Volume 3, Issue 5, May 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Comparison of Coverage Problem Solutions in Wireless Sensor Network

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Abstract—Wireless sensor networks are a rapidly growing area for research and commercial development. Wireless sensor networks are used to monitor a given field of interest for changes in the environment. They are very useful for to national security, surveillance, military, health care, environmental monitoring and scientific applications to name a few. The coverage of WSN has answered the questions about quality of service which can be provided by WSN. Therefore, maximizing coverage using the resource constrained nodes is a non-trivial problem. One of the most active areas of research in wireless sensor networks is that of coverage. Coverage in wireless sensor networks is usually defined as a measure of how well and for how long the sensors are able to observe the physical space. The coverage problem for wireless sensor network (WSN) has been studied extensively in recent years, especially when combined with connectivity and energy efficiency. In this paper we present a survey of coverage problem. And besides some basic design considerations in coverage of WSN we describe two challenges, namely, maximizing network lifetime and network connectivity. We also provide a brief summary and comparison of existing coverage schemes. In this paper, we take a representative survey of the current work that has been done in this area.

Keywords—*Wireless sensor network, Irregular sensing area, Connectivity, Coverage, Nodes, Mobiles, Lifetime.*

I. INTRODUCTION

In recent years there has been increasing interest in the field of wireless sensor networks. A WSN provides a new class of computer systems and expands people's ability to remotely interact with the physical world. Wireless sensor network mainly depend on the quality of service (QoS) and reliability. Furthermore, sensor nodes' limitation in power, computational capacities and memory are often deployed in large numbers and high density. wireless sensor network also consists of a number of wireless sensor nodes which have enabled the development of low-cost, low-power, multi-functional, tiny sensor nodes which can sense the environment, perform data processing and communicate with each other over short distances. Due to a wide range of potential applications object tracking, traffic control and etc. A typical large-scale WSN generally consists of one or more sinks (or base stations) and tens or thousands of sensor nodes that organized themselves into a multi-hop wireless network and deployed either randomly or according to some predefined statistical distribution over a geographical region of interest. A sensor node by itself has severe resource constraints, such as limited memory, battery power, and signal processing, computation and communication capabilities; hence it can sense only a small portion of the environment. However, a group of sensors collaborating with each other can accomplish a much bigger task efficiently. With integration of sensing, computation, and wireless communication, the sensor nodes can sense physical information, process crude information, and report them to the sink or base stations [1].We have been major focuses in this paper on the coverage problem of WSN. Coverage is a fundamental research issue in WSN because it can be considered as the measure of QoS of sensing function for a sensor network. For example, in an application of forest monitoring, one may ask how well the network can observe a given area and what the chances are that a fire starting in a specific location of forest will be detected in a given time frame. Additionally, coverage can also try to find weak points in a sensor field and suggest future deployment or reconfiguration schemes for improving the coverage performance. In proper way, the coverage usually involves two basic rules.

- How to evaluate the coverage performance when sensor nodes are deployed in a monitoring region.
- How to improve the coverage performance when wireless sensor network cannot effectively satisfy application requirements.

The purpose of deploying a WSN is to collect relevant data for processing. There are two types of reporting [2]: **event-drive** and **on-demand**. Consider a WSN with a sink (also called monitoring station) and a set of sensor nodes. In the event-driven reporting, the reporting process is triggered by one or more sensor nodes which detect an event and report it to the monitoring station. In the on-demand report, the reporting process is initiated from the monitoring station and sensor nodes send their data in response to an explicit request. A forest fire monitoring system is event-driven, whereas an inventory control system is on-demand. A more flexible system can be a hybrid of even -driven and on-demand. Many researchers are currently engaged in developing solutions that fulfil diverse requirements, at the same time, numerous algorithms that relating to coverage have been proposed. Some algorithms focus on pure coverage problems to characterize the coverage of WSN. Others integrate some considerations for optimizing the utilization of network resources or for supporting specific application requirements (for example, network connectivity, energy consumption) into coverage problem. Among numerous challenges, when designing an efficient coverage scheme, maintaining connectivity and maximizing the network lifetime stand out as the critical challenges.

This paper presents a thorough survey of the existing coverage schemes for WSN, and it also outlines several open problems. The purpose is to provide a better understanding of coverage technology and to stimulate new research directions in this area. The remainder of the paper is organized as follows. We introduce some design criterions in coverage problem for WSN that followed by the related problem in other fields. Next, we classify coverage schemes into three categories: point coverage and area coverage and what is more, we make a summary and comparison of existing coverage scheme for WSN. After that, we outline two directions that should be further studied in the design of coverage scheme. Conclusions are shown in the last section.

II. DESIGN CHOICE

There are several factors that must be considered when developing a plan for coverage in a sensor networks. Many of these will be dependent upon the particular application that is being addressed. The capabilities of the sensor nodes that are being used must also be considered. The coverage problem is centred on a fundamental question: “How well do the sensors observe the physical space?” On some occasions, we need to consider about *k-coverage* (Given any integer *k,* a monitored region *R* by WSN if and only if each point in *R* is covered by at least *k-* sensors). For example, in wireless sensor networks, because energy depletion, harsh environmental conditions, and malicious attacks may result in node failures or become inoperative at any time, it is desirable to have higher degrees of coverage. Sensor nodes, also called wireless transceivers, are tiny devices equipped with one or more sensors, one or more transceivers, processing, storage resources and, possibly, actuators. Sensor nodes organize in networks and collaborate to accomplish a larger sensing task. One important class of WSNs is wireless ad-hoc sensor networks (WASN), characterized by an “ad-hoc” or **random** sensor deployment method, where the sensor location is not known a priori. This feature is required when individual sensor placement is infeasible, for example battlefield or disaster areas. The characteristics of a WASN include limited resources, large and dense networks, and dynamic topology. The goal is to have each location in the physical space of interest within the sensing range of at least one sensor. Depended on different objectives and application requirements, there are different factors analysed in designing coverage schemes. In this way, a fair comparison among existing scheme has to be taken into consideration, since these factors affecting the coverage performance of WSN. Generally, there are many different criterions (factors) can affect the coverage performance of WSN. While it is impractical to cover all the possible factors, in this paper we review a wide range of factors that have dominating effect.

A. Development strategy

Your paper must use a page size corresponding to A4 which is 210mm (8.27") wide and 297mm (11.69") long. The margins must be set as follows: A deterministic deployment (such as grid deployment) is where and how many of sensor nodes placed. Deterministic sensor placement can be applied to a small to medium sensor network in a friend environment. In remote or inhospitable areas, or for military and disaster applications, or the network size is large, the exact positions and number of sensor nodes cannot be predetermined. Shown in the figure1.. A sensor network deployment can usually be categorized as either a dense deployment or a sparse deployment. A dense deployment has a relatively high number of sensor nodes in the given field of interest while a sparse deployment would have fewer nodes. The dense deployment model is used in situations when it is important to have multiple sensors cover an area.

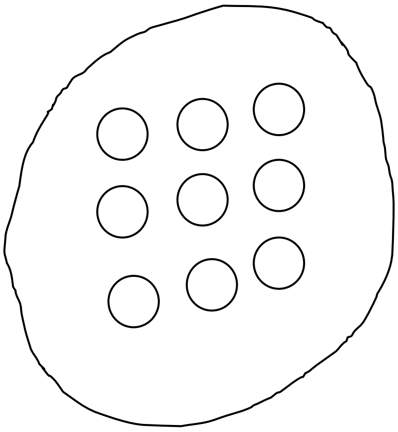

Figure 1: Deterministic placement

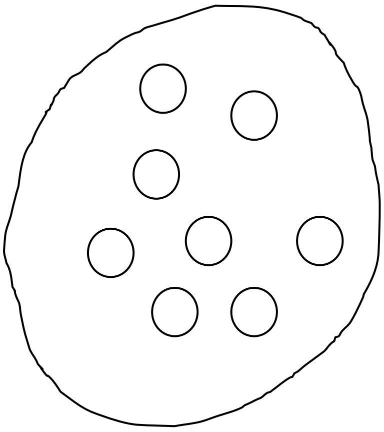

Figure 2: Random placement

Therefore, random deployment, where sensor nodes are distributed within the field stochastically and independently (e.g., air-dropped, scattered from an aircraft or launched via artillery), is required exclusively. Random deployments of sensor nodes are usually dense deployments as well since it is necessary to deploy additional sensors in order to achieve coverage if the sensor nodes are stationary. Networks with mobile sensors usually start out with a random deployment and utilize the mobility property in order to relocate to the optimal location.

B. Sensing Model

There are two mainly two different sensing models: one is Boolean sensing model where each sensor has a fixed sensing area and a sensor can only sense the environment or detect events within its sensing area. The Boolean sensing model assumes that sensor readings have no associated uncertainty. In reality, sensor detection is imprecise (not clear) hence needs to be expressed in namely the probabilistic sensing model, in which the detection probability of object or event and the sensor's sensitivity decreases as the distance increases.

C. Sensing Area

Where a sensor can detect an object or phenomena are inside its sensing range deterministically (a sensor can detect an object as long as the object is inside its sensing rang) or probably (the detection probability of an object is a function of the distance between the object and the sensor) depended on its sensing model. Generally, the sensors are assumed to have the same range. For example, the sensing area is considered to be isotropic (e.g., a circular area in 2-D). Moreover, there are several mechanisms that are extensible to any convex, no uniform sensing areas or irregular sensing areas.

D. Communication Ranges

In communication range different sensor having invariable transmission range, some sensor’s radio transceiver is capable for changing its transmission power in continuous steps to achieve different communication ranges. Practically, the actual communication ranges may also be affected by many external factors such as the height of the sensor and its surrounding objects.

E. Algorithm Characteristics

The sensor are deployed an algorithm run to determine if sufficient coverage exists in the particular area. This can be dividing in centralized or distributed algorithm. A centralized algorithm is run on one or more nodes in a centralized location usually near the data sink. the coverage algorithm is executed in a central node. In this case, information from all nodes needs to be transferred to the central node. In distributed (localized) algorithm, the coverage algorithm is executed based on information from only some nodes (e.g., neighbouring node) in WSN, and the decision is made locally. Distributed algorithms involve multiple nodes working together to solve a computing problem while localized algorithms imply that many or all of the nodes run the algorithm separately on the information each has gathered. Although the approach of centralization can provide more accurate information for coverage scheme, it more communication overhead and energy consumption.

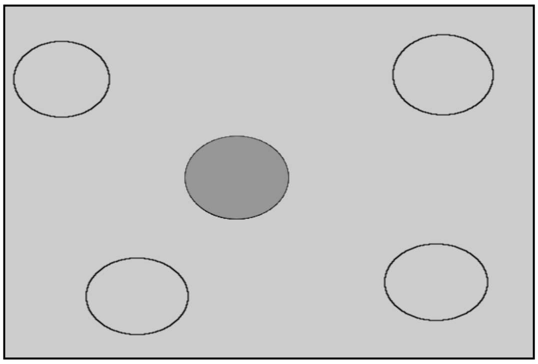

Figure 1: Centralized algorithm

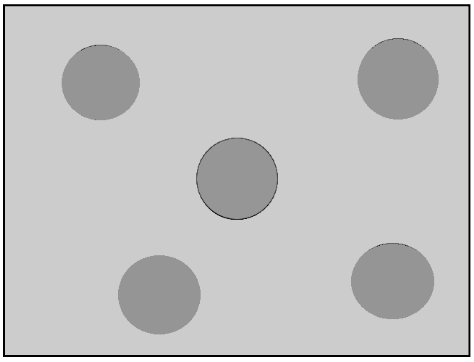

Figure 2: Distributed algorithm

F. Node Type

The set of nodes that are selected for a sensor network can be either a homogeneous or heterogeneous group of nodes. A homogeneous group is a group in which all of the nodes have the same capabilities. A heterogeneous group is one in which some nodes are more powerful than other nodes. Normally we have a smaller group of more powerful nodes known as cluster heads which would gather data from the less powerful nodes. Examples of homogeneous and heterogeneous nodes are given in figures 3 and 4.

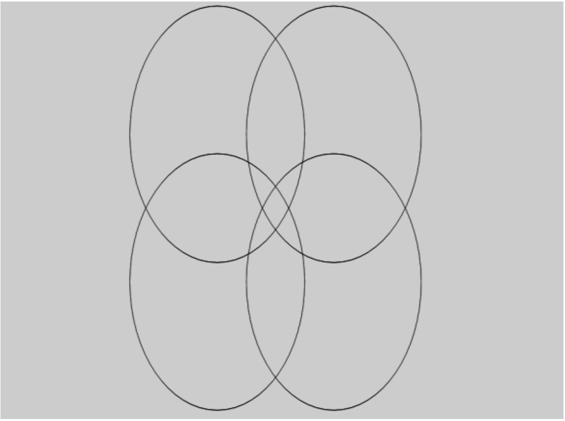

Figure 3: Homogeneous group

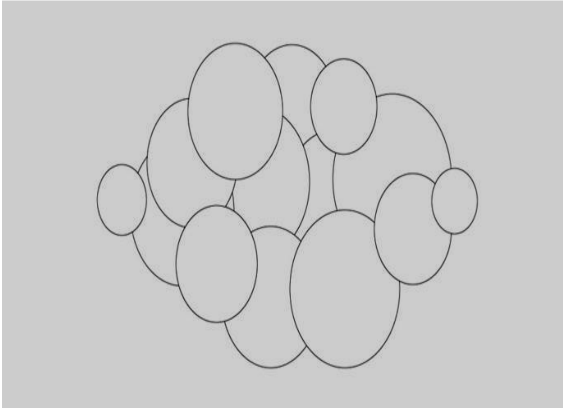

Figure 4: Heterogeneous group

III. COVERAGE PROBLEM

Coverage problems have been different in other fields. These problems greatly relating to the coverage in WSN include Art Gallery Problem, Circle and Covering Problem.

A. *Art Gallery Problem (AGP)*

The art gallery problem is a problem that has been studied in computational geometry and is related to the concept of coverage Imagine that the manager wants to place cameras in the gallery such that the whole gallery is thief-proof. Namely, one seeks to determine the minimum number of cameras that can be placed in a polygonal environment, such that every point in the environment is monitored by at least one camera. There are two questions arising: how many cameras are needed, and where these cameras should be deployed. A more formal definition of the art gallery problem is found in [3] A point x is visible by another point y (guard) if the entire straight line from x to y is within the polygon (area). If the entire polygon is visible from any of the guards then the polygon is considered covered. The polygons are classified according to the number of vertices n each contains. The proof states that *n/3* guards are sufficient to cover the polygon. A simple proof of this was given by Steve Fisk in 1978. He partitions the polygon into triangles colours each vertex of the triangle in one of three colours. The set of any colour vertex has visibility over every triangle in the polygon therefore the colour set with the fewest members represents the minimum number of guards needed for coverage. The proof of the art gallery is only valid for a two dimensional plane. A simple solution is to divide the polygon into non-overlapping triangles and place on camera in each of these triangles. When the problem is extended to a three dimensional space it become NP-hard to determine the minimum number of guards required in order to guarantee coverage.

B. *Circle Covering Problem (CCP)*

Given a fixed number of identical circles, the goal of CCP is to minimize the radius of circles that can fully cover a given plane. Namely, How to arrange identical circles on a plane that can fully cover the plane? Some approaches given number of circles are discussed, however, a universal method has not been found.

IV. EXISTING COVERAGE SCHEMES

Extensive research efforts have been made to develop energy efficient schemes integrating coverage and connectivity for WSN. Depended on the coverage objectives and applications, they can be roughly classified into three categories: area coverage, point coverage, and path coverage. They are first briefly summarized here:

A. *Area Coverage*

The most studied coverage problem is the area coverage problem, where the main objective of the sensor network is to cover (monitor) an area (as region). Where the main objective of the sensor network is to cover (monitor) a region (the collection of all space points within the sensor field), and each point of the region need to be monitored.

B. *Point Coverage*

The objective is to cover a set of point (target) with known location that need to be monitored. The point coverage scheme focuses on determining sensor nodes' exact positions, where guarantee efficient coverage application for a limited number of immobile points (targets). Generally, it can be solved as a special case of the area coverage problem when sensor nodes' number may leave out of account.

V. EXISTING SOLUTIONS TO POINT AND AREA COVERAGE

Firstly, we briefly introduce how to evaluate the coverage performance of a region covered by WSN. Given a set of sensors deployed in a monitored region, coverage-evaluating problem is to determine if all points in the region is sufficiently *k-covered*, in the sense that every point in the target area is covered by at least *k* sensors, where *k* is a given parameter. Rather than determining the coverage of each point, the area coverage problem is mostly studied in coverage problem, while, it also emphasizes coverage with minimum sensor nodes and energy consumption when the region is covered by connected WSN.

A. *Coverage Configuration Protocol (CCP)*

The goal of this protocol is to achieve to the guaranteed different degrees of coverage and connectivity while maximize the number of sleeping, and allow WSN to self-configure for a wide range of applications when the communication range is more than twice as the sensing range. To ensure K-coverage, a node only needs to check whether the intersection points inside its sensing area are K-covered. Note that it cannot guarantee network connectivity when the radio transmission range is less than twice the sensing range. Therefore, by combing CCP with SPAN (a distributed connectivity preserving mechanism for multi-hop ad hoc wireless networks that reduces energy consumption without significantly diminishing the connectivity of the network), the coverage and connectivity can be guaranteed in any case. In CCP, sensor nodes need accurate location information and a neighbourhood table. [5] The protocol attempts to maximize the number of nodes that can be put into sleep mode while guaranteeing k-coverage and connectivity. They use a Voronoi diagram to prove the assertion that coverage implies connectivity when$R_C \geq 2R_S$. They extend this by proving if the area is k-covered by the sensors then it is also k-connected. They also prove that in a convex region, the connectivity is 2Ks if $R_C \geq 2R_S$. To prove k-coverage focuses on the boundaries of the sensing range. If every boundary is k-covered then the entire region must be k-covered. The nodes in CCP can be in one of three states: SLEEP, LISTEN, or ACTIVE. Each node will periodically send out HELLO packets with its location and status. From this the nodes will compile a list of each of its neighbours when it is in the LISTEN state. If its entire sensing area is covered by its neighbours then it will transition into SLEEP mode. They will remain there until the sleep timer expires and then they will re-evaluate coverage. The CCP protocol does not guarantee connectivity when $R_C < R_S$. In order to accomplish decided to integrate CCP with another connectivity protocol SPAN. In this case a node will not enter the ACTIVE state unless it satisfies the eligibility rules for both CCP and SPAN.

B. *Optimal Geographical Density Control (OGDC)[6]*

This is a decentralized and localized density control scheme based on the proof that if communication range is at least twice of the sensing range, then a complete coverage of a convex area implies connectivity. It can configure a sensor network with the characteristics of full-coverage, network connectivity, and maximum energy conservation by assuming that the sensor density is high enough so that a sensor could be found at any desirable position and the sensing range could be different for sensors. The goal of OGDC is to maximize the number of sleeping sensors while ensuring that the working sensors provide 1-coverage and 1-connectivity. By using its own location and the working sensors' locations, a sensor can verify whether or not it turns on. When a sensor minimizes the overlapping area with the existing working sensors and when it covers an intersection point of two working sensors, itself will be activated. When the radio transmission range is at least twice the sensing range, OGDC can maintain both 1-coverage and 1-connectivity.

In OGDC, sensor nodes need accurate location information and time synchronization, and working nodes never go back to sleep, but different nodes may be working in different rounds so energy consumption may still be balanced among all the nodes. The nodes in OGDC can be in any of three states: ON, OFF, or UNDECIDED. They quantify time into rounds which are comprised of a node selection phase and a steady state phase. The nodes start off as UNDECIDED and then transition to either ON or OFF for the steady state phase. Nodes with greater power will volunteer to be active during the node selection phase. This will lead to more uniform energy depletion among the nodes.

C. *Random Independent Scheduling (RIS) [7]*

The goal of RIS is to determine the appropriate number of sensors that are enough to achieve *k-coverage* of a region when sensors are allowed to sleep most of their lifetime for extending network lifetime. It assumes that time is divided into cycles based on a time synchronization method. In RIS, independently sleeping approach that is energy-efficient and light-weight because each sensor doesn't require any interaction with their neighbour that can make a sensor is active with probability *p* or go to sleep with probability *1-p*. RIS does not require location information and the table of neighbourhoods.

D. *Low energy Adaptive Clustering Hierarchy (LEACH) [8]*

A cluster-based protocol architecture for micro sensor networks that combines the ideas of energy efficient cluster-based routing and media access together with application-specific data aggregation to achieve good performance in terms of system lifetime, latency, and application-perceived quality. The goal of LEACH is turning off non-head nodes as much as possible. In LEACH, the operation is divided into cycles and each cycle includes a set-up phase and a steady phase. During the set-up phase, cluster heads are selected and each sensor joins a cluster by choosing the cluster head that requires the minimum communication energy. During the steady phase, each cluster head aggregates the data from the sensors in its cluster and then transmits the compressed data to the base station. LEACH enables self organization of large numbers of nodes, algorithms for adapting clusters and rotating cluster head positions to evenly distribute the energy load among all the nodes and techniques to enable distributed signal processing to save communication resources.

VI. PROPOSED SOLUTION FOR POINT AND AREA COVERAGE

A. *Time Scheduling Deployment Technique (TSDT)*

The TSDT is to maintain long network lifetime as well as synchronized the scheduled sensor to sleep mode. Every node tries to maximize its coverage while maintaining the required number of neighbours. The goal of TSDT is to maximize the number of sleeping sensors while ensuring that the working sensors provide full coverage and connectivity. This technique provide the deterministic sensor deployment method, A fixed communication range for the sensor and sensor nodes provide the accurate location information, time synchronization and working node also go back to the sleep mode. The redundant sensing areas need a few sensors used to provide a coverage and connectivity, if time scheduling or synchronization did between the sensors for a particular area. Therefore, only one sensor provides a full coverage and connectivity for redundant sensing area. The number of sleeping node can also increase. In TSDT all the nodes are self organization and location adaptive. The main advantage of the TSDT is that there is also used to save communication resources, sensor system lifetime and energy. The TSDT is also minimizes sensor overlapping area with the used of one sensor node. Somehow one sensor does not work properly than loaded shifted to the next sensor. The disadvantage of the TSDT is that there is any error occurs in the timer than the complete system is break.

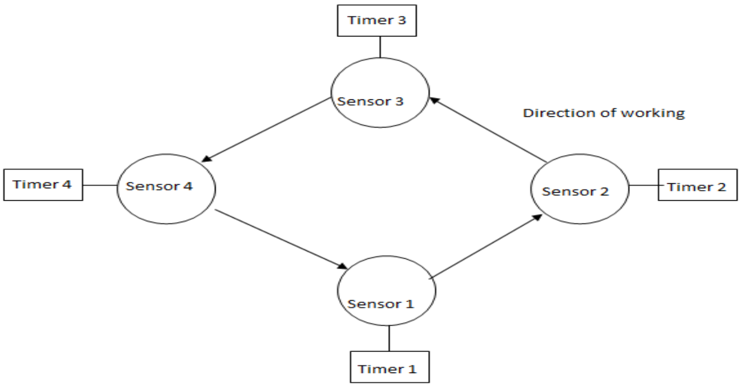

Figure 7: Architecture of TSDT

VII. COMPARISION BETWEEN PROPOSED AND EXISTING SOLUTIONS

SCHEMES	SENSING MODEL	COMMUNICATION RANGE	SENSING AREA	ALGORITHM CHARACTERISTIC	NETWORK STRUCTURE	DEPLOYMENT STRATEGY	SAME R_S FOR ALL SENSORS	IS R_S= =R_C ?
CCP	Boolean	Fixed	2-D circular	distributed	flat	Any	yes	No
OGDC	Boolean	Fixed	2-D circular	distributed	flat	Any	yes	No
RIS	probabilistic	Fixed	2-D circular	Distributed	flat	Deterministic	yes	NA
LEACH	Boolean	Fixed	2-D circular	distributed	flat	Any	yes	NA
TSDT	Boolean	Fixed	2-D circular	distributed	flat	Deterministic	yes	No

VIII. CONCLUSION

This paper reviewed the design considerations for coverage problems in WSN, and it presented the existing solutions. The existing researches focus on the following consideration: evaluating and improving coverage performance of area and point. While maintaining connectivity and maximizing the network lifetime. Although many schemes have been proposed and progress has been made in coverage problems of WSN, there are still many open research issues. More authentic model of sensor nodes must be incorporated with the coverage schemes in order to perform various real applications excellently. Effective coverage scheme should be proposed to implement real applications but limited to theoretical study.

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