# *Delaunay Triangulation and st-numbering in Wireless Sensor Network Topology*

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*Abstract*— **Significant advances have been made in Wireless Sensor Networks (WSN)s over the last decade. The advances in wireless communication and electronics have enabled the deployment of low-cost, low-power, multifunctional smart sensor nodes that are small in size and communicate in short distance. Energy-efficiency is one of the major concerns in wireless sensor networks since it impacts the network lifetime and performance. Network topology plays a very important role in determining quality of service of wireless sensor network because sensor nodes are remotely deployed in ad-hoc manner. For routing and information processing it is important to know the topological relationship of the network nodes. In this paper, we proposed a topology generation algorithm using Almost Delaunay Triangulation (ADT) which is power efficient. To obtain better performance in a wireless sensor network, it is important to have unique id of the nodes which can be achieved from the node numbering. So, we proposed *st*-numbering for assigning IDs to the nodes. This paper also presents the total complexity of generating the topology as well as assigning ID to them.**

***Keywords— Almost Delaunay Triangulation (ADT); st-numbering; ID assignment.***

## I. INTRODUCTION

Wireless Sensor Networks are networks that consist of sensors which are distributed in an ad hoc manner. They have a large number of dispensable and autonomous small devices, known as sensor nodes or motes. These sensor nodes are capable to store, process, transmit or receive the monitored data. There are some nodes which have much more computational capacity, energy and communication resources than the normal sensor nodes. These are called *base stations*. The collected data sensed by sensor nodes are usually transmitted to a fixed base station which is called sink [1].

Generally, sensor nodes are constructed with Sensing unit with sensors and ADCs, Small microcontroller or a Processor unit (with processor and storage), Radio transceiver or other wireless communications device, Energy source ( i.e. battery).

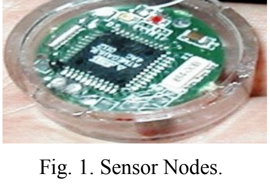


Fig. 1. Sensor Nodes.

Many potential applications of WSN are found at various fields such as: Area monitoring, Environmental Monitoring, Habitat monitoring, Intelligent Traffic Information Collecting System, Remote Medical Care, Industrial Safety & Disaster Relief, Condition based maintenance, Smart spaces, Water supply pipes, Precision agriculture, Factory instrumentation, Power Grid, Inventory tracking etc.

The lifetime, low energy consumption, message delay, message due dates, bit error rates, packet loss etc. determines the Quality of Service (QoS) of a WSN. With the rapid development of WSNs, the requirements for QoS are growing, particularly in applications where real time imaging, video or audio communications are involved [5]. QoS of WSNs mostly depends on topology. *Topology* is the arrangements of the nodes, base stations etc. in a network, where the nodes have knowledge about the neighbors such as their lifetime, connectivity and coverage area, routing path etc. *Topology control* [16, 17, 18, 19, 20] aims to reduce the transmission power by adjusting nodal radio transmission ranges while preserving necessary network properties (e.g., connectivity, coverage). Topology control is fundamental to solving scalability and capacity problems in large-scale wireless ad hoc and sensor networks.

In this paper, we proposed ADT based topology generation algorithm and introduced *st*-numbering for assigning IDs to the nodes. This paper also presents the total complexity of generating the topology and ID assigning of sensor nodes.

## II. RELATED WORK

### *A. Power Efficient Topologies for WSNs*

Power efficient topologies for WSNs are discussed in Directional Source Aware-Protocol (DSAP) [6]. DSAP is a communication protocol that has many advantages over other routing protocols, including incorporating power considerations and having no routing table. The routing works by assigning each node an identifier that places that node in the network. By considering the maximum available power and minimal directional value when picking which node route to take, the objective to incorporate energy efficiency can be achieved. To determine which topology gives the optimal number of neighbors that a node can handle to transmit to or receive from, the authors concentrate on 2D and 3D mesh topologies.

DSAP has a constant, renewable energy source and constrained by a very low-power dissipation allowance, which fits nicely with an energy-efficient scheme. This paper consists of three major topics, overall power dissipation, DSAP routing, and Power-DSAP routing. In general, they conclude that the 3D network dissipates less power than the 2D network for both DSAP routing and Power-DSAP routing, Moreover, Power-DSAP performs better than DSAP for the 3D network. It is clear that the path selection affects the amount of power used in the networks.

Efficient topologies for stationary wireless networks become more important as the importance of WSN grows. So, the Power-DSAP routing protocol is an effective solution for this problem. But in this paper [6] there is a possibility of error, when assigning identifier to each node. Which is an exponential error $2^n$, where n is the number of bits in identifier. In this paper [6], between any given source and destination the number of transmission using interior or edge routing is constant in 3D analysis. But if there is a weight in each neighbor of the source in the routing paths, then the transmission with less-power dissipation can be found.

*B. Low-coordination Topologies for Redundancy in Sensor Networks*

Rajagopal lyengar, Koushik Kar and Suman Banerjee discussed [7], low-coordination topologies for redundancy in sensor networks. In this paper [7] how nodes should be managed in dense sensor deployments to manage coverage and connectivity is described. They present simple low-coordination wakeup-based connected coverage topology construction scheme that can perform well in dense sensor deployments. By timesharing between different sets of sensor nodes they construct multiple independent sensor network topologies to achieve good fall tolerance as well as to increase the lifetime of the network. Their goal is to maximize the number of independent connected covered set where there is no common nodes among the sets and minimal or no coordination between the sensor nodes.

In this paper they propose and evaluate random-wakeup based cc-topologies and patterned-wakeup based cc-topologies. Three types of patterned-wakeup based cc topologies are described, they are square-grid based cc-topologies, hexagonal-grid based cc-topologies and strip-based cc-topology.

In the paper they constructed the STR and the HEX topology under the assumption that the network is so dense that we could active a sensor node at any location of our choice. But in realistic it is not exactly true.

In Approx-STR and Approx-HEX wakeup policies require a sensor node to know its location. The location information can be obtained if the nodes have access to GPS or the relative location can be computed using some distributed localization algorithm. Here the problem of these algorithms is that they require the knowledge of the location. To implement C-BFS a node needs to know its distance from its neighboring nodes. If it is not available then the distance have be calculated from the location. Again we need the location of the sensor node to implement the algorithm.

In practical optimality cannot be obtained using any of these algorithms. In practice it has been observed that the performance of C-BFS is better than other algorithm which is 70% with respect to the upper bound.

*C. Almost Delaunay Triangulation Routing in WSNs*

Md. Bahlul Haider and Kokichi Sugihara propose [8] an algorithm based on Delaunay Triangulation (DT) to organize the topology of the sensor network. The ADT routing graph is generated locally. This graph is generated only once and can be used during the whole lifetime of the wireless sensor network. At each round, the sensor nodes use a sub-graph of the ADT which is very easy to generate and also very much cost effective. The proposed algorithm shows good performance when the distribution of the sensor nodes is uniform.

Once the ADT is generated, all the nodes will have to only remember the neighbors in the ADT. In each round the head is selected and the head's location information is sent to all the nodes. Then each node will choose one neighbor in the closest direction to the cluster head for routing. This routing is known as compass routing. In compass routing only local information and the information about the destination is used to route the information.

They also show that if they select the destination nodes (cluster heads) from the central parts of the graph, the possibility that the compass routing will guarantee the delivery of information to the cluster head is much higher in the DT.

They analysis that, compass routing is possible in most of the cases. Only for a very few times some of the nodes could not reach to the cluster head by using compass routing in ADT. These situations arise when the cluster head is selected near the convex hull. In this algorithm they assign small probability for the nodes near the convex hull to become the cluster head and thus they avoid the situations like these. If some of the nodes fail, they reconstruct the graph in that region locally because the node insertion and deletion has only local effects.

*D. Success Guaranteed Routing in Almost Delaunay Planar Nets for Wireless Sensor Communication*

Md. Bahlul Haider, Shinji Imahori and Kokichi Sugihara proposed [3] a routing strategy for WSNs where the distribution of the sensor nodes is not always uniform. The authors first introduced an underlying graph, called the almost Delaunay planar net, is a planar graph with relatively short edges and it is possible to construct the graph with local computation only.

They also proposed a new routing strategy that always guarantees the reachability on planar graphs without increasing energy consumption and gave a theoretical proof of the reachability. The proposed routing strategy is a mixture of three existing methods (compass, perimeter, and face routings).

They conducted computational experiments and confirmed that, the almost Delaunay planar net is useful for both existing routing strategies and new strategy, the proposed routing strategy guarantees delivery on various planar graphs including the almost Delaunay planar net, and the path length computed by our routing strategy is shorter than that with face routing, which is a known routing strategy with guaranteed reachability on planar graphs.

The effectiveness of the almost Delaunay planar net depends on choosing an appropriate value of the transmission range r and this is a problem to be solved in the future. Multiple clustering could further improve path quality and energy consumption where only a single cluster model is considered in this paper.

### *E. Location-aware ID Assignment in WSNs*

Yunhuai Liu and Lionel M. Ni proposed [4] a local ID assignment scheme, called GREENWIS for WSN by considering the criticality of node ID in most applications. Without having the pre-knowledge of location, each node is able to generate a 5-tuple local ID within an application field in a distributed manner using the GREENWIS algorithm. Their experimental results showed that GREENWIS provides effective local ID assignment in a real WSN environment and also proved the correctness and show the effectiveness by comprehensive analysis.

The experiments based on Berkley Motes show that traditional multi-path routing protocols do not perform well as expected in real environments. Accordingly, the authors propose a semi-roaming routing based on GREENWIS ID scheme to increase the communication reliability which approaches the goals of energy-efficiency and robustness. However, they did not achieve the satisfactory reliability yet even the semi-routing protocol is applied.

In future work, they will focus on the reliability related issues in sensors network like, impact of local IDs, wireless link filtering algorithms, and neighbor set control by adjustable transmission power. Also, the GREENWIS system can be extend to multiple sink scenarios with support of sleeping algorithms where the current system is based on the assumptions of single sink and all the sensors keep active.

### *F. Distributed Global ID Assignment for WSNs*

E. M. Ould-Ahmed-Vall, D. M. Blough presented [15] a distributed algorithm to solve the unique ID assignment problem. There proposed algorithm has 3-phase. In the first phase, temporary long IDs are assigned which are used in the second phase to reliably determine the exact size of the network and, therefore, the minimum number of bytes to use. In the third phase, final IDs coded are assigned by using the minimum number of bytes. After the initial deployment phase the algorithm allows nodes to join the network and obtain unique IDs. This task is performed at the local level by allowing each node initially participating in the algorithm.

They demonstrated that the proposed algorithm can be tailored to obtain excellent results, both in terms of the percentage of participating nodes and the execution time. Besides, the algorithm terminates in a relatively short time that scales well with the network size.

When not enough spare IDs have been assigned and a large number of nodes waking up asynchronously cannot receive a unique ID, then the algorithm has to be restarted several times. They reduced this problem by properly choosing the spare ID allocation method and setting its parameters.

### *G. ZigBee-Based Long-Thin WSNs: Address Assignment and Routing Schemes Meng-Shiuan*

In 2012 Meng-Shiuan Pan and Yu-Chee Tseng [22] promotes a new concept of *long-thin (LT) topology* for WSNs, where a network may have a number of *linear paths* of nodes as backbones connecting to each other. These backbones are to extend the network to the intended coverage areas. At the first glance, a LT WSN only seems to be a special case of numerous WSN topologies. However, by observing, from real deployment experiences, that such a topology is quite general in many applications and deployments. They also show that the *address assignment* and thus the *tree routing scheme* defined in the original ZigBee specification may work poorly, if not fail, in a LT topology. Then they propose simple, yet efficient, address assignment and routing schemes for a LT WSN.

In ZigBee, network addresses are assigned to devices by a distributed address assignment scheme. The authors have proposed hierarchical address assignment and routing schemes for ZigBee-based LT WSNs. The proposed address assignment scheme divides nodes into several clusters and then assigns each node a cluster ID and a node ID as its network address. With such a hierarchical structure, routing can be easily done based on addresses of nodes and the spaces required for the network addresses can be significantly reduced. They also show how to allow nodes to utilize shortcuts. In this design, not only network addresses can be efficiently utilized, but also the network scale can be enlarged to cover wider areas without suffering from address shortage. They verify the schemes by simulation programs. It deserves to further discuss address assignment and routing schemes for more complicated topologies such as meshes that are connected by “long-thin” links.

## III. TOPOLOGY AND DELAUNAY TRIANGULATION

The ADT is generated based on Delaunay triangulation (DT) to organize the topology of the sensor network [8]. To generate the ADT we need to consider the battery power of a sensor node, which reduce the failure rate of data transmission. We are also concerned about the physical topology because, the lifetime of a sensor network depends on the physical topology of the sensor nodes [2].

### *A. Delaunay triangulation*

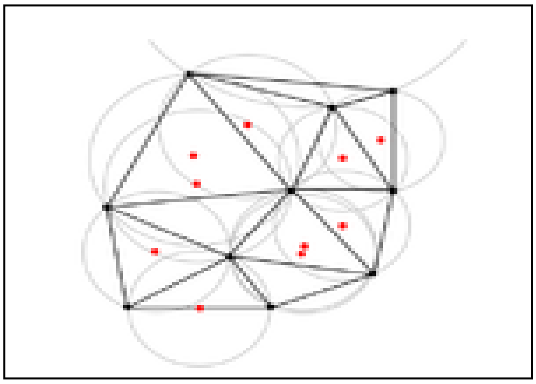
Our work is done for such a WSN where the underlying network topology is the DT of all wireless nodes. A DT for a set $P$ of points in the plane is a triangulation DT($P$) such that no points in $P$ is inside the circum-circle of any triangle in DT($P$) [8].

### *B. Voronoi diagram*

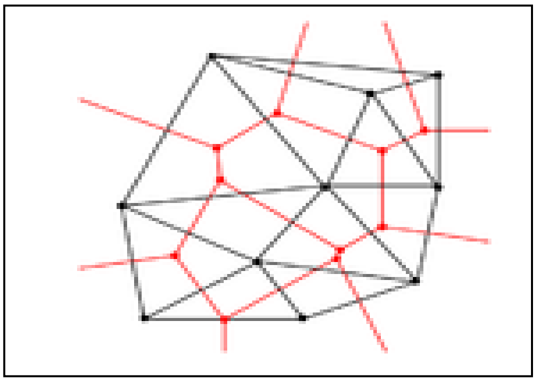
Dual graph of the DT is the Voronoi diagram [8]. The Voronoi diagram is actually the straight-line dual of the DT. That is, we can go from the Voronoi diagram to the DT by drawing in the edges which are perpendicular to the region boundaries and vice-versa. The closest pair of points corresponds to two adjacent cells in the Voronoi diagram.

### *C. Relationship with the Voronoi diagram*

The DT of a discrete point set *P* in general position corresponds to the dual graph of the Voronoi tessellation for *P*. Special cases include the existence of three points on a line and four points on circle [21].



(a)



(b)

Fig. 3.1. (a). The DT with all the circumcircles and their centers (in red). (b) Connecting the centers of the circumcircles produces Voronoi diagram (in red).

There are several algorithms to generate the DT in O(*n*log*n*) time. Most famous algorithm to generate the Delaunay triangulation is lift-up method which runs in O(*n*log*n*) time. Lift-up method cannot be implemented locally. It is well known that the DT cannot be generated locally by the nodes.

### *D. Why Delaunay triangulation*

We have chosen DT for many reasons. High Quality Triangular Meshes are possible in DT. As the network topology used in paper [DSAP] is a mesh topology, so we have to generate a mesh network for numbering the sensor nodes. An algorithm is presented in paper [9] to generate High Quality Triangular Meshes in two and three dimensions.

Some important graphs like Gabriel graph (GG), the relative neighbor graph (RNG), Euclidean minimum spanning tree and the nearest neighbor graph are sub graphs of DT [10]. Though both of RNG and GG can be computed by simple local algorithm, but they are not always spanner. DT is both planer and spanner [10, 11]. Another interesting property of DT is that compass routing is possible in DT [12]. In paper [13] it was proved that Compass routing in the DT will ensure that the packet will reach its destination.

### *E. Routing in Delaunay Triangulation*

Compass routing in the DT will ensure that the packet will reach its destination. This theorem was proved in [12].

*Compass Routing*: Let *t* be the destination node. Current node *u* finds the next relay node *v* such that the angle $\angle vut$ is the smallest among all neighbors of *u* in a given topology [12].

Fig. 3.2. shows compass routing. The current node *u* has six neighbors. Node *u* wants to send information to node *t*. The node *v* is in the closest direction of the node *t*. So, node *u* will send its sensed information to *v*.

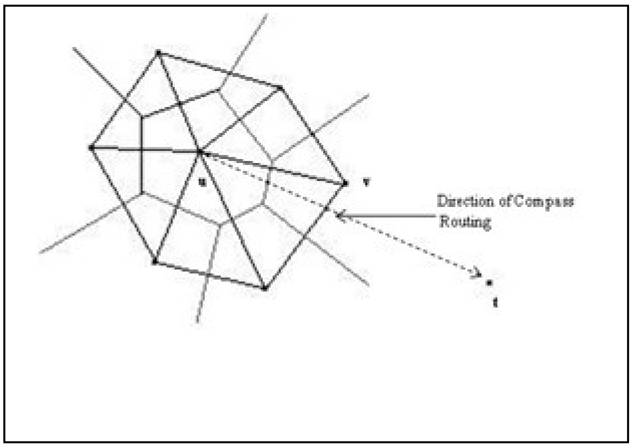


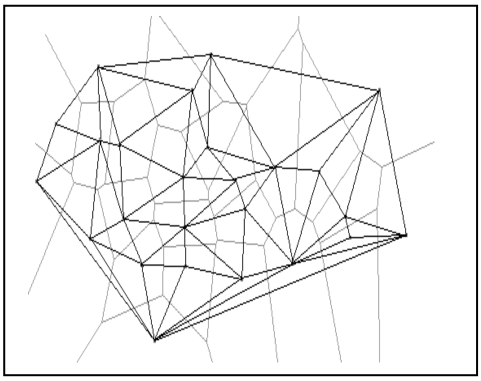

Fig. 3.2. Compass Routing.

Once the ADT is generated, all the nodes will have to only remember the neighbors in the ADT. On an average each node has 6 neighbors [21]. So, each node has to store the information about 6 adjacent nodes. In compass routing only local information and the information about the destination is used to route the information. No other external information is required for routing.

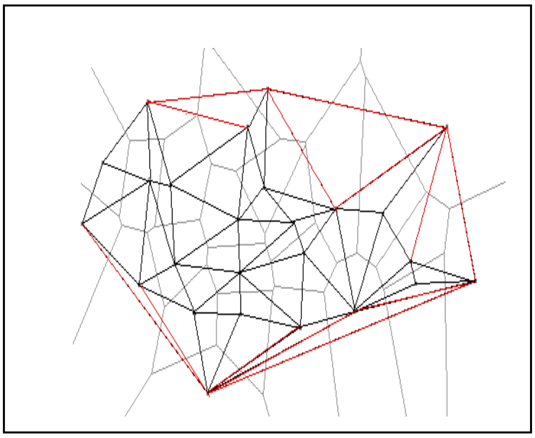
### *F. Almost Delaunay triangulation*

As DT is not possible to generate locally, we introduce ADT. ADT is a sub-graph of the DT. We define the ADT as the DT without the long edges [8].

Fig. 3.3. (a) shows a topology which is generated using DT and (b) shows another topology generated using ADT, where the long edges are removed.



(a)



(b)

Fig. 3.3. (a) Delaunay triangulation. (b) Almost Delaunay triangulation.

## IV. TOPOLOGY GENERATION USING ALMOST DELAUNAY TRIANGULATION

In the proposed approach each sensor node will perform the following tasks.

1. Gather neighbor lists.

2. Locally generate the ADT.

According to the paper [8], at first all the nodes should gather information about its neighbors. After deploying the nodes, each node will send a hello message with some energy that will reach up to the distance $C_x$ EMSTMAX. *EMSTMAX* is the longest edge in the minimum spanning tree of all the sensor nodes and *C* is some predefined constant. In our algorithm we use $C=1.5$. Here we assume that $C_x$ *EMSTMAX* is less than *r* (communication range of the nodes). Initially the nodes do not have any idea about the value of *EMSTMAX*. The nodes could approximate the value of *EMSTMAX* if they have prior knowledge about the target area *A* and the number of nodes *N*. When a node sends hello message, the neighbors within the distance $C_x$ *EMSTMAX* will receive the message. Then the neighbors will send an acknowledgement message alone with its location information back to the sender. Thus each node will get the list of all its neighbors. After all the nodes have got their neighbor lists, we will get a connected graph. $C_x$ *EMSTMAX* will ensure that the graph will be connected if $C \geq 1$.

In our proposed method, we also consider the battery power which determines the lifetime of a sensor node. We assume a constant power $P_{min}$ with which the power of each node will be compared. A battery may be rated at 500 *mAh* capacity under a rated current of 100 *mA*, at 25∘*C* [14]. If $P \geq P_{min}$, where *P* is the battery power of the concerned node then the edge between the nodes is to be considered. The improved algorithm is as followed.

### *A. Proposed Algorithm*

| **Algorithm:** | |
|---|---|
| **Step 1:** | Send hello message to the distance $C_x$ *EMSTMAX* and wait for the reply. |
| **Step 2:** | Upon receiving hello message, acknowledge the sender alone with the location information of the current node if $P \geq P_{min}$. |
| **Step 3:** | Update the neighborhood list according to the acknowledgements of the hello message. |
| **Step 4:** | For each node calculate the Voronoi polygon formed by the perpendicular bisectors of each line segment $(u,v_i)$, where $u$ is the current node and $v_i$ is the neighbor of $u$. |
| **Step 5:** | Then to generate the ADT we will connect $u$ to the neighbor nodes that has common edge in the Voronoi polygon |

The algorithm is very simple. After the execution of the algorithm each node will need to remember only the neighbors that have edge with it in the graph.

By considering the battery power, we can generate a topology which is more efficient as it reduces the number of failure of nodes. So the network lifetime is increased because to generate this topology, the nodes with low lifetime are not considered at all.

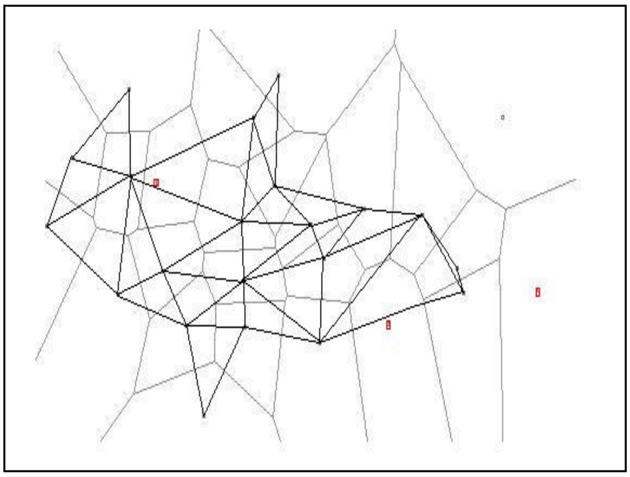


Fig. 3.4: Topology using almost Delaunay triangulation where nodes with (P < Pmin) are not considered (in red).

### *B. Algorithm run time*

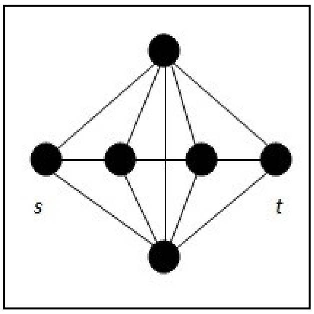
The Voronoi polygon can be calculated in O(*n*log*n*) time in the same way the 2D hidden surface removal algorithm works simply by using divide and conquer method [8]. The complexity of the algorithm depends on the calculating the Voronoi polygon. So, the algorithm will run in O(nlogn) to generate the topology.

## V. *ST*-NUMBERING ON DELAUNAY TOPOLOGY

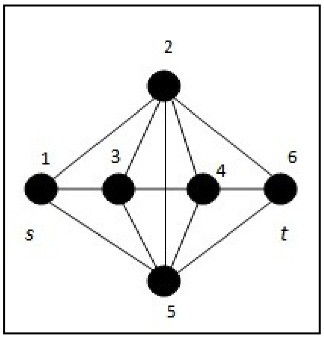
In our proposed topology we can apply *st*-numbering for assigning IDs to the nodes.

### A. st-numbering and st-routing

*st*-numbering has great significance in various areas of computer science. Different graph drawing algorithms use *st*-numbering as the first step of the drawing. Finding *st*-numbering is one of the fundamental steps of the planarity testing algorithm of a graph developed by Lempel, Even and Cederbaum [23]. Let $G = (V,E)$ be a bi-connected undirected graph, where $V$ and $E$ are the set of vertices and edges, respectively. The number of vertices in $G$ is denoted by $n$, that is, $n = |V|$,and the number of edges in $G$ is denoted by $m$, that is, $m = |E|$. Let $s$ and $t$ be any two vertices of $G$. An *st*-numbering of $G$ is a numbering of its vertices by integers $1, 2, \ldots, n$ such that a vertex $s$ receives number 1, a vertex $t$ receives number $n$ and every other vertex of $G$ is adjacent to at least one lower-numbered vertex and at least one higher-numbered vertex. The *st*-numbering of a graph is not unique. Fig. 4.1. (a) shows an undirected bi-connected graph $G$ and (b) and (c) represents two different *st*-numberings of the same graph $G$.




(a)

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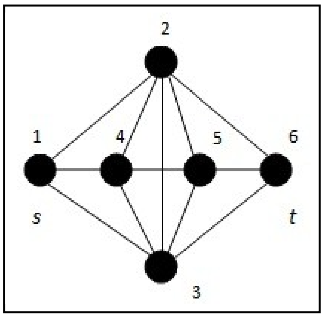


(c)

Fig. 4.1 (a) A bi-connected graph $G$ with $s$ and $t$, (b) an *st*-numbering of $G$, (c) another *st*-numbering of $G$

*st*-numbering has a wide range of applications in layout planning and project scheduling and great theoretical interest in many *NP*-hard problems. This numbering is used in designing routing protocols and in parallel processing.

A routing protocol chooses one of the several paths (routes) from a source node to a destination node in a computer network to send a packet of information. Recently a new routing protocol called st-routing protocol is developed [24] using st-numbering. The protocol provides a systematic way to retry alternative paths without generating any duplicate packet.

### B. Algorithm run time

In 1976 Even and Tarjan proposed an algorithm that computes an st-numbering of an undirected bi-connected graph in $O(n+m)$ time [25]. So, the run time to generate the topology is $O(nlogn)$ and assigning IDs to node is $O(n+m)$. the total cost is $O(nlogn) + O(n+m)$.

## VI. CONCUSION AND FUTURE WORK

We have presented a power efficient topology generation algorithm using the ADT by considering battery power within the transmission range. The algorithm locally generated the original (physical) topology by applying ADT graph. If some of the nodes fail, we have to reconstruct the graph in that region locally. The neighboring nodes will recalculate the Voronoi polygon and ADT which is very easy to generate and cost effective. Then, we assume logical topology of WSN to number each node by using st-numbering, and by assigning this numbers each node in a topology diagram of WSN has its own id and the id of its neighbors, so that it can identify all of its neighbors easily. Thus a unique identity of each node is ensured. The cost of topology generation is $O(nlogn)$ and assigning IDs to node is $O(n+m)$. Finally, the total cost is $O(nlogn) + O(n+m)$.

We are working on the simulation of our power efficient topology generation algorithm and st-orientation for routing. Here we consider the homogeneous WSNs, but in future we can also apply our method in heterogeneous WSN where there are different node attributes. Further research could be continued to implement the same algorithm with clustering method. Multiple cluster heads could possibly reduce the failure cases for compass routing and power consumption could be furthered reduced in this way.

## REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks”, IEEE Communications Magazine, Georgia Institute of Technology, August 2002.

[2] R. Agustı´ and O. Sallent, “Wireless sensor networks”, International Journal of Wireless Information Networks, vol. 12, no. 1, January 2005.

[3] Md. B. Haider, S. Imahori, K. Sugihara, “Success guaranteed routing in almost Delaunay planar nets for wireless sensor communication”, Int. J. of Sensor Networks vol. 9, no. 2, pp. 69 – 75, 2011.

[4] Y. Liu and L. M. Ni, “Location-aware id assignment in wireless sensor networks” IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS), pp. 525 – 529, 2006.

[5] W. Liu, L. Cui and X. Niu, " EasiTPQ : QoS-based topology control in wireless sensor network", Journal of Signal Processing Systems vol. 51, pp. 173–181, 2008.

[6] A. Salhieh, J. Weinmann, M. Kochhal, L. Schwiebert. "Power efficient topologies for wireless sensor networks". In Proceedings of the International Conference on Parallel Processing, 2001.
[7] R. lyengar, K. Kar, S. Banerjee. "Low-coordination topologies for redundancy in sensor networks", In Proceedings of the 6th ACM international symposium on Mobile ad hoc networking and computing (New York, USA), 2005.
[8] Md. B. Haider, K. Sugihara, "Almost Delaunay triangulation routing in wireless sensor networks". In Proceedings of the 10th ICCIT, 2007.
[9] L. P. Chew, "Guaranteed high-quality mesh generation for curved surfaces". Proceedings of the 9th Annual Symposium on Computational Geometry (San Diego, California), pp. 274-280, Association for Computing Machinery, May 1993.
[10] J. Gao, L. J. Guibas, J. Hershberger, L. Zhang and A. Zhu, "Geometric spanner for routing in mobile networks". Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing (Long Beach, CA, USA), 2001.
[11] X. Li, G. Calinescu and P. Wan, "Distributed construction of a planar spanner and routing for ad hoc wireless networks". In Proceedings of IEEE Infocom '02, June 2002.
[12] E. Kranakis, H. Singh, and J. Urrutia. "Compass routing on geometric networks". In Proceedings of 11th Canadian Conference on Computational Geometry, Vancouver, August, 1999.
[13] C. T. Vu and Y. Li, "Delaunay-triangulation based complete coverage in wireless sensor networks", Supported in part by the NSF under grants CCF-0545667 and CCF-0844829. In Proceedings of the 7th IEEE International Conference on Pervasive Computing and Communications (Galveston, TX, USA), March 2009.
[14] C. Park, K. Lahiri, A. Raghunathan, "Battery discharge characteristics of wireless sensor nodes", An Experimental Analysis. IEEE SECON (Second Annual IEEE Communications Society Conference) September 2005.
[15] E. M. Ould-Ahmed-Vall, D. M. Blough, B. H. Ferri, and G. F. Riley, "Distributed global id assignment for wireless sensor networks," Ad Hoc Network, vol. 7, pp. 1194–1216, August 2009.
[16] V. Rodoplu and T. H. Meng, "Minimum energy mobile wireless networks," IEEE J. Selected Areas in Communications, vol. 17, no.8, 1999.
[17] S. Narayanaswamy, V. Kawadia, R. S. Sreenivas, and P. R. Kumar, "Power control in ad-hoc networks: Theory, architecture, algorithm and implementation of the compow protocol," In European Wireless Conference, 2002.
[18] L. Li, J. Y. Halpern, P. Bahl, Y. Wang and R. Wattenhofer, "Analysis of a cone-based distributed topology control algorithm for wireless multi-hop networks," In Proceedings of the twentieth annual ACM symposium on Principles of distributed computing, 2001.
[19] K. Alzoubi, X. Li, Y. Wang, P. Wan, and O. Frieder, "Geometric spanners for wireless ad hoc networks," IEEE Transactions On Parallel And Distributed System, vol. 14, May 2003.
[20] N. Li, J. C. Hou, and L. Sha, "Design and analysis of an mst-based topology control algorithm," In INFOCOM, 2003.
[21] A. Okabe, B. Boots, K. Sugihara, and S. N. Chiu, "Spatial tessellations: concepts and applications of Voronoi diagrams". Second Edition. Wiley Series in Probability and Statistics, 2000.
[22] M. S. Pan and Y. C. Tseng, "ZigBee based long- thin wireless sensor networks: address assignment and routing schemes", J. Computer Communication, pp. 1585-1593, 2012.
[23] A. Lempel, S. Even, and I. Cederbaum, "An algorithm for planarity testing of graphs", P. Rosestiehl(ed.) Theory of Graphs: International Symposium July 1966, pp. 215-232, 1967.
[24] M. M. Akon, S. Asaduzzaman, M. S. Rahman and M. Matsumoto, "Proposal for st-routing protocol", Telecommunication Systems, vol. 25, no.3, 4, pp. 287-298, 2004.
[25] S. Even and R. Tarjan., "Computing an st-numbering. theoretical computer science", vol. 2, pp. 339–344, 1976.