Time Slot Assignment for Interference Reduction in Cluster Based Sensor Network

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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. Bothe 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 first used a clustering algorithm over several numbers of randomly deployed sensor nodes to form one hop clusters. After forming clusters, the time slots are assigned to each sensor node by using FDMA-TDMA technique for every cluster in the network. We have also studied the effect of transmission range on the number of clusters. The proposed system is simulated using a discrete event system simulator to how many slot will be required for the system for a given number of nodes and transmission range. We also find out the suitable frame size of the network by taking different numbers of sensor nodes and by varying the transmission range.

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 network is influenced greatly by their limited energy supply. 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 prevent energy saving by not allowing wireless nodes to selectively put their network interfaces into low energy sleep modes [7].In this article, first FDMA is used and then time slot is allocated, for implementing spatial TDMA in multi cluster sensor networks. In a multi access MAC, the non essential energy expenditures are contributed by the following four sources.(1) Protocol overhead, (2) packet collisions, (3) overhearing and (4) idle listening. Previous research [5, 7] has shown that idle listening accounts for most of the energy consumption at low traffic situations, which is prevalent for lot of sensor network applications.

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A significant amount of work [2, 4, 5, 7] has been done on reducing idle listening by powering off network interfaces when possible. The main goal is to operate at the smallest duty cycle while being able to support application loading requirements. A notable example of periodic active-sleep design is S-MAC [7]; in which node synchronize in active sleep cycle. A major shortcoming 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.

An alternative approach proposed by Singh [5] is Power aware multi-access protocol with signaling (PAMAS). In PAMAS every sensor node has a wake-up radio with a dedicated channel for that. A sensor node normally sleeps but when it has data to transmit, it first send wakeup signal through another channel to wake up the receiver node. After receiving and forwarding the data the node again goes to sleep. Since the only function of the radio for wakeup channel is to wake up sleeping nodes, the hardware for that interface can be simpler and less energy hungry .Nevertheless, this design adds an extra transceiver which is an added cost and complexity burden for low-cost sensor nodes.

While these contentions based protocol works well under low traffic loads, they degrade drastically under higher loads because of collision and subsequent retransmissions. TDMA MAC protocols have built-in active-sleep duty cycle that can be leveraged for limiting idle listening, thus have better energy efficiency. Although this makes TDMA a natural choice for sensor MAC, successful implementation would require some form of spatial TDMA [3] in the presence of overlapping MAC clustering [1, 2]. In such deployment, the main challenge is to devise TDMA slot allocation mechanisms with the goal of reducing allocation interference across overlapping clusters.

The rest of this paper is organized as follows. In section 2, we describe our system model. Section 3 contains the proposed Algorithms. We list our experimental results in section 4 and finally conclude the article in section 5 pointing toward future direction.

2. THE SYSTEM MODEL

Our system consists of several identical sensor nodes deployed in a region along with a sink node that accumulates the sensed data. The sink node is a powerful laptop or personal computer. The sensor nodes are organized in a hierarchical fashion by using the algorithm CLUSTER (N). Every cluster consists of (i) one clusterhead, (ii) one or more Gateway nodes, (iii) one or more intermediate nodes and (iv) several normal member nodes. Each and every node is a member of at least one cluster. Intra-cluster communication of the sensor nodes are totally handled by the clusterheads. Inter-cluster communications involves two clusters and so are done through the gateway nodes. Every clusterhead aggregates the data received from his cluster members and send it to the sink node through different clusterheads. So to reach the sink node, conventional shortest path routing algorithm through clusterheads and gateways is chosen. A gateway node can be associated with at most four clusters. While finding the path through gateway, we prefer gateway node which is associated with four clusters. If such is node is not present then, we target the gateway covering three clusters. If such gateway is not present then we choose the gateway associate with two clusters. If there exists more than one gateway covering the same clusters then we select the first one found. All other gateway nodes covering the same clusters are marked as Intermediate nodes. In each cluster the nodes who are neither gateway node nor an Intermediate node nor a clusterhead is a simple node.

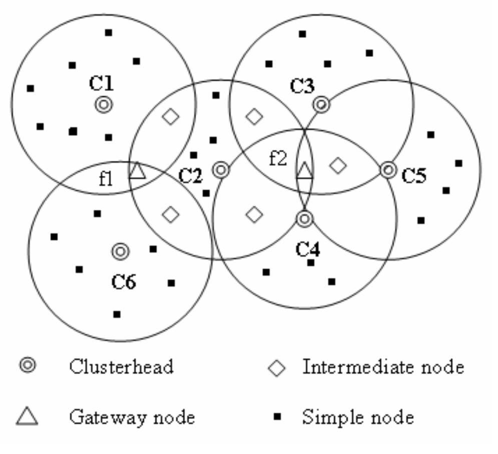

Figure 1: Sensor network with one hop clusters

For proper communication, we propose a different MAC algorithm which is basically a combination of TDMA and FDMA both. In a cluster, every node except the gateway nodes will sense the environment and send their data to their corresponding clusterhead. Every gateway node is assigned a frequency band. This frequency band should be different from all other gateway nodes covering the same clusters. The frequencies are reused over the network. When more than one clusterheads try to communicate with their connecter gateway node simultaneously, then there will be interference at the gateway node because all use the same frequency band of the gateway node. So to avoid the problem, all clusterhead will use 802.11 based RTS-CTS control signal. The proposed frequency assignment algorithm FRQNC (C_i) does this assignment. In figure 1 six clusters are shown, where C_1, C_2, C_3, C_4, C_5, and C_6 are the clusterheads. Two gateway nodes are using different frequency band f_1 and f_2. Gateway node of frequency band f_1 covers three clusters and the other of frequency band f_2 covers four clusters. Here the 2.4 GHz ISM band of total bandwidth is 80MHz is used for communication of the whole network. If there are maximum N numbers of gateway nodes in each cluster, then total numbers of frequency band required for all the gateway nodes will be (2N-1). The bandwidth of the frequency band is taken to be 2MHz. According to the cluster formation, each cluster may have maximum 6 gateway nodes. So total number of frequency requirement for the gateway nodes over the whole network is 22 MHz. The remaining frequency (80-22=58) MHz is used by all the clusters for the communication between simple sensor nodes and intermediate nodes. This ensures that there will be no interference among the gateway nodes and the remaining nodes in a cluster. To communicate with the clusterhead, nodes will use this remaining 58MHz frequency band. A TDMA time slot is assigned to every node excluding the gateway nodes within each cluster by its clusterhead to avoid the interference among member nodes. The advantage of using TDMA is that the sensor node will be in active mode at its own slot and other time it will be in sleeping mode. So this helps to avoid unnecessary energy loss. Time slot is assigned by the proposed algorithm TIME (C_i), in such a way that the time slot of the node will not overlap to other node's slot in a cluster and the slot of the other nodes, belong to different clusters, which may create interference. Slot size of each frame is equal to the fixed packet transmission time of the sensor node. Size of the frame means numbers of slot in each frame, should be equal for all the clusters in the network for synchronization. So after time slot assignment, maximum numbers of slots allotted for a cluster will be selected as the frame size. And this information should reach to every cluster in the network. After the frame size is known, if any slot is free in a cluster then the member nodes can use it provided that it will not create any interference. It is considered that clusterhead who has lower id number has higher priority. Frequency and time slot are assigned by the clusterhead according to the priority in descending order.

3. PROPOSED ALGORITHM

Let N= $\{N_1, N_2, \ldots, N_n\}$ set of n numbers of sensor nodes.

D_i = Degree of node i

NBD_i= $\{D_j \mid 1 \le j \le n\}$ set of degree of the neighboring nodes of node i including the node i itself.

M_i = Node with maximum degree in the set NBD_i and $M_i \in N$.

$RJ_i = \{N_j \mid i \neq j \text{ and } 1 \le j \le n\}$ set of nodes from where nodes gets REJ_j (Reject) message from node j. Initially the RJ set is ϕ.

RCH_i= Request for clusterhead from node i.

CM_i = request for cluster member from clusterhead i.

ACK_i=positive acknowledgement from node i.

LV_i=leave cluster request from node i.

RC_i= {N_j | i≠j and 1 ≤ j ≤ n} set of nodes from where nodes gets RCH_j message from node j. Initially the RC_i set is ϕ.

C = {C_i | 1 ≤ i ≤ n} ordered set of cluster heads. Priority of $C_i > C_j$ if i<j;

G_i= {G_j | 1 ≤ j ≤ n} set of gateway nodes in cluster i

IN_i= {IN_j | 1 ≤ j ≤ n} set of Intermediate node in cluster i.

S_i= {S_j | 1 ≤ j ≤ n} set of simple nodes which are not a gateway node or an intermediate node, in cluster i.

CL_i= {{G_i}, {IN_i}, {S_i}, C_i}

FR_i = {f_{ij} | 1 ≤ j ≤ 2g-1} frequency pool of cluster i. g is the maximum number of gateway nodes in a cluster.

T_{ij} = Time slot j of clusterhead i.

The clustering algorithm *CLUSTER (N)* is used to form one hop clusters. Initially every node calculates their degree of neighboring nodes including itself. Then they broadcast this degree information to every other neighbor. On receiving the degree information from other neighbor nodes, every node finds the node having maximum degree. This nodes is denoted by M in the algorithm. Each node send a clusterhead request message to node M. The node M declares itself as a clusterhead, if it has maximum degree among its neighbors. After declaring himself as a as clusterhead, node M sends the membership request message to its neighbors. Each node getting a membership request message from a clusterhead may accept it or reject it. If a node is not a member of any cluster then it immediately accepts the clusterhead's invitation and joins him as a member by sending positive acknowledgement. If a node is already a member of some cluster then it evaluates the number of members in both old and new clusters. If the sender of the new invitation message has lesser number of sensor members than the earlier selected clusterhead then it will leave the earlier clusterhead and choose the sender as the new clusterhead. It helps to distribute the sensor nodes to all clusters uniformly. It also sends reject message to all the nodes from where it got the clusterhead request message if the node is not willing to join them. On receiving the reject message, nodes will again calculate the maximum degree neighbors excluding the earlier selected nodes, for sending the clusterhead request message. When any clusterhead receives ACK message from a node j, selects it as a cluster member.

CLUSTER (N)

```
Begin
    Receive counter Cn=0;
    do ∀ i, 1 to n in parallel
        Node Ni calculate Mi
        Send a RCHi to node Mi for clusterhead request
        if (Ni = = Mi)
            Mark itself as clusterhead Ci.
            Broadcast a message CMi for requesting its neighbors for Cluster member.
        endIf
        if (received CMk)
            Cn++;
            if (Cn==1)
                Send all node j of set RCi, a REJi message.
                Send an ACKi to clusterhead k.
            endIf
            if (Cn>1)
                if (the chosen clusterhead has more members than the requested one)
                    Send LVi to clusterhead, earlier chosen.
                    Send an ACKi to newly chosen clusterhead k from which it got the request.
                else
                    Reject
                endIf
            endIf
        endIf
        if (received RCHj)
            if (it is not a member of any clusterhead)
                RCi=RCi ∪ {j}
            else
                Send a REJi to node j from where it got RCHj
            endIf
        endIf
        if (received a REJj)
            Modify the set RJi= RJi ∪ {j}
            NBDi=NBDi – RJi
            Find Mi again and send RCHi to Mi.
        endIf
        if (received a ACKj)
            Mark the node j as its cluster member.
        endIf
    enddo
End.
```

The algorithm *FRQNC(C_i)* used for frequency allocation by the clusterhead to its gateway members. Each clusterhead use total 11 number of frequency channels each of 2MHz in the frequency pool.

FRQNC (C_i)

```
Begin
  N=11
  if ((Ci = = highest_priority_clusterhead) || (get START
     message from Ci-1))
    do ∀ (G∈Gi)
      for j =1 to N
        if (FRij not assigned)
          Assign FRij to Gi;
          Mark FRij assigned in FRi;
            Send FRij to its neighbor clusters where it
            belong also to updates their FR list as
            assigned.
          endIf
          else
            Continue
        endfor
    enddo
      Send a start message to Ci+1;
  else
      Wait (START)
  End
```

The algorithm *TIME (C_i)* is used for time slot allocation for the intermediate nodes and simple nodes by the clusterheads. Frequency and time slot assignments are done by the clusterheads according to their priority in the descending order. After cluster formation all clusterheads got the list of all clusterheads. It is assumed that each node has an Id number and lower Id means higher priority.

TIME (C_i)

```
Begin
  if((Ci = = highest_priority_clusterhead) || (get START
     message from Ci-1))
    j=0
    do ∀ (IN∈INi)
      for(;;)
        j++;
        if ( Tij not assigned to his members or members
           of other clusters where IN also belongs)
          Assign Tij to IN;
          Mark Tij assigned in Ti;
          break;
          endIf
          else
            continue
        endfor
    enddo
    Send Ti list to its neighbor clusters to updates their
    FR list as assigned by this cluster.
    j=0
    do ∀ (S∈Ci)
      for(;;)
        j++
        if (Tij not assigned to his members)
          Assign Tij to Si;
          Mark Tij assigned in Ti;
          break
        endIf
        else
          continue
      endfor
    enddo
  Send a start message to Ci+1;
  else
    Wait (START)
  End
```

4. SIMULATION RESULTS

The node mobility and traffic generations are simulated using Omnet++ 3.3 [6] discrete event system simulator. The nodes are distributed over an area of 600 X 450 m^2. The numbers of nodes are varied from 200 to 800 with different transmission ranges. The speed of the node movement is varied between 10 to 170 m/sec. The transmission ranges of sensor nodes are varied from 10 to 150 units. No standard network protocol has been used for the total simulation. Simulation has been done on finite random sensor networks using the proposed FDMA-TDMA scheme, by varying the connectivity patterns and number of sensor nodes. Here, main aim is to see how many clusters are formed by varying the transmission range and most important how many slots are required for the sensor nodes in the cluster.

4.1 Results

The first experiment was conducted to see the effect of transmission range on the number of clusters. It is obvious that if the transmission range is short, there will be several clusters in the system. As the transmission range increases the number of clusters decreases. The graph of number of cluster changes with transmission range is shown in Figure 2. If range is chosen very high then numbers of clusters will be less and average numbers of nodes under each cluster will be high.

If the number of nodes in each cluster is very high then a large numbers of slot are required and each node has to wait long for their own slot. This will decrease the energy consumption because nodes will remain sleep a lot of time.

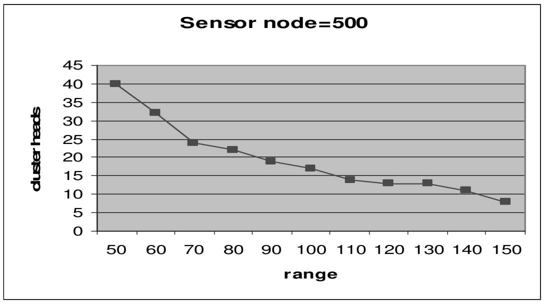

Figure 2: Variation of number of clusterhead with transmission range for 500 sensor nodes

But the latency of the packet delivery will increase. On the other hand if range is chosen very low then numbers of clusters will be high and average numbers of nodes in each cluster will be low.

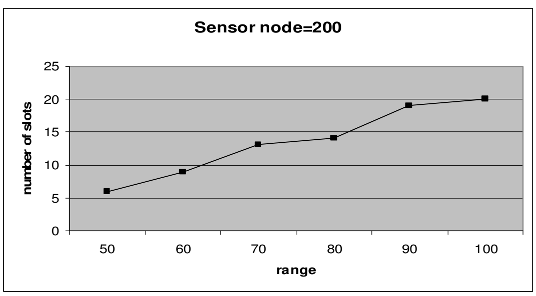

Figure 3: Variation of number of slot with transmission range for 200 sensor nodes

In that case slot requirement will be very low and so the sleeping time of the nodes will be very less. This will minimize the energy consumption because nodes will wake up frequently. But the latency of packet forwarding will decrease.

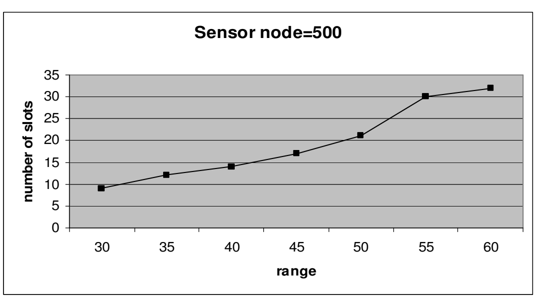

Figure 4: Variation of number of slot with transmission range for 500 sensor nodes

The variation of number of slots with the transmission range is shown in figure 3, 4 and 5. Figure 3 depicts the requirement of number of with varying range for 200 sensor nodes while figure 4 illustrates the requirements of slots with varying range for 500 nodes. Figure 5 depicts the change of slots with range for 800 nodes. From the figure 3, 4, and 5 confirms that as the range increases every cluster will cover more numbers of sensor nodes which increases numbers of slots in a frame. The other notable observation is that as more numbers of sensor nodes are deployed transmission range is becoming low for a fixed frame size as is evident form figures 3, 4 and 5.

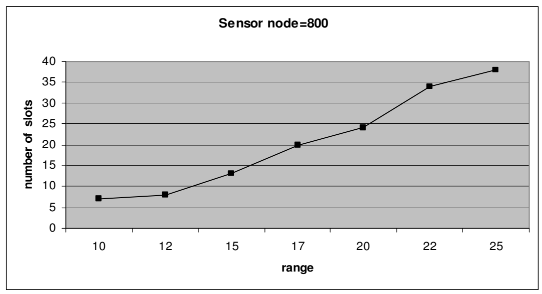

Figure 5: Variation of number of slot with transmission range for 800 sensor nodes

5. 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. There may be few free slots in each frame and these can be used by the sensor members of a cluster. But how these slot will be allocated and to whom these will be allocated, are not considered here. So it is future work, how it can be solved for using the slots efficiently.

6. REFERENCES

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