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LIFETIME ENHANCEMENT OF WIRELESS SENSOR NETWORKS THROUGH ENERGY EFFICIENT LOAD BALANCING ALGORITHM

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ABSTRACT

Each node in the wireless sensor network is equipped with a battery which cannot be replaced or recharged due to their ad-hoc deployment in unmanned environment. Maximizing the lifetime of the network by minimizing the energy is an important challenge. Due to the non-uniform distribution of nodes in network, the energy consumption and delay is increased. Designing an efficient Medium Access Control (MAC) protocol along with load balancing algorithm can be used to overcome this problem. Load balancing keeps the density of the clusters uniform and increases energy efficiency. In order to reduce the problems associated with delay, hybrid TDMA/FDMA concept is incorporated. Simulation is carried out in NS-2 and results show that the proposed approach can balance the load and increase the energy efficiency and network lifetime.

Keywords— *wireless sensor network, load balancing, energy efficiency, NS-2*

1. INTRODUCTION

Sensor networks are composed of large number of sensor nodes having computation and communication capabilities. Sensor nodes have to meet the properties of low-power processing and small-sized features, because if sensor nodes are scattered out, it is hardly impossible to replace or recharge their batteries. Therefore, sensor networks have to be designed with a requirement of low energy consumption to maximize each node's battery life and overall system lifetime.

Clustering of nodes is a scalable and energy efficient process for wireless sensor networks [1]. In clustering process, the network is divided into several clusters based on certain criteria, with each cluster managed by a cluster head (CH). Sensor nodes in a cluster transmit sensed data to their CH. The CH relays the data to a base station or an upper cluster in a hierarchy of clusters with possible aggregation and fusion operations. Clustering scheme increases energy efficiency by avoiding long-distance transmissions through CHs as intermediate nodes.

Clustering scheme gives rise to the uneven energy consumption problem: why some nodes deplete their energy and die much faster than others. This occurs because of the formation of clusters of unequal size which put uneven load on sensor nodes in the network. Load balancing technique can be used as a solution for this problem.

The primary goal of MAC protocol is to prevent collision which results in higher throughput and delivery ratio with reduced delay [2]. Major energy wastage in the MAC protocol is mostly due to energy consumption during idle state of the sensor node. This can be reduced by carrying out an alternation between sleep mode and active mode. But, this results in increasing the

delay in MAC layer. The energy and delay are two important parameters that have to be taken into account for the efficient design of MAC protocols. In order to reduce the problems associated with delay, hybrid TDMA/FDMA concept is incorporated in the proposed protocol.

Combination of the efficient energy consumption and load balance control is a challenging issue for extending the lifetime in WSNs. In this paper, an energy efficient load balanced algorithm is proposed. In our approach, the network re-configuration is determined based on measuring load of each cluster and comparing it with a threshold value. Reconfiguration fairly balances the load of cluster head and improves the energy efficiency.

2. RELATED WORKS

The research area for sensor networks is extensive for energy efficiency. Some clustering algorithms are proposed without considering the energy model. Many researchers have proposed the static clustering approaches based on energy model. They did not change the cluster formation that was organized first. Furthermore, the role of CH is shared in rotation by the nodes in the cluster to reduce the load of the nodes. On the other hand, various dynamic clustering approaches which elect new CHs in every round for controlling energy consumption efficiently to extend sensor network lifetime have also been proposed.

CAPNet: An Enhanced Load Balancing Clustering Algorithm [1] contributes to prolonging the lifetime of networks by reducing the energy consumption using a multihop clustering scheme. The algorithm is implemented in two separate phases. In the first phase, the determinant node (DN), a representative node is elected from existing cluster head nodes. The DN consumes less energy with high residual energy for communication with base station (BS). In the second phase, the network reconfiguration technique is introduced to solve the unbalanced residual energy among nodes and to control the network load balance. The elected DN determines whether to maintain or change clusters after comparing the average residual energy of CHs with the average energy consumption of the entire network. The approach does not consider situations where the clustering hierarchy must be maintained, for example, the addition of new nodes and existing node failures.

DECSA (Distance-Energy Cluster Structure Algorithm) [3] is a distributed competitive unequal clustering algorithm. It considers both the distance and residual energy information of nodes. The protocol is divided into initialization stage and stable working stage. In the initialization stage, the cluster head is elected and TDMA time slots are distributed to ordinary member nodes by the cluster head. The node with high residual energy in the network has greater probability to become cluster heads. In the stable working stage, the adverse effect on the energy consumption of the cluster head is reduced, resulting from non-uniform distribution of nodes in network and the direct communication between the base station and the cluster head is avoided. The algorithm effectively balances the energy consumption, prolongs 31% of the lifetime, reduces 40% of the energy consumption and has a better performance than LEACH protocol.

Load balancing using clustering can be used to extend the lifetime of a sensor network and increase the network scalability. Clustering technique which will balance the load among the cluster by using backup nodes is proposed. The proposed approach [4] assumes heterogeneous network with the sensor nodes having different energy levels and processing power. All the nodes with high initial energy level and processing power are selected. Some nodes from the set are selected as cluster head (CH) according to their location. Each CH defines its communication range in terms of power level to form cluster. Some nodes with comparable energy and processing power in the CH range are asked to go to sleep and information about those nodes is maintained with the CH. When the energy level of the CH will reach to the threshold value TL, the CH will activate one of the sleeping nodes and will make it CH. This information about the new CH will be sent to all the cluster members and other CH also. The old CH will become the general sensor node.

The protocol in [5] presents a multi-gateway architecture to cover large area of interest without degrading the service of the system. The algorithm balances the load amongst the different clusters at clustering time to keep the density of the cluster uniform. The network incorporates two types of nodes: sensor nodes which are energy constrained and gateway nodes which are less energy constrained. Gateways maintain the state of the sensors as well as setup multihop route for collecting sensor data. The disadvantage is that since the cluster heads are static and less energy constrained than the rest of the nodes and they are also fixed for the network lifetime, therefore the nodes close to the cluster head will die quickly compared to other nodes, thus creating gaps near the cluster heads and decreasing the connectivity of the network. Also if the network is to be deployed randomly then there is a good probability that the resultant distribution of the cluster heads is unbalanced.

HYMAC [6] is a hybrid MAC protocol for wireless sensor networks. It strengthens the MAC protocol design by incorporating TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) approaches together. Energy efficiency is improved in the network by avoiding collision. The multiple frequencies are used in the operation of HYMAC protocol, which reduces delay and improves throughput. The design of this protocol is done in such a way to provide maximum successful delivery of packets. The major drawback with this protocol is that, the receiver node has to shift its frequency according to the sender's transmission frequency. The end to end delay is longer when the number of required time slot is increased and this results in worst performance of the protocol.

IH-MAC [7] is a quality of service assured medium access control protocol. The advantages of TDMA and CSMA (Carrier Sense Multiple Access) are taken into account for achieving high channel utilization over heavy traffic load conditions. Both broadcast and link scheduling approaches are used in this protocol. IH-MAC is flexible enough to shift between broadcast scheduling and link scheduling to acquire high efficiency. The main reason behind utilization of less energy is the use of controlled transmission power in IH-MAC, as it creates some rendezvous slots

during heavy traffic. But, IH-MAC cannot create frequent rendezvous slots as the traffic declines. This decreases the scope for parallel transmission and hence energy efficiency deteriorates.

3. PROPOSED SCHEME

Load balancing algorithm

Wireless sensor network can have patches of high-density clusters and very low-density clusters. If the sensor nodes are not uniformly distributed, the high-density cluster head will be overloaded with processing and can cause delay in communicating events, while the low-density cluster head will be idle. Also the energy consumption varies among them. The overloaded cluster head drains its energy sooner. Hence, it leads to inactivation of all the sensor nodes in that cluster or re-configuration of the cluster.

The proposed approach can overcome the problem of non-uniform distribution of nodes by using load balancing algorithm. Each sensor node belongs to one cluster and communicates with the base station or sink only through the cluster head. Sink is located in the vicinity of the cluster heads to collect data from them.

The proposed load balancing algorithm is explained as follows: the nodes initially sense the data and process it. In the processing stage, the node measures the deviation between the previously sensed data and the current data. If there is no deviation, the node does not transmit any information to the cluster head (CH). If there exists any deviation, the information is transmitted to the cluster head. This method of transmission reduces the energy consumption of cluster head significantly. The cluster head then collects the data from the nodes which are in its vicinity and passes on the data to the base station or sink.

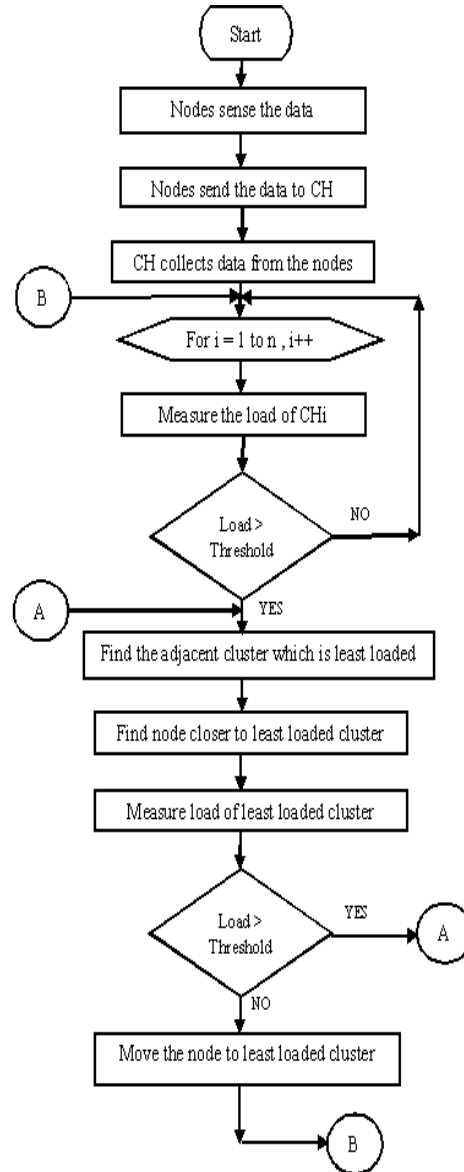


Fig.1. Proposed load balancing algorithm.

The sensor nodes are grouped into clusters with the cluster head coordinating the operation of nodes. The load of each cluster head is computed as

$$L_{CH} = N_{CH} * N_p(1)$$

where L_{CH} denotes the load of cluster head, N_{CH} denotes the number of nodes around the cluster head and N_p denotes the number of packets sent by each node

Each cluster head load is compared with the threshold value. When the load level of the cluster head reaches to the threshold value, it is an indication that the cluster head is overloaded. According to the algorithm, the cluster which is least loaded is found. The least loaded cluster is the cluster with load value less than all the other clusters. The node which is closer to the least loaded cluster is determined. Again the load of least loaded cluster is measured and compared with the threshold value. If the load of the least loaded cluster is less than the threshold value, then the node from over loaded cluster is moved to the least loaded

cluster. If the load is found to be greater, then the least loaded cluster is determined again. The process is repeated for all the cluster heads until the load is balanced.

Hybrid TDMA/FDMA MAC Protocol

We incorporate the working of load balancing algorithm with hybrid MAC. Hybrid MAC combines the strength of both TDMA and FDMA schemes and is suitable for WSN application in which data gathered by the sensor nodes has to be delivered to at least one base station in a timely manner. This allows the network to operate in an energy efficient collision-free manner and takes advantage of the multiple frequencies. As the nodes are scheduled to turn on its radio when necessary and to turn off otherwise, the network achieves high throughput, small bounded end-to-end delay and collision-free operation.

The communication period in hybrid MAC is a fixed-length TDMA cycle composed of a number of frames. Each frame is equivalently divided into several fixed time slots. Slot duration is the time required to transmit a maximum sized packet. With the hybrid MAC protocol, every node will be able to send data message using its assigned time slot and frequency in the way that it minimizes the overall delay.

Scheduling algorithm is used in such a way that the network topology is converted in the form of a tree where each node is allotted with a time slot and frequency. BFS (Breadth First Search) is done by scheduling algorithm where base node is taken as the root. A two stage checking is carried out in this protocol. In the first stage, the presence of neighbor nodes is checked. If a conflicting neighbor N_n is present for N_m , second stage checking is carried out to know whether they are siblings. If the result is true then N_m is allotted with different timeslot than N_n . If N_m and N_n are not siblings, N_m will be allotted with different frequency than N_n , allowing N_m and N_n to transmit data at same time slot.

When BFS starts with a new level or height, the default time slot number is increased by 1. After all nodes are processed, all time slots are inverted such that the slot number assigned to every node is smaller than that of its parent. This inversion is done as,

$$T_N = T_M - T_C + 1 \quad (2)$$

Here, T_N denotes the new inverted assigned slot, T_M denotes the total number of time slots and T_C denotes the current slot number assigned to the slots.

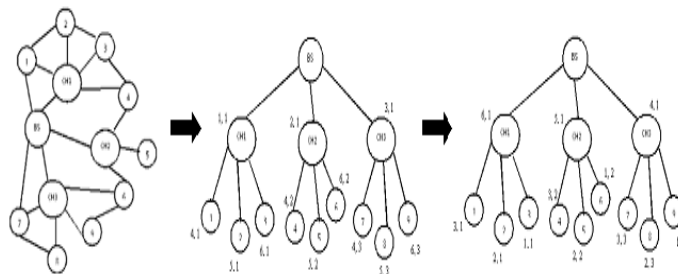


Fig.2. Operation of scheduling algorithm in hybrid MAC.

In the Figure 2, the operation of hybrid MAC with load balancing algorithm can be explained as follows: Each node is given the time slot and frequency denoted as (t, f). Nodes 1, 2 and 3 are the siblings of CH1. So, 1(t1, f1), 2(t2, f1), 3(t3, f1) have different time slot but same frequency. 1(t1, f1), 4(t1, f2) and 7(t1, f3) can reuse the same timeslot at different frequencies and hence can carry out transmissions at the same timeslot as they are not siblings. Delay can be reduced to a great extent by incorporating the concept of hybrid MAC.

PERFORMANCE EVALUATION

In this section, we provide an evaluation of the performance of proposed load balancing algorithm. The performance metrics taken into account are energy efficiency, packet delivery ratio and delay.

The energy efficiency of the sensor nodes can be defined as the total energy consumed/total bits transmitted. Energy is the scarcest resource of WSN nodes, and it determines the lifetime of WSNs.

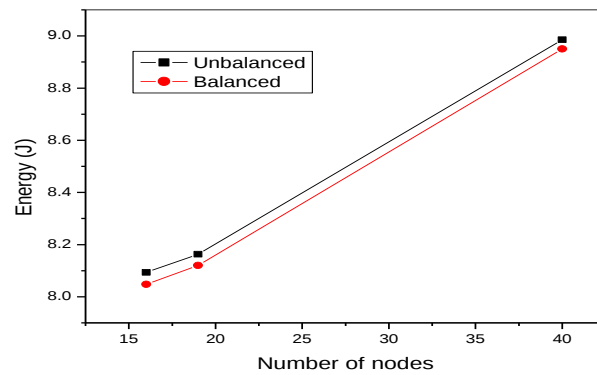


Fig.3. Number of nodes Vs. Energy.

Fig. 3 shows the energy comparison graph with number of nodes. The results are obtained in such a way that the proposed load balancing algorithm shows least energy utilization than unbalanced distribution.

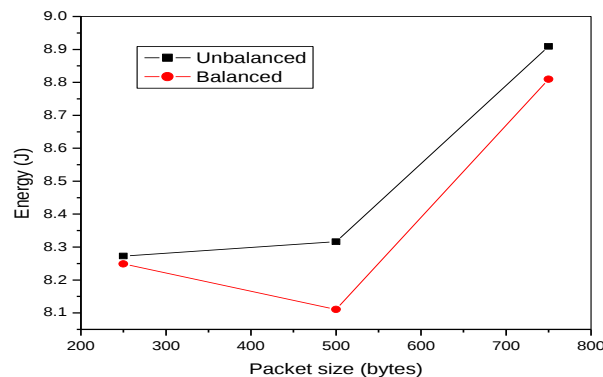


Fig.4. Packet size Vs. Energy.

Fig. 4 shows the comparison of energy Vs packet size. Unbalanced distribution has the high energy utilization. Energy utilization is less in the case of load balancing algorithm.

Packet delivery ratio is the ratio of number of packets received to the number of packets sent averaged over all the nodes.

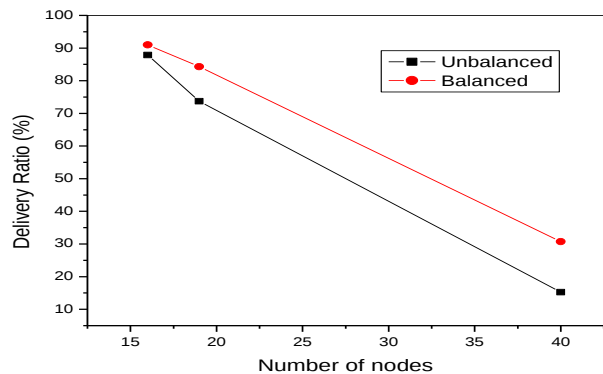


Fig.5. Number of nodes Vs. Delivery Ratio.

Fig. 5 shows the comparison of delivery ratio vs. number of nodes. From the results obtained, it has been shown that delivery ratio is very less in case of unbalanced distribution. Delivery ratio obtained in case of load balancing algorithm is higher.

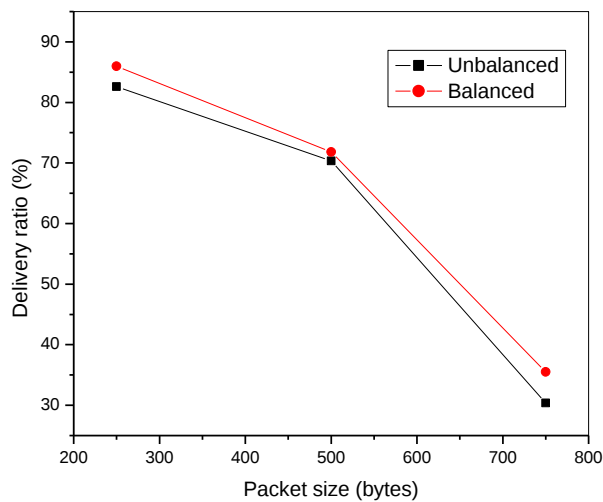


Fig.6. Packet size Vs. Delivery ratio.

Fig. 6 compares the delivery ratio parameter for variation in packet size. The delivery ratio is high for load balanced algorithm when compared to unbalanced distribution.

The average delay is the average time taken by the packets to reach the base station. Fig. 7 shows the comparison of delay with number of nodes. The delay is less in load balanced distribution than that of unbalanced distribution.

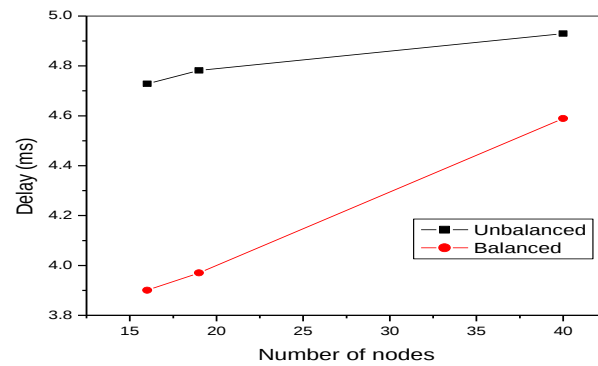


Fig.7. Number of nodes Vs. Delay.

Fig. 8 compares the same parameters for variation in packet size. Minimum delay is obtained for the proposed load balancing algorithm.

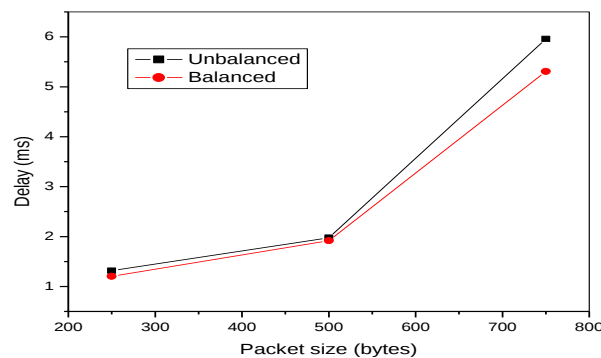


Fig.8. Packet size Vs. Delay.

CONCLUSION

As sensor nodes have very limited battery power and they are randomly deployed, it is impossible to recharge the dead battery. So energy is considered as scarce resource in WSN and should be efficiently used. If nodes are not uniformly distributed around the cluster heads, the clusters formed will be of varied load, which will affect the lifetime and energy consumption of the system. In this paper, an approach for load balancing in wireless sensor network is proposed and it is implemented by using NS-2. The performance of the algorithm is compared with the unbalanced algorithm with respect to parameters like energy, packet delivery ratio and delay. The energy efficiency and delivery ratio are high in load balanced algorithm. Also the delay is less in the proposed approach. Simulation results demonstrate that our algorithm consistently balances load along different clusters, performs well in all distributions of nodes and is effective in increasing the energy efficiency, thereby prolonging the network lifetime.

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