An Adaptive Energy Efficient Model for wireless Ad Hoc Networks

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Abstract: - Several transmit power control MAC protocols have been designed primarily to reduce the energy consumption in wireless ad hoc networks. On the other hand, many adaptive rate MAC protocols have been mainly proposed to improve the network throughput. Recently, very few MAC protocols have been suggested by combining the transmit power control and adaptive rate in one algorithm. In this paper, we proposed a new energy efficient MAC protocol for the Distributed Coordination Function (DCF) IEEE 802.11b based ad hoc networks which also maximizes the overall network throughput. We call this protocol s Traffic Sensing adaptive Rate Power (TSRP) control MAC protocol. In our technique, the MAC protocol selects the best rate-power combination for each data frame which can achieve the required Signal to Noise Ratio (SNR) at the receiver, maximize throughput and save energy. The basic idea of the TSRP protocol is that rather than just matching the channel condition, the sender sense outgoing traffic based on the traffic load and the queue condition. We have simulated the TSRP MAC protocol for two different scenarios – single flow single hop and two source two flows. The simulation results show that TSRP saves more energy saving and achieves higher throughput than IEEE 802.11b.

Key-Words:- Adaptive rate, Ad hoc Networks, MAC protocol, power control, TSRP, IEEE 802.11 DCF.

1 Introduction

Mobile ad hoc networks (MANETs) are multi-hop networks in which mobile nodes operate in a distributed manner without help of any central infrastructure. IEEE 802.11 provides Distributed Coordination Function (DCF) to manage concurrent transmissions and channel contentions. IEEE 802.11 exchanges RTS and CTS messages to avoid the well-known hidden terminal problem that causes interference. To overcome the problem of interfering with the ongoing transmission, all other nodes that hear the RTS or CTS message defer their transmission till the ongoing transmission is over [1].

Energy is an important factor in mobile ad hoc networks. Several energy saving schemes have been proposed to conserve energy that may also increase the network throughput. Energy conservation and throughput improvement are the two of the main performance objectives of the wireless ad hoc networks. All the previous research works shows a strong relation between these two metrics. For example, degrade in the throughput of the BASIC scheme due to excessive retransmission is completely reflected on its energy consumption metric. Several transmit power control MAC protocols have been designed primarily to reduce the energy consumption in wireless ad hoc networks. Later, they are used as a way to improve the spatial reuse and network throughput. Similarly, many rate adaptation MAC protocols have been mainly designed to improve the network throughput. Then it is found that they can be considered as a means to save energy.

In this paper, we proposed a protocol called TSRP MAC protocol that minimizes the communication energy consumption in the IEEE 802.11b based ad hoc wireless networks. This protocol is designed by combining the transmit power control with rate adaptation. The proposed protocol adaptively selects the rate-power combination for each data frame that satisfies the channel quality (SNR), maximize network throughput and save energy. The remainder of this paper is organized as follows. Section 2 reviews the related work. In section 3, we analyze and explore the theoretical relations and simulation results of simple single-hop mode for IEEE 802.11b. The outcome of this section is considered as the basis for our proposed TSRP protocol design that is explained in section 4. The investigations and simulation results of the TSRP protocol are presented in section 5. Finally, we conclude the paper in section 6.

2 Related Work

MAC protocols play an important role in mobile ad hoc wireless networks to ensure errorless, efficient and fair sharing of bandwidth. Power control MAC protocols have been studied primarily as a way to improve energy efficiency of MAC protocols for wireless ad hoc networks. In [2, 3, 4] nodes transmit RTS-CTS at maximum power, P_{max}, but send DATA/ACK at minimum necessary power P_{min}. The minimum necessary power P_{min} varies for traffic pairs with different transmitter-receiver distance, and different interference levels at the receiver side. This scheme is referred to as the BASIC power control scheme. In [5], the authors propose PCM (Power Control MAC) protocol that operates similarly to the basic power control scheme, except that the power level is periodically raised to P_{max} from P_{min} for a very short time during the transmission of the DATA packet. PCM achieves a comparable network throughput with IEEE 802.11 and consumes lower energy. In addition to power saving, the power control schemes also used to improve the spatial reuse of the wireless channel to increase the network throughput as in [6, 7, 8]. However, these schemes require additional channel that will increase the complexity of the system.

Instead of changing the transmit power, many MAC protocols have been proposed by changing the transmission rate of the data packets while keeping its power constant. In adaptive rate MAC protocols, transmission rate is changed in order to improve the network throughput. Adaptive rate schemes use the threshold SNR to predict the appropriate rate (modulation schemes). Several adaptive rate MAC layer protocols for wireless Ad Hoc networks have been proposed in the literature. Auto Rate Fullback (ARF) [9] is considered as a sender based protocol. The sender selects the best rate based on the previous data frame not the present. The adaptive rate MAC protocols such as Receiver Based Auto Rate (RBAR) [10], Opportunistic Auto Rate (OAR) [11] and Adaptive Auto Rate (AAR) [12] are considered as a receiver based protocols. The RBAR allow the receiver to estimate channel quality and to select an appropriate rate during RTS/CTS frame exchange for the next data frame. OAR and AAR protocols are considered as improved versions of the RBAR scheme. The Full Auto Rate (FAR) MAC layer protocol presented in [13] combines the sender based and receiver schemes into one. The rate adaptation of the RTS/CTS frames is done at the sending side of these frames while that for the Data/ACK frames is done at the receiving side of the frames.

Recently, very few MAC protocols are proposed by combining the transmit power and data rate into one scheme. The MAC protocol proposed in [14] computes the off line optimal rate-power combination table for IEEE 802.11a. Then at the run time, a wireless station determines the most energy efficient transmission strategy for each data frame by a simple table lookup. However, this scheme does not take the traffic load and nodes sharing the same transmission medium into consideration. The authors in [15] propose an adaptive protocol for IEEE 802.11 based wireless LAN's. This protocol uses a higher transmit power while changing to the higher coding rates. The purpose of increasing the power for the higher rates is to improve the network throughput by maintaining same transmission range so that the inference effects remain same. The MAC layer protocol presented in [16] is basically designed for IEEE 802.11a based ad hoc wireless networks. This scheme generates different transmission rates for the different types of traffic by tuning transmission power. Even this scheme takes the priority of the traffic packet in consideration, but the selected rate-power is not energy efficient. The second drawback of this scheme is that the network throughput gets affected badly if more than one node shares the same transmission medium.

3 Protocol Preliminaries

3.1 IEEE 802.11b Overview

The proposed MAC protocol for wireless ad hoc networks designed based on IEEE 802.11b standard as many IEEE 802.11b WLAN products has been widely deployed. The basic Medium Access Control (MAC) of IEEE 802.11b is DCF which employs carrier sense multiple access with collision avoidance (CSMA/CA). Each node needs to sense the channel before data transmission. Virtual carrier sensing is also employed to avoid collisions, by the use of the RTS and CTS frames. In IEEE 802.11b, the Direct Sequence Spread Spectrum (DSSS) physical layer operates in the 2.4 GHz ISM (Industrial Scientific and Medical) radio spectrum. It supports four different data rates with three different modulation schemes. They are Differential Binary Phase Shift Keying (DBPSK) for the 1 Mbps data rate, Differential Quaternary Phase Shift Keying (DQPSK) for the 2 Mbps data rate, and Complementary Code Keying (CCK) for the 5.5 Mbps and 11 Mbps data rates [17].

3.2 BER and SNR Relationship

The BER for a given modulation scheme can be calculated from the received SNR. We determined the required BER for the various SNR and modulation scheme using the equations given in [18]. We used DBPSK, DQPSK, 16-QAM and 256-QAM as modulation approach for a data rate of 1, 2, 5.5 and 11 Mbps respectively. The 16-QAM and 256-QAM are used instead of the CCK modulation which is specified in the IEEE standard because the M-ary QAM modulation is very well documented (as stated in [10] similar results can be expected for the CCK modulation). Fig. 1 shows the theoretical relationship between the BER and the SNR for the various data rates specified by the IEEE 802.11b standards. For given data rate (modulation scheme), the BER increases as the SNR decreases. From this figure we can find the most suitable modulation scheme based on the measured SNR at the receiver and the specific BER value. This BER value is considered as one of the quality of service parameter. The better communication service with negligible error is possible at lower BER (usually $\leq 10^{-5}$). This knowledge can be used to set the threshold SNR for the transmission rate selection based on the received SNR. For example, if the maximum BER is set to 10^{-}

5 and the current measured SNR falls below the required threshold value for the current modulation scheme, the sender node needs to adjust its rate.

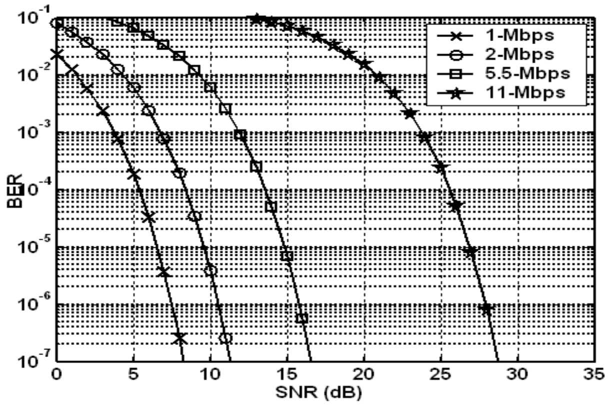

Fig. 1 Theoretical Bit Error Rates (BER) as a function of the Signal to Noise Ratio (SNR) for the several data rates used in IEEE 802.11b.

3.3 Throughput Calculation

Most of the adaptive rate schemes have considered the rate adaptation for the DATA packet only, while assuming that the control packets are always transmitted at a low basic rate. The basic rate set normally contains only 1 and 2Mbps. In this paper we have taken RBAR [10] as the adaptive rate MAC protocol. Since the channel quality estimation of the RBAR scheme is closer to actual channel condition. We assumed that RTS and CTS packets are transmitted at 1Mbps, whereas the ACK packet is transmitted at 2 Mbps whenever the transmission rate of the DATA packet is equal to or greater than 2Mbps [13].

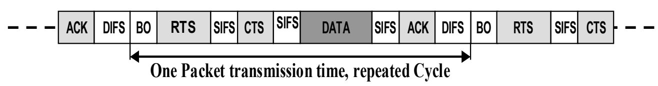

Fig. 2 Timing diagram for the CSMA/CA with the RTS-CTS-DATA-ACK handshake

Fig. 2 shows how the data packets are transmitted in the IEEE 802.11b which is based on CSMA/CA with the RTS-CTS-DATA-ACK handshake. If we consider a simple model with one active single-hop under the assumptions that there is no loss either due to collisions or buffer overflow, the transmission medium is always free to contend and the sender has sufficient packets to send. The same pattern will be repeated with a specific cycle for a given data rate [19, 20, 21]. The average time T required to transmit one packet [13] is:

$$T = T_{BO} + 3 \times T_{SIFS} + T_{RTS} + T_{CTS} + T_{DATA} + T_{ACK} + T_{DIFS} \qquad (1)$$

Where T_{BO} , T_{SIFS} , T_{RTS} , T_{CTS} , T_{DATA} , T_{ACK} and T_{DIFS} are back-off, IEEE 802.11 short inter-frame space, RTS transmit, CTS transmit, DATA transmit, ACK transmit and DCF inter-frame space times respectively.

The back-off time T_{BO} is selected randomly following a uniform distribution from $(0, CW_{min})$ giving the expected average value of $(CW_{min}/2) \times T_{slot}$, where T_{slot} is the slot time in microseconds. The transmission time taken by the RTS, CTS and ACK packets depend on the size (in bits) specified by the MAC layer in addition to the PHY header attached to these packets and the corresponding rates (Mbps) assigned by MAC layer. These times are given in the following equations:

$$T_{RTS} = \frac{8 \times (RTS + PHY\_Hdr)}{R_{RTS}} \qquad (2)$$

$$T_{CTS} = \frac{8 \times (CTS + PHY\_Hdr)}{R_{CTS}} \qquad (3)$$

$$T_{ACK} = \frac{8 \times (ACK + PHY\_Hdr)}{R_{ACK}} \qquad (4)$$

Where RTS, CTS, ACK, are size (in Bytes) of RTS, CTS and ACK packets respectively. R_{RTS} , R_{CTS} , and R_{ACK} are rates (in Mbps) of RTS, CTS, and ACK packets respectively. The PHY_Hdr is the header (in Bytes) added by physical layer to these packets. On the other hand, the time taken by the DATA packet depends on the packet size (bits) specified by the upper layer in addition to the MAC layer header, PHY header and the corresponding data rate chosen by the MAC layer as given in the following equation:

$$T_{DATA} = \frac{8 \times (L + MAC\_Hdr + PHY\_Hdr)}{R_{DATA}} \qquad (5)$$

Where L is the data packet size (Bytes) handed over by upper layer. MAC_Hdr and PHY_Hdr are headers (Bytes) added by MAC and physical layers to the data packet. R_{DATA} is the data rate selected by the MAC layer. The numerical results and the simulation model of the IEEE 802.11b presented in this paper depend on the specific setting of the IEEE 802.11b protocol parameters [1]. Table 1 gives the values for the parameters used to obtain all the results in the coming sections.

IEEE 802.11b	PARAMETER VALUES USED
T_{slot}	20 μsec
T_{SIFS}	10 μsec
CW_{min}	$31 \times T_{slot}$
T_{DIFS}	50 μsec
RTS Packet Size	20 Bytes
CTS Packet Size	14 Bytes
ACK Packet Size	14 Bytes
MAC DATA Header	28 Bytes
PHY Header	24 Bytes
DATA Packet Size	512 Bytes
Operating frequency	2.4 GHz

Table 1 simulation parameter

Therefore, the maximum theoretical throughput is given by the following equation:

$$Maximum\ Throughput = \frac{L \times 8}{T} \qquad (6)$$

Our one active single-hop model is used to generate bit errors according to the distance between the sender and destination. For our work we assumed an Additive White Gaussian Noise (AWGN) channel which can be considered as a worst case channel disregarding channel coding. The AWGN channel always results in an equal and independent distribution of bit errors over time. Hence the SNR at the receiver is a function of the communication distance for a given data rate and transmit power. Therefore, the throughput will be affected by this SNR value. The throughput given in equation (2) can be rewritten as follows:

$$Maximum\ Throughput = \frac{L \times 8}{T} \times PSR \qquad (7)$$

Where PSR is the Packet Success Rate given as PSR=(1-BER)^{C}, where C represents the complete data packet size during transmission and computed as C=L+$MAC\ Header$+ $PHY\ Header$.

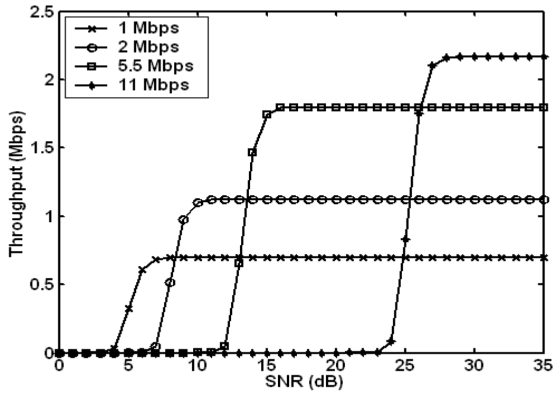

Fig. 3 Maximum throughput in IEEE 802.11b for the different data rates as a function of SNR (dB).

Fig. 3 shows the theoretical throughput for the single-hop model as a function of the SNR for the various data rates supported by IEEE 802.11b. it is clearly shown that the higher data rate provide higher maximum throughput compare to the lower data rates at extremely high SNR. While the lower data rates can perform much better than the higher data rates at the lower SNR.

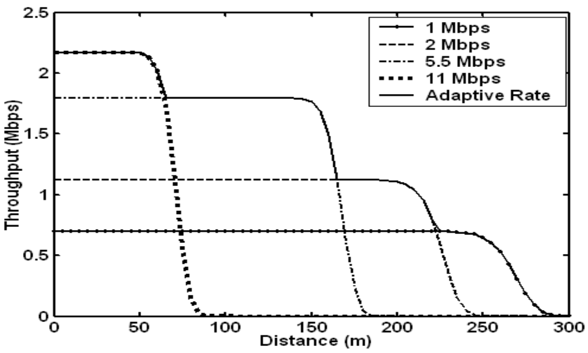

Fig. 4 Maximum throughput in IEEE 802.11b for the different data rates and adaptive rate as a function of distance (m).

Fig. 4 shows the maximum throughput as a function of the communication distance for the various modulation schemes and adaptive rate. This throughput is obtained by simulating a single-hop model. The source node generates Constant Bit Rate (CBR) traffic at a higher rate (5 Mbps).

The figure gives the exact relation between the data rates and the transmission range. It is noticed that the higher data rate can provides higher throughput but its transmission range is reduced compared to lower data rates. This transmission range improves as the data rate decreases. The adaptive rate scheme tries to dynamically choose the highest data rate that satisfies the estimated channel condition. This simple threshold technique is widely used in many adaptive rate protocols such as RBAR [10].

3.4 Energy Consumption Calculation

We used the data delivered per joule measure as another evaluation metric in our work. This metric is calculated as a ratio of the total data delivered to the total energy consumed for sending the data. We have considered only the energy consumed in transmission of all packets RTS, CTS, ACK and DATA packets. While the energy consumed by the nodes in idle or receiving states are not considered. The power control schemes [2,3,4,5] transmit RTS-CTS at maximum power, P_{max}, but send DATA/ACK at minimum necessary power P_{min} . Therefore, the energy consumed for transmitting one data packet and its control packets is given by the following equation:

$$EnergyConsumed/Packet = P_{max}(T_{RTS}+T_{CTS})+P_{min}(T_{DATA}+T_{ACK}) \quad (8)$$

Fig. 5 shows maximum data delivered per joule in IEEE 802.11b as a function of distance (m) corresponding to the maximum throughput taking the BER into consideration as shown in fig. 4 for the single-hop model. In our simulation, we consider the adaptive rates based on different data rates supported by the IEEE 802.11b standard using the maximum power P_{max}, (without power control). The IEEE 802.11b with constant data rates have been also simulated using power control scheme. With the power control scheme, we used 10 transmit power levels, 1 mW, 2 mW, 3.45 mW, 4.8 mW, 7.25 mW, 10.6 mW, 15 mW, 36.6 mW, 75.8 mW, and 281.8 mW as in [5] with maximum transmission range of 250 m at the basic data rate of 1 Mbps. As shown in Fig. 5, the higher data rate can deliver more data with the same amount of energy used than the lower data rate if power control technique is not used. Conversely as the communication distance increases, the lower data rate can provide better data delivered per joule than the higher rates. The adaptive rate scheme without power control dynamically follows the highest data rate that satisfies the estimated channel condition. The various data rates with the power control technique perform better than the corresponding rates without power control. Since with same data rate, the power control scheme uses less power so the energy consumption is reduced. When the distance increases, the power control scheme tries to increase its transmission power to satisfy the required higher SNR. When the transmitted power is reached its maximum level, the energy consumption performance of certain data rate with power control scheme exactly follow the curve of the same data rate that of without power control technique as clearly shown for the 11 Mbps data rate. It performs better for 5.5 Mbps, 2 Mbps and 1 Mbps but their throughput performance as shown in Fig. 4 are not well over all distances as the adaptive rate. Energy consumption for 2 Mbps and 1 Mbps are alternately changed with each other at a distance ≤200m but the 2 Mbps throughput performance is better at that distances. At distances >200 m, the 1 Mbps throughput and energy consumption performances are better than all the data rates. Since, it is only data rate that can provide the maximum transmission range.

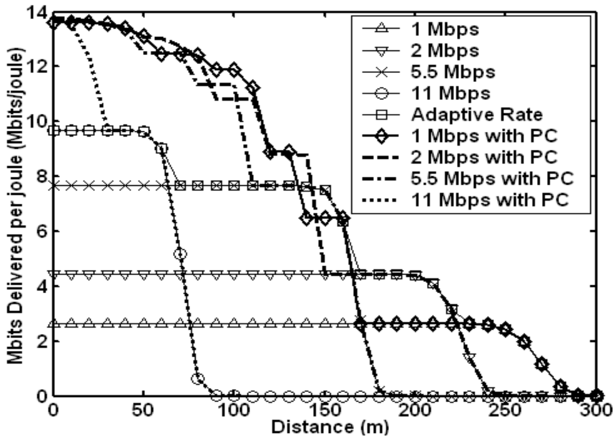

Fig. 5 Maximum data delivered per joule in IEEE 802.11b for the different data rates with/without power control and adaptive rate as a function of distance (m).

4 Traffic Sensing Adaptive Rate Power (TSRP) Control Mac Protocol

4.1 Important Remarks Considered in designing the new protocol

From the above given equations (1-8), we can notice that the throughput and the energy consumption metrics are related to each other strongly. The selection of the higher data rate based on the estimated channel quality can provides higher throughput. But this higher data rate need more transmit power to satisfy the required channel quality. As the energy consumption cost is directly proportional to the transmit power and inversely to the data rate. Therefore, the higher data rate can improve the throughput but it may not provide the minimum energy consumption cost. The energy efficient rate-power combination is the one that satisfies the required channel condition, required throughput and whose power to rate ratio is minimum. Therefore it is not necessary that the highest selected rate as suggested in the previous adaptive rate research works are energy efficient. If the required network throughput is low based on the traffic load, lower data rate can also satisfy the required channel condition as the highest rate. It is also energy efficient if combined with selected transmit power. Therefore, lower data rate is able to provide the required throughput with minimum energy consumption.

4.2 Proposed Protocol Basics

Our proposed protocol design is basically based on the remarks indicated in previous section obtained from the preliminaries. This new MAC layer protocol determines the optimum highest data rate that can satisfy the channel condition. This rate is declared after the successful exchange of the RTS-CTS control packets using the maximum transmission power. Then the protocol determines a set of all the possible rate-power combination that can also satisfy that channel condition. This rate-power set is consists of the all the data rates ≤ optimum highest rate with the transmit powers less than or equal the maximum transmit power. Then the sender node will select the most suitable rate-power combination that can provide the required throughput and consume less energy. To achieve the required throughput, the node selects the energy efficient rate-power combination from the set that can satisfy the traffic load or schedule the data packets waiting in MAC layer queue with minimum delay. The MAC layer will go to the higher rate if the traffic load is high or there is waiting packets in its queue. Our proposed adaptive MAC protocol tries to sense the outgoing transmissions by considering the traffic load and the number of the waiting packets. If the node is source node and the queue is empty, the scheme tries to send all the coming data packets from the upper layer using the energy efficient rate-power combination. Based on the traffic load, the selected rate should be able to deliver these packets without any delay as possible. Due to many reasons, the packet(s) has to wait in the queue, if the transmission rate is not able to completely send the packet before the new packet arrives. The source node found the medium busy by another node, so packet(s) coming from the upper layer will have to wait in its queue. Another major reason is that if the node is acting as a router in a multi-hop communication has to receive packet(s), store it in its queue for further forwarding.

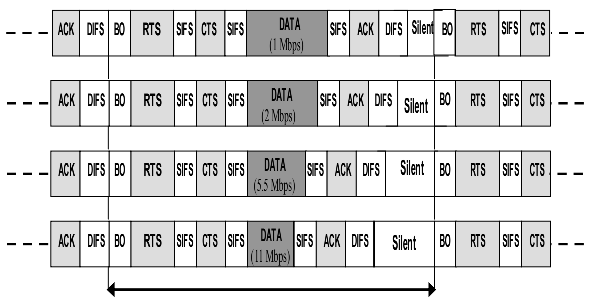

Fig.6 Timing diagram for the CSMA/CA with the RTS-CTS-DATA-ACK handshake using the different data rates.

Now suppose that the source node has no waiting packet(s) in its queue and also found the medium free to contend. It will directly transmit the coming packets from the upper layer. In case the estimated measured SNR at the receiver is high and the required throughput can be easily satisfy by the lowest data rate (1 Mbps). Therefore, the MAC protocol will select the most energy efficient rate-power for transmitting the coming packets. As shown in Fig.6, the traffic load is too low so the inter-arrival time (λ= L*8/Traffic_load) between successive packets is larger than the time required for transmitting a data packet at its lowest data rate. In this situation, the sender selects a rate with its corresponding transmit power that is energy efficient. As the measured SNR at receiver decreases or the traffic load increases, the elements of rate-power set will reduce. Therefore, the choice for energy efficient rate-power combination will be limited. This new protocol is more effective at higher SNR and lower traffic load.

Let now consider the operation of our proposed protocol under more complicated situation. In this situation, either a sender node finds the medium busy or the node has received packet(s) stored in its queue for forwarding to another destination. In this case, the protocol will find the minimum rate suitable to schedule these waiting packet(s) in order to achieve the required network throughput. This minimum rate is found by using only the rate values available in the rate-power set constructed using the highest rate that satisfies the channel condition. This set will be referred to as main rate-power set. Then the protocol constructs a new subset from the main rate-power set. This new subset contains only the rate-power combinations available in the main set with rates between the minimum rate to achieve the required throughput and the highest rate to satisfy the required channel condition. Then it will select the most energy efficient rate-power combination from the new subset. This rate-power combination will be able to maximize the network throughput and save more energy compare to any other power saving scheme.

To clear the idea of our proposed protocol, let us explain an example of two source nodes sharing the same transmission medium. The timing diagrams of such example are illustrated in Fig.7. All the numerical values shown in this Fig. are calculated using the data rates indicated and the equations mentioned in section 3. Each source node generates a traffic load of 500Kbps. It is noticed that the first packet generation of both the sources are not shown in Fig. 7(a). At the beginning of the second packet generation, the first packet is already generated and ready for the transmission. Assume that at certain distance, the main set contains the 1 Mbps, 2 Mbps, 5.5 Mbps and their corresponding transmits power. It is found that the 1 Mbps is more energy efficient, then the 2 Mbps when there is no packet(s) waiting in the queue. Therefore, the sender selects the 1 Mbps data rate to send the data packets using its corresponding transmit power. Suppose that the two senders generate the traffic at the same time. According to CSMA/CA, if source 1 has reserved the medium to transmits its packet. As a result it will select 1 Mbps data rate as it is can achieve the required throughput and is energy efficiency. Also source 1 did not have any idea that source 2 also sharing the same medium. But source 2 will sense the medium busy by the source 1, therefore its packet has to wait as shown in Fig. 7(b). Using the waiting time and the remaining time before the next packet will be available for processing; the source 2 will select the 5.5 Mbps as the transmission rate. Even the 5.5 Mbps is not energy efficient in the main set but it is the only element with its corresponding power in the subset that can provide the required throughput. This scenario will continue between the source 1 and source 2. Since the contention of the transmission medium in CSMA/CA is random between the shares nodes. If source 1 reserved the medium, then it will transmit at 1 Mbps while source 2 at 5.5 Mbps. on the other hand, if source 2 will reserved, then it will use 1 Mbps and source 1 at 5.5 Mbps. With such technique, the throughput of the network will maximize while more energy will be saved.

Now consider another case, when the distance between the senders and the destinations is large. Suppose the main set contain only 1 Mbps and 2 Mbps with the 1 Mbps more energy efficient. In this case, if source 1 has reserved the medium to transmits its packet. As a result it will select 1 Mbps data rate as it is can achieve the required throughput and is energy efficient. Source 2 will select 2 Mbps to achieve the required throughput. Suppose again the source 1 reserve the medium for transmitting its second packet. Even the second packet waited for certain time, but the source 1 will found that 1 Mbps will be suitable to transmit it before the next packet arrives as it can achieve the required throughput.

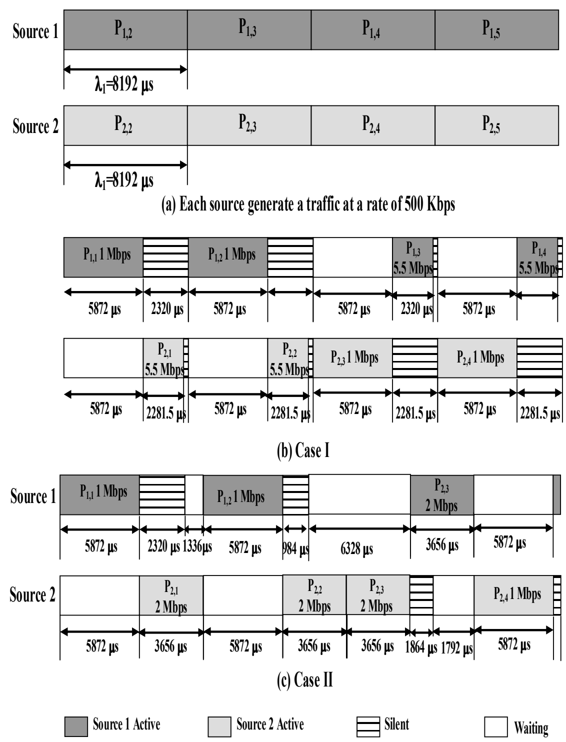

Fig. 7 Timing diagrams shows the adaptive operations of the proposed TSRP scheme to achieve the higher throughput with optimum energy consumption, when two sources with two flows shares the same transmission medium.

This scenario will continue between the source 1 and source 2 and the selection of the rate will based on the packet waiting times and the remaining time for the new packet arrives which based on the traffic load as shown in Fig. 7(c).

If more than one packet is waiting in the queue, then the rate should be selected so that these packets delivered as possible before the news arrive. The idea of this protocol is also applicable to the nodes involved in the multi-hop wireless ad hoc networks or more than two nodes sharing the same transmission medium.

4.3 Proposed Protocol Description

The proposed TSRP control MAC layer protocol works in the following steps:

1) Transmitter sends RTS packet with maximum

power level.

2) Receiver decodes the RTS packet and estimates the current channel condition by measuring the SNR at that time.

3) The receiver sends the CTS packet with maximum power level including the measured SNR to the transmitter.

4) Using the estimated SNR extracted from the CTS packet, transmitter find the highest data rate that satisfy the estimated channel condition. This highest rate is found by comparing the extracted SNR with the series threshold representing the desired performance.

5) Using the number of the waiting packets in the queue, node waiting time to contend for the medium and the required throughput is based on the traffic load; the transmitter finds the lowest rate that can maximize the network throughput.

6) The transmitter builds a subset table that contains certain rate-power combinations. The rates included in this subset must be (highest rate≤ rate ≤ lowest rate).

7) The data packet transmitted using the most energy efficient rate-power combination selected from this subset.

5 Simulation and Results

5.1 Simulation Model

In this section, we evaluate our proposed protocol through extensive simulations. We simulated IEEE 802.11b with power control scheme using its various standard rates, adaptive rate and our proposed TSRP control protocol. The IEEE 802.11b was modeled using the MATLAB based on discrete event modeling approach. The model actually contains all the mechanisms which use the CSMA/CA technique based on DCF access method as regulated by IEEE. The transmit power levels and other parameters values used in our simulations are as specified in the previous sections. The threshold received value and the thermal noise are -72 dBm and -80 dBm respectively. The antenna heights and gains of all nodes are 1m and 1 respectively. Two-ray path loss is used as the radio propagation model, where the signal attenuate as $1/d^2$ at near distance and $1/d^4$ at far distance. We performed the simulations using packet size of 512 Bytes and CBR traffic generated at a rate of 100Kbps. Each simulation runs for 1000 seconds

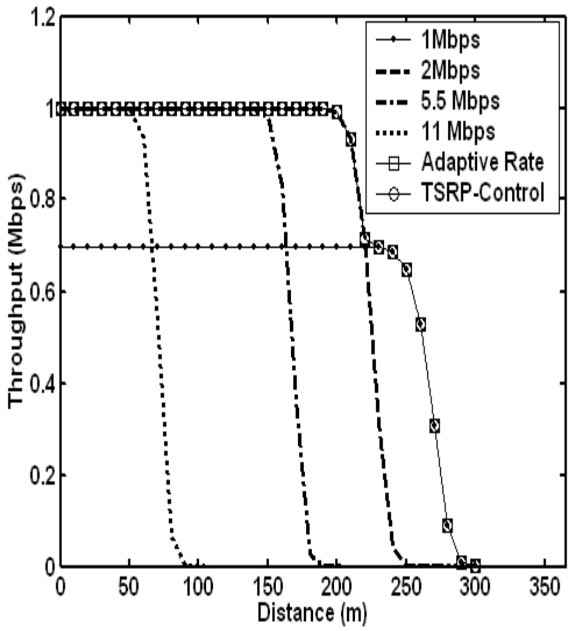

Fig. 8 Throughput comparisons at 1 Mbps traffic load in case of single flow single-hop.

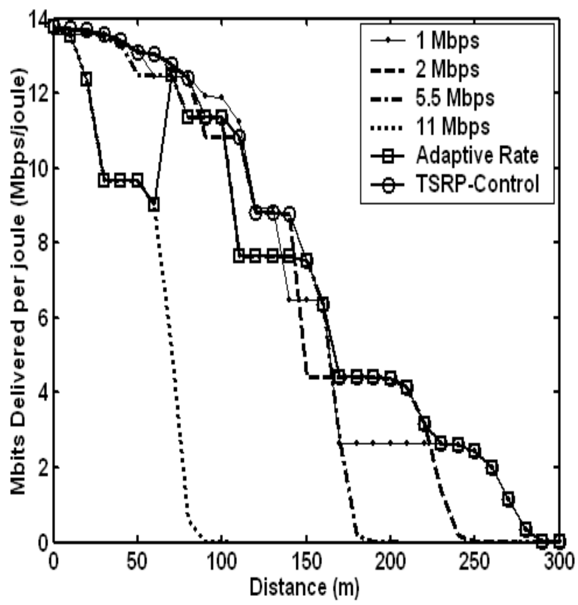

Fig. 9 Total data delivered per joule comparisons at 1 Mbps traffic load in case of single flow single-hop.

Two performance measures are evaluated. The throughput (Mbps) is defined as the total number of errorless data bits that reach their destinations per second. The data delivered per Joule (Mbits delivered per joule) is defined as the total number of errorless data bits that reach their destinations divided by the total amount of energy expended in the transmission of all data and control packets by all radios in the network. i.e. the energy used in the transmission of RTS, CTS, or ACK packets is included in the determination of this metric.

In these simulations, we consider two scenarios: single flow single-hop and two sources two flows sharing same transmission medium. In the first scenario, there is one sender and one destination. Where as in the second scenario, there are two senders wishing to communicate to their corresponding destinations respectively at the same time. These two senders sharing the same transmission medium.

5.2 Simulation Results for the Single Flow Single-hop Scenario

Fig. 8 shows the throughput obtained from the simulation for the single flow single-hop. The distance between two sender and the destination nodes varies and sender node generates traffic at the rate of 1 Mbps. The figure shows the comparison of the throughput of power control IEEE 802.11b with various data rates, adaptive rate and our proposed scheme. It is clearly shown that, only the 1 Mbps will not be able to provide the maximum throughput required at distances <230m but its performance is better than other rates as the distances increases toward the maximum transmission range . Even the data rate is same as the traffic rate but due to MAC and PHY overheads, the throughput will reduce. Whereas all other rates, adaptive rate and our protocol will be able to achieves the traffic rate. Excluding the 1 Mbps rate since its throughput is low, our scheme is more energy efficient compares to others as shown in Fig. 9. The new protocol adaptively selects the rate-power combination that can improve the throughput and energy conservation performances of the network.

The TSRP control technique adaptively selects the rate that can save more energy. While the adaptive rate scheme always follow the highest rate that satisfy the measured SNR. The proposed protocol always tries to use the rate such that ratio of power to rate is minimum. As the rate increases its transmit power also increases and vice versa. This phenomenon is clearly indicated in Fig. 10. This Fig. shows the transmit power used in single flow single-hop to achieve the throughput and data delivered per joule shown in Fig. 8 and Fig. 9 respectively.

We also simulate the single flow single-hop by fixing the communication distance and varying the traffic load. Fig. 11 and Fig. 12 show the throughput and its corresponding data delivered per joule in case of single flow single-hop considering such situation. In this case, the simulations perform by fixing the distance between the sender and the destination at 20 m whereas the traffic rate changed. Since the distance is small that means the measured SNR is large. For that the throughput curves of the 11 Mbps, adaptive rate and our protocol are overlapped as shown in Fig. 11. The benefits of our designed protocol compare to others can be clearly notice in Fig. 12. Since TSRP control scheme did not select the highest rate as in the case of the adaptive rate but it select the rate sufficient to deliver all the packets with minimum delay and should be able to save energy as possible. As shown in Fig. 12, The TSRP scheme will adaptively changes the rates according to the traffic load. At any traffic load, this new scheme will conserve energy while achieving maximum throughput. At higher traffic load the performance of our scheme, adaptive rate and 11 Mbps will be exactly same.

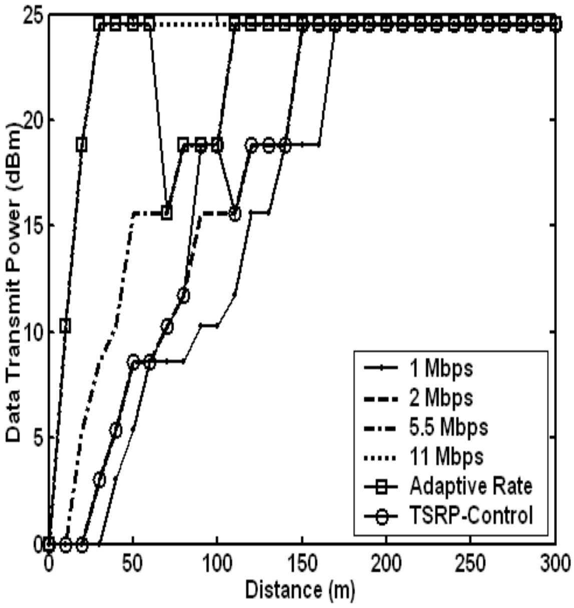

Fig. 10 Average data transmit power (dBm) comparisons at 1 Mbps traffic load in case of single flow single-hop.

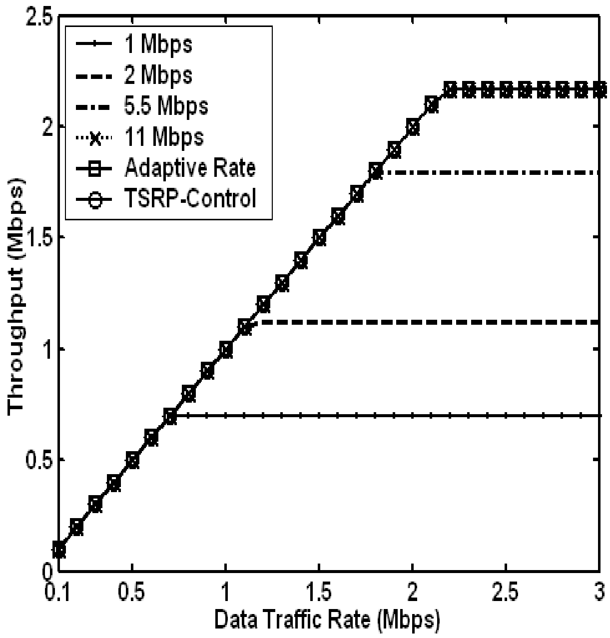

Fig. 11 Throughput comparisons in case of single flow single-hop by varying traffic load at a distance of 20 m.

5.3 Simulation Results for the Two Sources Two Flows Sharing Same Transmission Medium Scenario

In this scenario we considered the case when two sources two flows sharing the same transmission medium. In this case, each source is in the RTS-CTS ranges of the outgoing transmission carried by the other source or it is in the carrier sensing range of the other source. Each source generates the CBR traffic at rate of 100Kbps. Since the traffic load is low compare to the data rate specified by the IEEE 802.11b standards. The aggregate throughput of 1 Mbps, adaptive rate and our proposed scheme are the same. As for 11 Mbps, 5.5 Mbps and 2 Mbps the throughput falls respectively as the transmission range increases. Fig. 13 represents the advantage of the TSRP control MAC protocol among the adaptive rate and the various data rates supported by IEEE 802.11b. The total data delivered per joule is always remains maximum compared to others as its curve remains always at the top. Therefore, this new scheme is able to save more energy.

We have evaluated our scheme under various traffic rate and different packet size. All the simulation results show that our new protocol design performs better than others but it is not possible to include all the results in the paper due to space limitation.

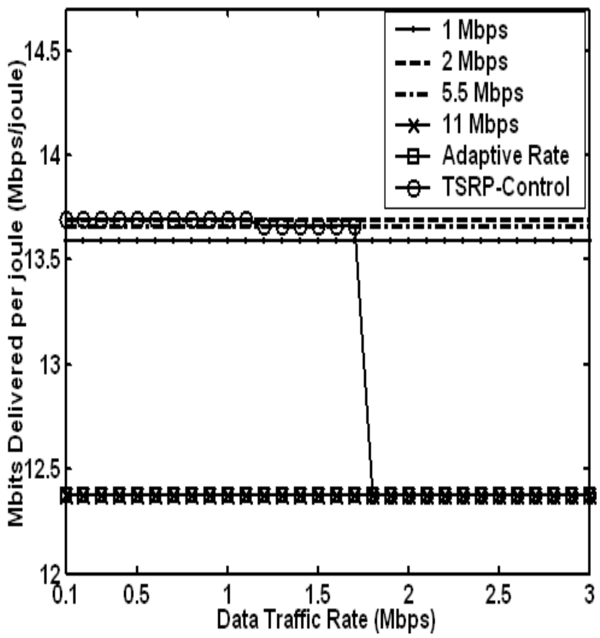

Fig. 12 Total data delivered per joule comparisons in case of single flow single-hop by varying traffic load at a distance of 20 m.

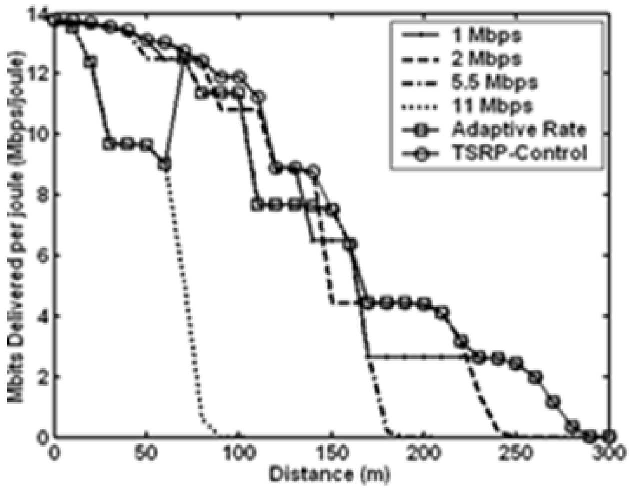

Fig.13 Total data delivered per joule comparisons at 100 Kbps traffic load in case of two sources two flows.

6 Conclusion

In this paper we have proposed and evaluated the performance of a new adaptive rate-power control MAC protocol for wireless ad hoc networks. The design of this new protocol takes the traffic load and the packets waiting in its queue into consideration. The protocol senses the outgoing traffic flow and selects efficient rate-power combination that can maximize the network throughput and save more power. This protocol called Traffic Sensing adaptive Rate Power (TSRP) control MAC protocol. The initial operation of this new protocol is quite similar to the adaptive rate MAC protocols. But instead of selecting the highest data rate that satisfies the channel condition, it selects the energy efficient rate-power combination that can maximize the network throughput.

We have compared the performance of the IEEE 802.11b based TSRP control scheme with the IEEE 802.11b with its various rates and adaptive rate with power control technique. We investigated its performance under two different scenarios, different traffic loads and various communication distances. Our simulation results showed that the TSRP control scheme achieves more total data delivered per joule while maintaining maximum throughput. This means that the new scheme can achieves a high reduction in the energy consumption. The TSRP control protocol is mainly designed to achieve the same throughput that can obtain by the adaptive rate protocol with minimum power consumption.

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