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# A New Method for Optimizing Wireless Sensor Network Coverage and Reliability in Agricultural Monitoring

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Abstract:Wireless Sensor Networks (WSN) having a large number of battery operated low-cost, low-power, and compact sensor nodes with limited memory and processing, are a self-monitoring intelligent network system. Due to the technical developments in the areas of sensing, computation, and wireless transmission, WSN has emerged as a frontier in providing cost-effective, fully distributed, and rapid solution. Quality of Service (QoS) in terms of network connectivity and sensing coverage are the two most significant performance metrics for WSN. Entire network sensing is measured by coverage. Whereas, connectivity measures transfer of data between sensor nodes and/or to a central unit. The objective of this research is to focus on coverage optimization with fault-tolerance connectivity in a network. Overall, the improved model proposed in this work is extremely useful for establishing Quality of Service to WSN. The focus of this work is on QoS techniques for wireless sensor networks based on criteria such as energy efficiency, coverage optimization with fault tolerance connectivity. The solutions provided are particularly valuable in prolonging the network's lifetime while not affecting the quality in monitoring applications

Keywords: Wireless Sensor Networks (WSN),Quality of Service (QoS), sensing, computation, wireless transmission

## Introduction

For the purpose of contemporaneous and co-sensing of environmental variables, Wireless Sensor Networks (WSN) consist of a small number of autonomous sensor nodes deployed in a defined region [1]. Many indoor and outdoor real-world applications, such as soil analysis, home automation, environmental sensing, medical, smart parking, and military, have been making heavy use of WSN in recent years [2]. The characteristics of the network are used to derive an optimization problem, the solution to which will specify the principles and measurements of advanced technology to be explored in terms of network performance and coverage accuracy. Analysis of intermediate goals, fulfillment of refrainments, predicate logic, sparse representation, and the creation of adaptive and socially influential models are all part of the optimization process. The goal of optimization is to provide the minimum or maximum value required by the problem. With the help of well specified networking protocols, this may be evaluated via quantitative analysis. Through carefully calibrated wireless connections, the sensor nodes send their collected data to a central hub. WSN can monitor a variety of surroundings by transmitting data from nodes in order to get accurate location data. In these uses, a sensor node collects information from the target region, including humidity, temperature, and pressure, and sends it to a distant sink (base station) through multihop communications. Determining the appropriate deployment schemes, cost, energy efficiency, scalability, communication range, and fault tolerance are only some of the

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problems in WSN agricultural applications as outlined by Rathinam et al. [3]. Recently, WSN have been employed to efficiently raise crop yields without increasing costs. However, modern environmental conditions are detrimental to most crops. To combat this, WSN plays a crucial role by assisting farmers in increasing their crop yields while simultaneously decreasing their per-unit-yield costs. According to [4] and [5], various wireless networking technologies are employed in a WSN depending on the application; for example, Zigbee, Bluetooth, Wifi, LoRa, and SigFox are all quite common in agriculture but have varying node layout capacity, data speed, and other characteristics. Zigbee is a low-cost, low-power technology often used for monitoring soil conditions and adjusting irrigation schedules. WSN aims to keep an eye on hop counts in a network of wireless sensors. Specifically, this entails setting up sensor nodes to monitor the area around the target and alert on any unusual activity. Cost-effectiveness, according to Farsi et al. [6], necessitates deploying the minimum viable number of sensors to meet coverage and connection needs while helping the greatest number of farmers.

**Wireless Sensor Networks in Agriculture**

Intelligent sensor techniques have attracted a lot of attention in the agricultural sector in recent years. All forms of life depend on agriculture to provide them with sustenance. Unfortunately, modern crops are vulnerable to a wide range of environmental stresses and catastrophes. WSN plays a crucial function in agriculture in order to combat this. The agricultural sector has found several applications for WSN, including temperature measuring, irrigation system monitoring, and water supply monitoring. These sensors collect data that is used to assess field conditions and crop development at a finer geographical scale. How the field should be maintained and when it should be harvested may be determined by the geographical distribution and interpretation of sensor data. Each sensor node, during data transmission, must routinely send its sensed data to the distant control unit, either directly or through other intermediary nodes in a multi-hop setup. Therefore, a sensor will typically follow the schedule of waking up at regular intervals, detecting data for a certain amount of time, then aggregating and transmitting that data to the next hop before going back to sleep [7]. Since wireless technologies rely on batteries for power, it stands to reason that their reach is restricted.

**Connectivity in WSN**

Connectivity, in WSN, is the transmission of sensed data from a source node to a sink node. Due to the low cost and resource availability of sensors, the coverage area might be inadequately monitored by a single node. Multi-hop communications are necessary when a sensor is physically far from the sink node. If two sensors can exchange data with each other, we call them neighbors. The network links in a WSN are shown in Figure 1. Connectivity constraints define a network's topology, which consists of sensor nodes and the communication links between them and their nearest neighbors. Using a communication topology represented as a data structure for a WSN, where G=(V,E) represents a collection of sensor connections and E represents a set of wireless communication connections, the concept of connectedness in a WSN may be easily stated.

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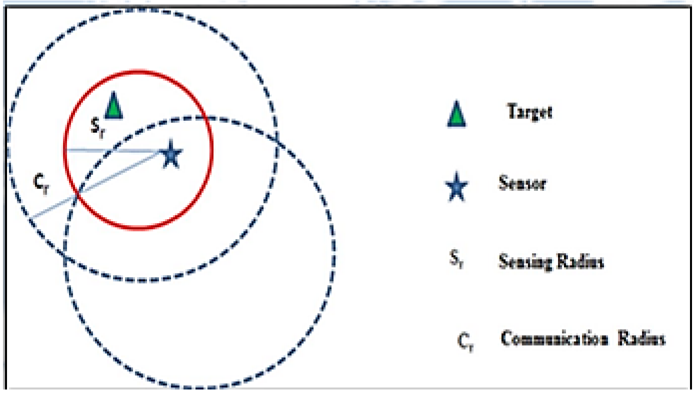


Figure 1: Connectivity in WSN

**Nature-Inspired Optimization Algorithms (NIOAS)**

Methods of optimization are crucial in solving several problems in engineering, business, and industrial design. Finding the ideal option among many choices is part of the optimization process. Single- or multi-objective; continuous or discrete; bound or unbounded, optimization techniques find the optimal answer by minimizing or optimizing the objective function down to a set of possible solutions. Optimization algorithms (NIOAs) that use cues from the natural world, such as swarm intelligence or physical-biological systems, are more popular. These algorithms are very valuable because of their flexibility and ability to find optimal solutions to a wide variety of dimensional and non-linear problems. It's effective in resolving NP-hard issues. Because of this, the NIOAs have found theoretical and practical applications in many fields. All NIAOS algorithms need both Exploitation and Exploration, also known as intensification and diversification. When an issue is being exploited, the information gained from it is used to inform the creation of better alternatives. Alternatively, exploration facilitates more effective search space exploration and the production of outcomes that are sufficiently different from preexisting answers.

**Reconstruction of Sensor Value**

There are a number of potential causes of data loss in experimental settings in rural agricultural regions. Intense sensor deployment may lead to signal degradation and communication breakdowns in a wireless network, leading to lost sensor data. In order to recover inaccurate or missing volumetric water sensor data, a unique model is required. Complementing soil temperature data with artificial neural networks and compressive sensing allows for the development of the model. Compressive sensing methods create a bias value and incorporate it into the prediction of artificial neural networks.

Sensor nodes and spine nodes are placed in a field at a predetermined area. The study's goal is to improve Quality of Service (QoS) in WSN via detecting node coverage using fault-tolerant connection. A challenging multi-objective optimization issue arises while attempting to optimize coverage while maintaining fault-tolerant connection. Since it is more probable to become stuck at local optima in randomly deployed nodes, the swarm intelligence based searchalgorithm has poor and inconsistent exploration difficulties. This means that the algorithm can't ensure network coverage in the considered field area and can't strike a good balance between exploration and increased network lifespan. By strategically arranging the system's ideal number of intelligent nodes, monitoring may be performed over the whole target area of the provided field, with data transmission that is resilient to failure. In order to aid the inexperienced user in getting quick analysis, a unique hybrid approach for sensor data reconstruction is developed. Wireless Sensor Networks (WSN) are extensively utilized in environmental monitoring, tracking, and other applications. This will allow farmers to plan crop yields and irrigation patterns in accordance with environmental circumstances and variables. Having enough environmental coverage is crucial to the success of WSN. Most modern deployment methods focus on reducing the impact on networks and increasing the effectiveness of sensors. Coverage is significantly affected by the infrastructure, which includes the number and placement of sensors. Network coverage is the key challenge in WSN implementation. By evaluating network coverage to determine if there is a communication blind region, the monitoring area of WSN coverage is achieved, which is essential for achieving maximum value under circumstances that assure a certain Quality of Service (QoS). Levy flying mechanism was utilized to enhance the present position of the search agents, allowing the algorithm to more effectively locate the exploration site while avoiding local minima. Therefore, the effectiveness and durability of WOA were further enhanced by Levy flight.

Levy integrated Whale Optimization Algorithm was first used to improve efficiency in order to locate the nodes in WSN and to increase search speed, ultimately covering the full network region. By strategically deploying the system's intelligent nodes with fault-tolerant data transmission in mind, the whole target area of the given field may be monitored effectively. It is required that the planned watering be checked every hour. Selecting effective fault-tolerant techniques may increase network reliability and coverage. The major aim is to identify the node failure in previously unseen scenarios. Fault tolerance in WSN is the quality of a network that maintains service availability despite the failure of certain sensor nodes. In real-world settings, sensor nodes are subject to failures such those caused by physical damage, radio interference, low battery, obstruction, collision, and asymmetric communication connections. Hourly data monitoring is required for irrigation scheduling in real-time agricultural applications. Agricultural planners' ability to analyze data is hampered if nodes fail for any reason. For this reason, we offer an efficient fault-tolerant strategy to enhance dependable network communication over a large area with high availability. In order to provide the highest possible network connection, WSNs offer multi-hop communication, in which each Sensor Node (SNs) connects with its nearby node over a communication link. As the distance between nodes grows, so does the quantity of energy needed for communication, hence shortening the lifetime of the network. Adding some smart nodes may help extend the life of the network as a whole.

Compressive Sensing (CS) is worth investigating because it can efficiently deal with data loss, incomplete reconstructions, wireless transmission issues, and sparse damage recognition. CS is also used to track how well plants are doing in the garden. Finding the optimal sparse optimization solution is the main difficulty in compressive sensing. A unique hybrid strategy for sensor data reconstruction is provided to aid the new user in obtaining quick analysis. Farmers will be able to adjust their crop yields and watering schedules in light of shifting weather patterns and other environmental factors. The innovative hybrid model described here aids the user in doing the necessary analyses promptly, allowing them to make plans for crop production that are in line with agricultural trends. This is analyzed by the model in a number of different contexts. Compressive sensing and artificial neural networks are used to analyze soil temperature data and create the model. As a result, the model can recover its vital parameters/features from compromised, corrupted, or otherwise compromised sensor data. Given the enhanced model for coverage optimization with fault-tolerance in WSN monitoring applications, this chapter will evaluate the state-of-the-art research in this area. Coverage optimization, connectivity fault tolerance schemes, and sensor value reconstruction make up its three main parts.

Through optimization, the optimal answer to a problem may be found for a given set of parameters. It is possible to optimize a single goal in such a manner that the goal is to reduce or maximize some parameter under a wide range of situations. In the case of multi-purpose optimization, many different goals might be improved simultaneously. Coverage optimization is an important criterion in WSN because of the significant and positive effects it has shown in areas such as environmental management, intelligence, social and economic cyber-networking, etc. Coverage, node utilization, node remaining energy, and network lifespan durability were all enhanced by providing a balanced and homogeneous distribution of sensor nodes, which was the purpose of WSN coverage augmentation. Rapid technical development and higher product quality requirements have resulted in a proliferation of practical optimization difficulties across several industries. However, optimization issues are notoriously difficult to answer within a practical timeframe, earning them the NP-hard label. Therefore, researchers have proposed a number of meta-heuristics that can efficiently apply to the optimization problem and discover a decent solution in a reasonable period of time. Cluster search approaches like meta-heuristic algorithms have many potential applications due to their ease of development, comprehension, and generalizability. These algorithms attempt to solve optimization problems by modeling their operations on those of natural biological or physical processes. At least three benefits may be gained by using these optimization techniques on technical problems. For starters, it uses intuitive notations and is easy to implement. Second, it doesn't need any gradient information to be used. As a third benefit, it helps avoid settling for a mediocre solution just because it's the best one around. These advantages make the optimization algorithms useful for solving issues in many different fields.

**Whale Optimization Algorithm (WOA)**

The unique predatory behavior of the humpback whale inspired the development of a new kind of optimization algorithm called the Whale Optimization Algorithm. The software attempted to mimic the whale's foraging behavior by surrounding prey and then blasting bubbles to maximize efficiency. Its adaptability, simplicity of idea and execution, few configuration options, and great resilience led to its widespread adoption. When compared to


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other optimization algorithms like differential evolution and gravitational search, studies show that WOA performs better in terms of solution reliability and algorithm durability. including other meta-heuristic algorithms, the fundamental WOA algorithm includes drawbacks including poor predictive performance, slow convergence, and the propensity to settle for a sub-optimal solution. Rather of relying on a single, inefficient technique for optimization, hybrid algorithms combine the best features of many approaches to create a single, more effective one. In population-based meta-heuristic algorithms, diversification and intensification are two frequent search strategies. During the diversification phase, the optimizer looks for a locally optimal solution, and the intensity step has to be sufficiently random to ensure it may be extended throughout the whole search space. The algorithm's internal search capabilities are reflected in the diversification operation, and what follows is a locally-focused development phase known as intensification. In this stage, the optimizer doesn't care about the global optimum solution so much as it does about the area around it. In order to boost algorithm performance, it is essential to strike a balance between diversity and intensity.

Wireless sensor networks (WSN) are adaptable and may be used in many different contexts, such as industrial, environmental, medical, and even military settings. Motes, also known as sensor nodes, are common and well-known equipment that aid in monitoring biological phenomena across large areas. Sensor nodes may use certain communication channels to send data wirelessly to a central hub. Integrating sensor nodes enables WSN to monitor diverse settings and collect accurate field data via communication across a broad range of basic to complicated sensors. According to the above-mentioned use cases, a sensor node sends data about the target area's humidity, temperature, and pressure to a faraway sink (base station) through multi-hop communications. The primary use of this technology is to keep tabs on hop and hop journeys in a certain setting. As part of this process, sensor nodes may be set up to detect the occurrence of any event. Changes at the target's location are something that WSN systems try to keep tabs on. So, keeping your network up and running is crucial if you want to keep tabs on a certain group of targets 24/7. In the beginning of this study, we thought about how much coverage we needed.

In addition, a new method of deploying "intelligent" (spine) nodes for monitoring ecosystem infrastructures was presented. Covering the whole area where the sensors are installed and collecting data are two of WSN's most crucial functions. Coverage is one of the most crucial problems in WSN since it is the benchmark for monitoring. There are now three distinct types of protection:

1. Area Coverage: The main purpose of area coverage is to track the area of interest. Every point in the area shall be monitored to obtain the full coverage; otherwise, there exist the coverage hole.

2. Target Coverage: The aim is to cover a range of target points with a well-known position to be tracked. This focus on active sensors and certain sensor nodes' locations are stated to cover all sensors.

3. Barrier Coverage: The goal is to identify the intruders to protect the area

Adaptation to Failure in Wireless Sensor Networks Fault tolerance is a highly sought after quality in a sensor network. Due to the nature of where WSN are placed, manual fault detection and correction are not an option. To ensure that as many sensor nodes as feasible survive, network longevity is a crucial aspect of WSN architecture. So, the system has to be able to detect problems, fix them, and stop them from happening again. The availability, dependability, and reliability of a system are guaranteed even in the presence of faults when the system is fault tolerant. In a given area, for instance, some applications need just a single sensor to monitor a position, while others require a much greater number of sensors to do the same. Deploying a multi-network to allow mapping of this location and supplying the acquired data is acceptable depending on the size of the item being monitored. Coverage and connection must be guaranteed in the implementation of such communication objects in order to fulfill the needs of the application. The primary goal of target coverage is to continually monitor a collection of targets using a limited number of sensors. Batteries dying, bugs in the software or hardware, and weather shifts are just a few of the ways in which these sensor nodes might go wrong. If a sensor node fails, it will disrupt coverage and communication, which will cause delays throughout the network and increase energy usage. Therefore, the issue of energy efficiency is critical to the longevity of the network.

Instead of turning on all sensors at once, we activated just those covering all targets at a predetermined activation time to keep them safe for as long as feasible. The idea is to set up the sensors such that they can follow each target in turn for some amount of time. A network's lifespan is the total amount of time that its activation times have been used. Assembling the sensor nodes into a cover set that allows for simultaneous coverage of all targets is the main focus of the suggested method. Another major concern in WSN is fault tolerance. Physical damage, radio interference, energy depletion, blockage, collision, and asymmetric communication connections are just some of the ways in which sensor nodes in real-time systems might fail. To properly time irrigation in real-time agricultural applications, data must be monitored hourly. Agricultural planners' ability to analyze data is hampered if nodes fail for any reason. This prompts us to propose a fault-tolerant technique that may effectively increase network reliability while maintaining adequate coverage. The sensor nodes use the majority of their power talking to their neighbors, therefore it's crucial that the data they gather be sent reliably and quickly to the base station, or sink. In order to provide the highest possible network connection, WSNs allow for multi-hop communication, in which each SNs talks with its neighboring node through a communication link. The network's lifetime decreases as the distance between nodes grows, since longer distance communications need more energy. Adding some smart nodes may help extend the life of the network as a whole. The algorithm's natural-world inspiration allows it to effectively address a wide range of optimization difficulties encountered while addressing practical engineering challenges. There are many other ways to classify these algorithms, including swarm intelligence and others. Swarm intelligence algorithms model their group dynamics after those of social animals and insects. To get where they're going, many species forage together and share information. Algorithms with a physics emphasis were influenced by ideas from fields as diverse as quantum mechanics, electromagnetic, and Newton's law of universal gravitation. The Gravitational Search Algorithm (GSA), the Intelligent Water Drop Algorithm, etc., are all examples of popular physics-based algorithms. Since neighboring sensor nodes may communicate with at least one spine node to report the connection status, limiting the number of spine nodes placement is seen as a key challenge when designing a WSN. The Bat Algorithm (BA), the Interior Search Algorithm (ISA), and the Moth Flame Optimization (MFO) are the three algorithms that have been developed and utilized for monitoring. MFO is advantageous because to its rapid convergence, ease of use, and low number of required setup parameters. It is shown that finding an ideal location for such nodes is an NP-hard task. The study effort provided two methods; first, sensor nodes are set up to keep an eye on all of the targets in a certain region. Second, a nature-inspired approach is examined for optimally arranging the spine nodes in a given sensing area, with the requirement that each sensor node should be able to interact with a neighboring spine node. Its wide range of use has led to its implementation in the resolution of several optimization issues.

**Efficient Monitoring With Fault-Tolerant Connectivity**

**Target Monitoring Phase**

Cover set (C-Cover) refers to a collection of sensors that can monitor an entire field of interest. It is presumed that a sensor will cover a target if the target is within its field of view, and the connection is shown when the target is within range. Each produced cover set will include all targets within its respective sub-region while simultaneously following those targets. Enabling just the necessary amount of sensor nodes at any one moment is an active strategy to conserve energy in the long run. During the phase of monitoring targets, sensor nodes are placed at random to cover each sensing zone A, as illustrated in Figure 2. Each sensor node is permanently installed and geolocated. Using its allocated ID and localization methods, each node may pinpoint its precise position. Initial network deployment includes not only the various target sites but also the base station and sensor nodes. To activate the sensor communication and kick off the hierarchical communication, the base station sends out a network-wide broadcast message. The sensor gadgets keep in touch with their neighbors by sending out beacon messages at regular intervals. Once the sensor devices have received the hierarchical communication message, they will begin sending the energy and position data to the sink. The information that the base station records about each sensor includes its location, power, and unique identifier.

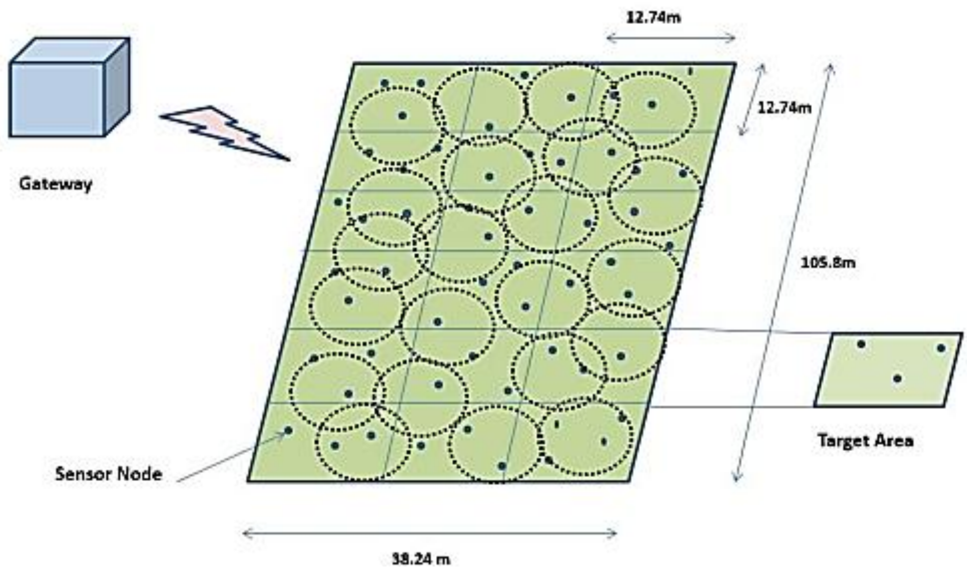


Figure 2: Target Monitoring Phase

Table 1. Information collected by the sink

| Location Coordinates | Sensor_Id | Energy |
|---|---|---|
| (75.42, 98.07) | 002 | 3J |
| (75.47, 98.09) | 003 | 4J |
| (75.45, 98.10) | 005 | 5J |

After collecting data from all sensors, the base station begins building the cover set. Connecting the sensor device to the target devices creates the coverage matrix. It takes shape when the sensing reachability to target locations has been confirmed. All of the objectives are stored in the exposed list from the outset. The initial target point is used as a starting point for constructing the cover set. Sensor devices covering the target are determined from the reference locations. In order to determine how long each sensor will last, we compare its energy consumption to its unit period cost. The bare minimum lifespan is determined by a comparison of all detected sensor nodes in the network. When a sensor is present at the current reference point, the covered target point is deleted from the list of exposed points. Using the Maximum Energy First condition, we can determine which node in the set of protected sensors has the longest expected lifespan. The greatest energy with the shortest lifespan is taken into account in order to optimize the utility of cover set selection based on energy constraint to cover the target. If the requirement is met, the sensors' C-covers are found to encompass the target reference point. C-cover is established by making sure that sensors covering the same target are not in a position where their coverage would overlap. If the detected C-covers are used to remove further target locations from the uncovered list, the cover set is said to be complete. All target points use the same method to determine which nodes in the initial cover set will serve as starting points. Once the cover set is established, the chosen nodes will transition directly to the active state, bypassing the sleep stage altogether.

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## Conclusion

Coverage optimization with error-tolerant communication is a challenging multi-objective optimization problem. The swarm intelligence based search method has weak and inconsistent exploration problems since it is more likely to become stuck at local optima in randomly placed nodes. As a consequence, the algorithm can't guarantee coverage in the studied field area or strike a good compromise between exploration potential and network durability. Additionally, the system employs a sufficient number of smart nodes to monitor the whole target area of the provided field while ensuring reliable data transfer in the event of a node failure. A unique hybrid strategy for sensor data reconstruction is suggested to aid the naive user in obtaining quick analysis. Farmers may adjust their agricultural production and irrigation patterns in light of shifting environmental and economic factors by using this method. Research in this area is directed toward such ends, as well as at the provision of sensing coverage, fault-tolerant connection, and the longest possible lifespan for networks. Using swarm intelligence algorithms, the suggested method decreases the optimal period of nodes in a coverage region with dependable connection.

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