Computational and Delay Efficient Distributed Computation over Uniform Grid

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COMPUTATIONAL AND DELAY EFFICIENT DISTRIBUTED COMPUTATION OVER UNIFORM GRID

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Abstract. In this research paper, we explore an optimization approach for finding minimum and maximum of sensed values over a Wireless Sensor Network. A Divide and Conquer Approach is introduced, which takes advantage of the parallel nature of operations in the Wireless Sensor Network to reduce the delay in achieving the results.

Keywords: Wireless Sensor Network, Divide and Conquer Approach, Distributed Computation, Delay Optimization

1 Introduction

Motivated by many practical applications, the research area of Wireless Sensor Networks (WSNs) was subjected to intense research efforts[1]. It is realized by researchers that planned deployment of sensors is possible in some applications such as weather monitoring, agriculture, etc. From a wireless networking point of view, the sensor field can be considered as a uniform rectangular grid. In research literature, problems like sensor placement over such a sensor field are thoroughly studied. It was well recognized that IN-NETWORK DISTRIBUTED COMPUTATION is desirable and necessary for many reasons. Also, in research literature, placement of sensors on a line connected sensor field was investigated. Furthermore, computationally efficient distributed computation over the connected sensor field is addressed[2]. In many applications, WSNs are deployed over a vast geographical region. In such applications, millions of tiny sensors are potentially involved in distributed network computation. Thus, delay efficient and computationally efficient network distributed computation is highly necessary. This research paper is an effort in that direction.

This research paper is organized as follows. In Section 2, efficient distributed computation over the uniform grid is discussed. In Section 3, a novel divide and conquer approach is proposed to minimize the communication complexity i.e. delay in the computation of minimum, maximum sensed value over the sensor field. In Section 4, fuzzy clustering is discussed. The research paper concludes in Section 5.

2 Efficient Distributed Computation over Uniform Grid: Tuple Approach:

To minimize the computation of global minima and maxima over a large WSN, the authors proposed the following approach.

We consider a rectangular network wherein a sensor is situated at every matrix point i.e. we consider a Wireless Sensor Network (WSN).

Objective: Proficiently calculate the minimum and maximum of all detected readings to the Base Station situated at the highest point of the Network. Calculation and Communication happens along each line (in the network) simultaneously. Likewise, every node keeps a 2-tuple containing the current maximum and minimum in the following format : (Current Maximum, Current Minimum). Each node calculates the current maximum and minimum and conveys the tuple to the node up the line. It promptly follows that the number of computations is 2N-3. We arrive at this value considering the fact that tuple at the last node contains the same value in both the positions. Additionally, the node up the line to the last node, makes just one comparison, while all other nodes perform two examinations (2(N-2) +1 = 2N-3). The delay in communicating the 2-tuple (i.e.(Maximum, Minimum)) to the base station will be Nd, with d being the delay taken for information to travel from one node to another. Without the 2-tuple thought, the number of comparisons will be 2(N-1)= 2N-2. Additionally, if maximum and minimum are not simultaneously computed the delay will be 2N(d) = 2Nd.

The following results follow readily when computation of minimum/maximum is performed using a single processor.

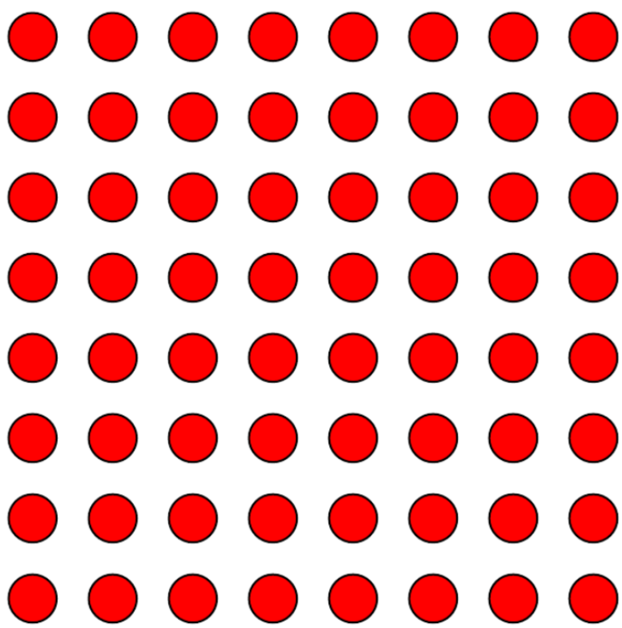
Claim: There is no serial algorithm (uniprocessor based) which has computational complexity less than O(N) to determine the maximum/minimum of N numbers.

3 Hierarchical Decomposition of Sensor Field: Delay Efficient Computation:

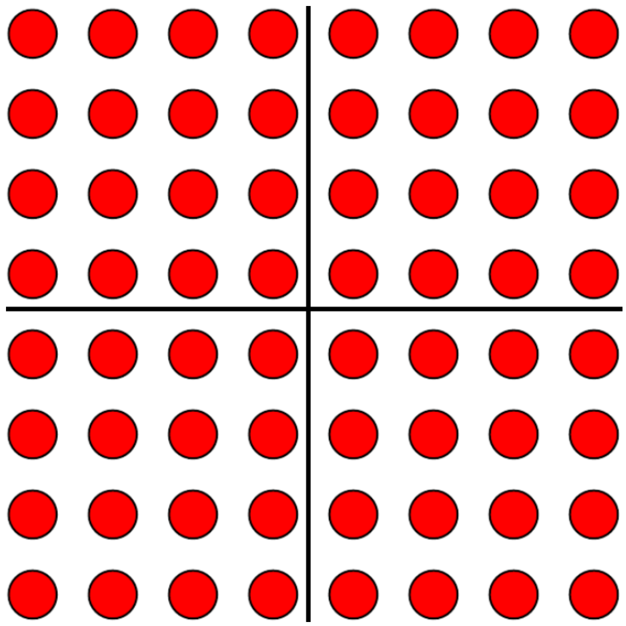
In the Divide and Conquer Approach, the 2x2 blocks form part of larger blocks. In essence an ultra large sensor field can be hierarchically decomposed. Such a hierarchical decomposition has the "SELF SIMILAR" Property as in the case of fractal sets. The simultaneous/parallel computation of minimum/maximum reduces the delay in computation of global minimum/maximum over the entire sensor field. The details are provided below.

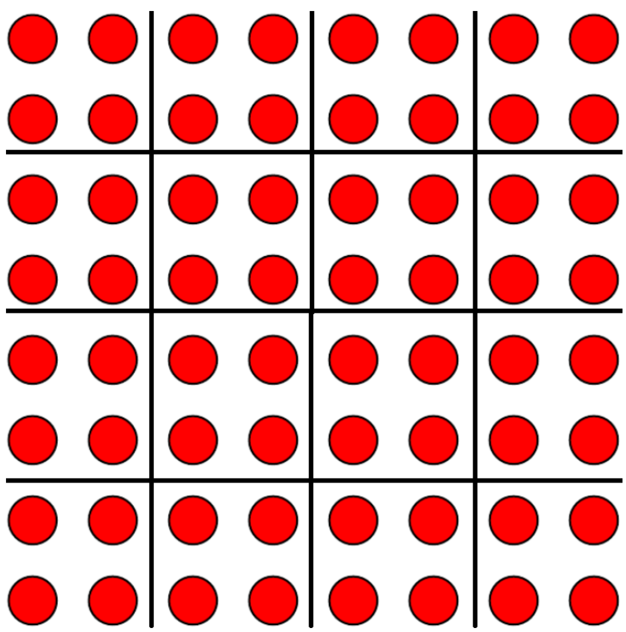
DIVIDE AND CONQUER APPROACH

Consider a grid of the following nature:



Here, each circular element is representative of a sensor node in a Wireless Sensor Grid. For minimization of number of computations, in the wireless sensor grid, we have previously proposed a 2-Tuple approach wherein we compute the minimum and maximum of each column simultaneously, and arrive at a delay of (2N - 3). Here, delay is the term used for the time taken to get the result. Using the Divide and Conquer approach we have developed, we can achieve a lower delay. The procedure is as follows:





Split the NxN Grid into 2x2 units as demonstrated above. Compute the minimum and maximum within every 2x2 unit simultaneously, and store it in a tuple. The no. of comparisons it would take to find the minimum and maximum inside a 2x2 unit is 6 comparisons. 6 comparisons is the general case, but when the 2x2 units contain nodes with single sensor values, it is actually 4 comparisons. Nevertheless, we take 6 as the general case.

Once all 2x2 units have their minimum and maximum results ready, they move onto comparing with each other. This process goes on until the final 2x2 units have compared their results, and we have the global minimum and maximum of the grid.

DELAY OPTIMIZATION

Since we are computing the minimum and maximum within all 2x2 units simultaneously, the time taken at each step during the procedure will ideally be equivalent to that of 6 comparisons, which is the number of comparisons taken by a single 2x2 unit. The question then becomes, how many steps does this method take? The number of steps is observed to be logN, for an NxN grid. Thus, our final time taken for this method will be 6logN for any NxN grid (due to the fact that we are computing 2x2 unit results in parallel). This is basically delay at a step x no. of steps. As we can see, this method gives us significant gains over the previous method of computing column results in parallel.

CHALLENGES

There are a 2 main challenges when it comes to implementing this method:

- Adapting it to non square grids (not of the form NxN)
- Implementing N-Tuple result for the same

We solve the problem of non square grids by transforming a non square grid into a square one, using some comparisons to shave off nodes from the edges as required.

We solve the problem of an N-Tuple result by maintaining an N-Tuple instead of a 2-Tuple in every unit. The complexity analysis of this is yet to be done.

4 Fuzzy Clustering

In the Low Energy Adaptive Clustering Hierarchy Protocol and its variants like Pagasis LEACH, sensors are grouped into clusters with a local leader node called a cluster head. In the PhD thesis [5] and references contained therein, the idea of placing the cluster head near the centroid (based on energy available in sensors) of the cluster was investigated. Motivated by such efforts, we generated the "fuzzy clustering" of sensors over the sensor field. In the following discussion we provide the details of fuzzy clustering

Clustering is a process of dividing the data points into countable groups so that similar data points fall into the same groups and dissimilar data points fall into different groups. These groups are known as clusters. Using Fuzzy C-Means, we can find clusters in the WSN Grid that allow us to split the grid and speed up computations through the idea of parallel computing.

Fuzzy C means Clustering is a process that allows the data points to belong to two or more clusters. It is based on minimizing the objective function mentioned below.

$$\sum_{j=1}^{k} \sum_{x_i \in C_j} u_{ij}^{m} (x_i - \mu_j)^2$$

Where,

- μ_{ij} is the degree to which an observation x_i belongs to a cluster c_j

- μ_j is the center of the cluster j

- m is the fuzzifier.

FUZZY C-MEANS STEPS

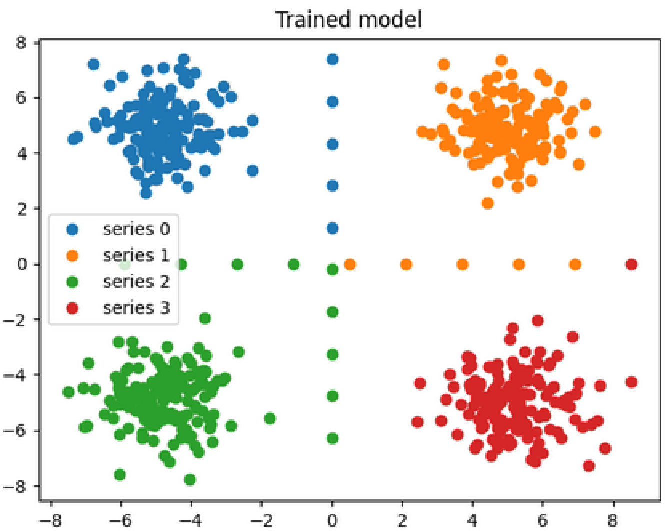
1) Randomly select ‘c’ cluster centers.

2) Calculate the fuzzy membership ‘uij’ using the above-mentioned equation.

3) Compute the fuzzy centers ’vj’.

4) Repeat steps 2) and 3) until the minimum objective function value is achieved.

FUZZY C-MEANS RESULTS



5 Conclusion

Using the Divide and Conquer Approach, we observe a huge improvement in the delay taken to compute the global minimum and maximum values of a large WSN. As discussed in the Tuple Approach section, The Tuple method requires the number of comparisions to be O(N), for an NxN grid. To be precise the number of required comparisions (of sensed values) are 2N - 3. Comparatively, the Divide and Conquer approach gives us a delay of order log N. 6 * logN, to be precise. Therefore, we believe this to be the superior approach, and hope to find more optimizations of a similar nature in the future.

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