Analysis of Power Control Mechanisms of MAC Protocol for wireless Sensor Networks

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Abstract: ***Power conservation is a major issue in wireless sensor networks, as most of the nodes are battery powered. Power control is not related to any particular layer, since we can apply power conservation methods in all layers. But most of the power control mechanisms are working in MAC layer. Here we analysis a Power Control MAC protocol for wireless sensor network with overall power consumption and improvement the throughput of the network. Thus our protocol includes two phases; in the first phase we reduce the power consumption and in the second phase we improve the aggregate throughput of the network. Our work is based on the IEEE 802.11 MAC protocol. We added an additional field to the RTS, ACK and CTS control packets for reducing the power consumption and throughput of the network. In the second phase we have to improve the throughput of the network. For that purpose we made some modifications in the virtual carrier sensing mechanism. In power control protocols, since nodes use different power for different transmissions, there is a chance to reduce the throughput of the entire network. A power control protocol can improve the throughput over IEEE 802.11 by creating better spatial reuse in the network. We use for above work done on QualNet 5.0 network simulator.***

Keywords: AODV, ACK, CTS, RTS, 802.11 MAC, QualNet 5.0

1. Introduction

Since the devices used in wireless sensor network are battery powered, power conservation is a major issue of such networks. The following principles may serve as general guidelines for power conservation in MAC protocols. First, collisions, a cause of expensive retransmissions should be avoided as far as possible. Second, the nodes should be kept in standby mode or sleep mode whenever possible. Third, instead of using the maximum power, the transmitter should use a lower power that is enough for the receiver node to receive the transmission. In this context we mentioned above, the MAC protocols can be classified into two: Power management protocols (using alternative sleep and wake up modes for nodes) and power control protocols (variation in transmit power) [1] [2]. The nodes in the ad hoc network remain in one of the three possible modes: active, idle or sleep. Power consumption in sleep mode is less compared to other two modes. So we keep some of the nodes those are not participating in data transmission in sleep mode. In a network power is consumed during computation and transmission of packet, but computation power is negligible as compared to transmission power cost. Hence efforts are made to control the transmission power by incorporating different power control mechanisms [2] [15].

Need for Power Control and Management in WSN:

The main reasons for power control and management in wireless networks are the following:

Limited Energy Reserve: The main reason for the development of wireless sensor networks is to provide a communication infrastructure in environments where the setting up of fixed infrastructure is impossible. Wireless sensor networks have very limited power resources. The increasing gap between the power consumption requirements and power availability adds to the importance of energy management. Difficulties in Replacing Batteries: In some situations, it is very difficult to replace or recharge batteries. Power conservation is essential in such situations [3].

Lack of Central Coordination:

The lack of central coordination necessitates some of the intermediate node to act as relay nodes. If the proportion of relay traffic is more, it may lead to a faster depletion of power source. Constraints on the Battery Source: Batteries will increase the size of the mobile nodes. If we reduce the size of the battery, it will results in less capacity. So in addition to reducing the size of the battery, energy management techniques are necessary [3].

Selection of Optimal Transmission Power:

The transmission power determines the reach ability of the nodes. With an increase in transmission power, the battery charge also will increase. So it is necessary to select an optimum transmission power for effectively utilize the battery power [3].

Channel Utilization:

The frequency reuse will increase with the reduction in transmission power. Power control is required to maintain the required SIR at receiver and to increase the channel reusability [4]. In this paper we have investigate and analyze a MAC protocol for reducing the power consumed by each and every node. This protocol also increases the aggregate throughput of the network. The power control approach discussed above is used for the improving of throughput; we should improve the spatial reuse of the network. We achieved this by make some modifications in the VCS scheme used in IEEE 802.11. Improving the spatial reuse allows more nodes to send frames at a time and which will increase the overall throughput of the network. The rest of the paper is organized as follows. In section 2, Overview of wireless sensor network and MAC protocols in WSN are discussed. In section 3 various approaches for power conservation are discussed. In section 4, simulation setup and results are placed. Finally section 5 discusses conclude and future research work.

2. Wireless Sensor Networks

Wireless sensor networks (WSNs) are typically characterized by battery-powered sensor devices that are expected to operate over prolonged periods of time. Because of the difficulties in replacing the batteries of these devices quickly and regularly and communication being a major source of power drain in such networks, energy-efficient communication protocols are of paramount importance in such networks. To achieve this goal, one needs to address the energy- saving measures in all possible fronts such as physical layer, MAC layer, network layer (e.g., energy-efficient routing) and application layer (e.g., data aggregation).The wireless sensor network (WSN), is a self configuring infrastructure less network of node devices connected by wireless links [4] [15].

A. MAC Protocols for WSN:

Nodes in an ad hoc network share a common broadcast channel. Since the bandwidth available for communication in such networks is limited, access to this shared medium should be controlled in such a manner that all nodes receive a fair share of the available bandwidth. A different set of protocols is required for controlling the access to shared medium in ad hoc networks, because they need to address unique issues such as mobility, limited bandwidth, hidden and exposed terminal problems etc [7].

1) Classification of MAC Protocols:

Based on different criteria such as initiation approach, time synchronization and reservation approaches, MAC protocol can be classified into 3 basic categories:

a) Contention Based Protocols:

These protocols follow a contention based channel access policy. Nodes do not make any resource reservation a priori. Whenever it receives a packet to be transmitted, it contends with its neighbour nodes for access to the shared channel. This protocol does not guarantee the QoS. Contention based protocols can be further classified into sender initiated and receive initiated. Sender initiated can be further divided into single channel sender initiated and multi channel sender initiated. In single channel sender initiated, the node who wins the contention can use the entire bandwidth. But in case of multi channel, the available bandwidth is divided into multiple channels which enable several nodes to simultaneously transmit data, each using separate channel [4].

b) Contention Based Protocol with Reservation Mechanisms:

Contention based protocols does not support real time traffic since nodes do not guarantee periodic access to the channel. For supporting such traffic, some protocols have mechanisms for reserving bandwidth a priori. These protocols can be classified into two: Synchronous protocols which require time synchronization among all nodes and asynchronous protocols which do not require any global synchronization among nodes [4].

c) Contention Based Protocol with Scheduling Mechanisms:

These protocols focus on the packet scheduling at nodes, and also scheduling nodes for access to the channel. Node scheduling is done in such a manner that all nodes are treated fairly and no nodes are starved of bandwidth. Some scheduling schemes consider the battery characteristics while scheduling nodes for access to the channel [4].

B. Investigate parameters issues for MAC Protocol:

The major parameters issues that need to be addressed while investigate MAC protocol for wireless sensor networks are: **Bandwidth Efficiency:** It is defined as the ratio of the bandwidth used for actual data transmission to the total available bandwidth. The MAC protocol should investigate in such a way that the bandwidth is utilized in an efficient manner. The control overhead involved must be kept as minimal as possible [5].

Quality of Service Support: The MAC protocol for wireless sensor network that are to be used in real time application must have some kind of a resource reservation mechanism that takes into consideration the nature of the wireless sensor networks [1].

Synchronization: Synchronization is much important for bandwidth reservation by nodes. The MAC protocols should consider the synchronization between nodes in the network. Exchange of control packets may be required for achieving time synchronization among nodes. The control packets must not consume too much of network bandwidth [12].

Mobility of Nodes: Nodes in wireless sensor networks are mobile most of the time. The MAC protocol has no role to play in influencing the mobility of nodes. But the protocol design should take mobility factor into consideration so that the performance is not significantly affected due to node mobility.

Error Prone Shared Broadcast Channel: When a node is receiving data, no other node in its neighborhood, other than the transmitter, should transmit. A MAC protocol must grant channel access to nodes in such a manner that collisions are minimized [2].

Lack of Central Coordination: Wireless sensor network do not have centralized coordinators. Therefore, nodes should be scheduled in a distributed fashion for access the channel. It requires the exchange of control information. The MAC protocol should make sure that the overhead occurred due to this control information exchange is not very high [5].

Hidden and Exposed Terminal Problem: The hidden terminal problem refers to the collision of packets at a receiving node due to the simultaneous transmission of those nodes that are not within the direct transmission range of receiver. The exposed terminal problem refers to the inability of a node, which is blocked due to transmission by a nearby transmitting node, to transmit to another node [6].

3. Power Conservation in WSN

Since nodes in an ad hoc network are limited battery powered, power management is an important issue in such networks. Battery power is a precious resource that should be used effectively in order to avoid the early termination of nodes. Power management deals with the process of managing resources by means of controlling the battery discharge, adjusting the transmission power, and scheduling of power sources so as to increase the life time of nodes in the ad hoc networks. Battery management, transmission power management and system power management are three major methods to increase the life time of nodes [8] [15].

1) Power Conservation Approaches:

Two mechanisms affect energy consumption: power control and power management. If these mechanisms are not used wisely, the overall effect could be an increase in energy consumption or reduced communication in the network.

a) Power Control:

The aim of communication-time power conservation is to reduce the amount of power used by individual nodes and by the aggregation of all nodes to transmit data through the ad hoc network. Two components determine the cost of communication in the network. First one is direct node to node communication or transmission. The transmission rate can be adapted by the sender. Second is forwarding of data through the networks. In the first case we can use the power control techniques to conserve the power. Whereas in the second case we can use the energy efficient routing schemes. Current technology supports power control by enabling the adaptation of power levels at individual nodes in an ad hoc network. Since the power required transmitting between two nodes increases with the distance between the sender and the receiver, the power level directly affects the cost of communication. The power level defines the communication range of the node and the topology of the net- work. Due to the impact on network topology, artificially limiting the power level to a maximum transmit power level at individual nodes is called topology control. MAC layer protocols coordinate all nodes within transmission range of both the sender and the receiver. In the MAC protocols, the channel is reserved through the transmission of RTS and CTS messages. Node other than the destination node that hears these messages backs of, allowing the reserving nodes to communicate undisturbed. The power level at which these control messages are sent defines the area in which other nodes are silenced, and so defines the spatial reuse in the network. Topology control determines the maximum power level for each node in the network. So topology control protocols minimize power levels increase spatial reuse, reducing contention in the network and reducing energy consumption due to interference and contention. The use of different power levels increases the potential capacity of the network. Once the communication range of a node has been defined by the specific topology control protocol, the power level for data communication can be determined on a per-link or even per-packet basis. If the receiver is inside the communication range defined by the specific topology control protocol, energy can be saved by transmitting data at a lower power level determined by the distance between the sender and the receiver and the characteristics of the wireless communication channel [8].

Power aware routing reduces the power consumption by finding the power efficient routes. At the network layer, routing algorithms must select routes that minimize the total power needed to forward packets through the network, so-called minimum energy routing. Minimum energy routing is not optimal because it leads to energy depletion of nodes along frequently used routes and causing network partitions [8].

b) Power Management:

Idle-time power conservation spans across all layers of the communication protocol stack. Each layer has different mechanisms to support power conservation. MAC layer protocols can save the power by keeping the nodes in short term idle periods. Power management protocols integrate global information based on topology or traffic characteristics to determine transitions between active mode and power-save mode. In ad hoc networks, the listening cost is only slightly lower than the receiving cost. Listening costs can be reduced by shutting of the device or placing the device in a low-power state when there is no active communication [8].

The low-power state turns of the receiver inside the device, essentially placing the device in a suspended state from which it can be resumed relatively quickly. But the time taken to resume a node from completely of state is much more and may consume more energy. The aim of any device suspension protocol is to remain awake the node when there is active communication and otherwise suspend. Since both the sender and receiver must be awake to transmit and receive, it is necessary to ensure an overlap between awake times for nodes with pending communication. Different methods such as periodic resume and triggered resume can be used when to resume a node to listen the channel. In periodic resume, the node is suspend the nodes most of the time and periodically resumes checking if any packet destined to it. If a node has some packets destined for it, it remains awake until there are no more packets or until the end of the cycle. In triggered resume method to avoid the need for periodic suspend/resume cycles, a second control channel can be used to tell the receiving node when to wake up, while the main channel is used to transmit the message.

2) Proposed Approach:

Here we investigating a Power Control MAC protocol for wireless sensor network with overall power consumption and improvement the throughput of the network. Thus our protocol includes two phases; in the first phase we reduce the power consumption and in the second phase we improve the aggregate throughput of the network. Our work is based on the IEEE 802.11 MAC protocol. We added an additional field to the RTS and CTS control packets (PRTS in RTS packet to indicate the power used to send RTS packet and PData in the CTS packet to indicate the power with which sender can send DATA packet) for the design purpose. For reducing the power consumption we used the following method: We send the RTS packet with maximum or default power. The receiver after receiving the RTS packet calculates the data transmission power PData using the received power Pr, RTS transmission power PRTS and the receiving threshold Rth. After calculating the PData that power is assigned to the PData field of the CTS frame and then the CTS frame will send with the same power PData. Then after receiving the CTS frame the sender will send the DATA frame using the power PData and the receiver will send the ACK packet with the same power. In the second phase we have to improve the throughput of the network. For that purpose we made some modifications in the virtual carrier sensing mechanism. We used a NAVR with NAV to make the VCS scheme suitable for our protocol. It makes more nodes to send packets at a time and thus improves the spatial reusability. The improvement in spatial reusability increases the aggregate throughput of the network. Our main motivation is to reduce the power consumption of each and every node. In addition to it we should have to improve the aggregate throughput. In power control protocols, since nodes use different power for different transmissions, there is a chance to reduce the throughput of the entire network. A power control protocol can improve the throughput over IEEE 802.11 by creating better spatial reuse in the network [10].

In this model, nodes are randomly deployed in a geographical area. It is assumed that nodes are stationary, homogeneous and use Omni directional antenna for transmission. The other assumptions we used in our protocol are as follows [11].

The gain between two nodes is same in both directions. The channel gain is stationary for the duration of the control and data packet transmission periods. The propagation model used is the two ray ground reflection model. The relationship between transmitted power and the received power can be represented as follows:

$$\mathbf{Pr = Pt * Gtr}$$

Where, Gtr is the gain from the transmitter to the receiver.

3) Protocol Description:

Our protocol is a power control MAC protocol with improved throughput. Our aim was to reduce the power consumption of each node in the network and in addition to it improve the aggregate throughput of the network. The protocol is organized as two phases. The first phase is used to reduce the power consumption of nodes and the second phase for improving the throughput of the network [9].

4) Reduce the power consumption:

Like most of the power control protocols, here also the power can be reduced by send the packets with optimum power. All of the existing power control MAC protocols were sending the RTS and CTS packets with maximum (default) power and the DATA and ACK packets using the minimum power. The protocol discussed in, The PCMA protocol, allows different nodes to send packets with different transmission power levels. PCMA uses the busy tones instead of RTS-CTS scheme to avoid the hidden terminal problem. If a node wants to transmit a packet, it senses the channel for busy tones from other nodes. The strength of busy tones received by that node is used to determine the highest power level with which a node can send without interfering other transmissions. Instead of this, here we send the RTS with default power and CTS, DATA and ACK packets with optimum power. This protocol requires the addition of a field to the RTS and CTS control packets [12] [15].

4. Simulation setup and experimental Results

A.Scenario Setup:

We designed and implementing our experiment on QualNet 5.0 network simulator with AODV as routing protocol [14]. The metrics we mainly focused are Power consumed and throughput. We setup scenario with a Terrain size 1500m*1500m and place 50 nodes in it. The node placement strategy used is random. The packet size used is 512 bytes. We simulated the same scenario using both PCM and proposed concept and observed changes in power consumption and Throughput. We repeated the experiment with scenarios having different packet size. In all scenarios, application is made between source node 1 and destination node 50. The table 1 shows the different configuration parameters used to setup the scenario [13] [14].

Table 1: Simulation setup parameters

Terrain	1500mX1500m
Number of Nodes	50
Application	CBR
Packet size	512
No of packets	100
Routing Protocol	AODV
Node Mobility	RWP
Antenna Model	Omni directional
Temperature (K)	290.0
Energy Model	MICAz Motes

5) Simulation Environment

QualNet Developer is a tool created improve the design, operation, and management of networks. QualNet Developer is a comprehensive suite of tools for modeling large wired and wireless networks. It predicts performance of networking protocols and networks through simulation and emulation. Using emulation and simulation it allows reproducing the unfavorable conditions of networks in a controllable and repeatable lab setting QualNet is a fast, scalable and hi-fidelity network modeling software. It enables very efficient and cost-effective development of new network technologies [13].

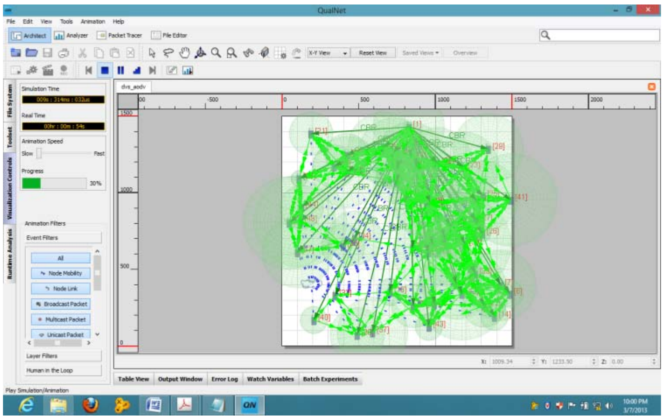

Figure 1: Run time scenario for proposed protocol

6) Simulation Result:

Figure 1 shows the runtime scenario of simulation for proposed protocol. The path represented in the scenario represents the route through which packet travelled from source node 1 to destination node 50. In the batch experiment, the simulations results for RTS, CTS, ACK packets with optimum power are calculated for all nodes. In fig.1, the simulation window of the QualNet 5.0 network energy simulator is shown. A setup parameters using for simulation are shown in table 1. In which each MAC protocols scheme for throughput and power consumption performance is calculated in an energy simulator respectively.

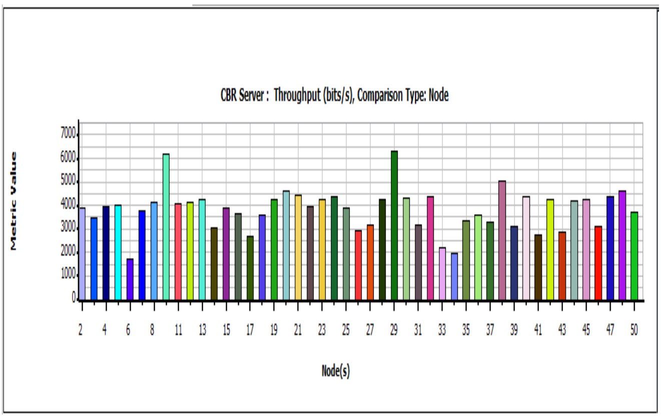

Figure 2: Run time scenario outcome for proposed protocol for throughput

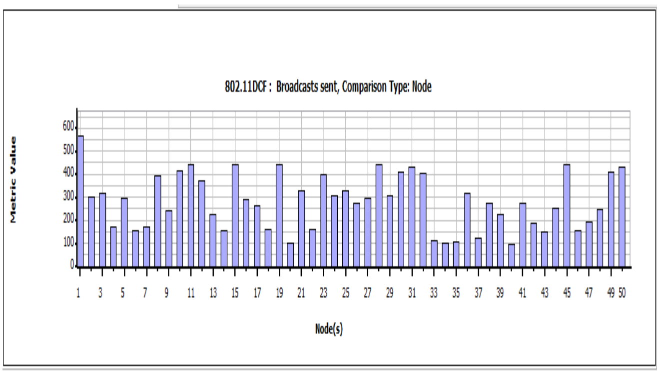

Figure 3: Run time scenario outcome for proposed MAC protocol for comparison broadcast sent

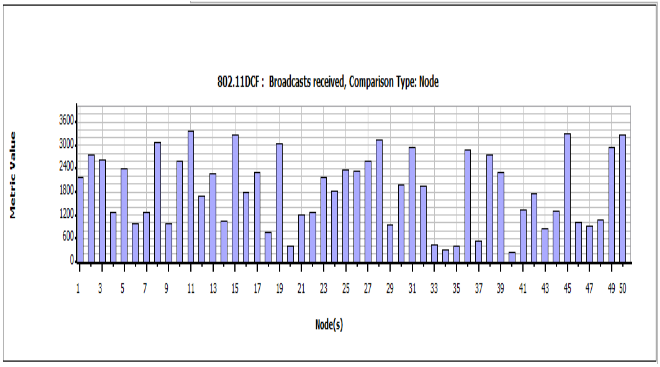

Figure 4: Run time scenario outcome for proposed protocol MAC protocol broadcast received

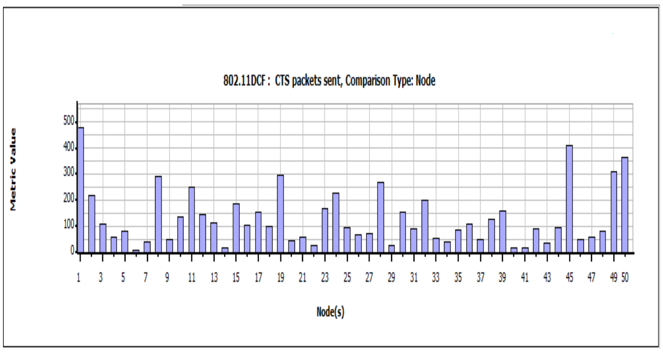

Figure 5: Run time scenario outcome CTS packet sent comparison type with nodes for proposed protocol

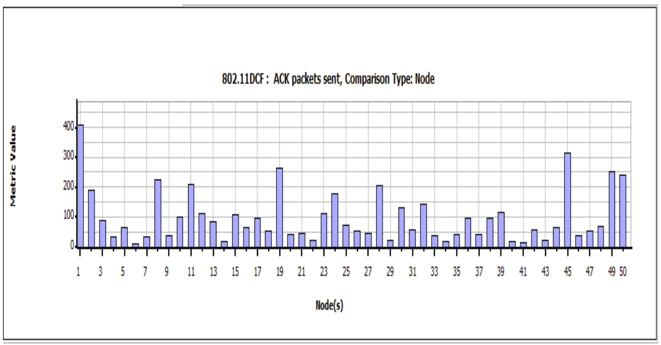

Figure 6: Run time scenario outcome ACK packet sent comparison type with nodes for proposed protocol

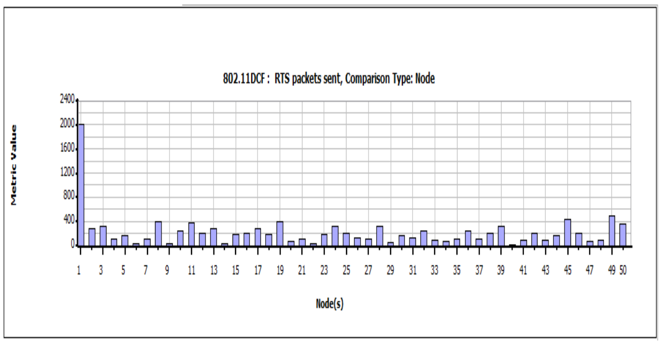

Figure 7: Run time scenario outcome RTS packet sent comparison type with nodes for proposed protocol

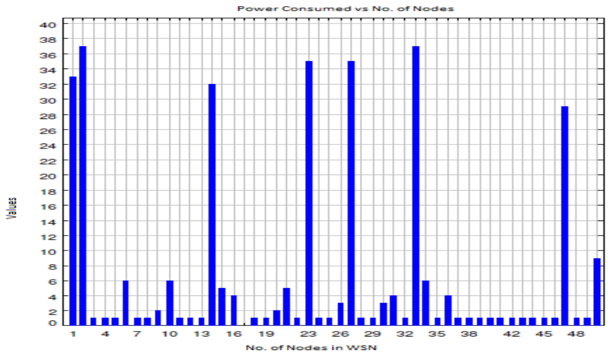

Figure 8: Power consumption of each node

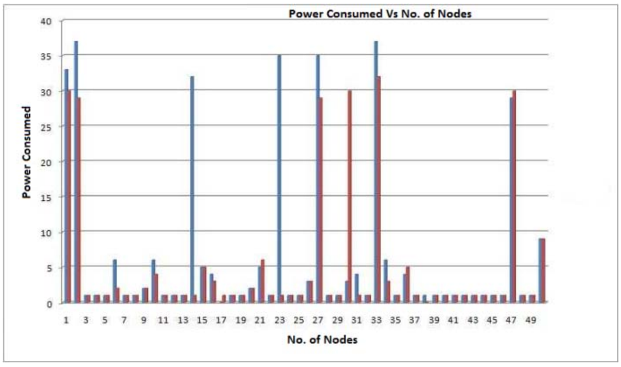

Figure 9: Power consumed by each node for proposed protocol and existing protocol

5. Conclusion and Future work

In this paper we have analysis of power control mechanisms of MAC Protocol for wireless sensor network using QualNet simulator. We considered a network environment where every node participate in data transmission and applied a power control concept in this environment. The main goal of this work was to understand the different power conservation techniques in wireless sensor network and propose a protocol to achieve this goal as shown above.

Here we have proposed a power control mechanisms of MAC protocol for wireless sensor networks which reduce the power consumption and increase the aggregate throughput. For that purpose we have made some modifications in the virtual carrier sensing scheme of 802.11 MAC.

In our work we consider a stable network environment. Mobility of the nodes did not take into consideration. In future works we can consider the different mobility modes of the nodes to make it more suitable for mobile ad hoc networks.

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