AN EFFICIENT TDMA TECHNIQUE WITH PRIORITY QUEUES IN WIRELESS SENSOR NETWORKS

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Received on: 18.10.2016
Accepted on: 11.11.2016

Abstract

Wireless Sensor Networks have limited power capabilities and also it has to serve real time applications which usually to be delivered before a deadline without collision. Hence it is essential to avoid collisions, reduce energy consumption and have real time behaviour. We propose a hybrid technique priority queues in combination with TDMA technique to achieve this goal. In this priority queue, each node except the node at the last level has three levels of priority queues. Real-time packets are placed in the highest priority queue. It can preempt the packets in the other queues. It can be processed with minimum delay. Non Real-time remote packets and local packets are placed in the second and third priority queue. Leaf nodes have one real-time packets queue and other for non-real-time local packets. A new approach to TDMA can enhance the parallelism in signal transmission and utilize the unused time slot using inter and intra level approach and also using the concept of local clock synchronization.

Keywords: Time Division Multiple Access, Priority Queues, Wireless Sensor Networks

1. Introduction

A sensor network consists of a large number of tiny sensors, which can be densely deployed close to the targeted environment for monitoring. The positions of sensor nodes are not required to be engineered or predetermined. This advantage allows fast random deployment in inaccessible terrains or hazardous environments. Some of the most important application areas of sensor networks include military, natural calamities such as forest fire detection and tornado motion, and different kinds of surveillance. They are limited in power, computational capacities and memory [7]. A wireless sensor node typically consists of sensing hardware, embedded processor and memory, transceiver and batteries. In most applications, replenishment of power resources might be impossible. In this case, energy-efficient
protocols may be applied in order to have sensor networks work longer, i.e. prolonging the network lifetime. The sensor network lifetime is the total time during which the network performs its monitoring duties without recharging batteries [6]. Message Collisions is one of the important problems in sensor networks. Sensor receives two messages simultaneously then the collisions occur in the node. The message collision problem can be avoided by using collision-avoidance and collision-freedom protocols. Collision avoidance protocols are Carrier Sense Multiple Access (CSMA) and Carrier Sense Multiple Access / Collision Detection (CSMA /CD). CSMA avoid collisions by sensing the medium before sending data. CSMA/CD is difficult to use in the Wireless Sensor Networks. It detects collision at some receivers and may not detect collision in some other receivers and senders. Collision-freedom protocols like Frequency Division Multiple Access(FDMA), Time Division Multiple Access(TDMA) and Code Division Multiple Access(CDMA). It ensures that collision doesn’t occur when the sensor communicate with each other. FDMA is not applicable since sensor network are restricted to transmit only on one frequency. CDMA is not applicable since it requires expensive operation for encoding and decoding a message. TDMA is the most applicable to sensor networks since it does not require expensive operations [5].

The main objective of wireless sensor networks is to minimize the energy consumption. The various reasons for energy wastage are control packet overhead, collision, overhearing, idle listening and over emitting. When a node receives more than one packet at the same time then they coincide partially. The packets that cause the collision have to be discarded and the re-transmission of these packets are required. It increases the energy consumption. The second reason for energy waste is overhearing. This means a node receives packet that are destined to other nodes. The third reason for energy wastage is control packet overhead. The number of control packets used for data transmission should be minimal. The fourth reason for energy wastage is idle listening. This means listening to an idle channel to receive traffic. The last reason for energy wastage is over emitting. The message is transmitted when the destination node is not ready [4]. The three types of communication patterns in wireless sensor networks are broadcast, converge cast and local gossip. Sink or Base Station is used to transmit some information to all sensor nodes of the network. Broadcast type communication pattern means all the nodes in the network are intended receivers. Broadcast type packet means the nodes within the communication range of the transmitting node are intended receivers. Local gossip means the sensors that detect intruder communicate with each other locally. Converge cast means the sensor that detect intruder send the perceived information to the information centre, where a group of sensors communicate to a specific sensor. Multicast means a sensor sends a message to a specific subset of
V.Akila* et al. /International Journal of Pharmacy & Technology sensors [8]. MAC protocol in wireless sensor networks has to be designed with the following attributes. The first attribute is the energy efficiency in order to prolong the network lifetime. The other important attributes are scalability and adaptability. Changes in network size, node density and topology should be handled rapidly and effectively for a successful adaptation. It should accommodate the network changes. Other typical attributes are latency, throughput and bandwidth utilization [1].

The communication of sensor nodes is more energy consuming than computation. The primary objective is to minimize the communication than their computation. Radio communication is one of the main sources of energy consumption. Collisions and interferences occur very frequently due to sharing of medium in dense network. In such cases, packet retransmission occurs due to packet loss and it contributes to depletion of energy in nodes. Medium Access Control (MAC) protocols have a direct impact on energy consumption by managing the access to the channel.

2. Tree Formation

Network consists of different group of sensor nodes called heterogeneous networks. Network can be represented as graph. Tree is generated from graph. Nodes can be represented as sensor nodes and the edges are assigned as time slots.

Algorithm 1

1. Nodes in the graph are divided into levels.
2. Selection of the parent is done using top-down manner and it starts from level 1 to level n.
3. The various criteria used for the selection of parent are based on distance from parent or residual energy of parent node or interference level at the parent node. But here we have used the nodes that have same hop distances from the base station are located at the same hierarchical level in the tree structure.
4. Node of level i selects any one node from level (i-1) as its parent.

![Fig.1 Tree Structure](image)

3. Construction of Three-Level Queues

The nodes are organized in a hierarchical structure using the above tree algorithm. Queue has three levels of priority
queue. It is denoted as priority 1($P_1$), priority 2($P_2$) and priority 3($P_3$). Real-time data packets are placed in priority 1 queue. It is processed using First Come First Serve (FCFS). Non real-time data packets that come from the lowest level or Non real-time remote data packets are placed in priority 2 queue. Non real-time data packets that sensed at local node are placed in priority 3 queue. The size of the Real time data packets queue is less than other queues due to the fact that real time tasks occur rarely. Real time task can preempt the presently running task in other queues. Two equal priority packets arrive at the ready queue at the same time then the task generated in the lower level has higher priority than the other tasks. Fig.2 represent the tasks or data placed in the three levels of queue.

![Scheduling of data with three level queues](image.png)

**Algorithm 2 for Priority Queues**

While packet is received by node at level k do

If type of the packet is equal to real time then

    Put the packet into $P_1$ queue

Else If node is not a leaf node then

    If packet is remote then

        Put the packet into $P_2$ queue

    Else

        Put the packet into $P_3$ queue

End If

4. **TDMA Based Data Transmission**

Our proposed approach (PQTDMA) employs the concept of local clock synchronization without using the global clock synchronization. It is calculated with respect to the local time difference between any sensor node and its parent.
The constructive modification on TDMA is done using inter and intra level scheme. It improves the collision free parallel data transmission with in a WSN environment.

The collisions among the sensor nodes can be prevented by using the levels in the tree. Sensor nodes keep track of direct neighbors and two-hop neighbors located at the same level. It requires very less memory space considering the limited storage capacity of the sensor node.

4.1 Clock Synchronization With Respect To Parent Node

All sensor nodes are randomly deployed with their own unique identification number which is an integer. Root node or master node located at level 1 can transmit a signal along with message and its id, local time of signal transmission and local time of the commencement of TDMA cycle to the children nodes. Consider the Fig.1, S is the root node with id1 and its local time of signal transmission $t_S$, local time of commencement of TDMA cycle $T_S$. Sensor node A receives the data from its parent S. Sensor node A synchronize itself with its parent by using the local time difference between parent and its time. Sensor node A receives signal from sensor node S at its local time $t_A$. Difference between its time and its parent time is calculated according to equation (1).

$$t_{\text{diff}} = (t_A - t_S) - t_P - t_T \quad (1)$$

Where $t_P$ is the signal propagation time and it is the time required to transmit from source to destination.

$$t_P = \frac{D}{PS} \quad (2)$$

Where distance between two nodes A and S (D) to data propagation speed (PS) and $t_T$ is the time required to place a data from a node into the medium. It is equal to..

$$t_T = \frac{DS}{TS} \quad (3)$$

Where DS is the data size and TS is the transmission speed. Sensor A also calculates its local time of the commencement of TDMA cycle by using the equation.

$$T_A = T_S + t_{\text{diff}} \quad (4)$$

Similarly all the children nodes calculate its time based on its parent node. All the nodes are time synchronized with their parent nodes by means of the local time difference between node and its parent node.

4.2 Inter Level Scheme

The collisions among the sensor nodes can be prevented by using the levels in the tree. All the levels cannot be transmitted simultaneously. The three different level from the root node are level 1, level 2 and level 3. Level 1 is the...
level of root node, level 2 is the direct neighbor of the root node and level 3 is the two-hop neighbor of the root node.

The nodes in the level 1 can transmit simultaneously with the nodes in the increment of level = level + 3 and till the condition level is less than equal to maximum level. For example level 1 can transmit with level 4, 7, 10… The nodes in the level 2 can transmit simultaneously along with the other levels with the increment of level = level + 3 till it reaches the condition level is less than equal to maximum level. Similarly level 3, 6, 9… can participate in the next time slot. After the completion of the above time slots again level 1, 4, 7…. get repeated. It improves parallel transmission of data and also reduces the collisions among the sensor nodes in different levels. Interference caused by the direct neighbor and two-hop neighbour reduced significantly.

4.3 Intra Level Scheme

Intra level scheme starts after the completion of inter level scheme. The sensors positioned at the same level are classified in to odd and even number sensors. The odd and even number sensors alternatively obtain time slots positioned at each level. Sensor nodes located at each level can be transmitted at the time slot allocated by inter level scheme. Sensor nodes at each level can have sorted list of direct neighbors, two hop neighbors and its own id. Each sensor node maintains its own turn (OT) which is the turn owned by the corresponding sensors. Each sensor node checks its own sorted list and its neighboring list in order to detect the conflicting nodes. If two sensors have same own turn then the sensor with lower priority can transmit. Other sensors search the sorted list of neighbour and select OT that is not belong to the sorted list of neighbour sensor. For example Sensor nodes C, D, E located at the level 3 can transmit in the time slot 3, 6, 9…. All odd sensors are transmitted at one time and all even sensors are transmitted at another time. If the odd sensors is not used the timeslot at that time then the slot is used nearby even sensors by using the concept of slot sharing.

4.4 Slot Assignment Principle: According to our algorithm even numbered sensors can share slot with an odd numbered sensors only. Similarly odd numbered sensors can share slot with an even numbered sensors only. Our slot sharing concept is based on the following two scenarios.

**Scenario 1:** Sensor node D is the odd numbered node and it is the owner of a time slot. It has no data to send and other even numbered nodes C and E have some data to send. Both C and E send a Request to Send (RTS) signal to D. RTS contains source address, destination address, time duration of transmission and priority of the packet. Sensor node D receives simultaneous RTS transmission form both C and E as shown in Fig.3. The higher priority packet
node can get the opportunity to send the data and the lower priority packet has to search the sorted list of nodes and assign its own turn (OT).

Scenario 2:

Sensor Nodes G and I are the two-hop neighbor of each other and both of them try access the unused time slots of different odd numbered sensors F and J, but the collision is detected by their common neighbour H as shown in Fig.4. The signal collision is avoided by giving preference to the higher priority packet and other packet has to search the own sorted list.

Algorithm 3 for Slot Sharing Principle

Duration of a timeslot t(k)

Processing time of real time packets \(Pr_1(t)\)

Processing time of non-real time remote packets \(Pr_2(t)\)

Processing time of non-real time local packets \(Pr_3(t)\)

If \((Pr_1(t) < t(k))\) then

P1 packet gets opportunity to utilize the time slot of the owner node

\[t(k) = t(k) - Pr_1(t)\]

P2 packets are processed for the remaining time \(t(k)\)

If \((Pr_2(t) < t(k))\) then

P2 packet gets opportunity to utilize the time slot of the owner node

\[t(k) = t(k) - Pr_2(t)\]
P₁ packets are processed for the remaining time t(k)

Else

P₂ packets are processed for the remaining time t(k)

No P₃ packets are processed

End If

Else

Only P₁ packets are processed for the remaining time t(k)

No P₂ and P₃ packets are processed.

End If

Algorithm 4 for slot sharing owner

Node senses the channel

If it has data to be send then

It sent the data to the desired neighbor

Call slot sharing principle function

Else

Wait \( t_{req} \) for slot sharing

If more than one sensor send request then

Check the priority of the requesting packet

Give permission to that higher priority node

Call slot sharing principle function

Else If one sensor send request then

Give permission to that node

Call slot sharing principle function

Else

Remains idle during the transmission

End If

End If

Algorithm 5 for slot sharing sensor
Node senses the channel

If it has data to be send then

   It send the slot share request to neighbor sensor.
   If it receives permission from the owner then
       Start transmission using owner timeslot
   Else
       Remains idle during the transmission
   End If
Else
   Remains idle during the transmission
End If

5. Simulation Framework

5.1 Simulation Model and Parameters

We have implemented the proposed framework in the Network Simulator (NS2). We have implemented the proposed technique under different simulation parameters like priority packets, local clock synchronization and queue size. It is evaluated based on the following metrics like delay, packet drop, energy consumption, end-to-end delay for real time packets.

Table 1 presents simulation parameters and their values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Nodes</td>
<td>20, 40, 60, 80 and 100</td>
</tr>
<tr>
<td>Deployment Region</td>
<td>500m x 500m</td>
</tr>
<tr>
<td>MAC</td>
<td>IEEE 802.11</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>250m</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>20.1J</td>
</tr>
</tbody>
</table>

5.2 Evaluation Metrics

The metrics used in the evaluation are specified as i) Message Delay denotes the amount of time consumed in order to transmit the message from the source to destination. ii) Energy Consumption denotes the amount of energy consumed by transmitter and receiver circuitry during transmission. iii) Packet Drops denotes the number of packets dropped during the transmission. iv) End to End data transmission delay of real-time data is the amount of time taken to transmit real-time data from the source to destination.
6. Results and Discussion

Fig. 5. EventLoad Vs Energy.

Fig. 6. Real Time Task Delay Vs Number of Levels.

Fig. 7. EventLoad Vs Delay.

Fig. 8. Nodes Vs Drop.

Fig. 5 shows the energy of CALCA[2] and PQTDMA techniques for different event load scenario. We can conclude that the energy of our proposed PQTDMA approach has 27% less energy consumption than CALCA approach. Fig. 6 shows the Real-time packets delay of DMP[3] and PQTDMA techniques for different number of levels scenario. We can conclude that the Real-time packets delay of our proposed PQTDMA approach has 15% less real-time packets delay compare to DMP approach. Fig. 7 shows the delay of CALCA and PQTDMA techniques for different event load scenario. We can conclude that the delay of our proposed PQTDMA approach has 36% less delay than CALCA approach. Fig. 8 shows the drop of DMP and PQTDMA techniques for different number of nodes scenario. We can
Conclude that the drop of our proposed PQTDMA approach has 57% less drop than DMP approach.

6. Conclusion

In this paper, we have proposed an Efficient TDMA technique with priority queues in WSN. Priority queues are used to schedule data packets based on their priorities and it reduces the delay of the transmission. Real time data packets are transmitted with minimum delay. Data Merge is used to merge the data packets before transmission. TDMA technique is used to improve the parallel transmission of the data with local clock synchronization. It further reduces the delay of the data packets. The number of collision is significantly reduced then it further reduces the energy consumption.

References


