Improved Power Control MAC Protocol for wireless Ad Hoc Networks

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Abstract: - In this paper, we propose an Improved Power Control MAC (IPCM) protocol which improves the throughput and yields energy saving. This protocol sends all the packets RTS, CTS, DATA and ACK with optimal transmit power, which save the energy, makes spatial reuse of the wireless channels, and achieves the maximum throughput. On the other hand, the power of the data packets is periodically raised to a suitable level (P_{ai}) to avoid the interference but not to the maximum so that it will not create unnecessary contention between nodes. The power level of P_{ai} is based on finding the optimum carrier sensing range that increase the network capacity and reduce the interference effect of the ongoing transmission. Our simulation results show that IPCM protocol scheme can achieve high reduction in energy consumption and also improves the throughput efficiency compared to the other schemes.

Key-Words: - Ad hoc networks, IEEE 802.11, MAC protocol, power control, IPCM,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 [5].

However, in [8,12], authors reveal that the transmission of nodes that exchanged RTS-CTS successfully, may collide with DATA/ACK transmission of other nodes that had not overheard the RTCCTS. Several drawbacks of IEEE 802.11 have been identified in the past several years. IEEE 802.11 uses maximum transmission power P_{max} regardless of the distance between the transmitter and receiver. This gives inefficient use of energy, since a successful communication between a transmitter and receiver pairs with short distance is possible with much lesser power than P_{max} . Most power control schemes for wireless Ad Hoc networks have been proposed to reduce the energy consumption for increasing the life- time of the network.

However, the authors of [7, 11] have mentioned that these schemes may increase energy consumption due to the increase in interference range. Other power control schemes that have been proposed to improve energy efficiency does this at the cost of throughput.

In this paper, we proposed a new power control protocol which simultaneously improves the throughput and yield energy saving. The rest of this paper is organized as follows. Section 2 reviews the related work. Our proposed IPCM protocol is explained in section 3. Section 4 presents simulation and experimental results. Finally, section 5 concludes the work presented in this paper.

2 Related Work

Power control has been studied primarily as a way to improve energy efficiency of MAC protocols for wireless ad hoc networks [17]. In [6, 9, 13, 14] 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. The authors [7] 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 [2, 10, 16, 18]. However, these schemes require additional channel that will increase the complexity of the system.

3 Improved Power Control MAC (IPCM) Protocol

3.1 Proposed Protocol Basics

Proposed IPCM protocol is similar to the PCM scheme [7] except that the source node transmits DATA with the optimum power level. This power level is periodically increased, for just enough time not to P_{max} as in PCM, but to a suitable level (P_{ai}) sufficient to avoid the collisions. The IPCM protocol can be considered as an improved version of PCM protocol. PCM transmit the data with maximum periodic pulse power. This means reserving maximum transmission area for the giving ongoing transmission even the distance between the transmitter and receiver is small. The objective behind using maximum periodic pulse power is to increase the sensing range for informing the neighbour nodes about ongoing transmission in order to reduce the interference and increase energy conservation.

But, increasing the carrier sensing range to maximum range affects the total throughput of the network, since some nodes in the maximum carrier sensing range can also transmit data successfully to its corresponding receiver without affecting the first ongoing transmission.

For example, suppose that there are two transmitters, each willing to send data to its corresponding receiver. In this, each transmission works as an interference node for the other. If the *SIR* (Signal to Interference Ratio) of the first transmission $\geq SIR_{th}$ (Threshold Signal to Interference Ratio) and the *SIR* of the second transmission $\geq SIR_{th}$, the two transmissions can take place at the same time instead of one transmission. Therefore, the overall network throughput will be increase. In our proposed protocol, all packets RTS, CTS, DATA and ACK are transmitted with the optimum power. But, instead of transmitting the data with maximum periodic pulse power, it is transmitted with required pulse power level (P_{ai}). This level is determined by using the observed *SIR* value at the receiver and the computed ratio of the channel capacity to the carrier sensing range. These values are calculated using the optimum power, distance between the sender and receiver, and the calculated interference power (P_i).Using the required pulse power level, firstly, reduces the energy consumption. Since, lesser pulse power will conserve a considerable energy compared to the maximum pulse power as in PCM. Secondly, the required pulse power reduces the reservation area, which results in concurrent transmission at the same time. This improves the throughput of the network.

In [7], the author's shows that the number of the interference nodes reduces in the chain topology with 30 flows using PCM scheme compared to the BASIC scheme. In IPCM protocol, since all the packets are transmitted using the optimum powers and with the help of the interference analysis, we find that optimum carrier sensing range lesser than the maximum is sufficient to avoid the collisions. This means other concurrent transmissions can take place at the same time. For example, in a chain topology of 31 nodes with 30 flows and the distance between adjacent node pairs is 40 m, the carrier sensing range of 134 m is enough to avoid interference compared to 550 m as in the case of PCM. Let R_{top} be the transmission range of the RTS using the optimum power. Since RTS and CTS use the same optimum power, the transmission range of CTS will be R_{top} also. Suppose that the periodic pulse power is also the same (i.e optimum), the carrier sensing range is at least twice times the transmission range [1]. If the receiver is just at the edge of the transmission range of the transmitter, carrier sensing range (R_{cs}) will cover both transmission ranges of RTS and CTS as shown in Fig.1. Actually, this case is considered as the worst case. Usually, the periodic pulse power will be greater than the optimum used power. It depends on the distance between the transmitter and the receiver for any optimum power lesser than the maximum power. This means, the ongoing transmission will be completely covered by the carrier sensing range. Any node in the carrier sensing range, but not in the RTS or CTS range will notice the transmission and therefore will defer its transmission request. According to IEEE 802.11DCF, this node will maintain a NAV

(Network Allocation Vector), which indicates the remaining time of the ongoing transmission session. When the transmitter completes the data transfer, a node in the carrier sensing range goes to a back-off period to sense the medium again. If the transmitter that received the ACK, has more data to transmit, the node in the back-off mode will notice the medium busy and maintains another NAV period.

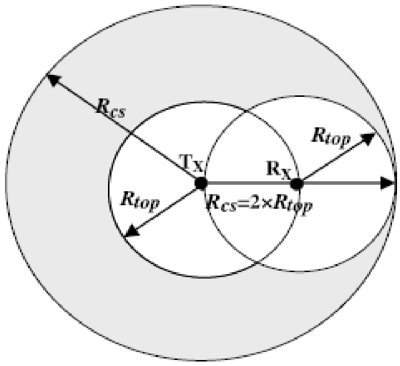

Fig.1 The carrier sensing range will cover both RTS and CTS transmission ranges for any used power.

3.2 Model Description

To accurately model the attenuation of radio waves between antennas close to the ground, radio engineers typically use a model that attenuates the power of signal as $1/d^2$ at short distances (free space propagation model) and as $1/d^4$ at longer distances (two-ray ground reflection model), where d is the distance between antennas. The crossover point is called the reference distance [3, 15]. Therefore, the signal propagation model used in our work is a combination of the free space propagation model (for distances less than the reference distance) and the two-ray ground reflection model (for distances greater than the reference distance). At near distance, the power received (Pr) is given by

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2 \qquad (1)$$

Where Pt is the transmitted power, G_t and G_r are the antenna gain of the transmitter and the receiver, respectively, λ is the signal wavelength, and d is the distance between the transmitter and the receiver.

On the other hand, the power received (P_r) at far distance is given by

$$P_r = P_t G_t G_r \left(\frac{h_t h_r}{d^2} \right)^2 \qquad (2)$$

Where h_t and h_r are the antenna height of the transmitter and the receiver, respectively. From Eq.(1) and Eq.(2), $d_{crossover}$ can be derived, which is considered as the crossing edge from the near to far distances. This distance is given by

$$d_{crossover} = 4\pi \frac{h_t h_r}{\lambda} \qquad (3)$$

The path loss (P_l,($d_{crossover}$)) at the distance $d_{crossover}$ is considered as the reference value in our model. This value is constant (C) that depends on the antenna gains, the wavelength, the antenna heights and the crossover distance $d_{crossover.}$

$$P_l(d_{crossover}) = \frac{P_r(d_{crossover})}{P_t(d_{crossover})} = G_t G_r \left(\frac{\lambda}{4\pi d_{crossover}} \right)^2$$
$$= G_t G_r \left(\frac{h_t h_r}{d_{crossover}^2} \right)^2 = C \qquad (4)$$

From Eq.(1), Eq.(2) and Eq.(3), the power received (P_r) at any distance can be rewritten in its general form as given below

$$P_r = P_t C \left(\frac{d_{crossover}}{d} \right)^{\alpha} \qquad (5)$$

Where α is the path loss exponent, α=2 in case of free space propagation model and its value is 4 in case of tworay propagation model. Let P_i represents the transmission power of an interfering node at distance d_i from a receiver. Since this interfering node will be at a distance at least equal to the carrier sensing range, it will be considered as a far distance. The receiving power P_{ri} of the signal from the interference node will be calculated as follows:

$$P_{ri} = P_i G_t G_r \left(\frac{h_t h_r}{d_i^2} \right)^2 \qquad (6)$$

Therefore the SIR value is given by

$$SIR = \frac{P_r}{P_{ri}} = \frac{P_t C}{P_i G_t G_r} * \frac{\left({d_{crossover}}/{d} \right)^{\alpha}}{\left[{h_t h_r}/{d_i^2} \right]^2} \qquad (7)$$

3.3 Proposed Protocol Description

The proposed IPCM protocol works in the following steps:

• Transmitter sends an RTS with the optimum transmit power level including the level of that power as shown in algorithm.

• Receiver decodes the RTS, find the power level value, observe the SIR value, attach the SIR value to the CTS packet and transmit CTS using the same optimum power.

• Transmitter extract the *SIR* value and sends the DATA with the optimum power, and periodically increases the power level of the DATA packets to P_{ai} to avoid interference. The P_{ai} value is selected based on the ratio of the channel capacity and the carrier sensing range.

• The receiver sends ACK using the optimum power level.

We use Shannon capacity [4] as the achievable channel rate,

$$\text{Channel Capacity} = W \log 2\,(1+ SIR) \qquad (8)$$

Where W is the channel bandwidth.

Since, we are interested in the maximum aggregate throughput, a busy network is assumed in which each station is always waiting, continuously backing off and it will initiate a transmission whenever it is allowed. The busy network situation always occurs, when nodes willing to transmit data but they occur in the transmission range or the carrier sensing range of some other ongoing transmission.

This aggregate throughput is directly proportional to the channel capacity and the total number of the concurrent transmission that can take place. By increasing the carrier sensing, the *SIR* value is increased. Therefore, channel capacity is increased. But this increase in channel rate enhances the reservation area, thus reduces the number of the concurrent transmissions, and results in reduction of network throughput. Our protocol tries to find the suitable carrier sensing range that makes a balance between the channel rate and the reservation area with an acceptable *SIR* value.

3.4 Proposed Protocol Algorithm

Before we introduce the IPCM protocol algorithm, it is important to explain the simple diagram shown in Fig. 2. Let $P_t[L]$ be a set of the power levels used for the transmission, where L is an integer varies from 1 to MAX. $P_t[MAX]$ is the maximum power level and MAX is the number of the power levels in the set. Let $R_{cs}[L]$ be the set of carrier sensing ranges corresponding to the set of power levels set $P_t[L]$.

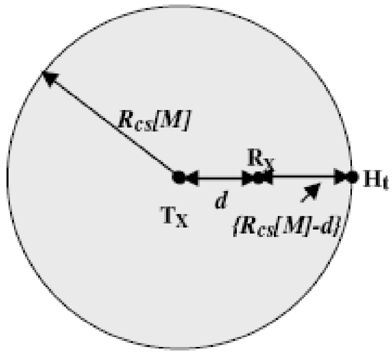

Fig.2 The carrier sensing range and the nearest hidden terminal that can interface with the receiver.

Let d be the distance between the transmitter (T_x) and receiver (R_x). Suppose the transmitter reserve a carrier sensing area $R_{cs}[M]$, where M is an integer variable between 1 and MAX. The nearest hidden terminal (H_t) that can be considered as an interference node will be at a distance $\{R_{cs}[M]-d\}$ as shown in Fig.2. This carrier sensing range will cover the receiver and $\{R_{cs}[M]-d\} \geq d$ as we mentioned in section 3.1.

A. Transmitter :

Step 1: Let $L=1$, $Max\_Capacity\_Area\_Ratio=0$, $P_{ai}=P_t[MAX]$.

Step 2: Check the node address and its stored S value.

Step 3: If S is available,
let $L=S$.

Step 4: Send RTS with T_x. Power $P_t[L]$ and include the L value in the RTS.

Step 5: If RTS timeout and CTS not received,
increase L goto 4.

Step 6: Receive CTS, observe its received power $(P_{r.})$, extract the *SIR* value from CTS packet, store node address and
let $S=L$.

Step 7: If $P_t[L] <= P_{t, cross}$
α =2
Else
α =4

Step 8: Using the values of P_r, α and $P_t= P_t[L]$, determine d according to Equation (5).

Step 9: Using the extracted SIR, P_r, α, $P_t= P_t[L]$, d with $d_i=\{R_{cs}[L]-d\}$, determine the interference power P_i according to Equation (7).

Step 10: Let $M=L$.

Step 11: If $M>L$
Determine *SIR* value according to Equation (7)
with $d_i=\{R_{cs}[M]-d\}$

Step 12: Determine the Capacity _Area _Ratio according to the following Equation :

$$Capacity\_Area\_Ratio = \frac{W \log_2(1+SIR)}{2\pi * \left(R_{CS}[M]\right)^2}$$

Step 13:If
Capacity_Area_Ratio>MAX_Capacity_Area_Ratio
MAX_Capacity_Area_Ratio =
Capacity_Area_Ratio
and $P_{ai} = P_t[M]$.
Step 14: If $P_t[M] < P_t[MAX]$
Increase M and goto 11.
Step 15: End.

B. Receiver :
Step 1: Receive RTS.
Step 2: Observe its *SIR* value, extract and store the *L* value.
Step 3: Insert the *SIR* value in the CTS packet.
Step 4: Transmit CTS using the power level $P_t[L]$.
Step 5: End.

Fig .3 IPCM protocol algorithm.

4 Simulation and Results

4.1 Simulation Model

In this section, we evaluate our IPCM protocol through extensive simulations. We simulated IEEE 802.11, BASIC, PCM and our proposed protocol IPCM using Glomosim-2.03 [19].The parameters values selected for simulations are given in table. 1.

Channel carrier frequency	2.4 GHz.
Antenna height	1 m
Antenna gain	1
Bandwidth	2 Mbps
CBR traffic rate	1 Mbps

Table 1 parameters values used

We assumed that the characteristics of all the nodes in the network and the propagation properties are same. The signal propagation model used in our work is a combination of the free space propagation model (for near distances) and the two-ray ground reflection model (for far distances). We performed some simulations using different packet size or traffic rate. Table.2 shows the transmit power levels and their roughly corresponding transmission ranges are considered in simulation.

Transmit Power (mW)	Corresponding transmission Range(m)
1	40
2	60
3.45	80
4.8	90
7.25	100
10.6	110
15	120
36.6	150
75.8	180
281.8	250

Table 2 Transmit power levels used and its corresponding transmission ranges

To compare our protocol with the results presented in [7], we simulated a chain topology, composed of 31 nodes, 30 flows with equal spacing as used there. We also considered random topologies with 100, 80, 60, 40, 20 stationary nodes distributed over 1000 X 1000 m2 area typically too many MAC protocol evaluations [7,10]. Single-hop traffic pairs are randomly selected with the random distance from 0 to 250 m. Each simulation runs for 20 seconds. All simulation results are an average of 10 simulation runs.

The following performance metrics used to evaluate the MAC protocols.

• Aggregate throughput overall flows in the network.

• Data delivered per Joule (Mbits delivered per joule).This is calculated as the total data delivered by all the flows divided by the total amount of transmitting and receiving energy consumption over all flows. We considered the energy consumption of all the packets RTS, CTS, DTA and ACK. In our work, we have taken into account the transmitting as well as receiving energy, where as in [7] only transmitting energy is considered.

• Effective throughput and effective data delivered per joule metrics are used to evaluate the chain topology. In this two metrics, we considered only the data delivered to the last node, which is the actual destination.

4.2 Simulation Results for the Chain Topology

Fig. 4 shows the aggregate throughput obtained from the simulation for the chain topology with 31 nodes and 30 flows. The distance between two adjacent nodes varies and each node generates traffic at the rate of 1 Mbps. The figure shows the comparison of the throughput of IEEE 802.11, BASIC, PCM and our proposed scheme IPCM. It is clearly shown that, IPCM achieves a higher aggregate throughput compared to all other schemes. This is because, IPCM uses a smaller carrier sensing range compared to IEEE 802.11 and PCM schemes, since a larger number of nodes can transmit concurrently. Also this carrier sensing range is larger than the carrier sensing range of the BASIC scheme, and it is sufficient to reduce the hidden terminal problem.

IEEE 802.11 and PCM schemes achieve comparable aggregate throughput as they reserve similar carrier sensing ranges, but the BASIC scheme performs poorly. Excluding IPCM scheme, the aggregate throughput of all the others schemes match the results obtained in [7]. As the distance between the adjacent nodes increases, the aggregate throughput of all schemes increases. The reason is a large number of nodes can transmit simultaneously as the distance increases.

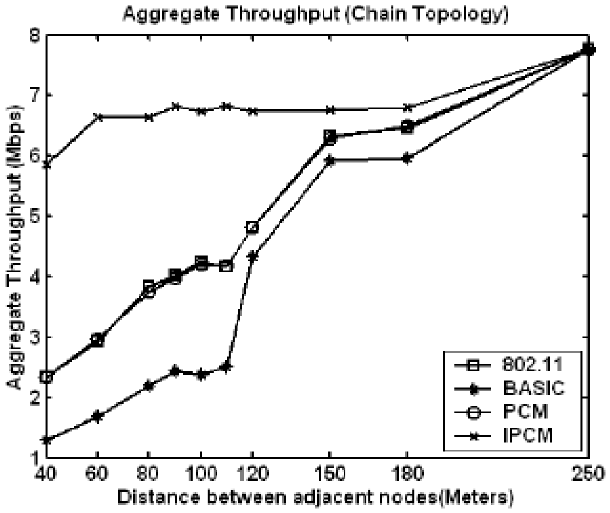

Fig.4 Chain topology: Aggregate throughput, at 1Mbps traffic rate.

Fig. 5 shows the total data delivered per joule (Mbits/Joule) for the different schemes. PCM scheme consumes lesser energy compared to IEEE 802.11 and BASIC schemes. Since it uses lower transmission power for the DATA and ACK packets compared to IEEE 802.11 scheme and has less hidden terminal problem compared to BASIC scheme. As the distance between the adjacent nodes is small (<120 m), the BASIC scheme performs worse than the IEEE 802.11 scheme due to extra energy consumption results from the collisions and retransmissions.

At higher distances (≥120 m), the BASIC scheme shows improvement in the total data delivered per joule compared to IEEE 802.11 scheme. This is because at the 120 m and 150 m, the aggregate throughput of the BASIC scheme jumps due to reduction in number of collisions.

The performance of the IPCM scheme is much better than all the other schemes, since it uses lower transmission power for all the packets, and lower periodic pulse power. On the other hand, reducing the periodic pulse in IPCM scheme is enough to eliminate the hidden node problem. But this reduction in periodic pulse power also reduces the number of deferring nodes, and thus, more data can be delivered per joule.

When the adjacent nodes are 250 m apart, the aggregate throughput and the total data delivered per joule for all the schemes are same. Since all the schemes use the maximum power for all the packets.

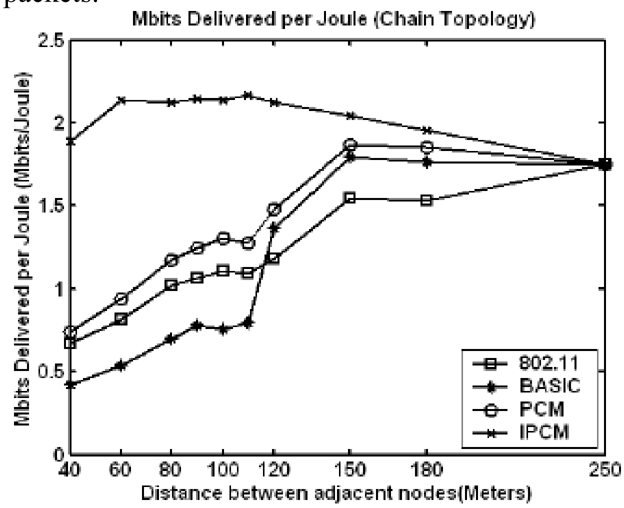

Fig.5 Chain topology: Total data delivered per joule, at 1 Mbps traffic rate.

To evaluate the performance of our scheme for the chain topology more accurately, we have considered only the data delivered to the last node 31. Since it is the final destination and all the other nodes are just route nodes for this destination. This data is known as effective data.

As shown in Fig. 6, the effective throughput of the IPCM is much higher compared to all the other schemes at all distances. The effective throughputs of the IEEE 802.11 and PCM schemes are comparable and are higher than BASIC scheme.

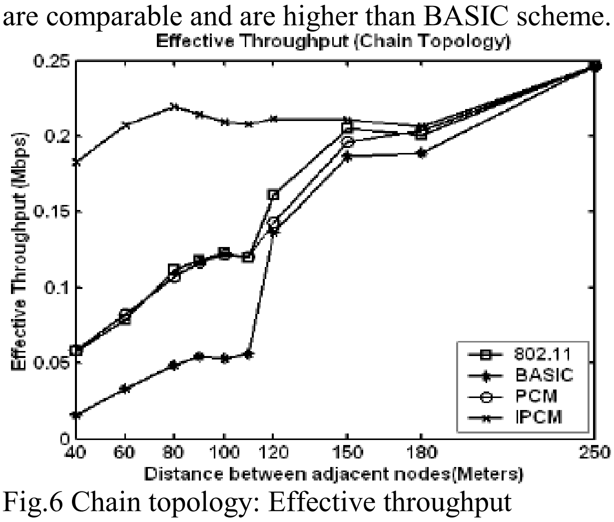

Fig.6 Chain topology: Effective throughput

The IPCM scheme delivers much more data per joule compared to all the other schemes as shown in Fig. 7. This means that the IPCM protocol is effectively better than the others.

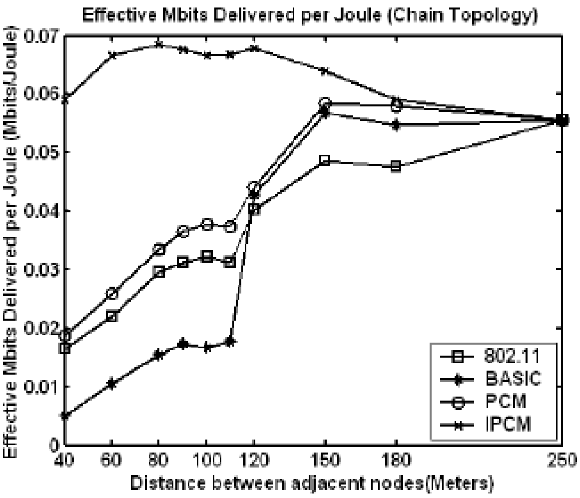

Fig.7 Chain topology: Effective data delivered per joule.

We also simulate the chain topology using 2 Mbps traffic rate instead of 1 Mbps. Each flow generates traffic at the rate of 2 Mbps. Fig. 8 shows the aggregate throughput for the four schemes with the traffic rate of 2 Mbps. At the distances (<120 m), the aggregate throughputs of IEEE 802.11 and PCM schemes are better than BASIC scheme. But at the distances ((≥120 m), the aggregate throughput of the BASIC scheme is to some instant comparable to the PCM scheme and IEEE 802.11 scheme. The aggregate throughput of the IPCM scheme is higher than all the other schemes at all the distances.

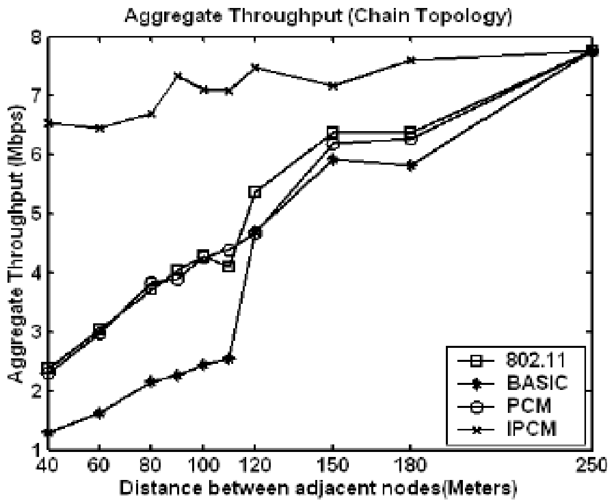

Fig.8 Chain topology: Total data delivered per joule, at 2 Mbps traffic rate.

Fig. 9 shows that, IPCM scheme has the highest data delivered per joule. The PCM scheme performs better than IEEE 802.11 and BASIC schemes at the distances (<120 m), where as the BASIC scheme is the worst. As the distances increases ((≥120 m), the amount of the data delivered by the PCM and BASIC schemes are comparable and better than IEEE 802.11 scheme.

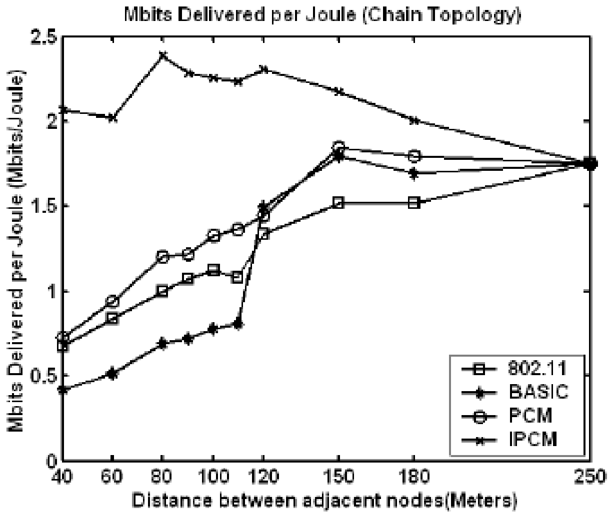

Fig.9 Chain topology: Total data delivered per joule, at 2 Mbps traffic rate.

4.3 Simulation Results for the Random Topology

We consider 5 sets of random topologies of 20, 40, 60, 80 and 100 nodes that are randomly placed in the area of 1000X1000 m^2. For the corresponding number of nodes, we have considered 5 sets of traffic pairs of 10, 20, 30, 40 and 50. Since the topology size is fixed, more traffic pairs imply higher traffic density. For each experiment, we have selected traffic pairs such that there are equal numbers of pairs within the destination ranges of 0-40, 40-60, 60-80,80-90, 90-100, 100-110, 110-120, 120-150, 150-180 and 180-250 meters. For example, our experiment with a total of 20 traffic pairs, we selected 2 pairs in each distribution range. All the other settings considered in the simulation of the random topologies as given in section 4.1.

Fig. 10 and Fig. 11 show the performance of four schemes in the random topologies. The IPCM scheme achieves a much better aggregate throughput than the others as shown in Fig. 10. The aggregate throughputs of the IEEE 802.11 and PCM schemes are quite comparable, where as the BASIC scheme performs poorly.

The IPCM scheme achieves a higher data delivered per joule as shown in Fig. 11. We can also observe a decrease in the data delivered per joule for all the schemes as the number of the traffic pairs increases. The reason is that when the number of traffic pairs increases, collisions also increase. This leads to more retransmissions, which reduce the data delivered per joule.

Fig.12 and Fig.13 shows the performance of the random topologies with varying network load. When the network is lightly loaded, the aggregate throughputs of the IEEE 802.11, PCM and IPCM schemes are identical as shown in Fig.12. But the aggregate throughput for the BASIC scheme is relatively low. When the data rate per flow is more than 30 Kbps, the BASIC scheme performs worse. Fig. 13 shows the total data delivered per joule for the random topologies for all the schemes. Even when the aggregate throughput of IEEE 802.11, PCM and IPCM schemes are the same, the total data delivered per joule for IPCM scheme is slightly better than the others. The PCM scheme is slightly better than IEEE 802.11 scheme and the BASIC scheme is the worst.

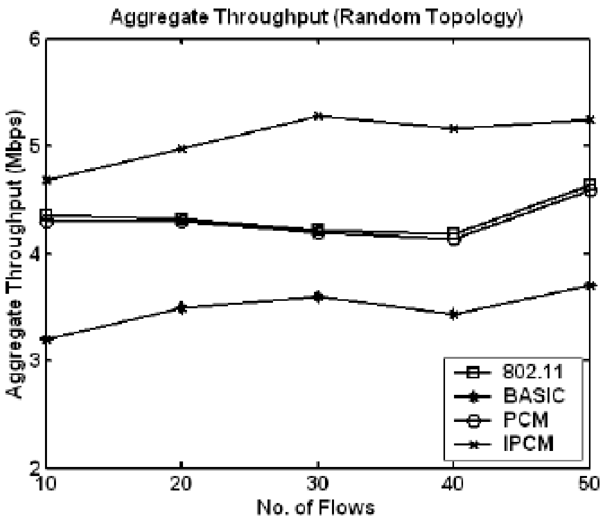

Fig.10 Random topology: Aggregate throughput

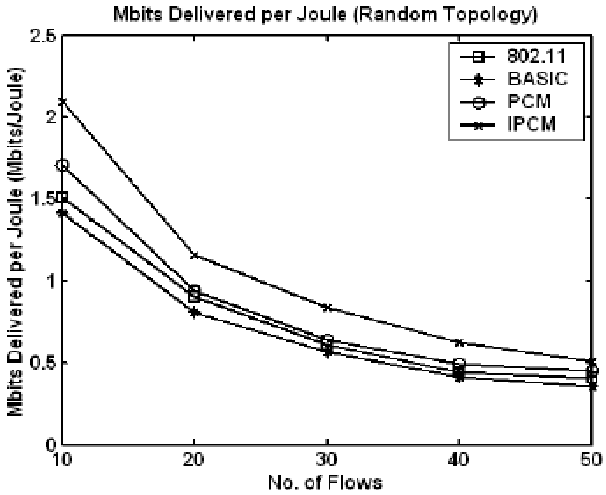

Fig.11 Random topology: Total data delivered per joule

It should be noted that with the light load, the data per joule for all the schemes increase as the number of the traffic pairs increase as shown in Fig.13 compared to heavy loaded network as shown in Fig.11.

Fig. 14 and Fig. 15 show the simulation result for random topologies with varying data packet sizes of 64, 128, 256, 512 and 1024 bytes at a traffic rate of 50 Kbps. The results of these figures represent an interesting evaluation of our proposed protocol. Fig. 14 shows the aggregate throughput of the IPCM scheme is better than all the other schemes with the packet sizes 64, 128 and 256 bytes. For the larger packet size (512 and 1024 bytes), the aggregate throughput of the IEEE 802.11, PCM and IPCM schemes are identical. The BASIC scheme performs poorly in all the cases.

It is well known that, the reason behind the bad performance of the BASIC scheme is the hidden terminal problem, collisions and retransmissions. With lightly loaded network (50 Kbps) and small packet size, the IPCM scheme allows more concurrent transmissions to take place that reflect on its aggregate throughput. For large packet size, the IPCM scheme is able to avoid collisions and the retransmissions. This leads to an aggregate throughput identical to IEEE 802.11 and PCM schemes.

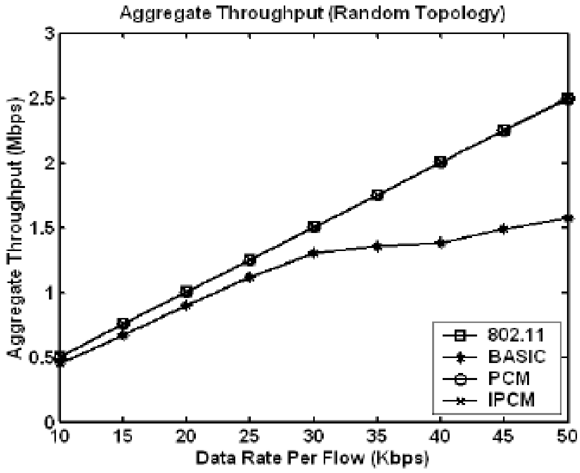

Fig.12 Random topology: Aggregate throughput with different network loads.

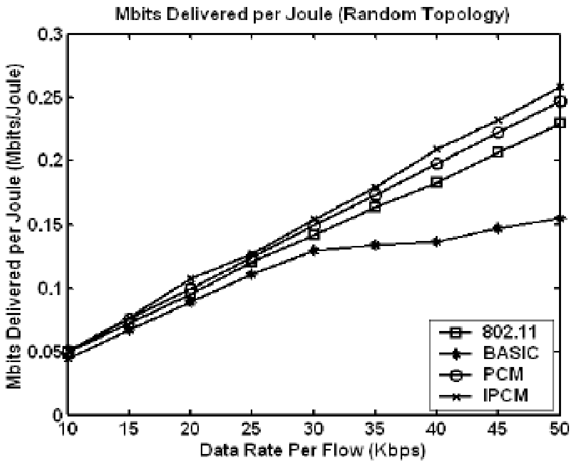

Fig.13 Random topology: Total data delivered per joule with different network loads.

The aggregate throughput of all the schemes is also reflected on their total data delivered per joule as shown in Fig. 15. The performance of the IPCM scheme is better than all the other schemes. Even with the same throughput, for IPCM, the total data delivered per joule is marginally better than PCM, since it uses lesser periodic pulse power compared to the PCM scheme. The PCM scheme performs better than IEEE 802.11 scheme, and the BASIC scheme performs the worst.

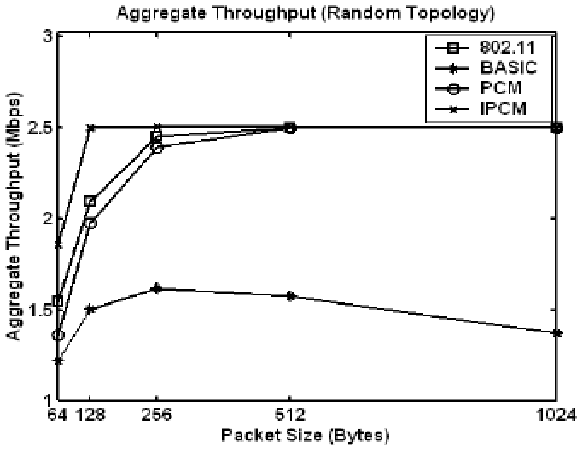

Fig.14 random topology: Aggregate throughput with different packet sizes at a 50 Kbps data rate per flow.

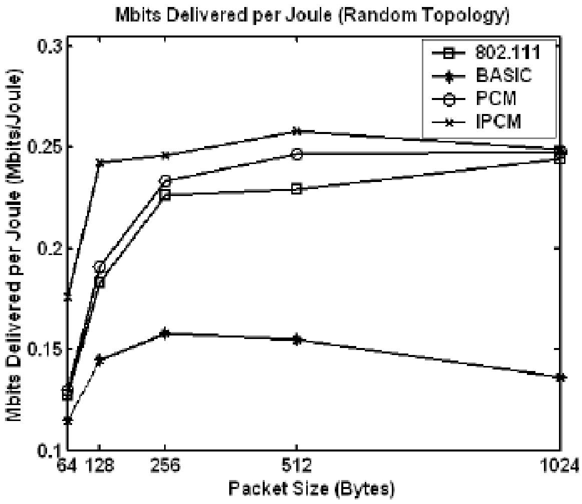

Fig.15 Random topology: Total data delivered per joule with different packet sizes at a 50 kbps data rate per flow.

5 Conclusions

In this paper we have proposed and evaluated the performance of a new power control protocol for wireless ad hoc networks called Improved Power Control MAC (IPCM) protocol. This protocol transmits all the packets

with the optimum transmission power and periodically increases the power of the DATA packets to a suitable level to eliminate the collisions. The periodic pulse power is found based on maximizing the channel capacity, reducing the carrier sensing range and considering the Signal to Interference Ratio (SIR). This reduces the number of unnecessary back-off nodes and allows successful concurrent but interference-limited transmissions to take place in the neighborhood of a receiver. We have compared the performance of the IPCM scheme with the IEEE 802.11, BASIC and PCM power control schemes. We investigated its performance under different network topologies, different data rates and different packet sizes. Our simulation results showed that the IPCM scheme achieved more total data delivered per joule. This means that the IPCM scheme can achieves a high reduction in the energy consumption. On the other hand, the simulation

results also indicate that the IPCM scheme highly improves the network throughput compared to all other schemes. The IPCM protocol is mainly designed to avoid the interference, save energy and improve the throughput.

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