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ORIGINAL RESEARCH ARTICLE

Hybrid energy balancer for clustering and routing techniques to enhance the lifetime and energy-efficiency of wireless sensor networks

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ABSTRACT

Clustering and Routing have been recognized as one of the most proficient methods for the conservation of energy. In addition, efficient routing further enhances the energy-saving capacity of WSNs (Wireless sensor networks). In this work, a hybrid technique is proposed that usages the prominent features as multiple energy-conserving techniques have been combined to develop a configuration that delivers a highly efficient Wireless network that not only saves energy but also transmits data efficiently. The Clusters are designed and Cluster Heads (CH) are designated by maintaining a minimum distance from the basic nodes for quick data transmission from source to destination. The concept of multiple cluster heads is proposed to provide secure and efficient transmission without losing the data packets. Three cluster heads are selected from each cluster so that when the energy in one Cluster head is exhausted the second Cluster head takes over to continue data communication thus increasing the lifetime of the network. The unequal clustering concept is used to avoid the issue of hot spots as well as Energy Balancing. In this clustering, lesser clusters are positioned closer to the base station. Depending on the energy distribution, the Nodes in the cluster are divided into advanced nodes, intermediate nodes, and normal nodes. The two paths routing method is adopted for rapid transmission towards the Base station. Finally, an evaluation of the proposed technique with the existing comparable techniques has been done which shows that the proposed system gives better results in terms of energy consumption, lifetime, and the number of alive nodes.

Keywords: clustering; routing; conservation of energy; Wireless Sensor Networks (WSNs); hybrid technique; multiple energy conservation techniques; cluster heads; unequal clustering; energy balancing; two paths routing method; energy consumption; lifetime; alive node

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1. Introduction

Wireless Sensor Networks (WSNs) play a crucial role in various applications, such as environmental monitoring, industrial automation, healthcare, and smart cities. These networks consist of a large number of tiny, resource-constrained sensor nodes that communicate with each other to collectively gather and transmit data to a central base station or sink node[1]. One of the most significant challenges in WSNs is to ensure an extended network lifetime and energy-efficient operation, given the limited battery power of sensor nodes. To address these challenges, researchers have been exploring innovative approaches that combine clustering and routing techniques with energy-balancing strategies. The proposed solution, known as the Hybrid Energy Balancer (HEB), aims to enhance the overall performance of WSNs by efficiently distributing energy consumption across nodes while optimizing data routing[2].

The universal concept of the Internet of Things (IoT) is the collection of information from billions of devices and sharing of this information with the same number of consumers. The Wireless Sensor Networks nodes are substantial in the applications of IOT because these nodes play a significant role in the collection and transmission of data[3]. The WSNs are the collection of sensor nodes that sense environmental parameters in any area and then transmit them to the base station. Once charged and distributed nodes cannot be recharged again, hence, increasing the network lifetime by saving the node energy is a critical as well as important issue that is being progressively explored[4]. Apart from the clustering method, routing is also one of the exclusive ways to save node energy. So, a combination of routing and clustering techniques (the proposed work) helps in conserving energy thereby improving the network's lifetime. Furthermore, a proficient clustering technique with a two-path routing technique that improves the lifetime of a wireless sensor network substantially as compared to the existing techniques is also proposed[5].

1.1. Clustering techniques

Clustering involves grouping sensor nodes into clusters, where one node acts as the cluster head (CH) and coordinates communication within the cluster. The use of clustering reduces energy consumption by minimizing long-distance transmissions and maximizing data aggregation within each cluster. This technique helps in prolonging the network lifetime by ensuring that only a subset of nodes, the cluster heads, participate in the long-range communication with the base station[6].

1.2. Routing techniques

Routing strategies determine how data is forwarded from source nodes to the base station or other destination nodes. Efficient routing protocols are essential to minimize energy consumption and prolong the network's lifetime. The Hybrid Energy Balancer leverages advanced routing techniques that consider factors like node energy levels, link quality, and network traffic to determine optimal paths for data transmission. These routing algorithms help in preventing energy depletion in specific nodes and enable load balancing across the network[7].

2. Literature review

Different techniques have been proposed in the field of wireless sensor networks that help in increasing the longevity of wireless sensor networks. The researchers have proposed a framework that uses a wireless external energy balancer to improve the lifetime of the network[8]. Initially, n-level clustering is proposed to reduce energy consumption and then an energy balancer is proposed to refurnish energy to the network. The proposed n-level clustering is going on varying with time. In the first stage initially, the clusters select a CH adjacent to other nodes to minimize the consumption of energy. Suitable CHs are selected in other clusters also based on the minimum distance to other Cluster heads so that data transmission requires lesser energy[9].

Some researchers proposed a wireless energy balancer, a mobile device with a sophisticated battery capacity, which will be able to exchange energy within the sensor nodes in the network. By using a suitable clustering method, energy balancing, which is a critical issue in WSNs, can be achieved[10]. A soft k means clustering algorithm is proposed for the balancing of WSNs. The authors find the concreteness peaks using fast search and kernel density estimation to find the initial cluster centers. The nodes with comparatively large distances and high local density are chosen as the initial centroids[11]. The nodes at the edges of the cluster are reassigned to lower-density clusters for proper balancing and better clustering results. Since the clustering process is a continuous process, multiple cluster heads are used to reduce the communication cost as well as to reduce the balance load of Cluster heads. An HMBCR i.e., hybridization of metaheuristic cluster-based

Routing for wireless networks[8]. This technique originally comprises brainstorming optimization with a distribution-based clustering process called Levy with four considerations as a load of the network for selection of CH based on its residual energy, Node distance towards the base station, Distance within the neighbor's nodes, and Energy. Furthermore, WWO-HC i.e., a water wave optimization with a hill-climbing method is proposed for route selection in the network[9].

Researchers say that recent advances in various heuristic clustering protocols have helped in energy conservation in various WSN applications. The authors here have proposed an improvement in the existing stable election protocol (SEP), which had proposed a threshold-based cluster head selection process for a heterogeneous network[10]. Therefore, for every round, CHs and Clusters keep on changing. Nodes that are nearer to the base station need not spend much energy for transmission of data and therefore consume lesser energy hence the same cluster can be continued[11]. The proposed work introduces a new threshold value for each type of node and this threshold value determines whether the CH and cluster need to change for the next round. If the CH is below the threshold value, the CH changes, and hence cluster have to change. Since CH requires higher energy as it has to perform many additional duties as compared to a simple node such as aggregation and fusion the CH must be equipped with extra energy and this is done by providing a high amplification level to CH only[12]. A new routing algorithm based on key factors such as stability period, network lifetime, and throughput is used for determining an optimum routing path in the proposed algorithm. The algorithm also proposes switching energy levels between CHs and sensor nodes so that energy is saved[13].

Some researchers focus on an efficient CH selection scheme that rotates CH position among nodes with higher energy levels as compared to others. The proposed algorithm considers the factors such as initial energy, residual energy, and an optimum value of CHs to elect the next group of CHs for networks that are suitable for IOT applications. It is proposed to have two stages which are the set-up and steady-state stages[14]. First, the clusters are formed and then CH is selected. For the transmission of data, all the redundant bits are removed to reduce the volume of data. Initially, CHs are selected using the Low-energy adaptive clustering hierarchy (LEACH)algorithm. After data transfer takes place there is an expenditure of energy that is different for every node depending on the distance to the Base Station (BS). Hence once the CHs are selected, they send messages to the member nodes to ask which of the CHs they would like to join[15]. Based on the signal strength of the nodes which is derived based on the signal strength of the request message transmitted, the nodes decide the CH that it wants to join. The CH then transmits the Time Division Multiple Access (TDMA) schedule to the nodes to transmit data to avoid data collision. This process continues till exhaustion of energy. During the data transmission process, only the transmitting node is active, and the remaining nodes are switched off to save energy. After the whole of the data is transmitted, then the CH removes the redundant data to compress the data for better utilization of bandwidth, and data is then transmitted to BS via single or multiple hops[16].

The authors have proposed an unequal clustering scheme to overcome the hot spot problem in WSNs. As is known clustering is one of the effective solutions to improve the longevity of WSNs by saving energy but it also gives rise to the hot spot problem. Unequal clustering solves the hot spot problem in WSNs[17]. Unequal clustering has proved to be successful in a varied number of network densities such as sparse, medium, and high-dense WSNs. The unequal clustering approach not only enhances the CH node lifetime but also the number of alive nodes resulting in a longer lifetime. The hot spot problem is solved by proper load balancing among CHs[18]. The concept of unequal clustering proposed by the authors consists of placing small-sized clusters near the base station and as one moves away from the base station cluster size goes on gradually increases. Since the clusters nearer to the base station are involved more in inter-cluster communication whereas clusters away from the base station have more intra-cluster communication, unequal clustering provides for a fair balance between inter-cluster and intra-cluster communication. This not only eliminates the hot spot problem but also increases the longevity of WSNs[19].

A variety of energy-efficient programs has been reviewed such as multi-sink, mobile sink, multipath, bio-inspired, and power control techniques. The authors suggest that these methods can be simultaneously applied for achieving more energy efficiency[20]. A common goal may be followed in the future wherein multiple sinks may be supported so that energy consumption reduces resulting in a prolonged lifetime of wireless sensor networks. The authors also suggest that the partitioning phenomenon can also be avoided by using multipath routing. Using this method helps in providing more than one path for routing of data, reducing the traffic problem and also reducing energy consumption[21]. Power control schemes can also be proposed to reduce energy consumption. Bio-inspired techniques are also suggested that help in finding the shortest paths. The authors also propose that in the future, there is a large number of open research issues that can be researched which includes combining more than one energy-efficient scheme for improving the lifetime of WSNs. The authors also propose cross-layer paradigms to conserve more energy[22].

The authors have proposed methods considering the critical problem of energy conservation. AnRadio Frequency (RF) energy-efficient harvesting scheme is proposed using multiple devoted RF sources to prevent energy holes. It aims to control the number of energy transmitters and then place them optimally[23]. In multi-hop WSNs, it is very essential to avoid energy holes. For doing that, the authors propose to enhance the lifespan of relay nodes. So the aim is to place the energy transmitters in such a way that, they are placed adjacent to the sink, where the energy hole exists[24]. For the optimal placement of energy transmitters, the authors adopt a utility function, to maximize the energy charged by relay nodes and to maintain a minimum energy level among all nodes. A utility function is defined for placing the energy transmitters, ensuring more weight for supplying energy to relay nodes, and maintaining minimum energy among all sensor nodes. For an optimum number of energy transmitters, an optimization problem is solved while satisfying the constraint on minimum energy charged by each sensor node[25].

3. Proposed methodology

A hybrid technique is proposed that builds a framework of a WSN that not only saves energy but also increases the network lifetime. This technique utilizes the salient features of some existing works. In the proposed work, 100 nodes are distributed randomly in an area. The base station is assumed to be placed away from the distributed area. The nodes are given different energies and the since nodes nearer the base station have a lesser load, the nodes with lesser energy are placed near the base station[26]. Nodes are divided into normal, intermediate, and advanced nodes depending on the energy distribution. The nodes are also placed in the same way that nodes with lesser energy are placed near the base station and are called normal nodes, followed by intermediate nodes which have medium energy followed by advanced nodes which have higher energy[27]. The nodes nearer the base station have only the function to work as relay nodes whereas the nodes far away from the base station have also to collect the data and transmit it to the CH and then to the base station. Secondly, in the system, it is proposed to have unequal clustering with the number of clusters nearer the base station being smaller in size and as one move away from the base station, the size of the clusters goes on increasing[28]. The advantage of such a system is that it provides for proper energy balancing as well as avoids the hot spot problem. For the clusters, circles are drawn from the base station with the size of the circles increasing as one move away from the base station. The nodes falling in each circle form one cluster. Once the clusters are formed, the next step is the selection of Cluster heads. For this, it is proposed to have three cluster heads[29]. The node with the highest energy is selected as Cluster Head 1 followed by a node with the second highest energy as Cluster Head 2 and a node with the third highest energy as Cluster Head 3. Thus, initially the data is transmitted through Cluster Head 1. After a few rounds of communication, when the energy of CH1 is exhausted, CH2 takes over and performs the functions of the Cluster head. Once the energy of the CH2 is exhausted, CH3 continues the process of data collection and transmission. Thus, the data transmission continues for a long amount of time thus increasing the lifetime of the network. Once clustering is accomplished the next step is routing[30]. For routing purposes, it is proposed to send the data from the Cluster head to the base station using two paths. An alternative path is established from the Cluster head to the base station. In case, the distance between the source and destination is more than a relay node is also used for data transmission. The advantage of the second path is that data may be transmitted rapidly through both paths simultaneously[31].

3.1. Clustering and routing

The process of clustering and routing consists of two stages which are the cluster set-up stage and the data transmission stage. In the proposed technique, at first, clusters are formed and then three CHs are selected in each cluster. During the transmission process, the cluster heads aggregate data from the nodes in their respective clusters and then sends it to the base station directly or through a relay node[32].

3.2. Cluster head selection

The process can be formulated as an optimization problem and may be mathematically expressed as

$$Ft_{CH} = \alpha \times R_{energy}^{CH} \quad (1)$$

Where,

α—Constant.$R_{energy}^{CH}$is the ratio of the average energy of Cluster heads to the average energy of normal sensor nodes in the current round.By maximizingR_{energy}^{CH}, the nodes with greater energy are nominated as CH.

3.3. Relay node selections

If the base station is at a distance more than the threshold value, then it is necessary to select a relay node and transmit the data through it. In the proposed method, the relay node is selected based on two conditions.

In criterion-1 node with the uppermost remaining energy should be selected.

In the second criterion, the nearest node to the base station is selected among the Criterion-1 selected nodes.

If there are ‘t’ potential relay nodes RN1, RN2, RN3, …, RNt, amongst the CH and Base station, then

The Relay node selection equation is expressed as

$$Ft_{RN} = \beta \times R_{energy}^{RN} + (1 - \beta) \times R_{location}^{RN} \quad (2)$$

where, R_{energy}^{RN} is the ratio of the average residual energies of Relay nodes and Sensor nodes,$R_{elocation}^{RN}$ represents the location of the nearest node to the base station. Maximizing the R_{energy}^{RN} results in the selection of a Relay node amongst all the higher energy nodes.

3.4. Energy consumption analysis

Let us assume that there are ‘n’ clusters and the number of nodes in every cluster is ‘m’. The proposed algorithm has given an idea of three cluster heads. Therefore, the number of the sensor nodes in each cluster is (m-3), which gives the total number of nodes in the cluster except the cluster heads. Furthermore, the energy consumed by a sensor node for signal transmission and reception and the occasional sleep phases can be computed as,

$$E_{sn} = (1 - ps)[E_{tx}(l, d) + E_{rx}(l)] + p_s E_s \quad (3)$$

The aggregated data, by the Cluster Head, is transmitted directly or through the CH node nearer the node to the base station[33]. Depending on the space between the cluster head and the BS i.e., base station, this free space model or multipath model is selected.

Hence energy dissipated by the Cluster head is given as,

$$E_{ch} = E_{tx}(l, d) + (m - 3)E_{rx}(l) + ml(E_{da}) \quad (4)$$

where, ‘m’ is the number of sensor nodes in a cluster, and the $E_{da}$is the energy dissipated per bit due to data aggregation.

Therefore, energy dissipation within a Cluster is given as,

$$E_{Cluster} = E_{ch} + mE_{sn} \quad (5)$$

Therefore, the total Energy consumed is given as,

$$E_{total} = E_{Cluster} \times n \quad (6)$$

where, ‘n’ is the number of Clusters in the network.

The proposed method is stepped as; the nodes (all 100) are distributed in an area of size 300 m × 300 m. The distribution is done in such a way that, the lesser energy nodes are placed near the base station; these nodes are called normal nodes. The sensor nodes with intermediate energy are the intermediate nodes and nodes with higher energy are called the advanced nodes. The base station is fixed at a distance away from the square area or area of distribution of nodes.

1) Overlapping circles are drawn in the square area where nodes have been distributed with smaller circles. These small cluster circles are near to the base station and larger circles were away from the base station for the unequal clustering.
2) Nodes in the corresponding area are made to join the clusters whose cluster heads are near the nodes in the overlapping areas.
3) The Cluster Heads are nominated once the processing of clustering is completed. As the proposed work three cluster heads are designated in each cluster to enhance the network lifetime to transmit the data from source to destination.
4) After every step of receiving, processing, and transmitting the data packets the residual energy of the CH is measured out. Finally, the node with the highest energy is elected as CH1, and the node with the second is CH2, and CH3 for the third highest energies node.
5) Initially, CH1 will act as the cluster head, and after data communication when the energy of the first CH1 is exhausted. Now, CH2 takes over and acts as CH and performs all the functions of a CH. This process is repeated for CH2 to CH3.
6) Once the CH2 is exhausted, the CH3 will be the new Cluster Head and the process of data communication takes place. This ensures that the lifetime of the network has been increased and the data communication takes place for a long amount of time.
7) For routing purposes, the nodes between the source and destination are selected. Data is transmitted through these nodes.
8) If the distance between the source and destination nodes is more than the threshold distance value, then through an intermediate node the data is transmitted. The place for these nodes is selected near the base station.
9) The ratio for distance and energy is computed for all the nodes. The nodes with a minimum ratio of distance and energy are selected and are called relay nodes. Through these relay nodes, the data is transmitted from source to Destination in the network.
10) Then an alternative second path with second minimum distance/energy is selected.
11) Once the second path is selected data is transmitted through both paths simultaneously. This not only helps in sending more amounts of data in lesser time but also increases the network lifetime.

4. Result analysis

Simulation with the proposed technique is implemented in NS2. Two ray ground propagation models are considered. For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. The threshold is 0.2 mj for every alive node; the energy consumption and lifetime of the network are recorded. For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. The threshold is 0.2 mj for every node. **Table 1** indicates the various parameters assumed in the simulation.

Table 1. Simulation considerations.

Sr. No.	Simulation parameters	Values
1)	Parameters considered	Lifetime, energy consumption, and number of alive nodes.
2)	Receiving power	1 mw
3)	Total number of nodes	100
4)	Transmitting power	2 mw
5)	Area of simulation	300 m × 300 m
6)	Type of the Channel	Wireless
7)	Size of packets	1000 bits

The figures below offer a graphical representation of performance comparisons of the proposed work with the existing one through various parameters. **Figure 1** shows the comparison of the proposed work and other conventional methods such as AODV, LEACH, and VLEACH. The outcome shows that the proposed work runs for the longest time in comparison with current methods. The calculated value is observed for 685 rounds. **Figure 2** gives the idea in terms of live nodes and made a comparison between the proposed and existing work. **Figure 3** will talk about the energy depletion clarifications for the various methods with the proposed one. Finally, the Statements of the diagram specify that the proposed technology consumes less energy in comparison with existing methods. The resulting outcomes say that the proposed works have an enhanced network lifetime in comparison with the existing methodologies.

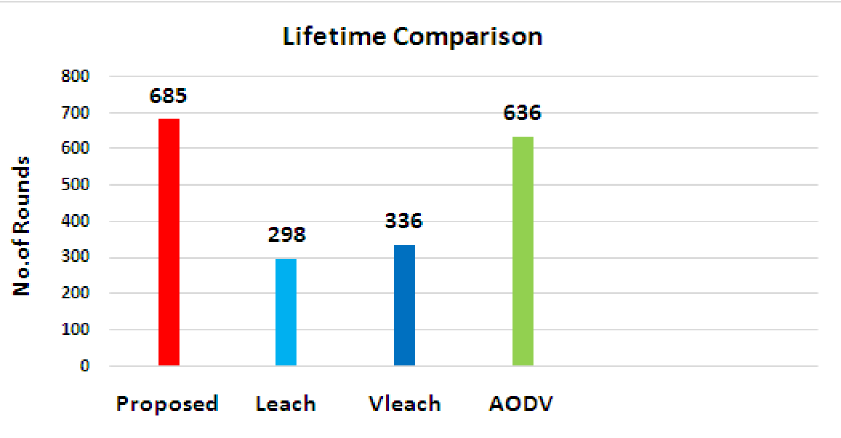

Figure 1. Comparison of the network lifetime.

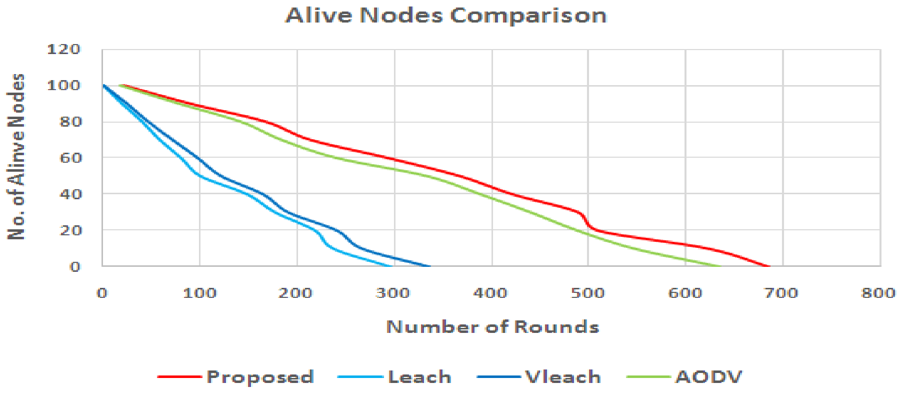

Figure 2. Comparison of alive nodes in the network.

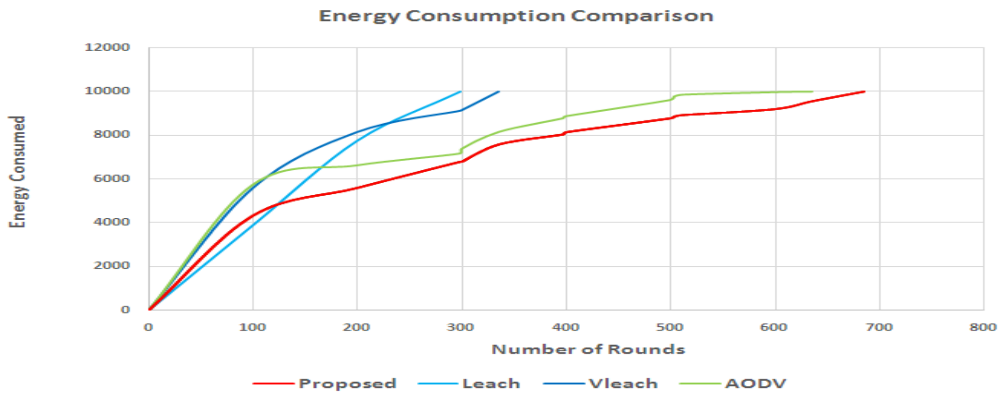

Figure 3. Comparison of the energy consumption.

5. Conclusions and future scope of the work

5.1. Conclusions

The concept of a "Hybrid Energy Balancer" is proposed as a novel approach to combine the advantages of clustering and routing techniques. This hybrid approach aims to balance the energy consumption across the network by intelligently distributing the workload and routing paths while considering the energy levels of individual nodes. The primary goal of the Hybrid Energy Balancer is to extend the network lifetime while maintaining efficient data transmission. In this work, hybrid clustering and routing methodologies are proposed that are obtained by combining salient features of the existing techniques. Here the clustering is performed by the overlapping circle method where smaller clusters are placed nearer to BS and if one goes away the scope of the clusters increases. The optimum cluster heads are selected with nodes nearer being connected to the nearest cluster head to decrease the cluster head load. Also, multiple heads CH1, CH2, and CH3 are proposed so that the network remains alive for a long amount of time. It is also proposed to send the data through two paths so that data is transmitted more quickly and efficiently. On observation and comparison with the existing techniques, the work proposed gives better results in comparison with the other existing comparable techniques. Hence, the outcomes conclude that the proposed methodology work proficiently in comparison with the existing methods.

5.2. Future scope of the work

By integrating the concepts of clustering and routing within the context of the Hybrid Energy Balancer, researchers and practitioners aim to achieve significant improvements in energy efficiency, network lifetime, and overall performance of wireless sensor networks. This approach combines the strengths of both techniques to mitigate energy imbalance and prolong the usefulness of these networks in various real-world applications.

Author contributions

Conceptualization, RKK and AKL; methodology, AKL; software, AKL; validation, AKL, AKL and AMM; formal analysis, AKL; investigation, RKK; resources, AKL; data curation, CA; writing—original draft preparation, RKK and AKL; writing—review and editing, AKL; visualization, ZHM; supervision, AKL; project administration, ASK; funding acquisition, MAM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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