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WSNs: Algorithmic Aspects of Topology Control and Maintenance

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ABSTRACT

Wireless Sensor Networks (WSNs) consist of devices equipped with radio transceivers that cooperate to form and maintain a fully connected network of sensor nodes. WSNs do not have a fixed infrastructure and do not use centralized methods for organization. Because of their unique structure, and limited energy storage, computational and memory resources, many of the existing protocols and algorithms designed for wired or wireless ad hoc networks cannot be directly used in WSNs. It is expected that topology control techniques will play an important role in managing the complexity of such highly complicated and distributed systems through self-organization capabilities. Topology issues have received more and more attentions in WSNs. While, WSNs applications are normally optimized by the given underlying network topology, another trend is to optimize WSNs by means of topology control and is composed of two mechanisms, Topology Construction (TC) and Topology Maintenance (TM). TC controls the topology, while maintaining characteristics like queue size, energy consumption and data transfer. It is very important for a network to work with low energy consumption, better coverage (queue size) with full efficient data transfer rate. In this paper a comparative study of A3, A3-Coverage (A3-Cov), Just tree and Simple tree algorithm have been discussed with results in terms of queue size, energy consumption and data transfer.

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1. INTRODUCTION

During the past decade, WSNs have received increased interest from the scientific community. Thanks to important developments in microelectronics, radio devices and low-power electronics, WSNs technology is being developed and deployed in many scenarios in which pervasive monitoring is necessary but cannot be done in person due to lack of resources, time or because the location or conditions represent danger to the individuals. Even today, one of the biggest constraints of WSNs is their energy consumption, data transfer rate and queue size [1], [2].
Topology Control is one of the most well known strategies for saving energy in the network. The main objective of this technique is to reduce the network topology, number of active links and active nodes, while maintaining connectivity of the nodes and coverage of the area. TC considers two main processes: TC, which is in charge of reducing the initial topology, and TM, which is in charge of restoring the network's reduced topology when the nodes start to fail [3]. There is a wide range of techniques that perform TC, however, most of those can be classified as those reduce the transmission range of the nodes and the other which turn the nodes off.

The first technique targets the fact that the most expensive activity, and also the most common one, from a node's point of view, is to transmit data; therefore, by reducing the energy needed to transmit, the node will save energy. In addition, it will also reduce the number of nodes that are able to listen to its message, which in turn reduces energy consumption in the sense of having good properties like avoiding collisions and reducing interference among the messages [1].

The second technique targets the fact that not all the nodes are necessary for coverage or connectivity: a small group of elite nodes can support the network, while the rest could go to a state of sleep in which the energy consumption is negligible. The reason behind this method is that an active idle node wastes energy, and it may be producing redundant information; for example, in the case of two nodes which are very close to each other and reporting the same information each time. The energy they use being redundant could be saved in order to replace nodes from the small elite set when they fail.

The simulation is performed on Atarraya software, an event-driven simulator for the design and evaluation of topology control algorithms WSNs [3].

2. THEORETICAL ANALYSIS

2.1 A3

The A3 algorithm [1], [5] produces an approximate solution to the minimal Connected Dominating Set (CDS) problem. The A3 algorithm assumes no prior knowledge about the position or orientation of the nodes; therefore, the nodes do not have an exact geometric view of the topology. However, nodes can determine how far a node is based on the strength of the signal received, and this information is enough to select a close-to-optimal CDS tree [4], [5] based on the belief that farther nodes will offer better area of communication coverage. The A3 algorithm is executed in two moments: Neighborhood discovery, children selection.

All nodes start with the unvisited state, except the stating node, which starts with the "Active" candidate state. An active candidate node sends a "Hello Message" to all its neighbours. The first one that sends this message is the sink node. In addition, this node sets a timer to wait for replies from unvisited neighbour nodes. All the neighbors send back a "Parent Recognition" message that includes their ID and their own selection metric, which is a convex combination of the ratio or remaining energy in the receiver, and the ratio of distance over the maximum transmission range. Also they adopt the sender as their "Parent nodes" and change their state to child.

After a period of time, the active candidate node stops listening for messages, sorts the list of "Children" nodes (neighbors who answered) in a decreasing order, and sends this sorted list back to its children. If the active candidate node has received at least one answer, it will change its state to active; otherwise, it will change its state to "sleeping" and will turn off its components until the next topology maintenance routine is executed.

The children nodes find themselves in the list and wait for a period of time proportional to their position on the list. When the timer in a node expires, and it has not received any "Sleeping" messages, the node will send a "Sleeping" message, change its state to active candidate and if the node receives a "Sleeping" message while in the timer set, it will change its state to "Sleeping Candidate", and will turn off its component for a period of time. After this timer expires, the node will change its state to active candidate.

2.2 A3-Cov

A3-Cov algorithm works [1] very similar to A3 protocol, but presents important changes in some portion: like, if there are any nodes that have not received any "Parent Recognition" message, it means that there are no nodes that depend on it for communication purposes; however, they may still be useful in order to extend the network's sensing coverage. In order to do this, A3-Cov defines a new variable in the nodes called "sensing covered" i.e. node "X" is sensing covered by node "Y" if "X" is inside the sensing range of "Y' and "Y" is an active node.

In A3 algorithm after the timer expire in node to receive "Sleep" message. If the node has been "Sensing Covered" by any other node (including its parent node), it sets a short timer to wait for "Sensing Covered" message from its active neighbor.

If the timer expires and the node is not "Sensing Covered" yet, it will turn itself on, changes its state to active and send a "Sensing Covered" message and a "Sleeping" message. If any node in its range receives the "Sensing Covered" message, it will evaluate if it has been covered by sender, in which case it will update the value of the "Sensing Covered" variable. If the node received a "Sensing Covered" message from any other node, it will stop the timer changes its state to "Sleeping" and turn its component off until the next topology maintenance routine.A3-Cov expands considerably the coverage area as compare to A3.

2.3 Just Tree

For the homogeneous network number of nodes, the deployment area, sink node and the virtual network interface (VNI) [3], play an important role. The Just tree algorithm [6] assumes one sink node responsible for message/ information broadcast. The sink nodes are capable of sending or receiving messages from other neighboring sensor nodes. If CDS rule-k is applied and the topology is constructed [5], this CDS rule-k is needed to run for a quite number of times, a lot of energy will be spent to maintain a particular topology if a sink node prefers to broadcast or send. The concept of spanning tree is considered in most of the cases. This concept can be employed for number of nodes starting from 50-1000 nodes or even more, but in order to achieve acceptable results the node number is increased in multiple of 100. As far as just tree protocol/algorithm is considered, less energy is spent with a reduced queue size, if number of nodes is increased. The message or number of events are propagated within the network using the same concept of parent node and child node, the parent node initiates the message and transfer this message to other sensing nodes acting as child node. Keeping itself in a dominant position i.e. if CDS rule-k is taken into consideration the parent node has maximum in build energy which gradually reduces as the number of nodes increases and message transfer takes place i.e. if the size of the tree is large (more number of nodes) the total energy spent will ultimately decreases till the last child node is covered in a general prospective, if the tree is giant it means that it will cover a larger deployment area and will have large number of children nodes connected with the parent node, which will be the main source of energy with some threshold value i.e. such topology will require atleast.

- Homogenous network
- Flexible deployment area
- Parent node that initiates a "HELLO" message with same reasonable amount of threshold in terms of energy in order to support varying queue size, if the number of children nodes are also varied.
- The recognition of the initiated "HELLO" message must be acknowledge by children nodes in order to estimate queue size, energy consumption, number of messages transfer during simulation, performed for different number of nodes for different time periods. The concept of just tree ensures that as the deployment area will increases or if the deployment area is constant the number of nodes if increased will denote the increase in the size of the tree in order to efficiently cover a flexible or constant deployment area.

2.3 Simple Tree

Simple tree [5] is a derivative form of one or more derivative of spanning tree derived from the just tree algorithm which considers only one CDS per one just tree. According to this, if this algorithm is further splitted into more than one CDS rule-k [7] the load on single parent node can be slightly reduced, however, the total energy spent may substantially increased and it may also affect the queue size. But such algorithm will also require more simulation time because there exist more number of subsets in the same deployment area for the increased node density i.e. such algorithm are not that much simple as far as their name highlights, but are complex requires a greater degree of simulation efforts, are hard to model, are dependent on large queue size and lastly at the out-set shows high value of energy i.e. spent energy. The only advantage of these type of algorithm lies in the aspect that they ensure complete message distribution within their individual CDS and further, if area of the topology is very sparse it can easily recovered by introducing a new CDS in the form of a simple tree rather than raising or disturbing the pre-existing just tree that have their individual CDS. Simple tree algorithm can also be modified to operate for heterogeneous network, if the CDS functions as a closed loop and even if the topology is homogenous and if the CDS functions as a close loop the number of event or messages floated within the complete network will be less as compared to the just tree algorithm.

3. Comparative Analysis

The algorithms were evaluated on a specifically designed simulator for WSNs topology. The simulator atarraya allows the scalability of the underlying network with the case of selecting different network parameters, such as energy utilization, number of message transfer (events) and Queue size.

For the simulations, a 600m X 600m virtual space was assumed in which nodes are randomly deployed. All the parameters were calculated by deploying th nodes in multiple of 50, ranging from 100 nodes to 500 nodes with the communication range of 100m. The results of the performance evaluation comparing all algorithms i.e. A3, A3-Cov, Simple tree, Just tree are presented. In the performance evaluation of the algorithm, the following assumptions were made.

- All nodes are located in a two dimensional space and have a perfect communication coverage disk.
- Nodes have no information about their position, orientation, or nieghbors.
- Distance can be calculated as a metric perfectly proportional to the Received Signal Strength Indicator (RSSI).

3.1 Simulation results

This section represents a detailed analysis in terms of simulation results. A comparative analysis between A3 and A3-Cov in terms of some important parameters such as number of nodes, energy, events and queue size is highlighted in table 1.
Similarly a comparative analysis between Just tree and Simple tree for the same parameters and similar computational complexity is shown in table 2 respactively.

Table 1.Simulation results of A3 and A3-Cov

Nodes	A3			A3-Cov		
	Energy(joules)	Queue Size	Events	Energy(joules)	Queue Size	Events
100	90.895	10	3143	106.489	6	3656
150	153.225	11	6580	189.601	14	7498
200	235.036	17	11344	290.600	11	12870
250	337.203	28	17218	414.080	21	19864
300	446.047	31	24024	569.275	24	28717
350	553.680	33	31254	713.718	30	37520
400	692.162	35	40359	859.013	36	45953
450	809.081	32	48936	1028.819	39	56944
500	1040.140	39	63098	1258.000	48	71074

Table 2.Simulation results of just tree and simple tree

Nodes	Just tree			Simple tree		
	Energy(joules)	Queue Size	Events	Energy(joules)	Queue Size	Events
100	24.261	9	889	98.13	7	2538
150	42.983	11	1745	203.342	11	5965
200	72.794	18	3294	344.116	14	11110
250	105.128	19	5008	539.719	21	18484
300	145.375	26	7202	712.907	23	24824
350	183.469	29	9276	970.415	26	35181
400	246.895	39	12926	1351.805	45	49592
450	292.534	34	15457	1554.1	31	58469
500	359.081	35	19302	1936.645	45	73834

The results of simulation respectively reproduced in table 1 and table 2 clearly shows that the discussed algorithm have their individual merits and demerits if applied for WSNs and have independent role for maintenance. The energy aspect, queue size and total number of events with respect to increasingly number of sensor nodes. The simulation results for A3, A3-Cov, Just tree and Simple tree in terms of energy, queue size and events respectively depicted in figure 1, figure 2 and figure 3.

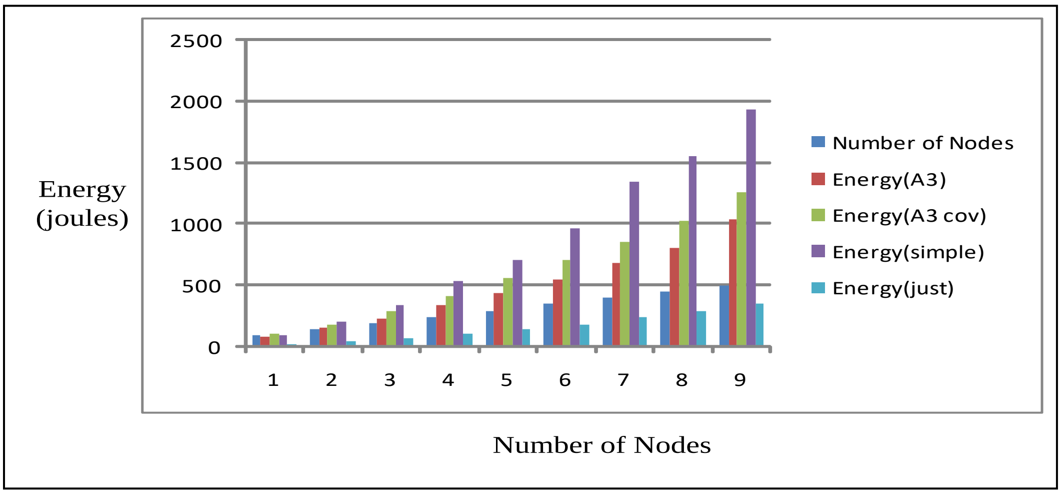

Figure.1.Number of nodes vs energy

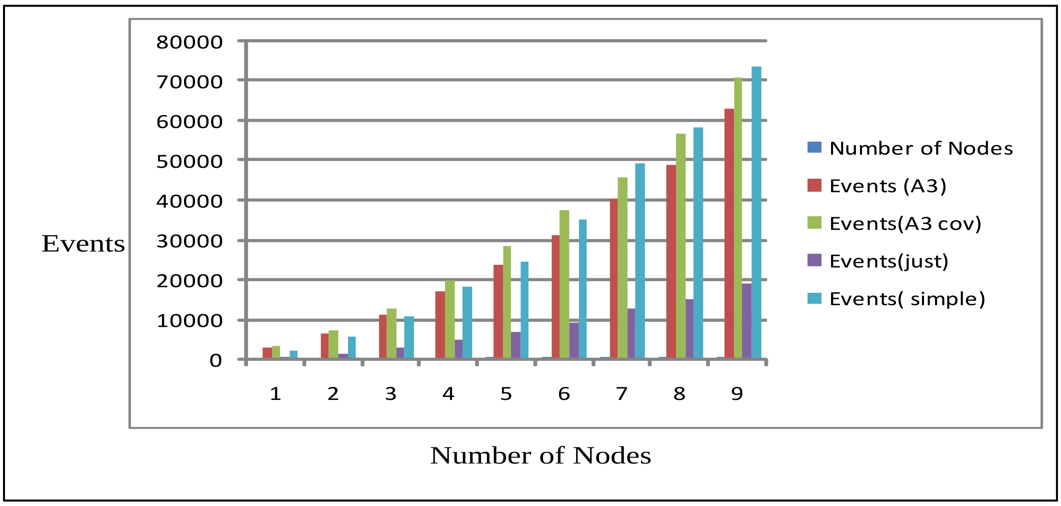

Figure.2.Number of nodes vs events

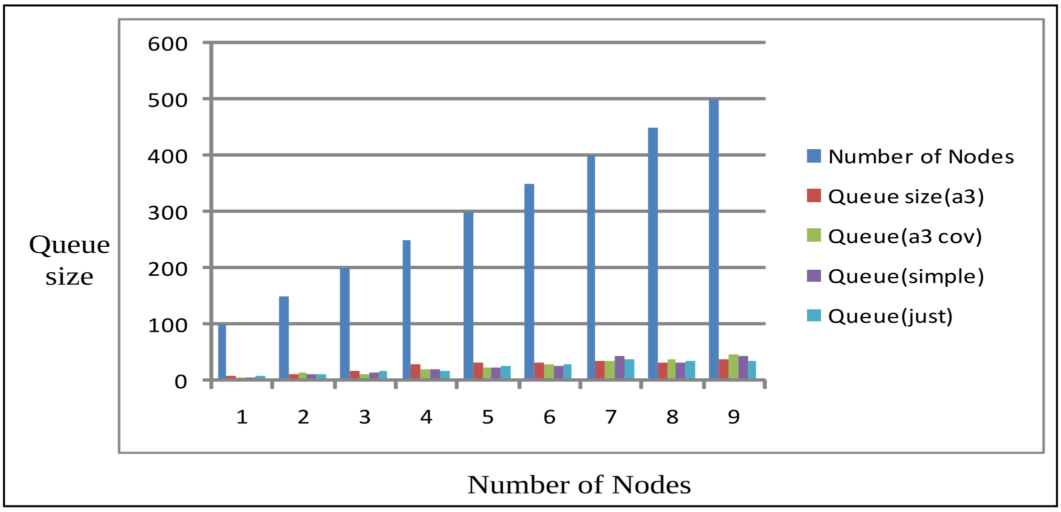

Figure.3.Number of nodes vs queue size

Further, the simulation result reveals that the energy, queue size and number of events varied to minimum, moderate, and maximum. Table 3 represents a cumulative analysis of energy, queue size, events with respect to A3, A3-Cov, Simple tree and Just tree.

Table 3.Observations based on simulation results

Algorithm/protocol	Energy Consumption	Events	Queue size
A3	Moderate	Moderate	Moderate
A3-cov	Moderate	Moderate	Maximum
Just Tree	Minimum	Minimum	Minimum
Simple Tree	Maximum	Maximum	Moderate

4. Conclusion

The work presented in this paper is an attempt to focus on the algorithmic aspect of existing techniques that is either tree based or area based. This paper has addressed some important parameter that includes energy, queue size, events in order to analyse the performance of A3, A3-Cov, Just tree and Simple tree by means of simulation. In future other algorithms EECDS, CDS rule K, K-NEIGH tree etc., can be worked upon as a extention to the work presented in this paper.

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