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A Survey on Distributed Algorithms for Constructing Minimum Spanning Trees in Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) is the one of the emerging networks which works under in-herent resource constraints. Topologies of these kinds of networks can also transform dynamically based on the location, number of sensor nodes and application. It is indispensable to build up effective distributed algorithms to handle the energy, bandwidth limitations of WSNs. Due to the arrival of several complicated network technologies, distributed algorithms have turned out to be an essential and rapidly growing field of research. The ma jor purpose of distributed algorithm is to transmit a large number of messages, which indirectly can consume a comparatively large amount of energy and time. Hence this requires the network to be reconfigured to dynamic setting regularly and quickly. Moreover, reconfiguration is essential to uniformly distribute the energy consumption among all the nodes and thus to enhance the network lifetime. The Minimum Spanning Tree (MST) problem is one of the most common problems in the field of distributed computing and a frequently occurring primitive in the design and operation of WSN. In this survey, several distributed algorithms for construct-ing MST are discussed in the literature.

Key words: Wireless networks · Sensor Network · Min-imum Spanning Tree · Distributed Algorithm · Energy-Efficient Algorithms

INTRODUCTION

Wsn is a fast growing field which integrates sensing, computation and communication into a single tiny device. At the same time the capabilities of a particular single device is minimum, the composition of hundreds of devices offers essential new technological possibilities [1, 2]. The power of WSNs lies in the capacity to organize huge amount of tiny nodes that pull together and arrange themselves [3]. These devices are exploited in several applications which range from real-time monitoring to observation of environmental conditions, ubiquitous com-puting atmosphere. To in, situ monitoring of the phys- ical condition of structures or equipment. At the same time, WSNs are also typically recognized as control actu-ators that widen control from cyberspace into the physi- cal world [4].

At present WSNs show the evidence of an unbeliev- able research momentum. Computer scientists and re- search engineers from almost all the fields are embracing this particular field. Sensor networks are taken up by re-searchers from hardware technology to operating systems, from antenna design to middle ware, from graph theory to computational geometry. Information and communi- cation researchers investigate the basic scaling laws, for instance, the capacity of a sensor network. Networking researchers continue to develop new protocols for all lay-ers of the stack and the database researchers consider sensor network as a typical database.

Distributed algorithms are of a major focus, because at the stage of first approximation, a sensor network can be represented as a message passing graph [5]. Consequently there is hope that distributed algorithms can either be directly used or at any rate adapted to sensor networks [6, 7].

In the recent past, distributed network algorithms have been an increasing research field. In contrast to other natural application areas like the Internet or peertopeer/overlay networks, sensor networks are less

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susceptible to side effects, for instance, selfish behavior of individual sensor nodes, normally the complete network is owned by a single entity [8].

Minimum Spanning Tree (MST) problem is a vital and frequently occurring primitive in the structural de-sign and operation of data and communication networks.

A MST is spanning tree with least amount of weight be-tween all possible spanning trees of the graph, in which the weight (or cost) of a spanning tree is the sum of the weights of the edges in the spanning tree.

In an ad-hoc sensor networks, MST is the most favor-able routing tree for data aggregation [9]. Convention-ally, the effectiveness of distributed algorithms is evaluated by the running time and the amount of messages interchanged between the computing nodes and several researches have gone into the design of algorithms that are optimal with respect to such condition. There are distributed algorithms that discover the MST [10, 11] and are fundamentally optimal based on the time complexity.

In several applications, the sensors are characteristically scattered generously in the region of interest and the network is created in an ad-hoc fashion by local self- configuration. Because each sensor typically recognizes only its neighbors, the network management and communication has to be carried out in a local and distributed fashion. In addition, because of battery restrictions, energy is an extremely fundamental resource. A distributed algorithm, which interchanges a huge number of messages, can utilize a comparatively large amount of energy and also time and is not appropriate in an energy-constrained sensor network, this is particularly true in a dynamic setting when the network requires to be reassembled recurrently and rapidly. Reconfiguration is also essential to consistently distribute the energy consumption between all nodes and thus, to increase the network life-time [9].

As a result, it is essential to build up simple local dis-tributed algorithms which are energy efficient and more-over it should be also time efficient, even at the cost of being suboptimal. This made a new dimension to the design of distributed algorithms for wireless sensor net-works.

Literature Survey: Traditionally, the performance of distributed algorithms has been evaluated on the basis of time and message complexity. Message complexity considers the number of messages broadcasted over all the edges throughout the course of the algorithm. On the other hand, in case of energy-constrained ad-hoc wireless networks, energy is a significant feature in evaluating the effectiveness of a dis- tributed algorithm. Broadcasting a message between two nodes has a related cost (energy) and furthermore this cost is based on the two nodes. Consequently, together with the time and message complexity, it is essential to consider energy complexity that is responsible for the to- tal energy related with the messages exchanged between the nodes in a distributed algorithm.

Yongwook Choi *et al*., [12] addressed the MST prob-Lem, an essential problem in distributed computing and communication networks. The author studied energy- efficient distributed algorithms for the Euclidean MST problem by presuming random distribution of nodes and revealed a non-trivial lower bound of Omega($\log_n$) on the energy complexity of any distributed MST algorithm. Then recommended an energy-optimal distributed algorithm that builds an optimal MST with energy complexity O($\log_n$) on average and O ($\log_n \log_n$) with elevated probability. This is an enhancement when compared to the earlier best known bound on the average energy com-plexity of Omega ($\log^2$ n). This energy-optimal algorithm utilized a new property of the massive component of sparse random geometric graphs. The author considered that all the nodes do not have any knowledge about their geometric coordinates.

Several distributed algorithms exist for the MST prob-lem, these approaches need comparatively large number of messages and time this makes these approaches un-feasible for resource-constrained networks such as ad-hoc WSNs. In these networks, each sensor has extremely in- adequate power and any algorithm must to be uncom- plicated, local and energy efficient for being convenient. Inspired by these considerations, Khan *et al*., [13] de- signed and investigated a class of simple and local distributed algorithms called Nearest Neighbor Tree (NNT) algorithms for energy-efficient construction of MSTs in a wireless ad-hoc network. The author assumed that the nodes are distributed equivalently in a unit square and demonstrated provable bounds on the performance based on both the quality of the spanning tree produced and the energy required to build them. In specific, the author showed that NNT produces a close approximation to the MST and they can be continued dynamically with polylogarithmic number of rearrangements under node insertions/deletions.

In Fangxiu Wang [14] approach, it is simple to get only a MST from the entire spanning trees with the cur-rent minimum spanning tree algorithm. This algorithm mainly uses the binary code and the features of the MST to obtain all the MSTs. Initially, this approach removed some of the non spanning trees based on the number of the graph edges. Furthermore, it eradicates some of the non-spanning trees based on the judgment of the graph connectivity. In reality, the fundamental work of this al-gorithm is to search for the most excellent in the global scope. Finally, it is simple to discover all the MSTs of the connected graph considering the algorithm.

MST problem is a standard problem in operation of network design. It can be solved efficiently, but its biobjective versions are non-deterministic polynomial-time hard. Sanger and Agrawal [15] compared three tree encoding approaches based on biobjective evolutionary algorithm. Three different tree encoding techniques in the evolutionary approaches are being utilized to provide so-Lution for three different instances of biobjective MST problem. Comparative study of the tree encoding techniques utilized is carried out on the basis of obtained Pareto optimal front. This approach involves biobjective MST problem by means of Non-dominated Sorting Genetic Algorithm II (NSGAII).

In practice, minimum spanning tree-based clustering algorithms are extensively used because of its potential to detect clusters with unbalanced boundaries. On the other hand, in these clustering algorithms, the search for nearest neighbor in these production of MSTs is the chief source of computation and the standard solutions take $O(N^2)$ time. Xiaochun Wang *et al*., [16] developed a fast minimum spanning tree-inspired clustering algorithm. This algorithm uses an effective implementation of the cut and the cycle property of the MSTs. And its performance is better than the $O(N^{2)}$.

Developing energy-efficient routing protocols to successfully enhance the networks' lifetime and provide the strong network service is one of the significant difficulties in the research of WSNs. By utilizing the hyper-graph theory, Yang Ting *et al*., [17] represented the large-scale WSNs into a hyper-graph model and this model can efficiently reduce the control messages in routing process. In accordance with the mathematic model, the author presented the Minimum Spanning Hyper-free routing algorithm in Synchronous wireless sensor Networks (MSHI-SN). This algorithm constructs a least amount energy consumption tree for data collection from multi-nodes to sink node. It can enhance the transmitting success rate and efficiently keep the scarce energy.

As discussed earlier, the sensor nodes in WSNs have very small dimensions for generating their energy, it is unavoidable to use batteries with inadequate power. The problem of energy reduction is constantly being a challenge in these networks. Routing is one of the major concerns that can reduce energy reduction. Khamforoosh [18] developed a new technique for routing in WSNs that makes effort to add nodes which have the least amount distances from each other rather than using the conventional routing techniques. In this technique, the author partitioned nodes to some clusters based on the LEACH algorithm then cluster heads produce MST in accordance with prim algorithm. At the same time the tree is balanced by using the AVL algorithm.

With the intention of efficiently exploiting the inadequate energy resources of sensor nodes to extend the lifetime of WSNs, Bencan Gong and Tingyao Jiang [19] developed a power-aware Tree-Based Routing Protocol called TRP. Every sensor node finds a parent node consistent with the energy dissipation of communication, the distance between neighbor nodes and sink and remaining energy of neighbor nodes. As a result, a near best possible MST rooted on sink is built. Data collected by sensor .

A node is transmitted along tree and is combined in over- lap nodes.

Ghosh *et al*., [20] investigated the consequence of routing topologies on increasing the aggregated data collection rate and reducing the maximum packet delay in TDMA-based sensor networks. The author developed a bi-criteria formulation to the best possible routing tree construction problem and confirmed that a tree with bounded node degree and minimum radius can accomplish the best trade-off between the data collection rate and packet delays.

In certain applications of WSN, every node can ex-change information with the base station. Whenever a node exchanges information with base station directly, there might be several duplication of information and hence occurs waste of nodes' energy. In order to over comes this issue. Yanrong Cui and Hang Qin [21] put for-ward Data Query Protocol based on Minimum Spanning Tree (QPMST). QPMST protocol can produce a MST with sink node as a root node and supplementary nodes as descendants, query tasks are broadcasted from sink node, query results are given to sink from leaves nodes and collected in their parents. This protocol considerably reduces the transmission of redundancy data, saves the nodes' energy and increases the network lifetime.

A sensor web is a network of spatially distributed sensor platforms, which in particular well suitable for environmental monitoring. Even though sensor nodes of a sensor web are important devices that carry out the monitoring work, the low-cost implementation of sensor nodes poses that they are cause to undergo failures and permanent damage. Consequently a life-condition monitoring method for sensor nodes is essential to ensure the function of a sensor web.

Yangfan Zhou *et al*., [22] investigated this sensor-node monitoring problem in this field where in-network sensor nodes are self-monitoring, specifically the condition of each sensor node is observed by another node. In order to be energy-efficient, a method for implementing self-monitoring sensor webs should reduce the energy required and proposed a formal formulation of this difficulty and demonstrated that it can be solved by discovering a MST of the graph built by in network nodes. The author pro-vided distributed algorithms for the purpose of solving this problem.

Field surveillance is one of the most significant applications for WSNs. Several sensors are organized in a region of distress to identify any potential targets. In contrast, intelligent target discovers the deployed sensors to demolish for fear of being identified and may lead to defunct surveillance. Because of the significance of sensor nodes, it is essential to hide them from the scope of target.

Wenzhe Zhang *et al*., [23, 24] introduced Proactive Stealthiness as the normal immune system covered on sensor networks and represented the stealthiest prob-lem and developed a distributed marking algorithm depending on Breadth-First Spanning Tree Dissimilar to previous approaches, in which only establish self protection to WSNs. This algorithm not only maintains the connectivity of all dominating sensors but accomplish the minimum hops of urgent message to gateway.

Problems and Directions: The above section discussed the existing distributed al- gorithms for constructing minimum spanning trees in WSNs. There are several problems in the above discussed techniques. In order to overcome these difficulties and design a better distributed algorithms for constructing MSTs numerous re- searches have to be done. The future research should take care of the following matters.

- The efficiency of a distributed algorithm should be focused on energy, rather than the number of messages involved.
- Several works have been done on local algorithms for generating the low-weight connected sub graphs based on the topology control and energy-efficient routing. But there has been only a limited number of researches have concerned the localized generation of accurate or approx- imate MSTs.

Table 1: An Overview of the Existing Distributed Algorithm for Construct- Ing Minimum Spanning Trees

Method	Technique Used
Yongwook Choi *et al*.,[2009]	Exploited a novel property (non- trivial lower bound, energy-optimal distributed algorithm)of the giant component of sparse random geometric graphs.
Khan *et al*., [2009]	Designed and analyzed a class of sim-ple and local distributed algorithms called nearest neighbor tree (NNT) al- gorithms for energy-efficient construc- tion of MSTs.
Fangxiu Wang [2011]	Used the binary code and the charac-teristics of the minimum spanning tree to g*et al*l the minimum spanning trees.
Sanger and Agrawal [2010]	This approach involves Biobjective Minimum Spanning free problem using Non-dominated Sorting Genetic Algo- rithm II (NSGAII).
Xiaochun Wang *et al*., [2009]	Presented a fast minimum spanning tree-inspired clustering algorithm, by using an efficient implementation of the cut and the cycle property of the min- imum spanning trees.
Yanu Ting *et al*.,[2007]	Represented large-scale wireless sen-sor networks into a hyper-graph model,which can effectively decrease the control messages in routing process.
Khamforoosh [2011]	Divided nodes to some clusters accord-ing to LEACH algorithm then cluster heads create minimum spanning tree according to Prim algorithm.
Bencan Gong and TingyaoJiang [2011]	Presented a power-aware tree-based routing protocol called TRP.
Ghosh *et al*.. [2010]	Proposed a bi-criteria formulation to the optimal routing tree construction problem.
Yanrong Cui and Hang Qin [2010]	Developed a Data Query Protocol based on Minimum Spanning Tree (QPMST).
Yangfan Zhou *et al*., [2007]	A mechanism for implementing self-monitoring Sensor Webs to minimize the energy required by finding a min- imum spanning tree of the graph con- structed by in-network nodes.
Wenzhe Zhang *et al*., [2010]	Modeled the stealthiness problem and proposed a distributed marking algo- rithm based on Breadth-First Spanning Tree.

- It is to be noted that MST cannot be built completely in a localized manner, i.e., each node cannot determine which edge is in the defined structure by using only the information of the nodes within certain constant hops.
- Moreover, when the radius of the network graph is very small, it would be more energy efficient to utilize the partially distributed algorithm although every iteration involves the update of a central variable. On the other hand, in case of large network radius, the fully distributed algorithm will work efficiently.

CONCLUSION

Wireless sensor networks are used extensively in large number of applications to perform various monitoring tasks like search, rescue, disaster assistance, monitoring target and several number of tasks in smart environments. In practice, a wireless sensor network is modeled as a graph, indicating nodes by vertices and wireless links by edges. Distributed al-gorithms are widely used to transmit a large number of nodes. MST is the most considerable problem in distributed algorithm. Several existing techniques are discussed in the literature and provided some directions to carry out the research in future.

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