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Comparative Study of Metaheuristics Cluster based Routing Protocols for Energy Aware Wireless Sensor Networks

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Abstract

A wireless sensor network (WSN) is an infrastructure-less network that has low cost, compressed sensor nodes (SNs)for monitoring the physical environments. WSN role a crucial play in surveillance and tracking applications such as precision agriculture, environmental monitoring, natural disaster prevention, smart cities, weather predicting, disaster management, border surveillance, and so on. Due torestricted and non-rechargeable batteries, the accessible energy of nodes is employed effectively. The clustering approachsplits the network and groups the neighboring nodes as clusters. The clustering technique was referred to as NP hard optimized problem and function of meta-heuristics isextremelyhigherthan the capabilityfor resolving continuous optimized problems. The routing system was required to send the data betwixt the SNs as well as base stations (BS), for establishing communications. The CH selection and routing procedure are assumed that NP hard problem and swarm intelligence (SI)approaches are utilized for resolving it. With this motivation, several researchers have concentrated on the design of swarm intelligence based clustering protocols to accomplish maximum energy efficiency and network lifetime in WSN. Numerous works have been developed on accomplishing energy efficiency via clustering and routing techniques in WSN. Therefore, this article aims to offer a detailed performance analysis of different cluster based routing techniques available in WSN. The paper mainly focused on the metaheuristic optimization algorithms for cluster based routing in WSN. In addition, the system model and energy model widely followed in WSN are explained briefly. Finally, a detailed experimental result analysis of different cluster based routing models takes place under different measures.

Keywords: Wireless sensor networks; Clustering; Routing; Energy efficiency; Metaheuristics

1. Introduction

A wireless sensor network (WSN) includes abundant low-cost and low power-sensing tools. An enormous amount of sensor nodes (SNs) self-assembled to form a largescale network, and SNs might observe information in the physical environment [1]. The weaker transmission abilities and utilization of the energy strictly confine the application and development of WSNs. SNs have a limited energy supply and are arbitrarily distributed throughout the region where the network coverage [2]. Such non-uniformity of distribution density makes variation in quantity of information transmitted from all the sectors. The higher density sector gathers extremely interrelated information whereas lowest one has coverage problems owing to early termination of isolated nodes. A consideration in each WSN is sensor battery lifetime which depends on utilization of energy by transferring information in these networks. The algorithm of lower energy consumption routing protocol become a primary area of R&D [3]. WSN comprises of small sensor that is distributed over the whole network and has abilities to sense the information, process, and convey it from one node to another. Such a sensor senses nature accepts, evaluates, and sends it. Weather forecasting, Military, industrial area, agriculture medical services, etc., uses WSN for transmitting information. The sensor is very compact in size and limited battery power. Once the sensor is located in the no-man harsh nature, such sensors are utilized in a satisfactory manner since they could not be charged and replaced [4]. Node drains its energy in two manners namely sense the natural information and convey the information to BS. Fig. 1 depicts the architecture of WSN.

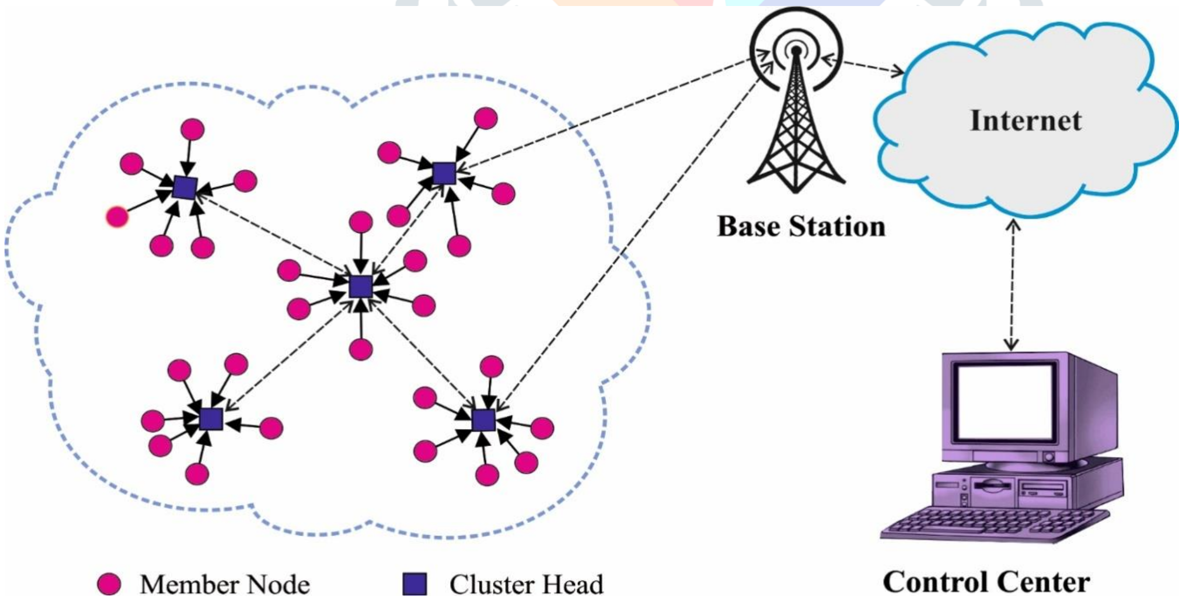

Fig. 1. Structure of WSN

The problem of CH selection (CHS) is assumed to be a significant problem because it is crucial to balance energy consumption. Also, the common CHS is another problem that should be extremely concentrated, meanwhile frequent CHS results in minimized network lifetime and energy imbalance. Most CHS scheme is incapable to sustain the balance among exploration and exploitation [5]. Currently, incorporation of global as well as local search algorithms is assumed to be prospective in preserving the degree of balance among exploration and exploitation. The inadequate power source of the SNs is regarded as a major problem in

WSNs. As a result, the failure in network rises due to node failures. Consequently, the significant variation among WSNs and others is susceptible and hypersensitive to the energy [6]. The SNs consume their energy rapidly due to direct transmission of information from all the sensors to BS. Furthermore, the optimum energy consumption in WSNs is essential to increase WSN performance and accomplish higher lifetime. As a result, integration of SNs into clusters is exploited for increasing the scalability and decreasing energy utilization of the networks. All the clusters of network have single header, called Cluster Head (CH) that interacts with other CHs of networks [7]. Since high quantity of energy is essential to directly transmit the sensed information to BS, a routing technique is utilized in the clustered WSN to recognize the better routes among the BS and CHs to decrease consumption of the energy.

Hierarchical based (or cluster based) routing method is a popular method with certain advantages that are related to efficiency and scalability in transmission. The model of hierarchical routing was executed for attaining energy efficacy in WSN [8]. On the other hand, low power node is only applied for sensors in the area that are nearby to the target. Thus, making clusters and assigning specific jobs to CHs could prominently give to its power efficiency, the scalability of the system, and its lifespan. Scalability is a crucial factor in WSN that hasn't been determined well in several protocols because of the early assumption made. For instance, cluster-based protocol considers single sink with CHs inside the coverage of sink [9]. In this consideration, WSN lacks scalability and causes communication that are extreme interms of power requirement. Therefore, moderately elevated the overall amount of device nodes or network width might result in overloading that exponentially progresses, and an interruption that only encompasses an individual sink; that could suppress the network. The hierarchical routing is an effectual means for reducing power utilization inside cluster and execute data accumulation. Besides, this methodology allows integration tasks to reduce the amount of transported packets to the sink [10]. Each perception of node, after hardware device to the obtained process, might assist to distribute the power load. In this regard, hierarchical routing has numerous parts to help in differentiating feasible phases in protocol process; the obtainability of two process modes from the SNs could evaluate moderately higher energy costs. But different communication modes, such as normal sensors and CHs, might be beneficial when implemented in all the layers.

Several researchers have focused on the design of swarm intelligence based clustering protocols to achieve maximum energy efficiency and network lifetime in WSN. Numerous works have been developed on accomplishing energy efficiency via clustering and routing techniques in WSN. Therefore, this article aims to offer a detailed performance analysis of different cluster based routing approaches available in WSN. The paper mainly focused on the metaheuristic optimization algorithms for cluster based routing in WSN. In addition, the system model and energy model widely followed in WSN are explained briefly. Finally, a detailed experimental result analysis of different cluster based routing models takes place under different measures.

2. System Model

Primarily, network models and their topological infrastructure is determined as distinct network configurations are introduced based on the necessities of applications. The network systems contain the features of SNs. Conversely, during the network infrastructure, the establishment of WSNs comprises the utilization of nodes from the sensing region for generating a topological infrastructure where the data is gathered. In such consideration, the presented protocol assumes the subsequent network models and infrastructure.

Network assumptions:

1. The network is one BS, a group of CH, and group of SNs n
2. The power of BS was externally provided, but the energy of SNs are restricted
3. SNis assumed that dead once it can be away from power
4. EachSN is homogeneous

Network structure:

a. Primarily, every node is arbitrarilyusedfrom the sensing region
b. The node place is not altered in the entire life of networks
c. The BSwas located at the center of sensing regions
d. The count of clusters could not be set
e. All the normal nodes (also termed leaf node) is along with their nearest CH

If the network topology was defined, the total network connection establishing procedurestarts, whereas the set-up stage was applied. During the set-up stage, primary CHs were selected for building primary cluster network configurations. During the selection of optimum CHs, the presented method assumes the subsequent energy consumption method.

3. Analysis of Different Cluster based Routing Techniques

Al-Otaibi et al. [11] grow a hybridization of meta-heuristic cluster based routing (HMBCR) approach for WSN. The HMBCR system primarily contains a brainstorm optimized with levy distribution (BSO-LD) based clustering procedure utilizing a fitness function (FF) incorporating 4 variables namely distance to neighbors, energy, network load, and distance to BS. In addition, a WWO-HC based routing model was implemented to an optimum selective route.Lakshmanna et al. [12] examine an improved meta-heuristic-driven energy-aware CBR (IMD-EACBR) approach for IoT-supported WSNs. The presented approach aims for achieving maximal energy consumption and network lifespan. To obtain this, the abovementioned technique initially plans an improved Archimedes optimization algorithm-based clustering (IAOAC) approach for CH selection (CHS) and cluster organization.

In [13], a Hybrid ABC and Monarchy Butterfly Optimization Algorithm (HABC-MBOA) dependent upon CHS approach were presented to predominant selective of CHs in clustering procedure. This presented HABC-MBOA exchanges the utilize bee step of ABC having with mutated butterfly altering function of MBOA to prevent previous trap of solutions as to local optimum point and delayed convergence with maintained the trade-off betwixt exploitation as well as examination. This presented method as an anchor role in eradicating insufficiency of ABC technique concerning universal searching potential. This projected HABC-MBOA even removes the probability of CHs presence overloaded with maximal count of SNs which outcomes from quick death of SNs in the deployment of ineffective CHS procedure.

In [14], employed a Butterfly Optimization Algorithm (BOA) for selecting an optimum CH from node groups. The CHS can be maximized through the nodes RE, node centrality, the neighbor's distance, aloofness to BS, and node mark. The route among the BS and the CH can be recognized through the use of ACO, it chooses the best route related to the node gradation, distance, and RE. In [15] grant a hybrid meta-heuristic algorithm-related clustering including multihop routing (HMA-CMHR) protocol for WSN. The proposed algorithm includes various stages like data transmission, node initialization, and clustering, routing. First, the HMA-CMHR algorithm will use quantum HSA (QHSA) related clustering procedure for choosing an optimum CH subset. Then, the enhanced cuckoo search (ICS) technique-related route approach was used for the best assortment of routes.

Mohan et al. [16] present an enhanced metaheuristic-related clustering including multihop routing protocol for underwater WSNs, called the IMCMR-UWSN approach. The main purpose of the aforementioned approach was to select CHs and best routes to destiny. The IMCMR-UWSN approach includes 2 procedures one is the self-adaptive glow worm swarm optimization algorithm (SA-GSO)-oriented multi-hop routing and the chaotic krill head algorithm (CKHA)-oriented clustering. The CKHA method will select organizes and CHs related to various variables like inter-cluster distances, RE, and intra-cluster distances. Also, the SA-GSO technique will derive a FF including 4 variables, such as trust, RE, detachment, and delay.

In [17] study BOA can be utilized for choosing the optimal amount of CH from the nodes. The variable that can be regarded to choose the CH was the RE of the node, interspace from nodes, and interspace from the BS, node degree, and node importance. The PSO can be employed for constituting the CH through selection of some variables like interspace from the BS and the CH. The path can be selected through ACO system. The route was maximized by the remaining power, interspace, and select node degree.BARNWAL et al. [18] focused on model of metaheuristics cluster-related routing approach for energy-efficient WSN (MHCRT-EEWSN). The proposed MHCRTEEWSN method mostly focuses on the enhancements of energy efficiency and lifetime of WSN through routing and clustering procedures. For successful clustering procedure, the MHCRTEEWSN method uses whale moth flame optimization (WMFO) approach employed for FF linking balancing factor, intra-cluster distance, and inter-cluster distance.

In [19], a multi-Objective nature-inspired technique relevant to Shuffled frog-leaping algorithm and Firefly Algorithm (named MOSFA) as an application-specific clustering-related multi-hop routing protocol was modelled. MOSFA's multi-objective operation regards various criteria (e.g., intra -and inter-cluster detachments, load of clusters, the RE of nodes, overlap, and distances from the sink) for choosing suitable CHs at every round. Furthermore, another multi-objective function can be modelled for choosing the forwarding nodes from the routing stage. The controlled variables of MOSFA in cluster and multi-hop stages are optimally tuned for achieving the optimal performance relevant to the network necessities in accordance with the particular application.

In [20], an energy efficient clustering and routing protocol was formulated. An ICSA that would use an innovative multiobjectiveFF was modelled for optimum CHS. Additionally, Monkey search algorithm was employed for identifying the optimum path from the CH to sink nodes. In [21], proposed new energy-efficient clustering routing protocols for WSNs related to Yellow Saddle Goatfish Algorithm (YSGA). TIT can be envisioned for strengthening the lifespan of network through reduction of energy consumption. The network will consider BS and CHs sets in its clustering structures. The count of CHs and assortment of best CHs can be decided through the YSGA approach when SNs were allotted to their nearest CH. The network's cluster structure can be reconfigured by YSGA for ensuring the best distribution of CHs and to minimize the communication distance.

In [22], the author provides a reactive hybrid protocol for enhancing lifespan of the network utilizing the hybridization of ACO along with PSO technique. For enhancing the energy efficiency, the estimated RAP technique will use a reactive data communication technology which can be incorporated into the hybridization of PSO and ACO methods. At first, the clusters can be systematized dependent on the RE, and then the devised RAP approach is performed for improvising inter-cluster data aggregation and minimizing information communication.In [23] modelled a fuzzy knowledge-related meta-heuristic algorithm related to multi-objective fuzzy inference system (moFIS) and bacterial foraging optimizations (BFOs), called moFIS-BFO, as an effective routing protocol for gathered WSN. In this presented approach, the moFIS can be used for computing the chance of every node to become a CH relevant to distinct criteria which include detachment of BS, degree difference, total distance to neighbors, and RE. Considering the computed chances of nodes, the BFO was used for choosing appropriate CHs at each round.

Vaiyapuri et al. [24] devise an IoT supported CBR protocol for data centric WSNs (ICWSN), called CBR-ICWSN. The devised approach would undergo a black widow optimization (BWO) related clustering algorithm to elect the optimum set of CHs. In addition, the above-mentioned method includes an oppositional ABC (OABC) related routing procedure for choosing paths optimally.In [25], a method for both selecting the CH and choosing the effectual path in a WSN for IoT tenders was devised. The CHS can be a portion of clustering performed through a multi objective rider optimized algorithm (ROA) that assumes three objectives such as delay, energy, and distance. The routing was executed through selection of optimal and efficient paths utilizing the multi-objective sailfish optimization method (SFO).

4. Performance Validation

This section evaluates the performance of diverse cluster based routing techniques.Table 1 and Fig. 2 report the alive node (ALN) examination of several cluster based routing techniques [11-13]. These results implied that the existing models have shown improved ALN values compared to other methods. For instance, on 250 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR models have obtained ALN of 94, 96, 98, 93, and 99 respectively. Besides, on 500 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR approaches have acquired ALN of 88, 88, 89, 84, and 87 correspondingly. Moreover, on 750 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR methodologies have accomplished ALN of 80, 87, 87, 78, and 79 respectively. Along with that, on 1000 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR techniques have realized ALN of 75, 82, 82, 73, and 70 correspondingly. At last, on 1250 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR systems have obtained ALN of 65, 78, 73, 74, and 63 correspondingly.

Table 1 ALN analysis of several cluster based routing techniques under distinct count of rounds

Alive Nodes (%)					
No. of Rounds	**FUCHAR**	**GWO**	**HABC-MBOA-CHSS**	**FFCGWO-CHSS**	**IMD-EACBR**
0	100	100	100	100	100
250	94	96	98	93	99
500	88	88	89	84	87
750	80	87	87	78	79
1000	75	82	82	73	70
1250	65	78	73	74	63
1500	60	65	61	51	57
1750	51	59	60	0	53
2000	46	42	0	0	45
2250	32	30	0	0	40
2500	30	20	0	0	29
2750	19	16	0	0	10
3000	10	12	0	0	6
3250	0	8	0	0	4
3500	0	0	0	0	2
3750	0	0	0	0	0
4000	0	0	0	0	0
4250	0	0	0	0	0
4500	0	0	0	0	0

4750	0	0	0	0	0
5000	0	0	0	0	0

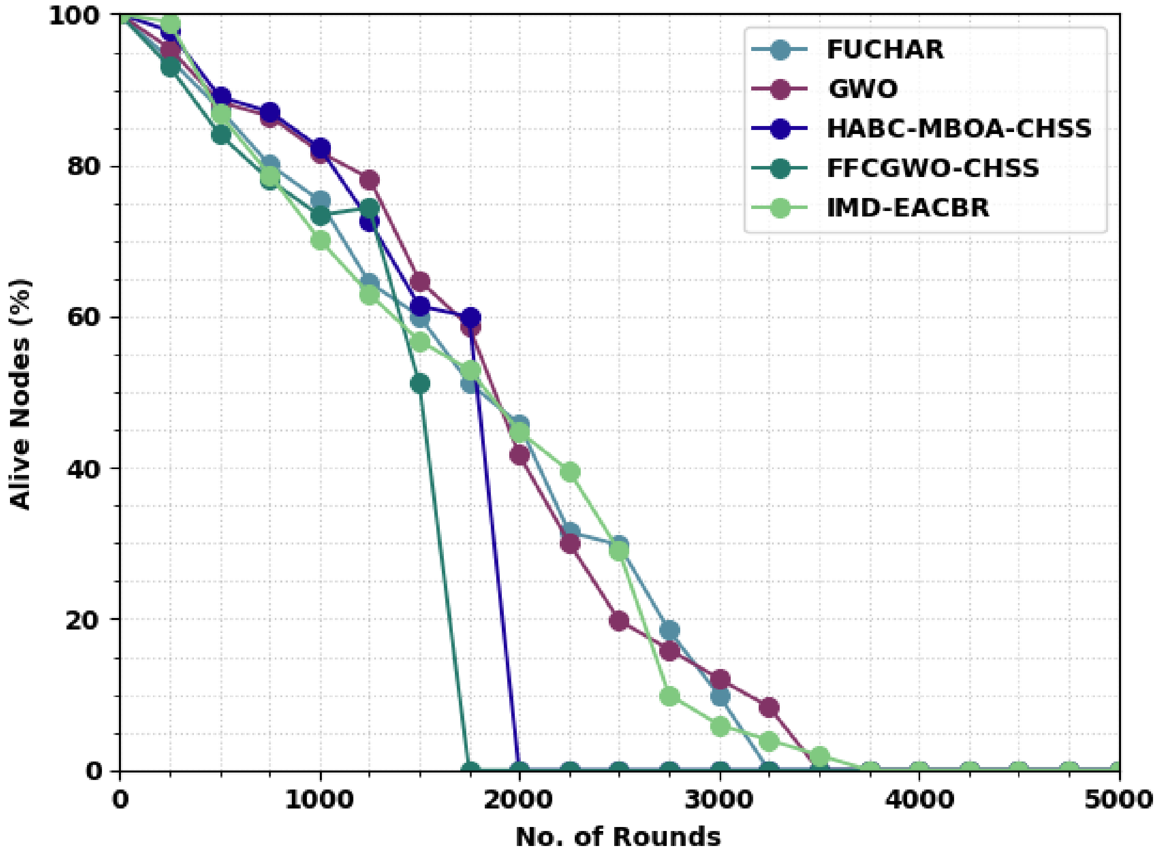

Fig. 2. ALN analysis of several cluster based routing techniques

Table 2 and Fig. 3 offer the average residual energy (ARE) investigation of several cluster based routing approaches. These outcomes revealed that the existing approaches have exhibited improved ARE values compared to other methodologies. For instance, on 250 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR models have achieved ARE of 0.9805, 0.9831, 0.9660, 0.9095, and 0.9470 correspondingly. Besides, on 500 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR techniques have gained ARE of 0.9705, 0.9781, 0.8180, 0.8895, and 0.9410 respectively. Moreover, on 750 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR techniques have obtained ARE of 0.9655, 0.9681, 0.7430, 0.8655, and 0.8550 correspondingly. Besides, on 1000 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR models have reached ARE of 0.9605, 0.8981, 0.6015, 0.8625, and 0.8500 respectively. Eventually, on 1250 rounds, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR techniques achieved ARE of 0.9555, 0.8981, 0.6015, 0.8625, and 0.8500 correspondingly.

Table 2 ARE analysis of several cluster based routing techniques under distinct count of rounds

Average Residual Energy					
No. of Rounds	**FUCHAR**	**GWO**	**HABC-MBOA-CHSS**	**FFCGWO-CHSS**	**IMD-EACBR**
0	1.0000	1.0000	1.0000	1.0000	1.0000
250	0.9805	0.9831	0.9660	0.9095	0.9470
500	0.9705	0.9781	0.8180	0.8895	0.9410
750	0.9655	0.9681	0.7430	0.8655	0.8550
1000	0.9605	0.8981	0.6015	0.8625	0.8500
1250	0.9555	0.7831	0.5840	0.8055	0.5550
1500	0.9505	0.6481	0.5650	0.7615	0.5280
1750	0.8305	0.5481	0.3940	0.7275	0.3440
2000	0.6805	0.4181	0.3820	0.6615	0.3230
2250	0.6605	0.3481	0.3670	0.6095	0.2840
2500	0.4305	0.1981	0.0200	0.5475	0.2440
2750	0.3605	0.1631	0.0130	0.2445	0.1190
3000	0.3005	0.1281	0.0000	0.2265	0.0230
3250	0.0000	0.0981	0.0000	0.1465	0.0000
3500	0.0000	0.0000	0.0000	0.0275	0.0000
3750	0.0000	0.0000	0.0000	0.0265	0.0000
4000	0.0000	0.0000	0.0000	0.0205	0.0000
4250	0.0000	0.0000	0.0000	0.0045	0.0000
4500	0.0000	0.0000	0.0000	0.0000	0.0000
4750	0.0000	0.0000	0.0000	0.0000	0.0000
5000	0.0000	0.0000	0.0000	0.0000	0.0000

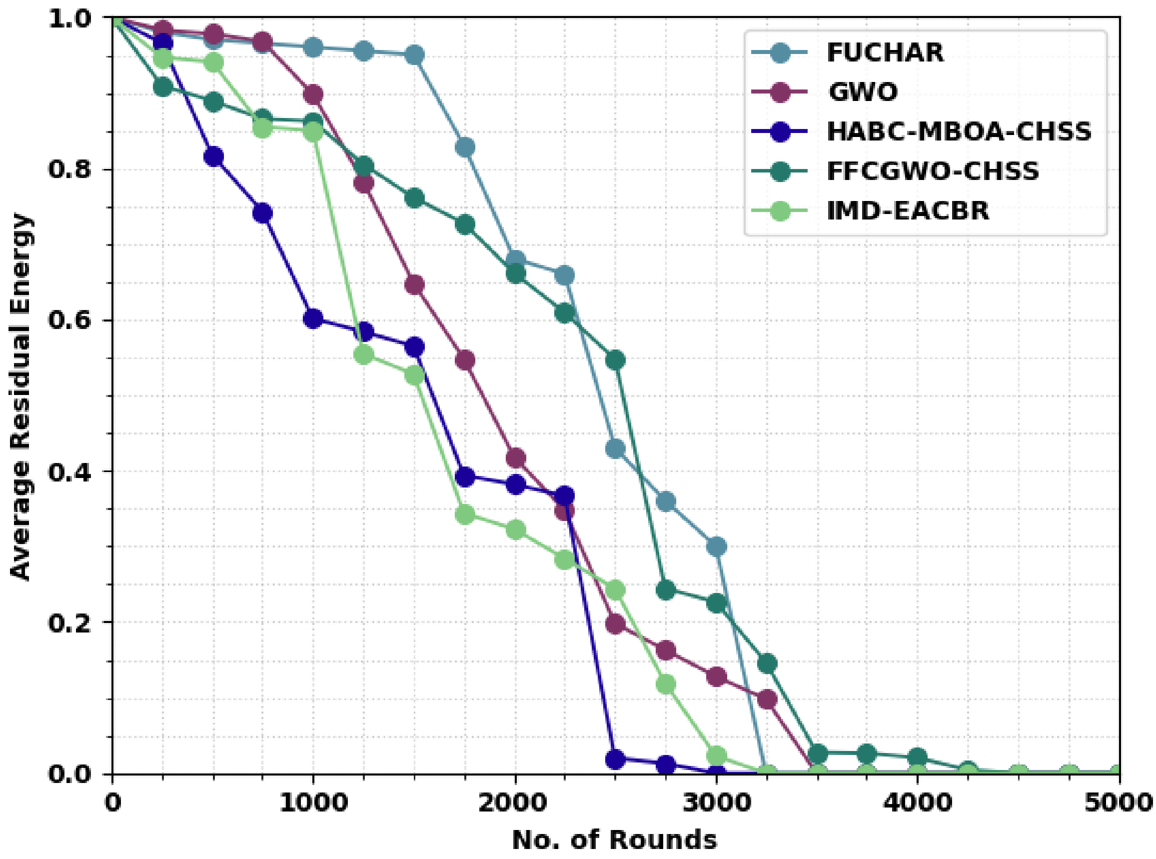

Fig. 3. ARE analysis of several cluster based routing techniques

Table 3 and Fig. 4 determine the packet delivery ratio (PDR) inspection of several cluster based routing approaches. These outcomes revealed that the existing techniques have outperformed enhanced PDR values compared to other methods. For instance, on 10% nodes, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR models have achieved PDR of 98.77%, 98.39%, 96.53%, 95.59%, and 94.39% correspondingly. Moreover, on 20% of nodes, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR systems have gained PDR of 98.51%, 97.91%, 96.41%, 95.48%, and 94.01% correspondingly.

Table 3 PDR analysis of several cluster based routing techniques under distinct count of nodes

Packet Delivery Ratio (%)					
Nodes (%)	**FUCHAR**	**GWO**	**HABC-MBOA-CHSS**	**FFCGWO-CHSS**	**IMD-EACBR**
10	98.77	98.39	96.53	95.59	94.39
20	98.51	97.91	96.41	95.48	94.01
30	98.52	97.59	96.42	95.34	93.72
40	98.20	97.65	96.29	95.13	93.53
50	97.99	97.37	96.04	94.87	93.27
60	97.57	96.55	95.88	94.47	92.85
70	97.14	96.66	95.38	94.31	92.65
80	97.00	96.11	95.02	94.00	92.56
90	96.50	95.15	94.60	93.50	92.27
100	96.63	95.18	94.72	93.50	92.37

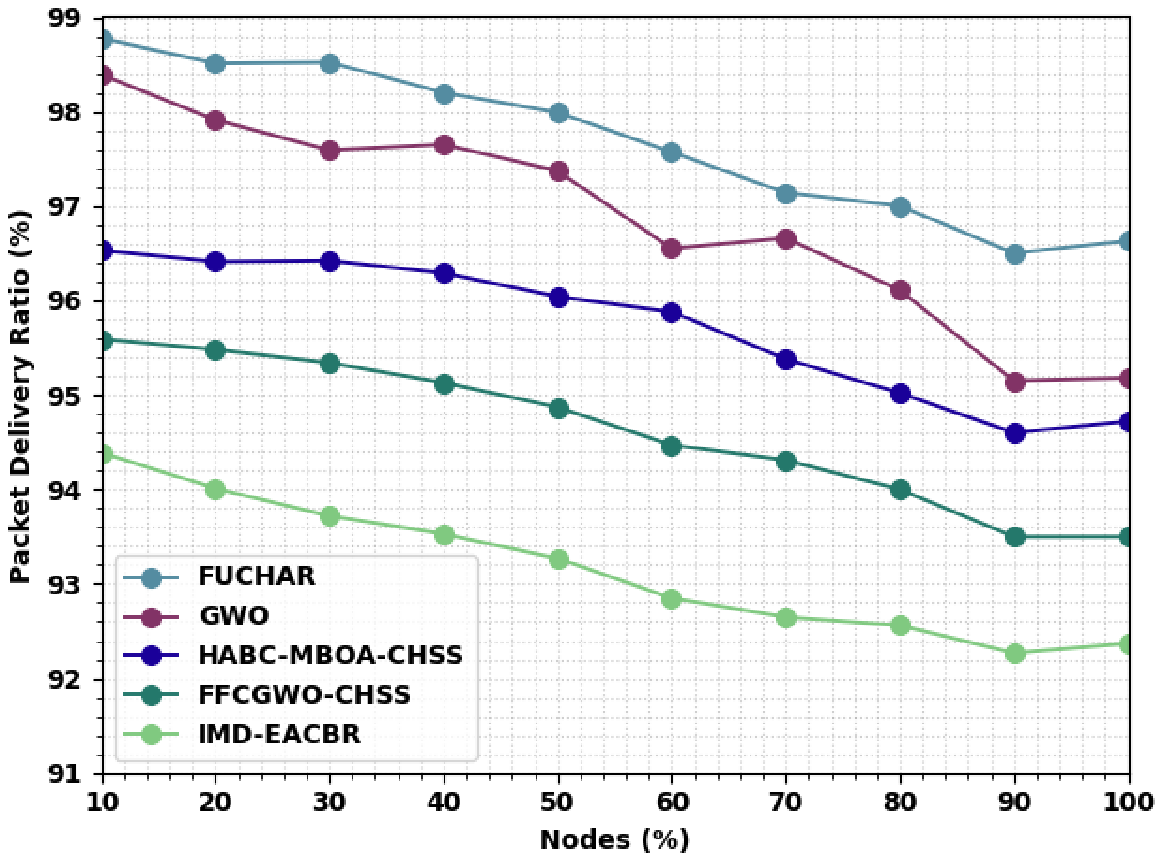

Fig. 4. PDR analysis of several cluster based routing techniques

Additionally, on 30% of nodes, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR techniques have obtained PDR of 98.52%, 97.59%, 96.42%, 95.34%, and 93.72% correspondingly. Followed by, on 40% of nodes, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR systems have achieved PDR of 98.20%, 97.65%, 96.29%, 95.13%, and 93.53% respectively. Finally, on 50% of nodes, the FUCHAR, GWO, HABC-MBOA-CHSS, FFCGWO-CHSS, and IMD-EACBR techniques have obtained PDR of 97.99%, 97.37%, 96.04%, 94.87%, and 93.27% correspondingly.

5. Conclusion

Several researchers have concentrated on the design of swarm intelligence based clustering protocols to achieve maximum energy efficiency and network lifetime in WSN. Numerous works have been developed on accomplishing energy efficiency via clustering and routing techniques in WSN. Therefore, this article aims to offer a detailed performance analysis of different cluster based routing techniques available in WSN. The paper mainly focused on the metaheuristic optimization algorithms for cluster based routing in WSN. In addition, the system model and energy model widely followed in WSN are explained briefly. Finally, a detailed experimental result analysis of different cluster based routing models takes place under different measures. In future, the performance of the clustering techniques can be extended to the development of unequal clustering approaches for hot spot mitigation in WSN.

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