Performance analysis of MAC protocol and Routing protocol for Wireless Sensor Networks

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Abstract

During the decade, wireless sensor networks have gained increasing attention from both the research community as well as actual users. The most critical aspects of wireless sensor networks is to face concern how to reduce the energy consumption of nodes due to fact that sensor nodes are generally battery-powered devices in order to extend the network lifetime to reasonable times. Hence in this paper we are presenting the model of microsensor node and energy model in order to verify the various aspects of minimizing the energy consumption of sensor nodes according to applications. Considering the heterogeneous aspect of a sensor node, the developed model allows comparing different node configurations in order to make the best choice of components according to the specifications of the application. The experimental evaluations of this approach will carried out through the NS2 tool in which it is designed to the WSN for various applications or network sizes and analyze its performance by applying the energy models with different configuration parameters of transmitter node and receiver node. In this project we have evaluated four MAC protocols (802.11, TMAC) with two routing protocols (AODV and DSDV) in terms of all energy parameters.

Keywords: WSN, Energy efficient, MAC protocols, Routing protocols.

I Introduction

Advances in wireless communication made it possible to develop wireless sensor networks (WSN) consisting of small devices, which collect information by cooperating with each other. These small sensing devices are called nodes and consist of CPU (for data processing), memory (for data storage), battery (for energy) and transceiver (for receiving and sending signals or data from one node to another). The size of each sensor node varies with application [1]

Today, wireless sensor networks are widely used in the commercial and industrial areas such as for e.g. environmental monitoring, habitat monitoring, healthcare, process monitoring and surveillance. For example, in a military area, we can use wireless sensor networks to monitor an activity. If an event is triggered, these sensor nodes sense it and send the information to the base station (called sink) by communicating with other nodes.

The use of wireless sensor networks is increasing day by day and at the same time it faces the problem of energy constraints in terms of limited battery lifetime. As each node depends on energy for its activities, this has become a major issue in wireless sensor networks. The failure of one node can interrupt the entire system or application. Every sensing node can be in active (for receiving and transmission activities), idle and sleep modes. In active mode nodes consume energy when receiving or transmitting data. In idle mode, the nodes consume almost the same amount of energy as in active mode, while in sleep mode, the nodes shutdown the radio to save the energy.

All the protocols that are designed and implemented in WSNs should provide some real-time support as they are applied in areas where data is sensed, processed and transmitted based on an event that leads to an immediate action. A protocol is said to have real-time support if and only if it is fast and reliable in its reactions to the changes prevailing in the network. It should provide redundant data to the base station or sink using the data that is collected
among all the sensing nodes in the network. The delay in transmission of data to the sink from the sensing nodes should be short, which leads to a fast response.

The goal of our study is to find protocols that are energy efficient and support real-time traffic for environments like habitat monitoring or area surveillance. Wireless sensor nodes which are battery operated are used for detecting and collecting information from the areas where there is very little scope for manual handling to recharge or change batteries.

Here these node detect and collects information regarding any object that is moving or any event that’s triggered. The network carrying this information uses an ordinary protocol stack which carries out the general process of transmission without any concerns for energy efficiency factor.

II Communication protocols for WSN:

In a wireless sensor network there are two types of protocols used to carry out the communication process between the nodes, so that they can transfer the collected data towards the sink. Routing protocols and Medium Access Control (MAC) protocols are used.

The basic communication types considered send periodic data or event-driven data to the base station or to the sink. The other major type extracts data from a particular location or specific Real Time Support and Energy Efficiency in WSN nodes or set of nodes (region), here there is a requirement of multicasting and broadcasting capabilities. Routing protocols fulfil these requirements along with energy conservation and focus on Quality of Service (QoS) factors.

The MAC layer is a sub-layer of the data-link layer. It provides efficient usage of the communication channel so that nodes can access the channel without collision. It helps the node to access the channel for data transmission. The MAC protocol plays an important role in energy saving, throughput, QoS and minimum delay.

A study is carried to find out the best protocols that suits for a given network topology, and also to evaluate them depending upon their transmission, communication and energy utilization factors. A study of routing protocols and MAC protocols provides information about which protocols that are energy efficiency.

III Routing Protocols for WSN Networks:

1. AODV Routing Design
   AODV is a reactive routing protocol. Reactive routing protocols are also called on Demand routing protocols and follow two major phases:
   • Route set-up phase:
     In this phase, as demand arises, a route is set up between the source and the destination. Then, the following process takes place: The network is initially flooded with requests for the route; then the request is flooded until the TTL becomes 0; after that, the request packet is discarded. The next stage involves caching a route that is set up. The route will be cached for a specified period of time. This is a variable, and its value changes based on the protocol being used
   • Route maintenance:
     This phase is responsible for maintaining the routes. If the route is not available, then an error message will be sent, and all the nodes will be notified.

   A. The drawbacks of AODV routing are as follows:
      AODV lacks the support for high - throughput routing metrics. The hop count decides which route will be installed. This metric favors short - living, low - bandwidth links over long – living, high - bandwidth links.
      AODV lacks an efficient route - maintenance technique. During the AODV operation, a route that is discovered may not be the optimal route later on. This situation can arise because of the mobile and fluctuating characteristics of wireless links.
      This thesis concentrates on the routing protocol AODV. Hop count is the routing metric used in AODV. As explained earlier, if a node receives replies from two different nodes with the same destination sequence number or a greater sequence number, then the route with a lower hop count is updated.

2. DSDV Design
   The Destination Sequenced Distance Vector (DSDV) routing protocol is a proactive routing protocol, developed in 1994 by C. Perkins. It is a modification of conventional Bellman - Ford routing algorithm. This protocol adds a new attribute, sequence number, to each route table entry at each node. Routing table is maintained at each node and with this table; node transmits the packets to other nodes in the network. This protocol was motivated for the use of data exchange along changing and arbitrary paths of
interconnection which may not be close to any base station

A. Bellman Ford Algorithm
The Bellman – Ford algorithm, a label correcting algorithm, computes single source shortest paths in a weighted digraph (where some of the edge weights may be negative). Dijkstra's algorithm solves the same problem with a lower running time, but requires edge weights to be non-negative. Thus, Bellman-Ford is usually used only when there are negative edge weights. The algorithm was developed by Richard Bellman and Lester Ford.

Procedure Bellman Ford (list vertices, list edges, vertex source)

// Step 1: Initialize graph
For each vertex v in vertices:
if v is source then distance: = 0
else distance:= infinity
v.predecessor:= null

// Step 2: relax edges repeatedly
For i from 1 to size (vertices) - 1: for each edge uv in edges: // uv is the edge from u to v
u: = uv.source
v := uv.destination
if u.distance + uv.weight < v.distance:
v.distance:= u.distance + uv.weight
v.predecessor:= u

/ Step 3: check for negative weight cycles for each edge uv in edges:
u: = uv.source
v: = uv.destination
if u.distance + uv.weight < v.distance:
error "Graph contains a negative - weight cycle".

IV MAC (Medium Access Control):
Non-mobility-aware MAC Protocols

In this paper, for evaluation we have considered two different types of general MAC protocols such as TDMA and 802.11, with above said two routing protocols. In this section we will present their designs and working procedure.

1. Timeout-MAC (TMAC) Protocol:
In wireless sensor networks, idle listening wastes lots of energy of a node. The TMAC protocol introduces the time out scheme in which a threshold value is defined and if a node does not hear anything within the duration of the threshold value then it will go to sleep state.

Fig 1: TMAC Duty Cycles
In above figure 1 shows the TMAC duty cycle. We can see that TMAC’s listening and sleeping time changes according to the traffic. Also TMAC active time varies with message rate. It uses the time-out value to reduce the idle listening .

Fig 2: Early sleeping Problem
Figure 2 shows how early sleeping problem occurs. There are four nodes A, B, C, and D. Only A can talk with B, B with C, and C with D. If node C wants to talk with node D, then there is a possibility of contention loss due to the RTS packet from B or it can overhear the CTS packet from B to A. If node C listens to a RTS packet from node B, it will reply with CTS to communicate with it and the CTS packet can be heard by D. Each control packet contains information about how long the transmission will take. When node D hears the CTS packet, it will set the alarm according to the CTS and it will awake when the transmission ends. After finishing the transmission with B, if node C overhears a CTS packet from B to A, then it has to keep quiet and node D doesn’t know about the communication between A and B. So node D will go to sleep state and C will be unable to send the data to node D.

A. To overcome this problem, TMAC introduced two solutions [3]
- Future Request to Send
- Taking Priority on Full Buffers

**Future Request to Send**

![Fig 3: Future Request to Send](image)

In the FRTS scheme, a Source sends FRTS packet to inform the destination that it still has data for it. Whenever a node overhears a CTS packet, it will immediately send an FRTS packet to the destination so that the receiving node can wake up at that time. When node C overhears a CTS packet from B to A, it will immediately send the FRTS packet to node D and it will tell how long the transmission between A and B will take so that D can awake when the transmission will finish. FRTS packets can disturb the transmission between A and B so to avoid this, node A will postpone the data packet and during this time, another node can get access to the medium. In order to hold the medium, node A will send the Data Send (DS) packet and after the DS packet it will send the data packet.

B. Taking Priority on Full Buffers:

Taking priority on full buffers is another scheme to overcome the early sleeping problem. In this scheme, when a node buffer (memory containing routing information) is full then it will prefer sending to receiving. Whenever a node receives a RTS packet which is destined for it and if its buffer is full, then it will immediately send its own RTS packet instead of replying with a CTS packet. In this situation, the node has higher chances of getting access to the medium. On the other hand, the transmission flow will be limited. The taking priority on full buffers scheme is good for node to sink or node to node communication. It is not good for omni directional communication where traffic load is high and due to limited flow, latency can be increased. TMAC uses this scheme only when node loses access to the medium two times.

C. Overhearing:

TMAC uses a control packet to avoid overhearing. A node will only listen to the control packet and will go to sleep state and set the timer to awake itself according to the information in the control packet. Control packets are smaller than data packets and contain information about how long the transmission will continue so that other nodes remain in sleep state during this transmission.

D. Synchronization:

Synchronization is important to increase the performance of the network. TMAC uses the SMAC synchronization scheme in which a group of nodes makes a virtual cluster and for synchronization each node broadcasts the sync packet in the network which contains a schedule of the node, so that other nodes can know when it will go to sleep state.

2. 802.11

 Unlike the schedule-based MAC protocols in which the channel is pre-allocated to nodes, nodes compete for a shared medium to operate communication in the contention-based MAC protocols. A typical example of these approaches is the IEEE 802.11 protocol. The fundamental mechanism it applies to access the medium is the Distributed Coordination Function (DCF). This is a random access scheme, based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique. Retransmission of collided packets is managed according to a binary exponential backoff rule. DCF describes a four way hand-shaking mechanism for data transmission. Before sending a packet, a node reserves the channel by broadcasting a short Request-To-Send (RTS) frame. The destination node acknowledges the receipt of a RTS frame by sending back a Clear-To-Send (CTS) frame. Only after the transmitter and the receiver occupy the medium, can the normal data packets and the response Acknowledgement (ACK) frames start to be transmitted. By using control packets, collision can be avoided and the retransmission cost can be considerably decreased. The working mechanism of the 802.11 protocol is described in Figure 2.
V Performance Metrics

A. Energy Consumption:
The metric is measured as the percent of energy consumed by a node with respect to its initial energy. The initial energy and the final energy left in the node, at the end of the simulation run are measured. The percent energy consumed by a node is calculated as the energy consumed to the initial energy. And finally the percent energy consumed by all the nodes in a scenario is calculated as the average of their individual energy consumption of the nodes.

\[
\text{Percent\_Energy\_Consumed} = \frac{(\text{InitialEnergy} - \text{FinalEnergy})}{\text{InitialEnergy}} \times \frac{1}{100}
\]

\[
\text{Average\_Energy\_Consumed} = \frac{\text{Sum\_of\_Percent\_Energy\_Consumed\_by\_All\_Nodes}}{\text{Number\_of\_Nodes}}
\]

B. Scenarios
There number scenario and traffic files needs to generate in order to evaluate the performance of the routing protocols under the different network conditions. In this simulation the main parameter which is varied during the simulation is the number of nodes, number of connections and size of the network. Following are parameters which are varied for these simulations:

- Nodes of maximum velocity
- Maximum number of data connections
- Number of nodes
- Size network area

<table>
<thead>
<tr>
<th>Mac protocols</th>
<th>Routing Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
<td></td>
</tr>
<tr>
<td>1) 802.11</td>
<td>1) AODV</td>
</tr>
<tr>
<td>2) TMAC</td>
<td>2) DSDV</td>
</tr>
<tr>
<td>3) 75 nodes</td>
<td>2) 50 nodes</td>
</tr>
<tr>
<td>1) 25 nodes</td>
<td></td>
</tr>
</tbody>
</table>

| Number of Nodes | 25 |
|-------------------------------|
| Traffic Patterns              | CBR (Constant Bit Rate) |
| Network Size                  | 500 x 500 (X x Y) |
| Max Speed                     | 10 m/s |
| Simulation Time               | 15s |
| Transmission Packet Rate Time | 10 m/s |
| Pause Time                    | 2.0s |
| Routing Protocol              | AODV/DSDV |
| MAC Protocol                  | 802.11/Simple/TDMA/SMAC |
VI Simulation Environment:

NS2 is stand of the Network Simulator Version 2 which is targeted specially for the networks simulations. NS2 is nothing but the discrete event simulator for the researches in the area of networking. NS2 provides the simulation and research supports for the wired networks, wireless networks by using TCP, and UDP, IP, and CBR patterns of the communications. NS2 is made of two parts basically such as NS means network simulator and other one is NAM means network animator.

VII Results and Discussion-

As per the discussions, here we are presenting the calculations and results obtained from simulation work done over estimated two MAC protocols and Two Routing protocols.

We have recorded the metrics such as average energy consumption, total energy consumption and residual energy consumption for all MAC protocols and routing protocols. Below is the comparative analysis graphs based on practical readings.

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Patterns</td>
<td>CBR (Constant Bit Rate)</td>
</tr>
<tr>
<td>Network Size</td>
<td>1000 x 1000 (X x Y)</td>
</tr>
<tr>
<td>Max Speed</td>
<td>10 m/s</td>
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<tr>
<td>Simulation Time</td>
<td>25s</td>
</tr>
<tr>
<td>Transmission Packet Rate Time</td>
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<tr>
<td>Pause Time</td>
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</tr>
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<td>Routing Protocol</td>
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<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>50</th>
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</thead>
<tbody>
<tr>
<td>Traffic Patterns</td>
<td>CBR (Constant Bit Rate)</td>
</tr>
<tr>
<td>Network Size</td>
<td>1000x1000 (X x Y)</td>
</tr>
<tr>
<td>Max Speed</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>20s</td>
</tr>
<tr>
<td>Transmission Packet Rate Time</td>
<td>10 m/s</td>
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Fig 5: 802.11 Average Energy Consumption

Fig 6: 802.11 Residual Energy
From the graphs showing in figure 5, 6, 7 for 802.11 Mac protocol, it shows that energy consumption in case of AODV in all scenarios is very much as compared to DSDV. DSDV for large networks utilizes less energy whereas AODV consumes very high energy. And hence the less residual energy remains.
Fig 10: TMAC Residual Energy

From the graphs showing in figure 8, 9, 10 for TMAC protocol, it shows that energy consumption in case of DSDV is more as compared to AODV, and also it's very low as compared to 802.11 protocols.

VIII Conclusion:
The emergence of wireless sensor networks as a concept for research in the early years of the 21st century has spawned an explosion of proposals that address and meet the generally understood requirements for efficient WSN operation. As sensor nodes are typically considered to be small, inexpensive, and low processing power devices, energy-efficiency has been perceived as the primary metric of concern in WSNs. At the heart of research, medium access control is an intriguing topic, since it directly controls the radio transceiver operation that is considered to be the most energy-consuming operation of a sensor network node. As a consequence, there have been numerous MAC protocol proposals in the scientific community, as well as industrial and institutional standards for wireless sensor and personal area networks. The proposed MAC protocols can be categorized in multiple ways according to their type of operation, topology, layers involved, etc. to group the nuances of different proposals and perceive the scope.

In this paper we have considered four MAC protocols under investigation for WSN and Two routing protocols against them for varying network conditions. We have observed that for low energy consumption, TMAC is better option, for the scalability means very large networks we can have only option of 802.11 MAC protocol.

The main disadvantage of TMAC is that its scalability issues, its stop working in case of large number of sensor nodes.

IX References