ON FOUR TIER WIRELESS SENSOR NETWORKS

To make the most of the algorithms proposed for homogeneous networks in the past, four-tier networks based on the aforementioned approaches are proposed [17-19]. Network stability, data aggregation, and durability can all be enhanced by the proposed network in comparison to two-tier and three-tier designs. Each iteration of this process starts with the cluster setup phase and ends with aggregation in the next third layer node, S3. The CHs with greater residual energy and closer proximity to the BS constitute the fourth layer node, S4. This node goes to the BS with all the network data, as shown in Figure 1 that shows how a four-tier clustering network works.

Assuming $k = \lceil r / (1/p) \rceil$ ensures that every node will transform into a CH precisely once per $k/(p+1)$ rounds. Each node in a network is considered to have completed one epoch when the total number of rounds is equal to $k/(p+1)$. This choice is made by any node that chooses a random integer between zero and one [19]. The updated cutoff is provided by

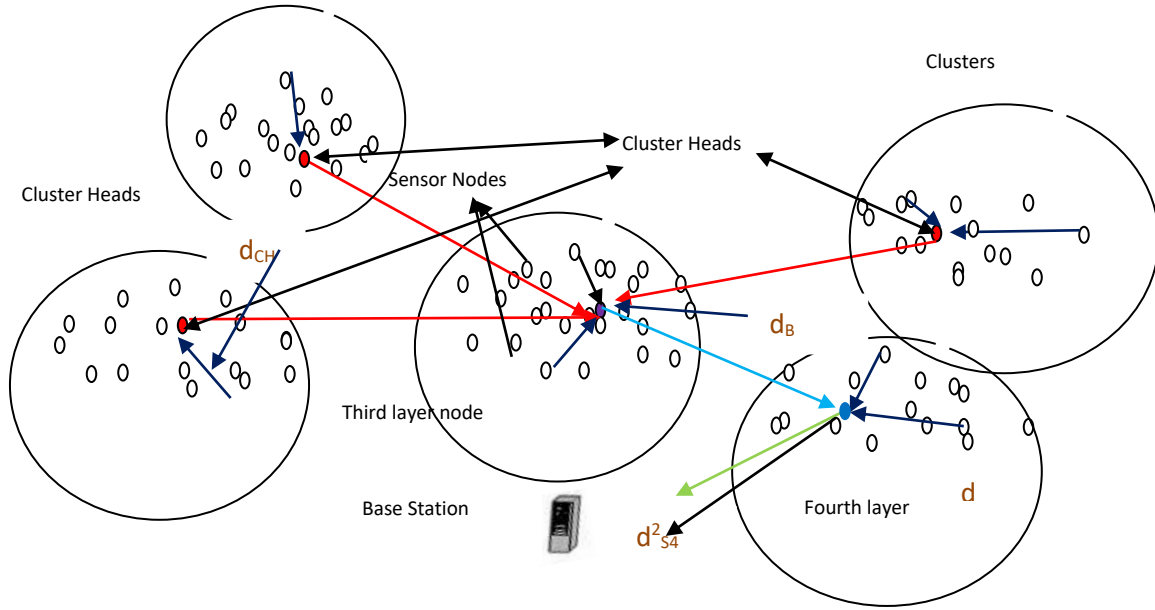
$$n(i) = \begin{cases} \frac{p \cdot N}{(1-p) \lceil \text{rem} \left\{ (r-1) \left(\frac{1}{p} \right) \right\} \rceil} & \text{if } n_i \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

In this context, where N is the currently unformed CH count, G is the set of nodes that were unformed in the previous $1/p$ round, r is the round count of this iteration, and p is the desired proportion of nodes that should form CHs. Should the value fall below the threshold $Th(i)$, the node assumes control of the cluster in this cycle. A threshold is defined by and used to pick the third layer node, S3, from the CHs.

$$Th(i) = \frac{E_{\text{residual}}}{\text{distance}} \quad (2)$$

Distance is the separation from every CH, and residual is the CHs' remaining energy.

Fig. 1. Energy Conservative Four-tier homogeneous system



Using the threshold established by, the fourth layer node (S4) among the CHs is picked.

$$Th(i) = \frac{E_{initcl}}{M^2} \quad (3)$$

where $M \times M$ is the region's area and E_{initcl} is the initial cluster energy.

The S4's energy dissipation is

$$E_{S4} = H * L * d_{S4}^2 = l * \{(3d_{S4}^2 - 1)E_{elec} + E_{amp}d_{S4}^2 y\} \quad (4)$$

where d_{S4}^2 is the distance from BS, H is the number of hops, while L is the amount of data transmitted and received.

The network's overall energy dissipation from constraint Eq. (1) is

$$\begin{aligned} E_{total} &= E_{S4} + k \left[2(z + q - 1)E_{elec} + E_{amp} \left(\sum_{i=1}^z d_{i-1,i}^2 + \sum_{i=1}^q d_{Bj-1,j}^2 \right) \right] \\ &= l * [(3d_{S4}^2 - 1)E_{elec} + E_{amp}d_{S4}^2 y + E_{S4} + k \{ 2(z + q - 1) \} E_{elec} + E_{amp} \left(\sum_{i=1}^z d_{i-1,i}^2 + \sum_{i=1}^q d_{Bj-1,j}^2 \right)] \end{aligned} \quad (5)$$

The proposed four-tier networks as a solution for complex topologies that require longer transmission lines and greater fault tolerances. These networks are designed to be two-tiered since three-tiered networks cannot sustain the complete network for extended periods of time.

IV. A FOUR TIERED WSN NETWORK MODEL FOR ENERGY CONSERVATIVE HETEROGENEOUS NETWORKS

When certain nodes in a heterogeneous sensor network have greater power than the average nodes in the same network, hierarchical routing using this technique is

employed [20]. Assuming that 'm' represents the proportion of nodes that have advanced and that 'α' represents the difference in energy between regular and advanced nodes.

$$p_{nrml} = \frac{p}{(1+\alpha m)} \quad (6)$$

$$p_{adncd} = \frac{p}{(1+\alpha m)} \quad (7)$$

The threshold is as follows :¹⁹ $Th_{(nrml)}$ for conventional sensors and $Th_{(adncd)}$ for advanced nodes.

$$Th(n_{nrml}) = \begin{cases} \frac{p_{nrml}}{(1-p_{nrml}) \left\lceil \text{rem}\left\{(r-1)\left(\frac{1}{p_{nrml}}\right)\right\} \right\rceil} & \text{if } n_{nrml} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

$$Th(n_{adncd}) = \begin{cases} \frac{p_{adncd}}{(1-p_{adncd}) \left\lceil \text{rem}\left\{(r-1)\left(\frac{1}{p_{adncd}}\right)\right\} \right\rceil} & \text{if } n_{adncd} \in G'' \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

In earlier iterations of the epoch, which took place every $1/p_{nrml}$ rounds, the non-CH normal nodes were collected as G' , and the new cutoff for a "population of $n(1 \rightarrow m)$ normal nodes is $Th(n_{nrml})$ ". Assume round as an r . This guarantees that, independent of the round or epoch, every normal node will transform into a CH once per $1/p(1 + \alpha m)$ rounds, and that the average number of normal nodes in cluster heads is $n(1 - m)p_{nrml}$ ". In the last $1/p_{adncd}$ epoch cycles, G'' is the set of nodes that haven't turned CH, and new $Th(n_{adncd})$ is the cutoff for $n*m$ advanced nodes.

This network's overall energy dissipation was determined using Eqs. (6), (7), (8), and (9). Only when a certain percentage of the nodes have more energy than the other nodes can the energy consumption be equal to restriction.

$$E_{total} = l * [(3d_{S4}^2 - 1)E_{elec} + E_{amp}d_{S4}^2y + E_{S4} + k\{2(z + q - 1)\}E_{elec} + E_{amp} \left(\sum_{n=1}^z d_{i-1,i}^2 + \sum_{a=1}^z d_{i-1,i}^2 + \sum_{i=1}^q d_{Bj-1,j}^2 \right)] \quad (10)$$

where 'm' is an advanced node and 'n' is a normal node.

Heterogeneity is expected to increase the extension of network lifetime, as indicated in previous works. Findings are followed by the next section.

V. IMPLEMENTATION OUTCOMES WITH COMPARATIVE RESULTS

For the purpose of comparing algorithms and comprehending the impact of knowledge availability on routing performance, this section assesses the efficiency of two-tiered, three-tiered, and four-tiered networks with diverse routing problems. Here are the metrics from the simulation [20].

Figure captions should be below the figures; table captions should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig.

1” in the text, and “Figure 1” at the beginning of a sentence. Use 8 point Bookman Old Style for figure labels. Use words rather than symbols or abbreviations when writing figure-axis labels to avoid confusing the reader

TABLE 1 Simulation Metrics

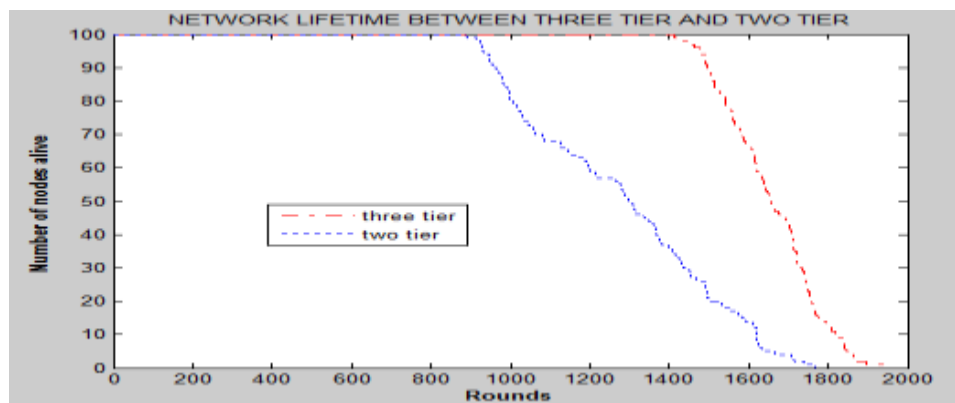
Parameter	Value
Packet length	200 bytes
E_{init} (Initial energy of node)	0.5J
Data Aggregation(EDA)	0.5nJ/bit
E_{elec} (Radio electronics energy)	50nJ/bit
Size of Network	100m X 100m
ctrPacket Length of EDA	2000 bytes
Number of nodes	100
E_{amp} (Radio amplifier energy)	100pJ/bit/m ²
Bandwidth	1Mb/s

The sensor network consists of one hundred sensor nodes that are randomly placed inside a 100 m x 100 m region. Depending on the homogeneity of the sensors, a number of WSN groups with various topologies have been taken into consideration. Data packets transmitted to BS, network stability, energy consumption, and the selection of cluster heads have all varied among the various tiers of networks. One way to determine the lifetime and stability of a network is by looking at the total energy left in the system and the quantity of aggregated data packets delivered to the base station (BS).

A. Comparison of two-tiered and three-tiered networks' lifetime longevity

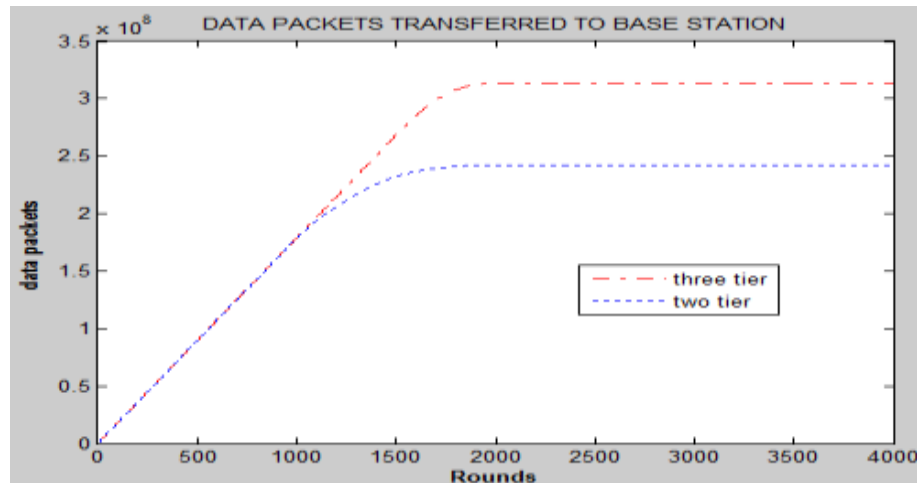
Simulations of two-tier and three-tiered networks have been conducted using the parameters described in the previous papers. Networks with three tiers outlasted those with two tiers, as seen in Figure 2, due to the third layer node. This third-tier node relays information from the cluster nodes to the base station. By minimizing transmission distance and energy dissipation between nodes, three-tier networks are able to prolong their lifetime.

Fig. 2. Comparison of the lifetimes of three-tiered and two-tiered networks.



For two-tiered networks, it shows that all nodes died at 1770 rounds, while for three-tiered networks, it shows that all nodes died at 1979 rounds. Both networks show signs of stability after 848 and 1303 cycles, respectively. These numbers demonstrate that three-tiered networks can outperform their predecessors with a revised selection criterion for the node in the third layer.

Fig. 3. Two-tiered and three-tiered networks' data packet to base station comparison.

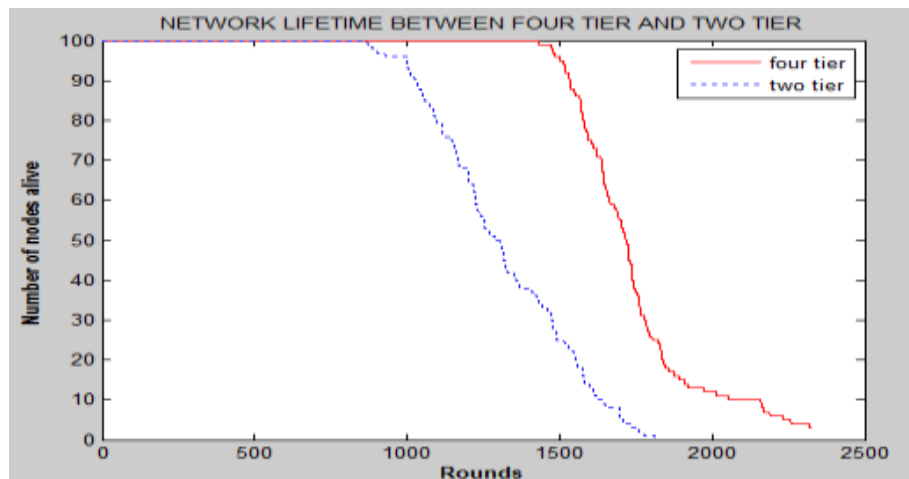


In Figure 3, we can see a comparison of the data packets transmitted to BS using each of the given strategies. Two-tiered networks can transport 2.4×10^8 data packets, while three-tiered networks can transfer 3.1×10^8 data packets. As a result, it can send more packets to the third layer node.

B. Network lifespan comparison between two-tiered and suggested four-tiered networks

When compared to two-tiered networks, the four-tiered networks in Figure 4 exhibit superior network longevity and stability.

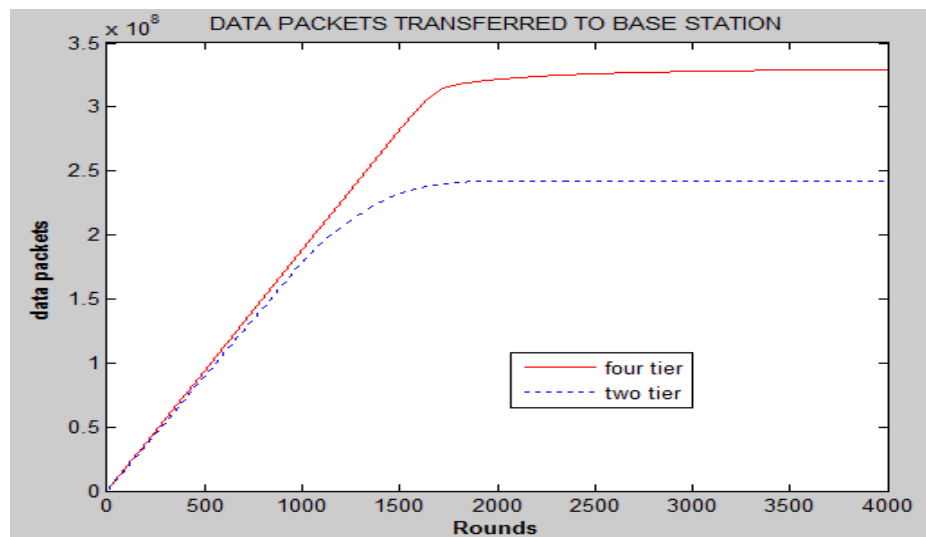
Fig. 4. A comparison of the lifetimes of two-tiered and four-tiered networks.



The data in Figure 4 shows that for two-tiered networks, every node died at 1770 rounds, but for three-tiered networks, it was 2403 rounds. The duration of stable operation for these two networks is 848 and 1342 cycles, correspondingly. The node in the fourth layer of such networks helps with the energy-efficient preset paths.

Figure 5 shows that unlike the two-tiered networks, which can only transport 2.4×10^8 data packets, the four-tiered networks can transfer 3.35×10^8 data packets. According to these figures, the four-tiered networks had a higher capacity for information gathering with effective routing methods and shorter transmission distances.

Fig. 5. Two-tiered and four-tiered networks' data packet to base station comparison.



C. Network lifespan comparison between heterogeneous and two-tiered networks

Previous studies have shown that four-tiered heterogeneous networks, like the ones shown in Figure 6, are more stable and last longer than two-tiered networks. The suggested algorithm was also applicable to heterogeneous networks.

According to the data in Figure 6, for two-tiered and three-tiered networks, respectively, the death of every node occurred at 1770 and persisted for over 4000 cycles. The maximum number of rounds that either network may remain stable is 848 or 3350.

Fig. 6. Lifespan of heterogeneous networks: comparing four-tier and two-tier designs.

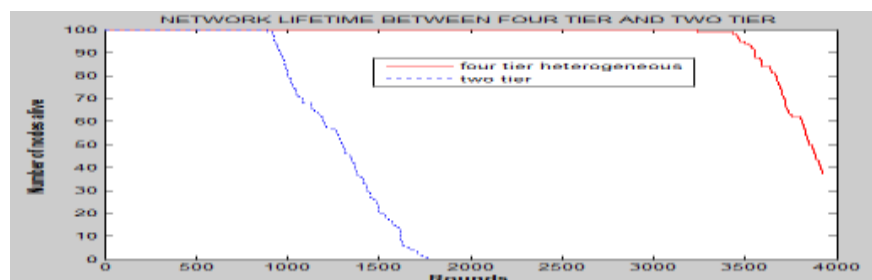
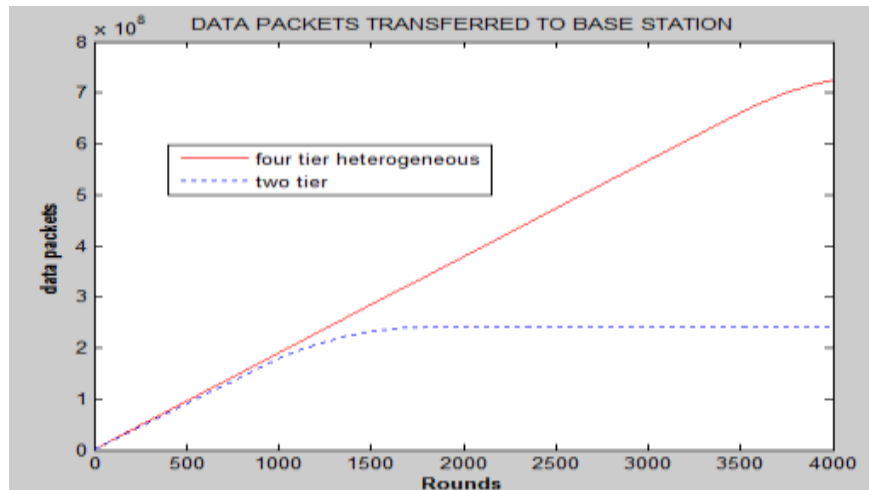


Figure 7 illustrates that the four tiered heterogeneous networks can transfer 7.2×10^8 data packets, but the two tiered networks can only transfer 2.4×10^8 data packets. When compared to the earlier networks, the statistics show that it performed exceptionally well in every way.

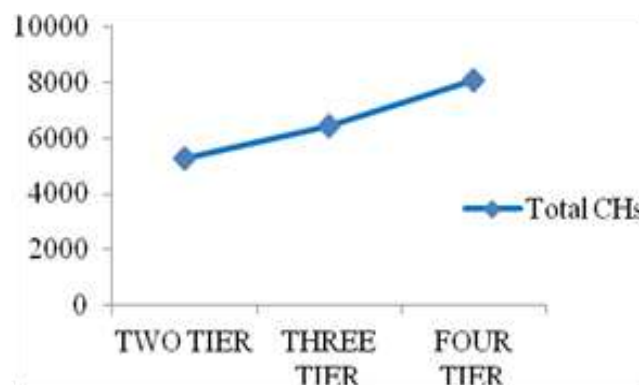
Fig. 7. Comparing data packets sent to base stations in two-tiered and four-tiered heterogeneous networks.



D. Additional characteristics of the suggested algorithm in comparison to two- and three-tiered networks

Additional features, such as cluster head selection and the lifetime history of CHs utilizing alternative networks, can be investigated using the simulations described in the preceding section. Over the course of their lives, Figure 8 compares the overall number of CHs generated in each round". Over the lifetime of a two-tiered network, there are 5257 rounds generated; for a three-tiered network, the total number of rounds is 6451; and for a four-tiered network, it is 8078 CHs.

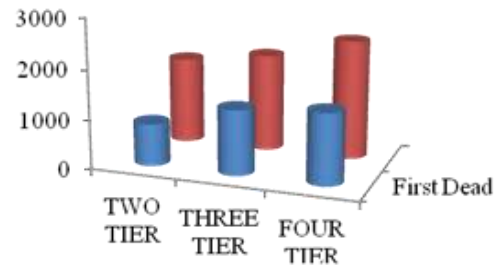
Fig. 8. Comparison of CHs created over the course of each tiered network's lifetime.



Unlike the two-tiered and three-tiered networks, where all nodes perished at 1770 and 1979 rounds, respectively, the proposed network had no such fatalities at 2401.

Compared to the other two networks, the one with the proposed algorithm has kept energy efficiency higher in Figure 9.

Fig. 9. Network stability and longevity comparison across all tiered networks.



The performance of each of the three networks over the course of their lives is shown in Table 2, which is based on simulations using the corresponding tiered networks. According to these figures, the four-tiered network outperformed the other two networks in terms of network lifetime.

TABLE 2 Comparison of all algorithms with the simulations' features

Algorithm	FND	LND	Total CHs formed	Packets sent to BS
Four tier homogeneous	1421	2401	8078	3.35×10^8
Four tier heterogeneous	3350	>4000	10990	7.2×10^8
Three tier homogeneous	1303	1979	6451	3.1×10^8
Two tier homogeneous	848	1770	5257	2.4×10^8

These findings indicate that four-tiered networks have outperformed the other two networks. The benefits of any other network include specified channels with shorter communication lengths for nodes, communication bandwidth, energy-efficient nodes to become cluster heads, and appropriate threshold values for transmission distances. Without proper attention in selecting nodes for the third and fourth layers, a network may not last as long. Hence, a distance-and residual-node-based threshold needs to be built for different topologies. Another important consideration is the potential energy loss to the nodes in the upper layers when building networks beyond the four levels.

VI. CONCLUSION

In this paper, using distance and high residual energy as thresholds for the second and third tiers of the network, this study suggests a four-tiered architecture that can increase network longevity, reduce energy dissipation, and ensure data packet delivery to both base stations. Results from simulations and analyses comparing the three networks show that the four-tier design uses the least amount of energy. Various

topologies for future development are also taken into consideration in the enlarged suggested work.

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