Clustering in Sensor Networks using Quorum Sensing

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Abstract: Scalability is a major issue in sensor networks since they will be expected to operate with up to millions of nodes. This will have implications particularly with energy which ideally should not be wasted on sending data to base stations that will potentially be far away. This can be prevented by separating the sensor networks into clusters and nominating nodes that will carry out aggregation and forward the data to the base station. This paper proposes that the clustering carried out could be based on the rate of change of the data that is measured through the application layer. The protocol developed was inspired by the bacterial signalling process called quorum sensing.

1. Introduction

The applications of sensor networks span a broad area, encompassing everything from the environmental monitoring of agricultural areas for crop quality to providing support to aspects of health management. The decreasing size and cost of computing and communication devices and the possibility of connecting them whether they are heterogenous or homogenous through mediums such as the Internet means that the unattended and autonomous operation of sensor networks can become a reality. These networks are expected to consist of a large number of devices making a centralised approach to network management infeasible. If every sensor node was to send its measured data to the base station regardless of its distance away from it then they are prone to becoming burnt out well before the rest of the network ceases to function [1]. This high-energy communication between the base station and the sensor nodes can be reduced by separating the network into clusters where the clusterhead is a nominated sensor node that can send aggregated data collected from the whole group to the base station [2]. Lower energy communication needs be encouraged between the sensor nodes, thus a distributed peer-to-peer approach to sensor networks is required. This is offered by the quorum sensing (QS) protocol, which is inspired by bacterial behaviour and builds on previous work on self-organizing protocols [3].

2. QS Protocol Description

Quorum Sensing (QS) is a type of intercellular signalling used by bacteria to monitor cell density for a variety of purposes. Vibrio fischeri is a type of bacteria that can be found living symbiotically in association with a number of eukaryotic hosts such as squid and uses QS for bioluminescence. This is carried out through the exchange of autoinducers, signalling molecules that are produced by a bacterium and can diffuse through its' permeable cell membrane. These autoinducers accumulate as the number of cells in the light organ of the squid multiplies and at a high concentration of 10^{10} cells/ml, the autoinducers indicate to each cell that the minimum population for producing luminescent (lux) proteins is present. As a result, visible light is emitted and is used by the squid for antipredation strategies or attracting a mate. Hence, QS is where the gene expression of the luminescent bacteria is regulated according to cell-density [4].

This is a useful concept for sensor networks because the bacterial cells need to be aware of the global cell concentration in the light organ of a squid so that it knows when to participate in producing light in the same way that a sensors need to know if there are enough of them to form a cluster for the purpose of monitoring a particular area of the network. Hence the use of autoinducers in QS can be mimicked by sensor nodes in order to co-ordinate their behaviour for environmental monitoring. Applying QS to sensor networks involved building on a protocol that is scalable and robust to node failure while allowing the sensor nodes to communicate in half-duplex mode and delay responses to messages until a more convenient time for the node. Previous work involved developing a protocol based on firefly synchronization and a distributed dissemination method called gossip that met these requirements for active networks. Group communication functions inspired by quorum sensing were incorporated into this firefly/gossip protocol to produce a solution for clustering in sensor networks.

The aim is to sensor nodes in a network into clusters according to the gradient of the signal they are monitoring, thus the QS protocol developed is intended to be applied to the application layer. This is particularly useful in environments where the data to be measured changes gradually, which makes this protocol suitable for the SECOAS project which focuses on coastal applications [5]. The flow chart in Figure 1 shows how the sensor nodes execute the QS protocol.

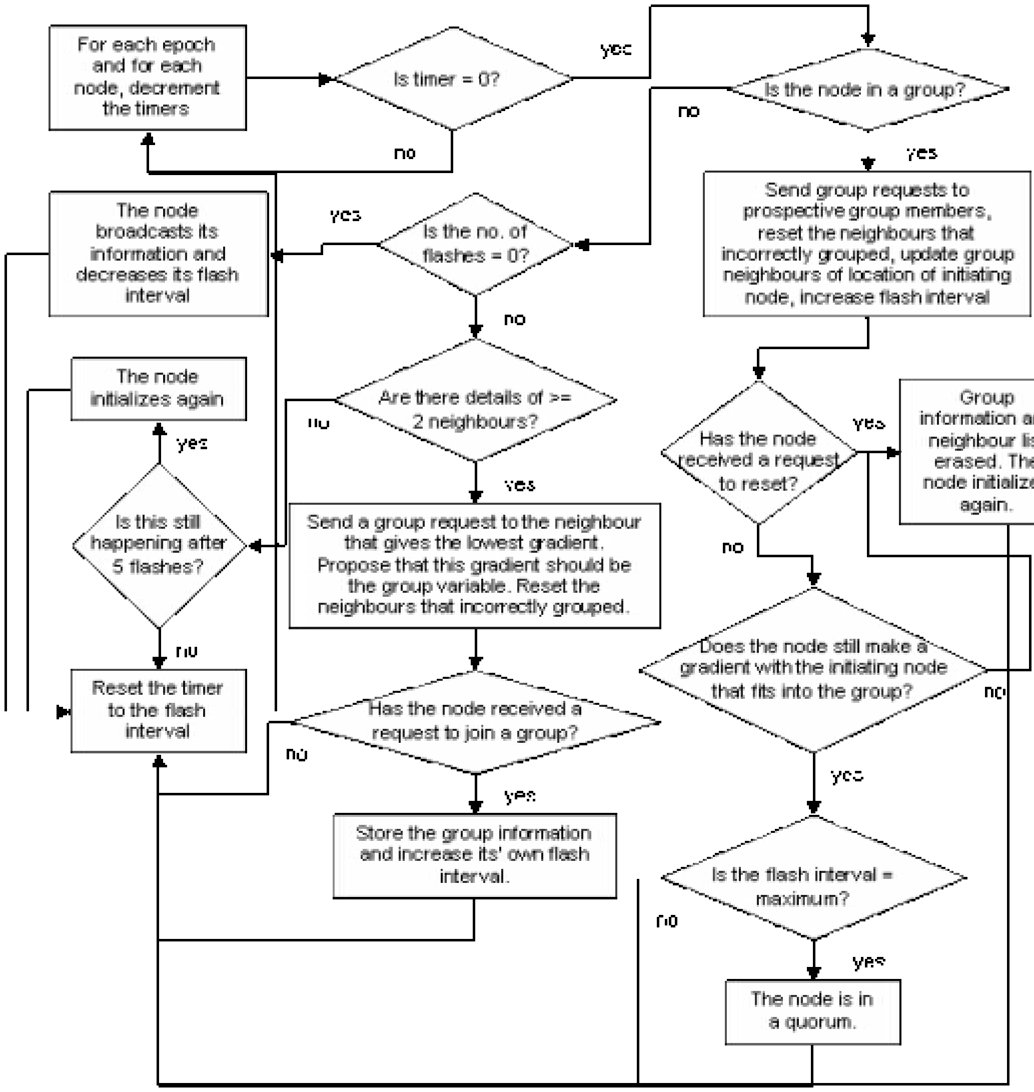

Figure 1: Flow chart showing the operation of the QS protocol

3. Performance Characteristics

Several tests were carried out on using the QS protocol in a linear network of 60 nodes that monitored an environmental signal that was sinusoidal. The nodes periodically “flash”, which means that they broadcast information to their neighbours and the maximum rate at which they can do this was set to 60 epochs, where an epoch is one time unit. The network was allowed to execute the QS protocol until all the nodes flashed at this rate because this indicates when all the nodes have settled into clusters. A centralised approach was carried out to achieve the same method of clustering was obtained where one of the sensors decided on which node went into which cluster. Each sensor was once given a flash interval of 60 epochs and to begin with the sensor on the far left flashes and sends its’ co-ordinates to the next neighbour which carries out the same action on its’ next flash. This will stop when the sensor on the far right receives all the co-ordinates and stores them in a list which is used to calculate the gradients between different sensors. The gradients are used to determine the groups and each time a group is assigned to a node its co-ordinates are removed from the list. The centralised and QS protocol was compared and the results are given in Figures 2 and 3. The number of clusters formed using each protocol is given in Figure 2 along with the accuracy of the QS protocol is shown. The amount of processing was assessed by looking at the number of times the nodes had to calculate a gradient and the traffic was represented by the number of flashing nodes per epoch. Both were compared in Figure 3.

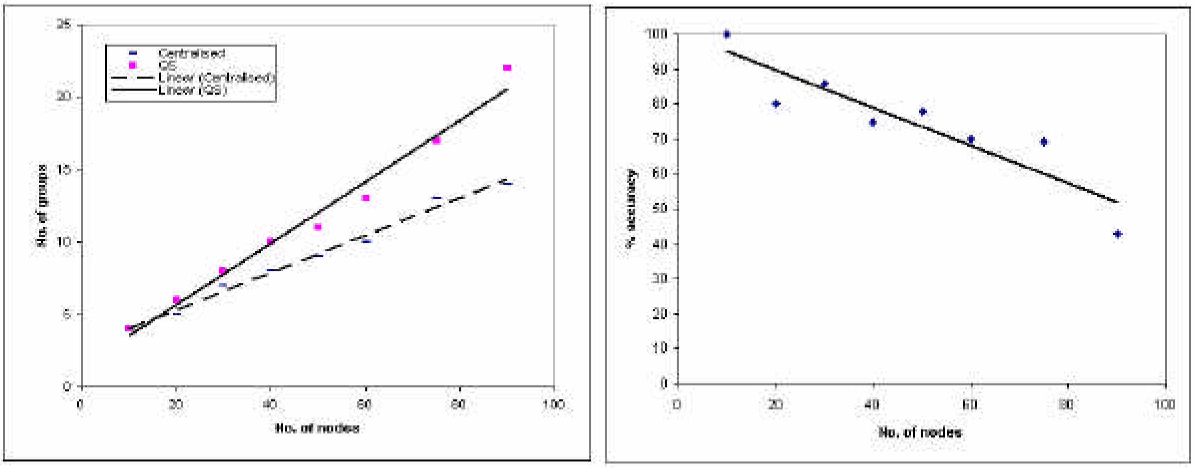

Figure 2: The numbers of groups created as the network size increases for both the centralised and QS protocol and the accuracy of the QS protocol

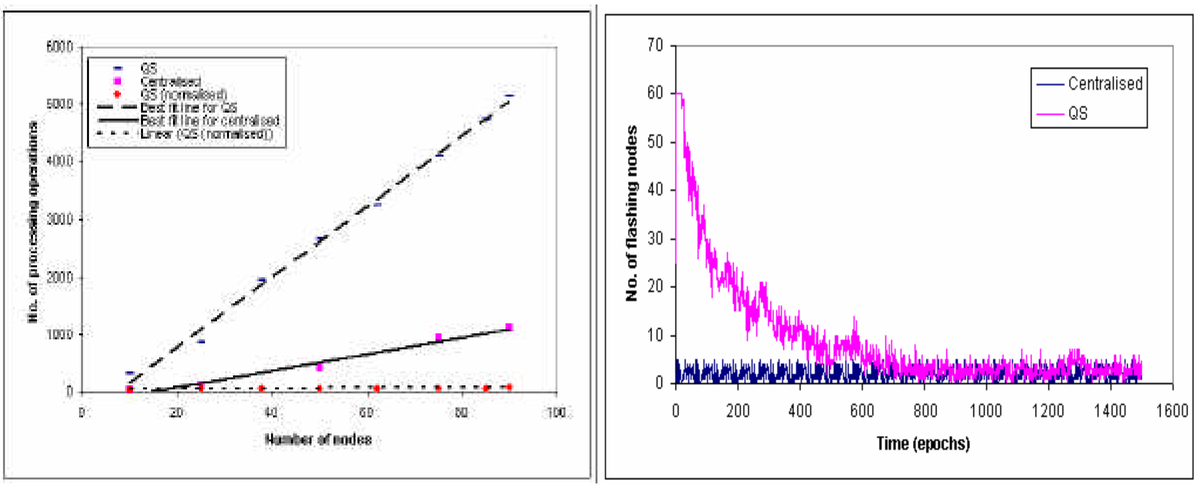

Figure 3: The amount of processing versus the number of nodes and the network traffic over time for both the QS and centralised protocols

Figure 2 shows that as the number of nodes increase, the QS protocol tends to make more clusters than the centralised protocol. Since the centralised protocol gives the ideal result, the QS protocol creates more groups than is necessary and this is highlighted in the accuracy versus number of nodes plot. Even though 100% is achieved when using 10 sensors, only 4 clusters are formed and from visually looking at the signal this does not give enough samples to recreate the signal. More sensor nodes are needed for the network so there will be a trade-off with accuracy but using 50 nodes or less does give an accuracy of at least 70% which is fairly acceptable and is adequate for the needs of SECOAS.

Figure 3 shows that the number of processing operations required by the centralised protocol is less than the QS protocol for any given network size. Additionally, as the network size increases, the number of processing operations increases at a lower rate than for the QS protocol. This means that the QS protocol will need more processing power to carry out the self-organization into groups, however this processing power is easily introduced to the network because the processing power is shared evenly over all of the nodes. When the processing power is normalised, the power required by each node in the QS protocol is very small compared to the power required by the main node in centralised protocol. It is much simpler to add nodes that are capable of processing data to the network than one node with a large amount of energy especially if the network size was to increase while the centralised protocol was in operation. When the nodes want to join new clusters and leave others, due to data measurement changes, or if they die because their battery supply runs out, the main node needs to be informed. This may be time-consuming if the main node is far away. The QS protocol operates in such a way that the nodes only need to inform their nearest neighbours when such situations arise.

The traffic generated in the centralised protocol is constant because the nodes always flash once every 60 epochs. This is higher than the QS protocol at first according to Figure 3. This is because the nodes go through initialization in the QS protocol which causes them to flash frequently in an effort to introduce them to their neighbours and get settled into groups as quickly as possible. As group formation progresses, the nodes flash less often and the traffic as a result decreases to the same amount as in the centralised protocol as time goes on. The traffic generated using the QS protocol can also increase if noise is added to the environmental signal but after the nodes re-organize themselves in response then the traffic decreases again in the same way as at initialization.

4. Conclusions.

The QS protocol is more scalable than the centralised approach and can respond to changes in the environmental signal and network topology more efficiently because there is no dependence on any particular node. The distributed peer-to-peer approach of the QS protocol allows the arrangement of the clusters to be quite flexible and offers a high degree of accuracy as long as the network is not too large. The QS protocol is a contribution to application layers protocols for sensor network design, and area that has been largely unexplored [6]. By applying concepts from biological entities to self-organization in technical systems, a novel approach has been created. The ideas can be extended by incorporating the QS protocol into the rest of the frame work for SECOAS that deals with network management and routing protocols. The protocol can be developed by including the different types of data aggregation, the selection of an appropriate clusterhead, the improvement of accuracy for large networks and the change in the sampling rate with response to the change in the data.

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