Design of Hybrid MAC Protocol for Wireless Sensor Network

Sankar Mukherjee and G. P. Biswas

Abstract Time division multiple access (TDMA) and frequency division multiple access (FDMA) are two popular multiple access technique that used in several wireless sensor networks. Both TDMA and FDMA have their own advantages and disadvantages. In this article, we have tried to use these two together for reducing the interference of inter-cluster and intra-cluster communication. We have considered a model of sensor network where, there are some high power nodes, which are placed in a regular hexagonal pattern and some ordinary sensor nodes which are placed randomly. High power nodes will act as clusterhead. Inside the cluster sensor nodes communicate with the clusterhead. TDMA and FDMA are being used for both time slot assignment and interference reduction. The proposed system is simulated to show the throughput of the system for different numbers of nodes. It is also shown how the packet loss of the whole system varies with low load and peak load. Our proposed system also compared with the contention based system and shown the improvement over the contention based system.

Keywords TDMA · FDMA · Frame · Cluster · MAC · Polling

1 Introduction

A sensor network typically consists of very large number of low cost sensor nodes which collaborates among each other to enable a wide range of applications. Unlike traditional data networks, communication protocol design in sensor

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network is influenced greatly by their limited energy supply [1]. Therefore it is crucial for the sensor network protocols to be energy efficient in order to extend network lifetime. Traditional wireless medium access control (MAC) protocols such as IEEE 802.11 are designed for optimizing throughput, latency, and fairness without specifically concentrating on their energy usage. The asynchronous nature of these protocols prevents energy saving by not allowing wireless nodes to selectively put their network interfaces into low energy sleep modes [6]. Few works [2, 4, 6] has been done on reducing idle listening by powering off network interfaces when possible. A notable example of periodic active-sleep design is S-MAC [6]; in which node synchronize in active sleep cycle. A major drawback of SMAC is that it cannot have very small duty cycle and guaranteed bounded delivery latency because the basic medium access mechanism is contention based.

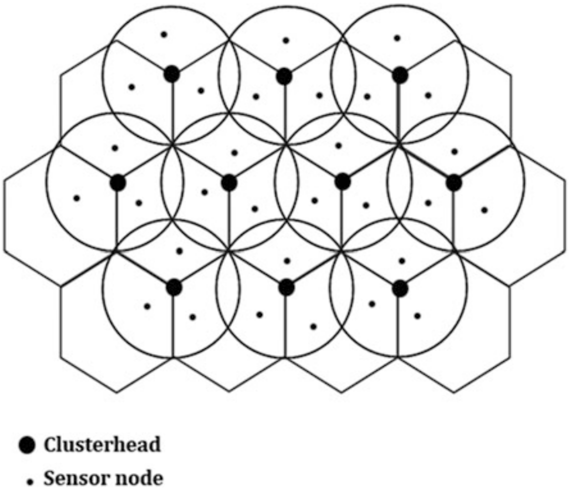
TDMA MAC protocols have built-in active-sleep duty cycle that can be leveraged for limiting idle listening, thus have better energy efficiency [3]. Here we have used TDMA and FDMA both as the MAC protocol. As we have used both TDMA and FDMA, that is why it is called hybrid MAC protocol.

2 System Model

The total area of the network is divided into some hexagonal cells. Some high power wireless nodes are deployed in this regular hexagonal pattern and placed in the three vertices of each hexagon as shown in Fig. 1. Sensor nodes are placed randomly in this area and Clusters are formed using the high power nodes. From the Fig. 1 it is seen that high power nodes are acting as clusterheads. The clusterhead nodes are generally used for data sensing just like normal sensor nodes as well as data aggregation. It also takes the responsibility to send the data to the sink node. So the clusterheads are used also for routing the data to the sink nodes. Clusterhead nodes have more energy than the normal sensor nodes.

Every sensor node must be under one cluster. Here some of the sensor nodes are belonging to more than one cluster boundary. So to resolve this problem, maximum received power among different neighboring clusterheads can be chosen as the clusterhead. The transmission range of each clusterhead node is considered as the length of the side of the hexagon. Transmission range of the sensor nodes is also same as the high power nodes. So the sensor nodes in each cluster are one hop away from its own clusterhead. Here each sensor node communicates to its own clusterhead only. There are two types of communication happen here, one is between sensor nodes to clusterhead and another is between clusterhead to clusterhead. So to overcome the interference for simultaneous communication among these nodes we have proposed TDMA and FDMA combinedly. In each cluster TDMA is used to assign the slots to the sensor nodes for communicating with their clusterhead. And for the communication between the clusterhead to clusterhead node, FDMA is used. Here every clusterhead nodes are being given fixed frequency channel for their communication and these frequencies are assigned in

Fig. 1 Network Structure of clusterheads and sensor nodes



such a way that there will not be any interference between them. These frequency channels are reused throughout the whole network in such a manner that the requirement of the frequency channels should be minimized. So the clusterheads and the sensor nodes can communicate independently without interfering each other.

Here we have considered that the network is using the ISM band. The whole bandwidth (83.5 MHz)) is divided into two parts in the ratio of 1:3. Higher part of the bandwidth is allocated to the clusters. According to the division higher part bandwidth is 62.62 MHz. This bandwidth is divided among the clusters in such a way that no two neighboring clusters use same frequency band. Sensor nodes use this frequency band along with TDMA technique to communicate with their clusterhead. The lower part of the bandwidth is used for communication between clusterhead to clusterhead. The lower part bandwidth is 20.87 MHz. Here the clusterheads use FDMA technique for communication between them.

2.1 TDMA and Time Slot Assignments

Here we have proposed that each cluster uses four time slots and each slot of length of one packet time. These four slots make one frame. Sensor nodes choose one slot among these four to send the data to the clusterhead. Slot assignment to the sensor nodes is done in a dynamic manner. Here we have used the polling method, asking to the sensor node for sending data in the slot. We have assumed that each cluster has sensor nodes which are 2^n in numbers. So out of this numbers of sensor nodes, ¼ th of the numbers use the first slot, ¼ th use the second slot and so on. Now which sensor nodes will use which slot that will be identified by their node id. Suppose each cluster has 16 sensor nodes and the node id of the nodes are from decimal value 0 to 15. Now the sensor nodes will use the slot according to the most significant 2 bits of their node id. 0000, 0001, 0010, 0011: Most significant two bits 00, use slot 0; 0100, 0101, 0110, 0111: Most significant two bits 01, use slot 1; 1000, 1001, 1010,1011: Most significant two bits 10, use slot 2; 1100, 1101, 1110, 1111: Most significant two bits 11, use slot 3. So all the sensor nodes in the cluster are divided into four groups according to their most significant bits. This division is done irrespective of their location in the cluster. In each frame only one node from each group will transmit the data and it is controlled dynamically. Clusterhead will poll the node in each group in a round robin fashion for data transmission in a slot. If a node does not have anything to send the next node will get the chance. Here the advantage is that no slot will be free and as every body is not sending the data at a time, so there will be a great energy saving. The polling algorithm and its implementation by the clusterhead are given below.

Polling Algorithm

1. Each clusterhead use four queues, Q1, Q2, Q3, and Q4 for four slots.
2. Insert node ids, eligible for sending in slot 1, in ascending order in the queue Q1.
3. Insert node ids, eligible for sending in slot 2, in ascending order in the queue Q2.
4. Insert node ids, eligible for sending in slot 3, in ascending order in the queue Q3.
5. Insert node ids, eligible for sending in slot 4, in ascending order in the queue Q4.
6. For slot No 1, pop the node ID from the Q1 and poll it for sending data in that slot. Insert node ID again into the Q1.
7. If node has data to send it will send the data,
8. else go to level 6 for next node.
9. The whole procedure is same for slot2, slot3 and slot 4 also. Slot 2 will be started after slot1; slot 3 will be started after slot 2 and so on.

In each cluster, clusterhead accumulates data that is send by the sensor nodes. It is the responsibility of the clusterheads to send the aggregated data to the sink node. Here we have assumed only one sink node. So to reach the sink node, clusterheads use their neighbor clusterheads. But communication between the clusterheads may create interference with each other, so they use FDMA as MAC protocol in the link layer. On the other hand when sensor nodes of different clusters communicate with their clusterhead, then intercluster interference may occur. So each cluster is assigned different frequency band to overcome the intercluster interference.

2.2 Frequency Assignment

Here we have assigned different frequency to different clusterheads. In the Fig. 2 the connection pattern of the clusterhead nodes are shown. Frequencies are assigned to the clusterhead nodes such that there will not be any interference between them.

Theorem 1: *Minimum 9 frequency bands are required to assign to the clusterheads so that there will not be any interference.*

Proof: From Fig. 2 it is seen that the shaded area is a rectangle and this pattern repeats the whole figure. If we see the shaded rectangle the centre node is surrounded by four smaller rectangles. In fact every node is surrounded by maximum four smaller rectangles. And total numbers of nodes in all the four rectangles is eight. These eight nodes and the centre node should use different frequency band. So minimum number of frequency bands required for the clusterheads is 9(f1–f9).

Each clusterhead node is assigned a frequency channel such that its one hop and two hop neighbor does not use the same frequency channel. These frequency channels are basically use the lower part of the whole bandwidth. So the lower part of the bandwidth (20.87 MHz) is divided into equal 9 channels and each channel bandwidth is 2.31 MHz. These 9 channels are reused in the whole network.

On the other hand each cluster is also given different frequency band. Here each cluster can be thought of a cell of cellular network. Like cellular network here also the frequency reuse factor is 7.

Theorem 2: *Seven frequency band is sufficient to assign to the clusters so that there will not be any interference of nodes belonging to different clusters.*

Proof: Here from Fig. 1 it is seen that each cluster is surrounded by six clusters that means there are at most 6 neighboring clusters of each cluster. When the sensor nodes of one cluster communicate with its clusterhead, it may interfere with the communication of other sensor nodes which belong to neighbor clusters. So if the six neighboring clusters and the centre cluster use different frequency band, there will not be any interference in inter-cluster nodes. That is why minimum seven frequency band is sufficient to assign the clusters so that there will not be any interference of nodes belonging to different clusters.

To implement it, the higher part of the bandwidth (62.62 MHz) again divided into seven parts and each cluster will be given one part of it and the assignment is done in such a way that all six neighboring clusters and the cluster itself will get different frequency band each of 8.94 MHz. Inside each cluster, sensor nodes communicate with the clusterhead. So there will be interference among the sensor nodes if more than one sensor transmits at the same time. To overcome intra cluster interference problem here we have proposed TDMA in the MAC layer. So in the higher part of the bandwidth we have used FDMA and TDMA combindly.

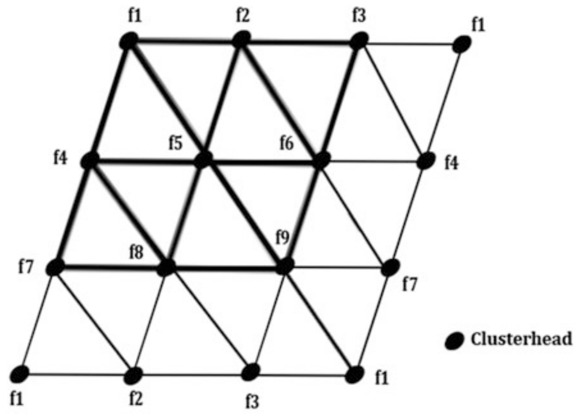


Fig. 2 Connection pattern of the clusterheads and Frequency assignment

3 Simulation Result

The node mobility and traffic generations are simulated using Omnet++ 4.0 discrete event system simulator [5]. The nodes are distributed over an area of $600 \times 600\ m^2$. The numbers of nodes has been taken 16 and 32 in each cluster. Range of the transmission of the high power nodes as well as sensor nodes are considered 100 units. Simulation has been done on finite random sensor networks using the proposed FDMA-TDMA scheme. In the simulation we have considered that the network is using the 2.45 GHz ISM band and data size of the sensor packet is 1 Kb.

Simulation is done on our proposed model and the contention based model. In the contention based model nodes will send data as they want and it may interfere with other neighboring nodes. So to send data, nodes have to contend with other nodes. In Fig. 3a we have shown how data transmission varies with time. It is found that our proposed model has more throughput than the contention based system. With time as the packet waiting time is more for contention based model that is why our proposed model gives better throughput than the contention based model.

In the second experiment we have seen how packet drop varies with total packet send. In Figs. 3b and c we find that our proposed model works better than the contention based model. Here we have drawn the curve for packet loss with successful packet send in the system in different simulation time with fixed number of nodes. Figure 3b has been drawn when number of nodes in each cluster is 16 and Fig. 3c has been drawn when number of nodes in each cluster is 32. Packet loss in the case of contention based model is more. Every packet has a TTL value. If a packet has to wait more time than TTL, the packet will be expired. That is why in the contention based model the packet drop rate is more than or proposed model. As we increase number of nodes in the whole system, contention will be more for contention based model which causes more packet drop. Similarly in the case of our proposed model as we increase number of nodes packet waiting time will be

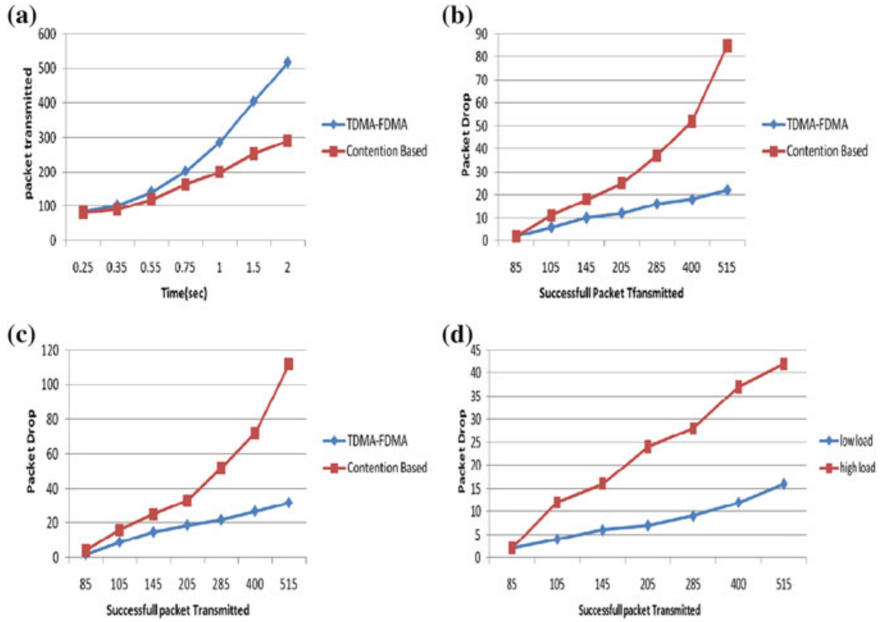


Fig. 3 **a** Packet transmitted with Time. **b** Packet drop with successful packet transmission for 16 nodes in each cluster. **c** Packet drop with successful packet transmission for 32 nodes in each cluster. **d** Packet drop while low and high load

increased because number of slot is fixed. Which causes more packet drop due to packet's TTL value is expired. In the Fig. 3c, when the number of nodes per cluster has been increased to 32, packet drop also increases compare to the Fig. 3b where number of nodes is 16 per cluster.

Finally we have observed how the packet drop varies with low load and high load in our system. Here load means packets generated in the system. We have assumed that packet generated in the system follows Poisson distribution formula. In our simulation, every sensor node generates 5 packets/sec in low load and 10 packets/sec in high load. From Fig. 3d it has been seen that when load is low packet drop is low compared to high load in the system. When load is high, packets has to wait more than when load is low. That is why high load create more packet drop than low load.

4 Conclusions

The proposed technique is to use frequency division and time division in a cluster based sensor network to reduce the interference in the inter cluster and intra cluster communication. It achieves less energy consumption which is most important for sensor network. Though we have divide the whole spectrum 84.3 MHz into two parts in the first step and again these two parts are divided into 9 and 7 parts respectively. But still it fulfills the bandwidth requirement of each node in the sensor network. Here after bandwidth division each node gets channel whose bandwidth is more than the requirement. Finally the model is such that it implementation is easy and that is why it consumes very less amount of energy.

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