Energy Comparison of Balanced and Progressive Sensor Networks

Maneesha V Ramesh[1], Sreedevi A. G[2], Kamalanathan K[3], P Venkat Rangan[4]
Amrita Centre for Wireless Networks and Applications, Amrita Vishwa Vidyapeetham , Amritapuri, India
[1]maneesha@am.amrita.edu , [2]agsreedevi@gmail.com, [3]kamalanathan@am.amrita.edu, [4]venkat@amrita.edu

Abstract— **Wireless Sensor Networks are deployed in almost all areas as they are one of the efficient solutions for monitoring, detecting and providing early warnings. Energy minimization being one of the main challenges in WSNs, we present four different topology control algorithms which will compute the aggregated data in a distributed way, addressing this issue. Each algorithm optimizes power to different levels, by reducing the number of computations and transmissions. The discussed methods include two level and multi levels of balanced and progressive network and its analysis of energy savings. Among the four networks, multi-level progressive is found to be better for small number of sensor nodes (N<500), at the same time, multi-level balanced proved its efficiency when the number of sensors are large. The comparisons of four networks are discussed for atmost 4000 sensor nodes in a WSN.**

Keywords— **Wireless Sensor Network, Distributed Computing Topology Control Algorithm, Multi-Level Balanced Network, Multi-Level Progressive Network, Per Node Power Optimization**

I. INTRODUCTION

Wireless Sensor Networks hold promise as an effective technology for saving lives when used to monitor, estimate the probability of occurrence, detect, and issue early warnings in most of the applications. A WSN employed contain sensor nodes which needs different types of sensors to sense and collect the data. Most of the sensors employed, use solar energy as the major source of power. Solar power tends to rapidly diminish by the eminent use of the sensor nodes in sensing, computing and transmitting the data. Hence minimizing the energy becomes an overwhelming priority for sustained operation of the network. This indeed is discussed as the major goal in this paper. After analysing various methods to reduce the power consumption in distributed networks, we concluded that the best way to preserve energy is by controlling the topology that reduces the number of transmissions between them and also the distributed computations performed. In applications where duty cycle method is not a good solution, the discussed distributed topology control method finds its way and gives an efficient way to optimize power. This paper proposes topology control methods which will reduce the power consumption of sensor nodes by utilizing the above discussed criteria, thereby reducing per node energy consumption of the distributed network.

Topology Control of a WSN network is important because a randomly connected WSN may suffer from short lifetime, poor utilization of network, high packet delays, high interference, and decrease in robustness. The topology of a network depends on nodes mobility, failure and duty cycle, directional antennas, and transmission power. And in most cases when node density is low, topology control algorithm is not effective.

There are many algorithms and protocols available to optimize power. In this paper, section II discusses about the importance of optimizing power in a distributed network like WSNs, section III provides a brief idea of the related works existing in the same area, followed by sections explaining the basic two level and multi-level topologies, section VIII contains study and comparisons of the four networks over various parameters, then section IX, results and conclusions inferred from them.

II. IMPORTANCE OF POWER OPTIMIZATION

Power optimization is the key issue in a WSN. There are many methods available to optimize energy in such distributed networks. To limit the energy consumption, one may reduce the number of sensors employed. But in applications where the key importance is accuracy in prediction, such removal of sensors is not considered as a good solution. Another way is to introduce sleep and wake up times for sensing (duty cycles), but here the efficiency is limited to the time period we choose. Since the prediction happens only when they are in wake up state, efficiency of the system and its power consumption is deeply dependent on the wake up time interval. There are solutions based on reducing the sampling intervals and introducing many power saving states.

But the major energy saving, would be established with the help of a topology control protocol over distributed computing. There are many protocols and algorithms available, which can be chosen based on the applications. They will conserve energy to different levels. The selection of the protocol depends on lifetime, utilization of network, packet delays, interference, robustness, mobility, failure and duty cycle, directional antennas, and transmission power. And in most cases when node density is low, topology control algorithm is not effective. Considering all these we proposed the four distributed topologies like two-level balanced, two-level progressive, multi-level balanced and multi-level progressive network, which concentrates on two major subsystems of the sensor node: communication and processing (computation) subsystem. The protocol and its power optimization strategy are discussed later in this paper.

III. RELATED WORKS

As a part of literature survey, many criteria's to optimize power at different levels was studied. [3,8] describes some duty cycle control algorithms to optimize power in WSNs. In such networks when power is conserved, efficiency of the network in computation and prediction is compromised. At the same time [4,5,6] discusses topology control algorithms which are hierarchical and location based. This group of networks involves different categories of algorithms each efficiently focussing on the network structure and how its structure reduces power consumption. There is novel Energy-Aware Data-Centric Routing algorithm for wireless sensor networks which is explained in [7].

Paper [9] discusses a new energy conservation scheme for efficient data propagation in wireless sensor networks using Directed Diffusion protocol. This incurs a small propagation delay with implicit failures due to obstacles and communication disruption. At the same time paper [10] explains the importance of using energy-efficient forwarding strategies for many-to-one communication with several sensor nodes reporting data to one sink node. But it fails to consider the network lifetime. [11] focuses on dropping out inefficient links in the network in order to reduce the overall energy consumption whereas [12] speaks about control of power transmission levels in prolonging the lifetime of a node in a wireless sensor network mainly with respect to MICA2.

Also there are power optimization techniques with the help of ant colony algorithm's, which can reduce the node power and re-establish of new node routing links [13].

Application oriented Sensor Networks were also studied. Different sensor networks have different power requirements as per their area of application and the place where it is deployed. Considering all those factors together with increase in demand for hierarchical network, the following sections will explain how tree structure like sensor topologies can conserve power, thereby increasing the lifetime of the network

IV. DISTRIBUTED COMPUTING TOPOLOGY CONTROL ALGORITHMS

Each sensor in sensor nodes utilizes energy in different amounts and there comes the requirement of reducing the power and sampling rates, at the same time provide the same accuracy in prediction. There are many topologies and duty cycle algorithms that are developed for the same purpose. In this paper we show the results obtained on simulating two 2 level tree topologies: Balanced and Progressive, which will conserve the per node energy by controlled distributed computations and transmissions.

Certain WSNs follow hierarchical tree pattern, where lower level nodes will transmit data to its parent, and each parent will find the average, maximum or minimum from the received values, and will transmit that result to its parent. By carefully adjusting the tree structure, we can reduce the energy consumed by the whole distributed network. We make use of concept that as number of computations and transmissions reduce, energy consumed by the processing and radio system will also reduce. There by reducing the overall energy consumed by the WSN. The described work also shows that the same network is capable to obtain the final result of the distributed computations at the gateway node with minimum delay.

A sensor node with n children nodes, will receive data from all the n nodes. It needs to perform n-1 computations to reach the final result of the comparison (maximum, or minimum). Our aim is to reduce the number of computations and transmissions involved. So as the pre mentioned criteria decreases, the power consumed will also decrease. So in this paper the time taken to complete n-1 computation is assumed as proportional to the per node energy consumed.

Table 1 summarizes all of the symbols used in the paper.

Symbol	Description
N	Total number of sensor nodes in the network
m	Total number of intermediate nodes on the network
m_{max}	The count of intermediate nodes for which the network yields minimum delay
Tcomp	Time taken for comparing two sensor values
Tnet	Transmission time from one wireless node to another in the WSN
Tmax	Total time taken by the WSN for computing the maximum value among all of its sensor

	values

Table 1: Symbols used in the paper

V. TWO LEVEL BALANCED AND TWO LEVEL PROGRESSIVE TOPOLOGY

A. Two Level Balanced Network

In such a network, the total number of sensor nodes is divided equally among the intermediate nodes, and together with the sensors and intermediate nodes they form a 2 level tree hierarchy. Given N sensors, and m intermediate nodes, for a balanced network, each intermediate node has N/m sensors.

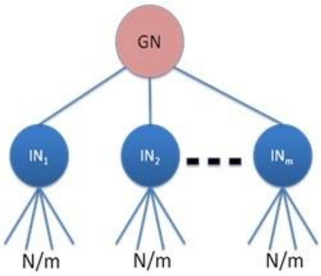

Fig 1: Two level balanced network

The total energy consumed by the gateway node is proportional to the number of computations and number of transmissions.

The total delay or energy consumed or time taken by the gateway node to complete the aggregate computation in a Two Level Balanced Network is,

$$T_{max} = 2\,(N/m - 1)\,T_{comp} + 2\,T_{net}$$

B. Two level Progressive Network

It is an alternating configuration with staggered processing of data in the gateway node in a two level hierarchy. The data being send from the lower level nodes is pipelined to prevent collisions. The gateway starts the pipeline operation as soon as it gets the packets from the first 2 lower level nodes. The packet from the third node will have a delay pipelined equal to the computation time required to process the first two packets. We call such a network as progressive network.

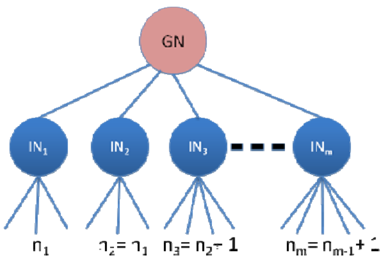

Fig2: Two Level Progressive Network

Let n1, n2, n3, … , nm be the number of nodes under intermediate nodes IN1, IN2, IN3, … , INm respectively, in a progressive network with N sensor nodes and m intermediate nodes. The first two sub trees will have n1=n2 since the data values from the first two subtrees can arrive at the same time at the gateway node. The third sub tree will have n3=n2+1=n1+1 so that the third data value will arrive just when the gateway has completed the aggregation of the first two values. Continuing in this manner each sub tree has a one sensor node more than its preceding sub tree, the mth (last sub tree) will have nm = n1+m-2 nodes.

Here also total number of computations and transmissions at the gateway node can be calculated. This is observed to give minimal computations when compared with two level balanced networks.

Here, the total delay for aggregation or max computation is given by

$$T_{max} = (n1 + m - 2)T_{comp} + 2T_{net}$$

VI. MULTI LEVEL BALANCED NETWORK

In multi level balanced network, similar to two level balanced, the total number of sensor is divided equally among the intermediate nodes. But here the intermediate nodes are again divided equally for each intermediate node above it, and like wise they form a multi level network.

For H level balanced network, at each level the nodes are balanced. Given the total number of sensor nodes N, we need to find out the optimum height of the tree so that the hierarchical arrangement of sensors will yield minimum number of computations and transmissions. Then for each height H to 0, arrange the sensors and intermediate nodes in a balanced way. The results obtained for number of computations are discussed in section VII.

The mathematical proofs and studies show that for a H level network, $\sqrt[H]{N}$ subtrees connected to every intermediate node and the gateway node yields the lowest delay for max computation.

$$T_{max} = H\left(\sqrt[H]{N} - 1\right)T_{cmp} + HT_{net}$$

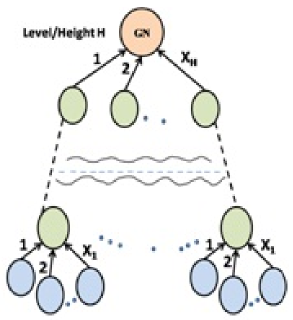

Fig3: Multi Level Balanced Network

VII. MULTI LEVEL PROGRESSIVE NETWORK

For a multi level progressive network, as height increases the delay will also increase. Since our objective is to reduce the number of computations, a small modification is brought in the tree structure. The tree structure considered is shown in figure 4.

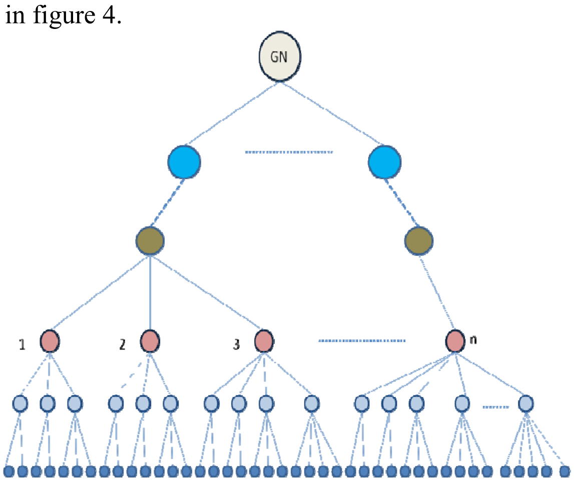

Fig4: Multi Level Progressive Network

This network follows progressive hierarchy at each level. Given the total number of sensors N and x=2+2 i.e 4 initial number of sensors, the tree follows 2+2+3, 2+2+3, 2+2+3+4, 2+2+3+4+5......hierarchy. Therefore,

$$N = n.x + \left(\frac{n^2 - n + 2}{2}\right) d + \left(\frac{n(n-2)(n-1)}{6}\right)$$

and $T_n = x + (n-1)d + (n-2)n - (n^2-n-2)/2$

Arrange each Tn progressively using two level progressive concept. Finding value of n, from equation of N, will give the number of intermediate nodes at level 3 from below. In this level, if the number of sensors is greater than 2*d, it's appropriate to go for next higher level. Likewise continue, to find the optimum height of the topology.

VIII. RESULTS AND OBSERVATIONS

Two level networks and multi level networks, all optimizes power to different level depending on their properties. This section contains various graphs showing the performance metric of these networks when (i) number of sensors are small and (ii) when N is large. The results are obtained for a maximum of N=4000 values. These experimental results prove the efficiency of the network in WSNs monitoring small and large areas with less and more amount of sensors when the sensors are arranged in a hierarchical structure.

Among the two level networks, progressive topology yield minimum number of computations leading to more optimization in energy (figure 5). Among the multi level topologies, we came across two conclusions. When the number of sensors were small, multi level progressive was better performing (figure 6). As the number of sensors got increased, multi level balanced prove to be efficient (figure7). But both stand very close in terms of number of computations involved.

For two level networks, keeping N constant different m values (number of intermediate nodes) were considered. The graph (fig: 8) shows the same. As m value increases the energy consumed decreases for both progressive and balanced. At the same time, as N increases for the same m, the energy consumed also increases.

A constant difference is observed between the 2 two level networks, for same m value i.e even though the total number of sensors are increasing, the difference remains constant. Figure 9 graph shows the energy consumed by the networks for 2 different values of m. When m=20, the graph of the two networks differs by a constant value, giving rise to two parallel lines. Same is the case with m=30.

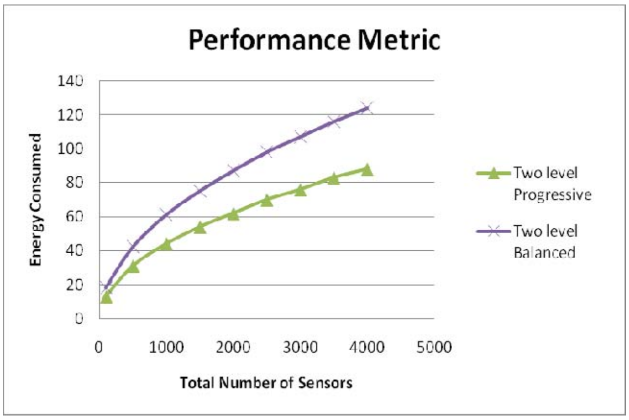

Fig 5: Performance Metric of two level networks

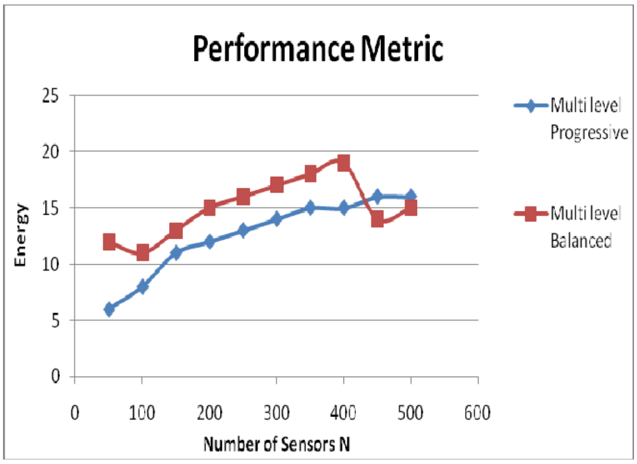

Fig 6: Performance Metric of multi level networks when N is small

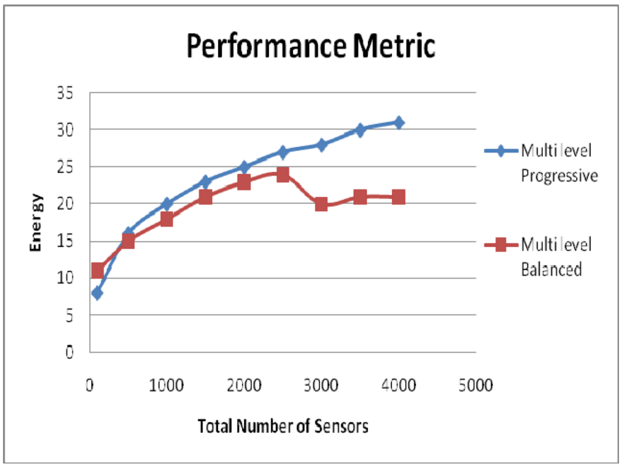

Fig 7: Performance Metric of multi level networks when N is large

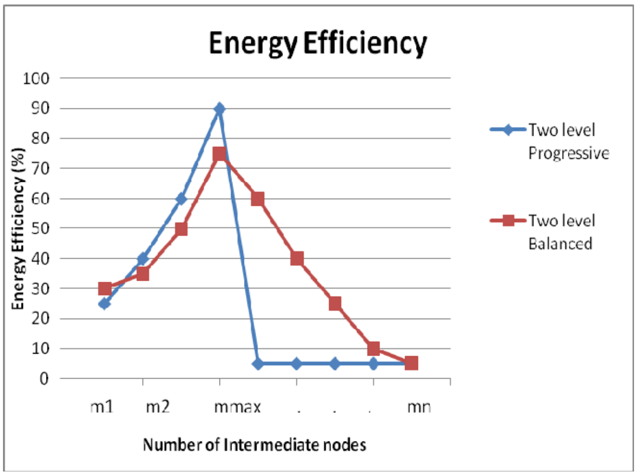

Fig 10: Efficinecy amoung two level networks for different number of Intermediate nodes

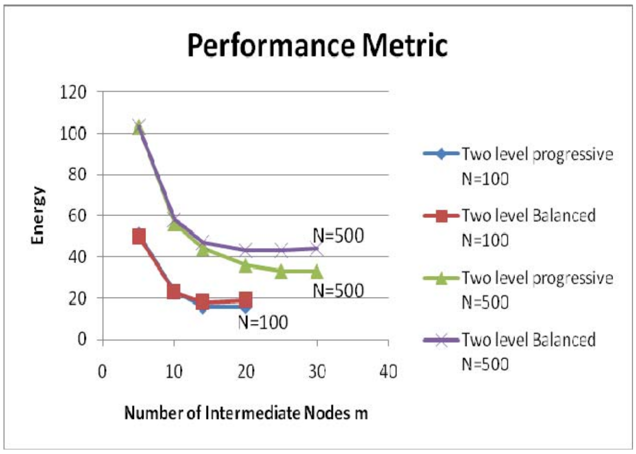

Fig 8: Performance metric when m is constant

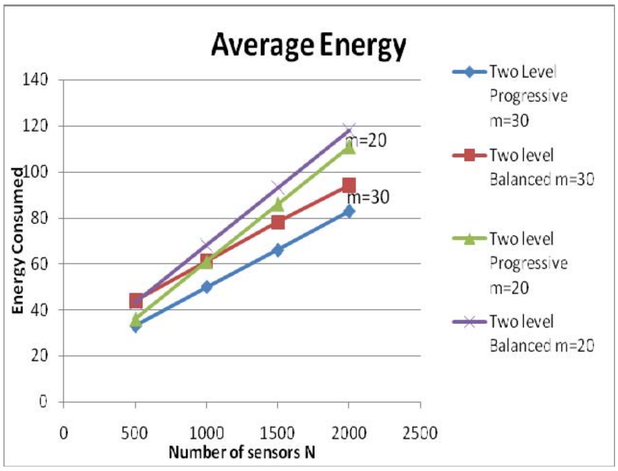

Fig 9: Energy consumed by the network for constant number of intermediate nodes, for different values of N

In figure 10, as the number of intermediate nodes increases, the efficiency of two level progressive networks on reducing the energy consumption also increases. But as the number of intermediate nodes crosses a maximum count mmax, then n1 becomes negative, the two level progressive topology's efficiency drops suddenly. But for the same case, balanced network do provides some amount of efficiency, but decreases slowly.

IX. CONCLUSION AND FUTURE WORK

Our objective is to optimize the overall energy consumption of a WSN network, by reducing the per node energy consumption in distributed computations and transmissions. We simulated two level and multi level of balanced and progressive networks, to study its efficiency in optimizing power in each sensor node. Each topology was observed to be reducing power consumption at different levels, in which multi level progressive network was found to be more efficient compared to any other topologies when number of sensors is small. At the same time, multi level balanced proved its efficiency when the number of sensors is large. Even though multi level balanced is better when N is large, the results obtained show that multi level progressive stands close to it.

The results obtained were studied for different parameters, which enabled to understand the network Topology control algorithms like multi level balanced and multi level progressive can be used in situations where power optimization is a major criteria. Here the computation power of each node is same, these topologies shows how can such a computational power enabled sensor node reduces power. As an addition to this, one can use different computational power enabled nodes also, because the structure of the topology demands less computation intensive operations at the beginning nodes, where as more computations at nodes at the end of the network structure.

As a future work of this, we would like to bring in modifications to the topology which can result in further reduction of energy consumed. Also will consider the overload that can come in lower level, and the situations where lower level or intermediate nodes fail.

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