DS Journal of Digital Science and Technology
Volume 2 Issue 2, 1-12, Apr - Jun 2023
ISSN: 2583-5416 / https://doi.org/10.59232/DST-V2I2P101

Original Article

The Improvements of Cluster Head Optimization Problems in WSNs Using an Improved Node Selection Model

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Received: 4 February 2023 ; Revised: 24 February 2023; Accepted: 06 March 2023; Published: 27 April 2023;

Abstract - WSNs are networks of tiny wireless sensors that track changes in environmental variables like pressure, temperature, humidity, and motion. In these networks, data is often transmitted from the source to the sink node through a gateway connected to sensor nodes. In a WSN, choosing a CH is a crucial choice that must be made to guarantee effective network operation. Choosing a CH wisely is essential for the network to run effectively and offer its consumers high-quality service. This work addresses the CH problem in WSN using a novel optimization approach and an improved node selection model (EENSA). The new system's effectiveness is evaluated regarding energy consumption, network lifetime, CH selection, power-aware routing, and throughput compared to the existing methods, Multi-Objective Genetic Algorithms (MOGA), and Gravitational Search Algorithm (GSA). As a result, our suggested technique improves throughput and network longevity while consuming less energy.

Keywords - WSN, CH, Energy-Efficiency, Node selection, Genetic algorithm.

1. Introduction

The strategies for CH optimization have made significant strides in recent years. Various applications have utilized these strategies to improve how well the overall networks are executed [1]. For instance, CH optimization techniques can be applied to wireless ad hoc networks to lower the amount of interference between stages and improve the network's overall performance [2]. CH optimization methods can be employed in distributed computing systems to lessen communication traffic and boost system dependability. CH optimization can lower the cost of establishing and maintaining networks and enhance network performance [3–4]. WSNs are networks of small, low-cost devices that can detect and measure various environmental factors, including movement, temperature, humidity, and light intensity [5]. These gadgets can connect wirelessly with one another or with a centralized gateway and are made to be low-power and inexpensive [6]. They can use the information they gather for various purposes, including geographic surveillance, home automation, medical monitoring, and industrial automation [7]. WSNs provide real-time condition monitoring and can be utilized to spot changes that conventional monitoring techniques would miss [8–9]. Selecting a node to lead a cluster, or collection of nodes, in a WSN, is known as choosing Cluster Head [10]. Choosing a CH is crucial since it significantly impacts how the entire network operates and how effective communication is as a whole [11]. The energy level of the node, the number of its neighbors, and its distance from other nodes are three factors that influence the selection of an optimal Cluster Head [12–13]. Other factors, such as the node's mobility and data processing capabilities, may occasionally be included in the selection process [14–15]. The selection of the Cluster Head is frequently carried out via a distributed function provided by the network's member nodes [16]. Evolutionary function, developed from the fundamentals of typical choice and genetics, is one unique optimization strategy for the CH selection problem [17–18]. They start with solutions to a problem that are generated randomly. Then they employ a process of selection, crossover, and mutation to evolve the answers and pick the best one [19–20]. This method can solve a wide range of issues, including scheduling issues, the optimization of financial portfolios, and machine learning algorithms [21].

Think about this multi-objective genetic method [22], which is employed to simplify multi-objective optimization issues. They use multiple objective functions to produce clarity that reflects the trade between the various aims [23]. Pareto's law, the ideal non-inferior to any other support, describes the answers produced by multi-objective genetic algorithms [24]. This method searches and has a set of Pareto's laws using determination, traversal, and novelty [25]. The crossover operator combines the features of two different solutions to produce a new key.

In contrast, the selection operator chooses the best solutions from the population [26]. Using the mutation operator, new and improved solutions can be produced by randomly introducing changes into the population [27]. The key benefit of multi-objective genetic algorithms is that they can deliver optimal results that show the trading of several analytical, which is impossible with conventional optimization techniques [28-29]. The Gravitational Search Algorithm (GSA), used to solve maximizing problems, is a metaheuristic algorithm influenced by Newton's law of gravitation. It is derived from swarm behavior and the rule of gravitation [30]. The mass of each particle in GSA is inversely proportional to its fitness value, and the potential energy of a system is described as the gravitational potential energy between groups [31]. The algorithm mimics the motion of particles in the cosmos and directs them toward the global optimum by applying gravitational force [32]. A wide range of optimization problems, from engineering design to economic forecasting, has been solved using GSA.

This study seeks to maximize system performance while choosing the best node to serve as the CH and considering many factors, including the node's energy limit, the number of nearby nodes, the distance between them, dynamic mobility, and data processing. Several selection algorithms can be utilized, depending on the needs of the network specifically. The energy-based, mobility-based, and load-based algorithms for selection are most frequently used. The energy-based algorithms selected the Cluster Head node with the highest energy level. While acting as Cluster Head, the mobility-based algorithm selected the node with the most increased mobility, and during the chosen load-based approach, the node with the lowest load. Various tactics can be used in addition to the selection algorithms to ensure the best possible selection of a CH. Power control and load balance are two of these tactics.

2. Related Works

For monitoring, gathering, and processing data from physical or environmental conditions, WSNs are networks of compact, low-power, and reasonably priced devices [33]. Radiofrequency (RF) technology, such as Wi-Fi or Bluetooth, enables the nodes to connect with the gateway and one another. Environmental observation, industrial automation, and healthcare are just a few of the many applications that WSNs are familiar with [34]—choosing a node to act as CH is known as CH selection. Data collection from nearby network nodes, data routing decisions, and data transmission to other nodes are all the responsibility of CHs [35]. Standard selection criteria for CH include network topology, node mobility, and node energy. According to the needs of the network, CH selection can be made centrally or decentralized [36]. While distributed algorithms choose a CH based on node mobility, network topology, and other factors, centralized CH selection algorithms often select the node with the highest energy level [37]. The challenge of choosing WSN nodes to serve as CHs to maximize network evaluation is known as CH selection [38]. The fundamental goal of the optimization challenge is to solve the network's energy consumption problem while optimizing performance [39]. The purpose of the problem, which is typically classified as a combinatorial optimization problem [40], is to select a set of nodes that will reduce the total amount of energy consumed by the network. Many algorithms, including genetic algorithms, simulated annealing, search, and ant colony optimization, can be used to address the optimization problem [41]. A form of evolutionary optimization method that can be used to address multi-objective optimization problems is the multi-objective genetic algorithm (MOGA) [42]. It is a modified version of the traditional genetic algorithm (GA) used to find a set of outcomes known as the Pareto front that are ideal for several objectives [43]. To construct successive generations of the population, the MOGA first creates a population of potential solutions and then uses genetic manipulators like crossover and mutation. The Pareto front, which represents the best trade-offs between the various objectives, is obtained after optimization [44]. The law of gravity and mass interactions drive the community-based optimization method known as the gravitational search algorithm (GSA). Problems involving optimization are resolved with this approach. It is based on the velocity of the particles and Newton's law of universal gravitation [45].

The gravitational force is employed in this approach to address optimization problems. The particles, their masses, and the gravitational constant are the three main elements of GSA [46]. Every molecule represents an efficient fix for the problems. Every molecule's quality is characterized by its mass. The gravitational constant is a measure of the gravitational field's strength. The particles use gravitational force to interact with one another [47]. In the search space, the particles travel under the gravitational pull. The higher-mass particle draws the other particle, and the lower-mass particle is drawn to it when two particles come into contact [48]. The particles migrate in the direction of the overall ideal solution. GSA is easy to use, quick, and effective. It can handle complex issues and is simple to implement. Several optimization jobs employ it, including engineering design, scheduling, and routing. Several problems in the real world have been successfully solved using this technique [49].

In a WSN (WSN), the routing algorithm determines which nodes are used in the shortest path. The shortest path between two nodes is often chosen based on how many hops are necessary to get from one node to another. Other criteria, such as the nodes' residual energy, the distance between them, and the caliber of their communication lines, can also be used to choose the nodes in the path. The selected nodes for the shortest path could be chosen according to their location in the WSN. The proposed model concentrated on the concerns listed in Fig. 1

- Power Control: This technique aims to increase coverage while reducing the power consumption of CHs. Algorithms like the k-means clustering algorithm can be used to overcome this issue.
- Cluster Formation: The process of forming node clusters within a WSN is called cluster formation. Algorithms like the DBSCAN (Density-Based Spatial Clustering and Applications with Noise) method can be used.
- Data Scheduling: Choosing which nodes will send data to the CHs and when is known as data scheduling. Algorithms like the Max-Min Fair Scheduling algorithm can be used to resolve this.
- Routing: In a WSN, routing determines the most effective route between two nodes. Algorithms like the Ant Colony Optimization algorithm or the Shortest Path Bridging algorithm can be used to resolve this.
- Location estimation: The process of estimating node positions in a WSN is known as location estimate. Algorithms like the Maximum Likelihood Estimation algorithm or the Least Squares Estimation algorithm can be used to resolve this.

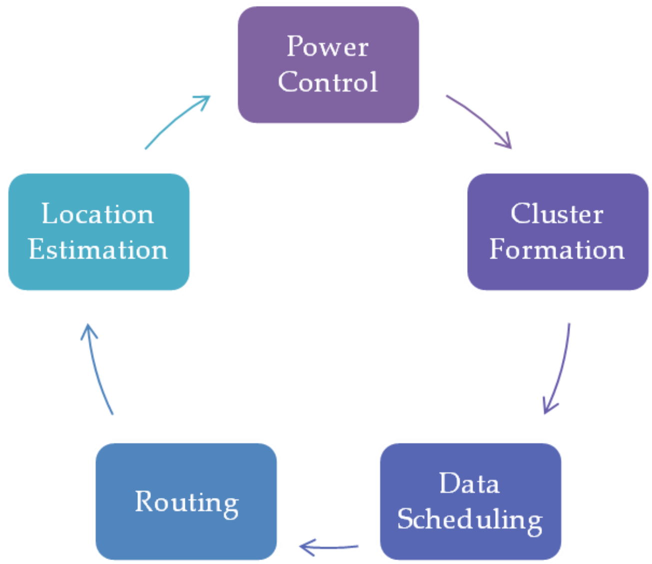

Fig. 1 Focused issues in the proposed model

WSNs are large-scale distributed systems made up of numerous sensor nodes. These nodes detect and gather environmental data and transmit it to a base station or sink node in charge of processing and transmitting the data. Yet, improving energy use and extending the network lifetime has become a significant challenge because of the sensor nodes' limited energy resources. Using a cluster-based strategy is one of the primary answers to this problem. This method divides the sensor nodes into clusters and gives each group a CH (CH). The CH is responsible for gathering information from its cluster and sending it to the washbasin node. The CH additionally serves as a coordinator between the sensor nodes and the washbasin node. In WSNs, the best CH selection is a crucial problem. A poor CH choice will result in subpar network performance and a shorter network lifetime. Consequently, a robust CH selection mechanism is required to enhance the network's performance.

An improved node selection model is a technique for choosing the top nodes from a network for a specific job. With this approach, the network's energy consumption will be reduced while the task will still be accomplished. The algorithm determines how much energy is needed to complete the job. The nodes with the lowest energy requirements are identified using this information. The nodes are then selected per their energy needs and other aspects like their load and location. The algorithm will then schedule the jobs to be completed at the most productive periods to maximize the energy usage of the nodes once they have been selected. This indicates that the tasks will be carried out when the nodes' energy consumption is the least. Turning off the nodes that are not in use can also be used to lower the nodes' energy usage. As a result, the network's overall power consumption is decreased, and its energy efficiency is increased.

3.1. Reduced Energy Consumption

By choosing the nodes with the lowest energy usage as the CHs, the Enhanced Node Selection Model (EENSA) aims to lower energy consumption. This promotes energy conservation to be used for other network-wide operations. Optimizing the choice of nodes for communication is the most efficient technique to cut energy usage in enhanced node selection models. Many methods, including energy-conscious node selection, heuristics, and clustering algorithms, can achieve this. By choosing the nodes with the lowest energy usage, energy-aware node selection algorithms optimize the node selection for communication. Heuristics can also be used to select the communication nodes that utilize the least amount of energy. These algorithms employ pre-established rules to choose the communication node with the least power. In node selection algorithms, clustering algorithms can also maximize energy efficiency. These algorithms combine nodes according to factors like proximity and energy usage. This lowers energy use and enables more effective routing. Energy-efficient routing methods might be applied to cut back on energy utilization. These protocols optimize data packet routing to save energy usage and guarantee that packets get to their destination on time.

3.2. Improved Network Performance

The performance of the network is enhanced by choosing the nodes that consume the least amount of energy. This is so that the selected nodes can offer superior communication services compared to nodes that consume more power. By lowering the quantity of data that needs to be transmitted, network coding technology effectively enhances network performance. Moreover, it can reduce the energy required to send the data, strengthening the network's energy efficiency. A method known as distributed caching can lower the volume of data requests made over the web and, as a result, reduce the number of resources required to process the requests. This may result in increased performance and energy efficiency.

3.3. Better Routing Capabilities

The EENSA algorithm is created to select the best nodes for routing, which aids in enhancing the network's routing capabilities. The network's overall performance is improved as a result. Optimizing routing protocols can reduce the hops necessary to reach a destination. This may result in a decrease in the energy needed to transfer data, increasing energy efficiency.

3.4. Improved Scalability

Because the EENSA algorithm is built to scale with network size, the network can expand without performance suffering. This makes it more likely that the network can fulfill its function even as it grows. By offering virtualized representations of the network's physical infrastructure, network virtualization can be utilized to lower the network's energy consumption. This may result in a decrease in the energy required to transfer data, increasing energy efficiency. It is possible to reduce energy use by using energy-efficient gear. Hardware that uses components that are intended to be energy-efficient minimizes power usage. Using low-power CPUs, memory controllers, and energy-efficient networking hardware are a few examples of achieving this.

3.5. Greater Fault Tolerance

Greater fault tolerance is a goal of the EENSA algorithm. This is so that the nodes that use the least energy are more dependable and can sustain failure better than those that consume more power. This makes it more likely that the network will be able to continue operating even if a node fails. Investing in energy-efficient equipment can decrease the amount of energy utilized by the web. Performance and energy efficiency gains may result from this.

The most prevalent optimization challenge in CH selection algorithms is to maximize network longevity while minimizing network energy consumption overall. These algorithms aim to choose the CHs with the highest remaining energy to increase network lifetime and decrease overall energy usage. While selecting the CHs, there are additional considerations besides energy consumption. The transmission range, mobility, and node density are some variables. The optimization problem must also consider these elements to choose the best CHs. In WSNs, the best CH selection is a crucial problem. To tackle this issue, several optimization strategies have been suggested. These methods account for the CHs' energy requirements, transmission range, mobility, and node density. The network's overall performance can be raised using these methods, extending its lifetime.

4. Results and Discussion

WSNs are networks of inexpensive, compact, low-power devices that monitor, gather, and process data from environmental or physical conditions. Radiofrequency (RF) technology, such as Wi-Fi or Bluetooth, enables the nodes to connect with the gateway and one another. The improved node selection model (INSM) that has been proposed has been evaluated against the existing improved fish migration optimization (IFMO), improved sunflower optimization algorithm (ISOA), improved artificial bee colony algorithm (IABCA), and genetic algorithm-based techno-economic optimization (GATEO)

4.1. Nodes Management

Applications for WSNs include industrial automation, healthcare, and monitoring the environment. An enhanced node selection model must consist of node management. This algorithm aims to reduce energy usage while maintaining dependable node-to-node communication. The algorithm must choose trustworthy and energy-efficient nodes to accomplish this goal. The following Figure 2 compares the administration of several nodes.

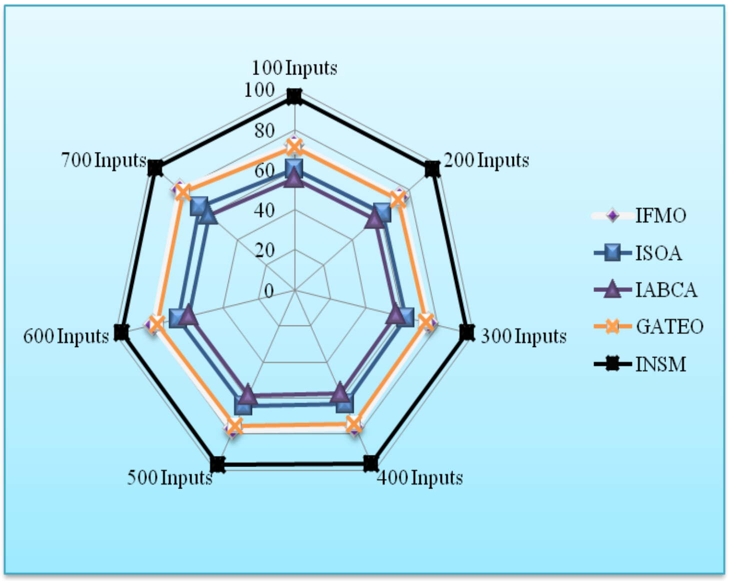

Fig. 2 Comparison of nodes management

Comparatively, the proposed Improved Node Selection Model (INSM) manages 96.56% of nodes. The existing improved fish migration optimization (IFMO) has a node management success rate of 76.12%, the improved sunflower optimization algorithm (ISOA) has a node management success rate of 63.18%, the improved artificial bee colony algorithm (IABCA) has a node management success rate of 57.67%, and the genetic algorithm-based techno-economic optimization (GATEO) has a node management success rate of 74.47%.

4.2. Availability Management

Choosing a network node to serve as a CH is called CH selection. Data collection from other network nodes, data routing decisions, and data transmission to other nodes are all the responsibility of CHs. Analysis of each node's energy needs is part of node management. This can be achieved by determining the network's required communication range and frequency as well as the power consumption of each node. The following Fig.3 compares various availability management strategies.

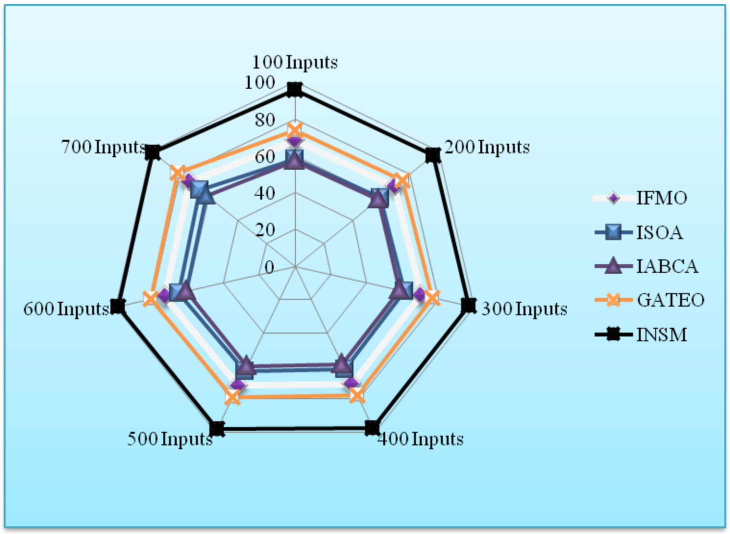

Fig. 3 Comparison of availability management

Regarding availability management, the suggested improved node selection model (INSM) has a 97.52% success rate. In the same range, an enhanced artificial bee colony algorithm (IABCA) obtained 59.34%, an improved sunflower optimization algorithm (ISOA) received 62.15%, improved fish migration optimization (IFMO) obtained 71.03%, and genetic algorithm-based techno-economic optimization (GATEO) obtained 77.73% of availability management.

4.3. Network Speed Management

Usually, factors like network topology, node mobility, and node energy are considered when choosing a CH. Depending on the needs of the network, CH selection can be made centrally or decentralized. To guarantee reliable communication between the nodes, the dependability of each node must also be assessed. This can be accomplished by evaluating the network's signal strength, interference levels, and other reliability elements. The following Fig.4 illustrates a comparison of various network speed management techniques.

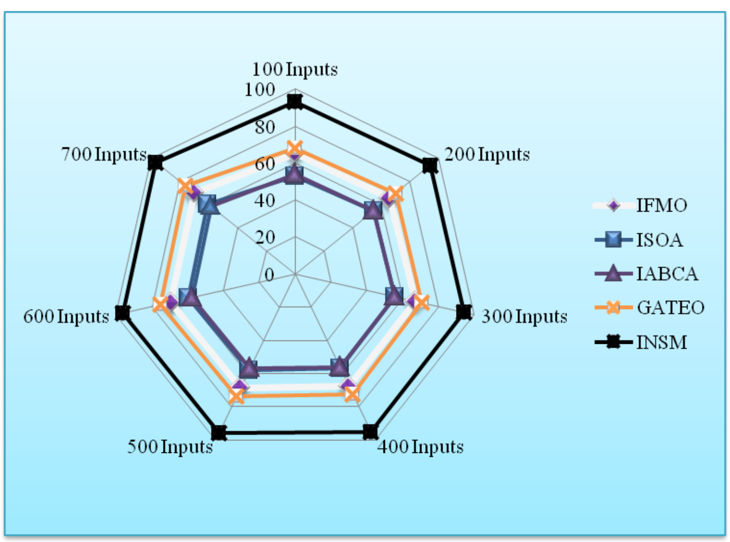

Fig. 4 Comparison of network speed management

When compared, the suggested improved node selection model (INSM) has a Network Speed Management success rate of 96.56%. The currently improved fish migration optimization (IFMO) has achieved 76.12% in this range. In comparison, the improved sunflower optimization algorithm (ISOA) has attained 63.18%, the improved artificial bee colony algorithm (IABCA) has gained 57.67%, and the genetic algorithm-based techno-economic optimization (GATEO) has reached 74.47% of network speed management.

4.4. Network Security Management

Centralized CH selection algorithms often choose the CH based on the node with the highest energy or best connection. The nodes must be monitored and updated to keep them dependable and energy-efficient. Regular tests and any necessary node adjustments can be used to achieve this. The following Fig. 5 illustrates a comparison of various network security management techniques.

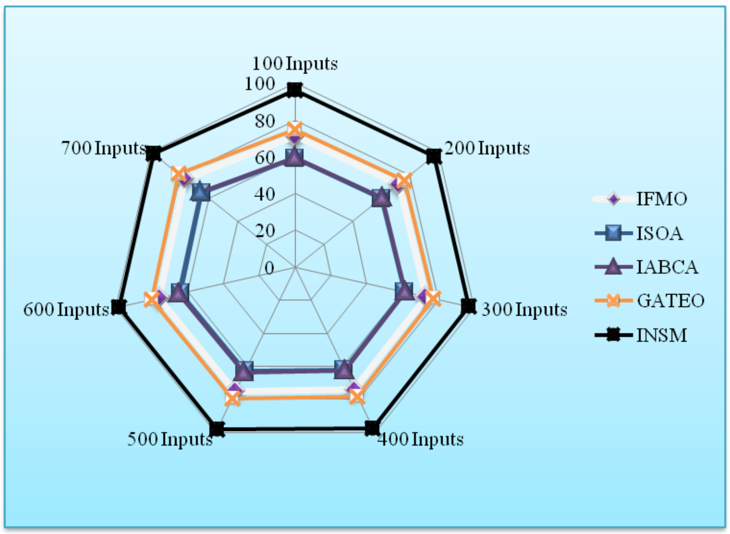

Fig. 5 Comparison of nodes management

When compared, the suggested improved node selection model (INSM) has a Network Security Management success rate of 97.53%. In the same range, an enhanced artificial bee colony algorithm (IABCA) obtained 62.76%, an improved sunflower optimization algorithm (ISOA) received 61.80%, improved fish migration optimization (IFMO) obtained 74.08%, and genetic algorithm-based techno-economic optimization (GATEO) obtained 78.10% of network security management.

4.5. Scalability Management

Whereas distributed algorithms choose a CH based on the network topology, node mobility, and other factors. The next stage is to select energy-efficient nodes once each node's energy requirements have been examined. This can be accomplished by contrasting each node's power consumption and choosing the nodes with the lowest consumption. The following Fig.6 illustrates a comparison of various scalability management strategies.

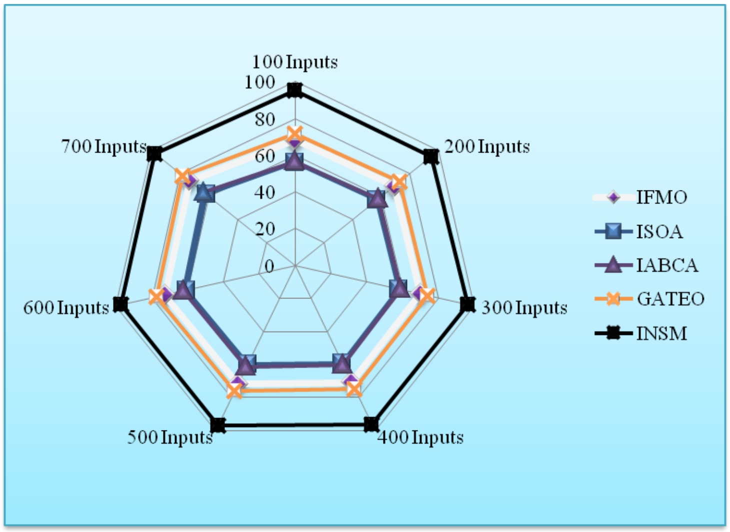

Fig. 6 Comparison of scalability management

When compared, the suggested improved node selection model (INSM) has a Scalability Management score of 96.34%. The current Improved Fish Migration Optimization (IFMO) has achieved 70.86%, the Improved Sunflower Optimization Algorithm (ISOA) has attained 58.86%, the Improved Artificial Bee Colony Algorithm (IABCA) has reached 60.07%, and the Genetic algorithm based Techno-economic Optimization (GATEO) has reached 75.03% of Scalability Management.

5. Conclusion

CH optimization issues are essential in many computer science and engineering domains. CH optimization seeks to lessen the quantity of communication traffic produced by a cluster, or network, of computers. The network's overall communication traffic can be significantly decreased by strategically placing CHs. This can therefore result in increased network efficiency and lower operating expenses. Several mathematical and algorithmic methods are frequently used to solve CH optimization challenges. They include heuristic algorithms, dynamic programming, and graph theory. To discover the best location for CHs, the network topology is examined using graph theory. Dynamic programming determines the best communication traffic for a particular topology. Sub-optimization issues are solved using heuristic techniques. The cost of establishing and maintaining a network can be significantly decreased by placing CHs as efficiently as possible. Both organizations and consumers may experience cost savings as a result of this. Overall, network design and optimization must include CH optimization. Advanced mathematical and computational techniques can enhance system performance while reducing the quantity of communication traffic a network generates. Moreover, businesses and customers may save money due to CH placement optimization. As a result, it plays a crucial role in contemporary network design and optimization.

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