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A Power Conservative Cross Layer Design for Mobile Ad-hoc Networks

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Abstract: In this study, we proposed a simple cross layer design between Physical (PHY) and Medium Access Control (MAC) layers for power conservation based on transmission power control. The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism of IEEE 802.11 Wireless Local Area Network (WLAN) standard is integrated with the power control algorithm. In this method, the exchange of RTS/CTS control signals is used to piggyback the necessary information to enable the transmitting nodes to discover the required minimum amount of power that is needed to transmit their data packets. We have implemented this simulation using Global Mobile Simulator (GloMoSim) and studied its performance using on-demand routing protocols such as Ad-hoc On-demand Distance Vector (AODV) and Node Transition Probability (NTP) based Routing. AODV is a standardized protocol that uses shortest path metric, whereas NTP based routing is a recently proposed protocol that uses transition probabilities of nodes and chooses the nearest neighbour for next hop. We obtained around 7% power conservation with AODV and 17.5% power conservation with NTP based routing protocol.

Key words: Mobile ad-hoc networks, power conservation, CSMA/CA, cross layer design, AODV, NTP based routing protocol

INTRODUCTION

Ad-hoc wireless network is a collection of mobile nodes that self-configure to form a network without established infrastructure[1]. It is highly attractive since it can be rapidly deployed and reconfigured. The ad-hoc networks have both military and commercial applications. They can support data exchange between laptops, palmtops, personal digital assistants and other information devices. Mobile ad-hoc networks are characterized by multi hop connectivity and frequently changing network topology. There are several on-demand routing protocols have been proposed to facilitate communication in these dynamically changing networks. These on-demand routing protocols create routes only when desired by the source node in order to minimize routing overheads and to conserve resources.

According to AODV protocol, a source node initiate route discovery process by broadcasting a route request packet which is flooded by intermediate nodes until it reaches the destination or intermediate node with fresh enough route to respond with a unicast route reply packet. The intermediate nodes record their route tables the address of the upstream neighbour from which the first copy of the Request/Reply packet is received, in order to establish a reverse/forward route for Reply/Data packet. If a node along the route moves, its upstream neighbour notices the route failure and propagates a route failure notification message to inform the source node to re-initiate route discovery in order to maintain the route[1]. As AODV algorithm prefers long hops and hence uses minimum number of hops to reach the destination in general AODV goes with weak links and leaves little scope for power conservation.

The recently proposed NTP based routing protocol is also an on-demand routing algorithm for Mobile Ad-hoc Networks. It is shown that NTP algorithm produces lesser control overhead when node density, mobility and traffic intensity are high[2]. The basic idea behind NTP based routing is to assess the stability of neighbours by initiating beacons and computing node transition probability based on strength of return beacons. It is found that NTP algorithm mostly chooses the closest neighbour as best next hop neighbour. So, the distance between transmitting and receiving nodes of a hop is very small in general, but the transmitting node uses maximum transmission power, which is actually a power-wasting event. And hence NTP based routing provides a big scope for power conservation.

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Many ad-hoc wireless network nodes are powered by batteries with limited lifetime. Power constraints impact signal processing and transmission of all nodes as well as network lifetime. So, power conservation is a key requirement in the design of ad-hoc network. The current wireless network design is largely based on the layered approach where each layer protocol is designed and operated independently, with interfaces between layers that are static and independent of the individual network constraints and applications. This leads to simplified network design but the inflexibility and sub-optimality of this approach results in poor performance for wireless ad-hoc networks. Cross layer design is a new idea which suggests that information (performance parameters) must be exchanged across all layers in the protocol stack[3]. This allows the protocols to adapt in a global manner to the application requirement and underlying network condition. In an adaptive cross layer protocol stack the physical layer can adapt rate, power and coding to meet the requirements of application, given current channel and network conditions. On the other hand, power conservation requires a cross layer design and power control has a significant impact on protocols above the physical layer. The level of transmitter power defines the local neighbourhood and thus defines the contest in which access, routing and other higher layer protocols operate. Therefore power control will play a key role in the development of efficient cross layer networking protocols.

At the MAC layer, unnecessary collisions should be eliminated since retransmission incurs power consumption. The collisions due to hidden terminals are addressed by a four-way handshake mechanism in 802.11 MAC protocol[4]. But this collision avoidance MAC protocol uses fixed transmission power and has not considered power control mechanism based on the distance between transmitting and receiving nodes. Present study proposes a power conservative cross layer design with in the CSMA/CA framework which is provisioned for ad-hoc networks and does not require the presence of base station to manage transmission power. The proposed modified 802.11 MAC protocol combines the mechanism of power control with RTS/CTS dialogue. The main idea is to use the exchange of RTS/CTS control signals to piggyback the necessary information to determine the required minimum amount of power that is needed to transmit the data packets.

POWER CONSERVATION

Power conservation protocols[5] can be divided into two categories: (I) Transmitting power control mechanism and (ii) Power management algorithms in MAC, network and higher layer implementations. Power control refers to the technique of tuning station's transmission power to the proper range. Power control has to advantages: (I) it can conserve battery energy and (ii) it can reduce interference and thus increases the network capacity.

NTP based routing: The NTP based routing algorithm uses beacons to assess the stability of neighbours and computes reliable routes with longer connectivity between the source-destination pair. The steps involved in preparing the neighbour table and routing the packets are as follows[6]:

- Nodes transmit beacons for 'n' times to their 'N' number of neighbours and record the power levels of return beacons in individual power tables of n x N size. The power levels recorded are rounded to the nearest discrete levels.
- The power levels are processed and based on their distribution pattern, the transition probabilities of neighbours are calculated.
- The transition probabilities are sorted by giving due weightage to the neighbours replying with higher power levels and corresponding index (address) is stored as neighbour table. The first entry in the table denotes the best neighbour.
- A sender checks whether its needed destination is present in its neighbour table. If so, it transmits the data packets. Otherwise it sends a search packet to its best neighbour, which in turn checks for the presence of the destination in its neighbour table. If the destination is found, the search process is terminated and this node is entered as the next hop in the routing table of the sender. Otherwise this node forwards the search packet to its best neighbour (other than the node from which the search packet has come). The search process continues until a route is found to the destination. In this process if a node receives an already processed (duplicate) search packet, it forwards the packet to its next best neighbour and does necessary changes in routing table entries to avoid looping in routing.
- If an established route breaks, the upward node finds a new route through its next best neighbour. If not feasible, all entries in the tables are deleted and new ones are prepared by repeating all the above steps.

It is shown that NTP based routing is a scalable protocol with reduced control overhead. But its throughput performance is not superior than that of AODV, because more delay is experienced with NTP based routing in establishing the routes and forwarding the data as it forwards packets through more number of hops. This leads to excess power consumption, which can be minimized by controlling transmission power with reference to the distance between transmitting and receiving nodes with the help of incorporation of power control mechanism in 802.11 MAC protocol.

IEEE 802.11 Standard: Distributed Co-ordination Function (DCF) of 802.11 WLAN standard that uses CSMA/CA medium access mechanism[7] supports ad-hoc operation. In order to perform collision avoidance, the 802.11 protocol uses a four-way handshake mechanism with a positive acknowledgment scheme as shown in Fig. 1.

A sending node first transmits a short control packet called Request To Send (RTS). The receiving node responds with a response packet called Clear To Send (CTS). The RTS and CTS packets include the duration of intended packet and acknowledgment (ACK) transaction. All the other neighbouring nodes receiving the RTS and/or CTS set their virtual carrier sensing indicator called the Network Allocation Vector(NAV) for the given duration to indicate the busy state of the medium. Now the intended transmitting node sends out its data packet and receives an ACK packet from the corresponding receiving node. This mechanism reduces the probability of collision due to hidden nodes. Because RTS and CTS are short frames the mechanism helps to recognize collision quickly and also reduces the overhead of collisions. If the sender does not receive the ACK, it retransmits until it receives an ACK or discards the packet after certain number of retransmission.

The 802.11 is a reliable MAC protocol but it uses fixed transmission power. When nodes do not perform power control during communication with near by nodes, the transmission power is unnecessarily wasted.

Power controlled medium access: Earlier works on power control have primarily dealt with cellular networks, where separate frequency bands are allocated for uplink and downlink channels and base station provides centralized control[8]. Distributed power control algorithms have also been employed in the sense that individual base stations control the power[9]. Hybrid technique combining handshake, busy tone transmission and power control is investigated by Wu *et al.*[10], but this scheme works well only when centralized controller can be heard by all the users throughout the network. A power control strategy for a multiple access that trades off delay constraints is proposed which optimizes the transmission power relative to both channel condition and delay constraints via dynamic programming[11]. Recently research works focus on power conservation protocols for ad-hoc networks where all nodes share a single channel and there is no centralized control or access.

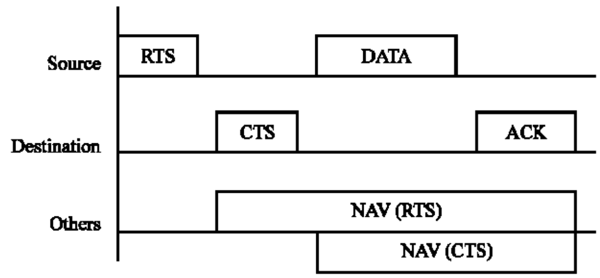

Fig. 1: Four-way handshake mechanism

POWER CONSERVATIVE CROSS LAYER DESIGN

To increase the number of simultaneous transmissions in a shared channel wireless network, a pair of communication nodes must only use the minimum transmission power. In other words, it must only acquire the minimum area (range) that is needed for it to successfully complete data transmission. But as per 802.11 protocol the control and data packets must be transmitted with a fixed maximum power, because RTS must reach every exposed node and CTS must reach every hidden node to avoid collision. This means that an RTS- CTS exchange must acquire the channel over the maximum range over which any hidden or exposed station can cause collisions. Because control packets will need to be transmitted at the same fixed (max) power and adjusting transmit power for data packet alone has no impact on network capacity. An approach to use a separate busy tone channel to allow nodes to advertise their tolerance to interference by manipulating the transmit power of control signal to achieve more spatial reuse of the shared channel is discussed by Monks *et al.*[12]. But we focus on power control as a mechanism for increasing battery life rather than as a mechanism increasing channel efficiency in order to keep the cross layer design for interaction between physical layer and MAC layer as simple as possible. Hence we proposed minor modification in the MAC protocol to do transmit power control for data packets alone.

Cross layer design: Layered structure designed for wireline networks is inflexible as various layers can only communicate in a strict manner. Also the layers are designed to operate under worst conditions, rather than adapting to changing conditions. This leads to inefficient

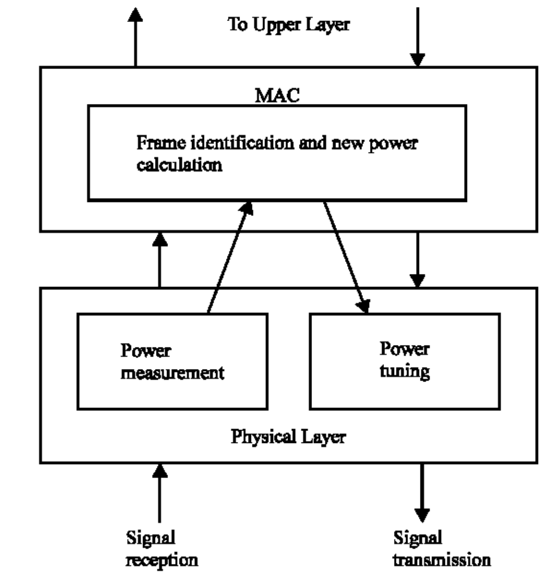

Fig. 2: Cross layer interaction

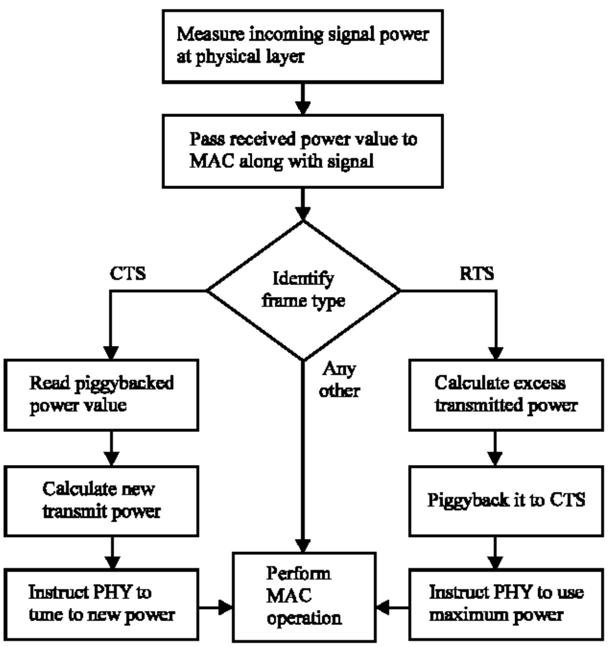

Fig. 3: Flow diagram for power tuning

use of energy. Many techniques have been developed to support efficient packet transmission over wireline networks. Unfortunately they are not applicable to wireless networks due to adverse channel condition and limited battery life of the mobile devices. Due to dramatic difference between wireline and wireless communications, the technical challenges of wireless networks, the various layers must be considered together, which leads to the cross layer design methodology that blurs the lines between layers. The cross layer design emphasizes interaction among different network layers to integrate underlying channel and network characteristics and hence, promises to improve the overall performance. A simple way to perform cross layer interaction between PHY and MAC layers of a node for tuning transmit power level for data packets alone is presented in Fig. 2 and the steps involved are presented in the flow diagram (Fig. 3).

When a sending node broadcasting RTS packet, it piggybacks its transmission power. On receiving the RTS packet, the intended receiving node measures the signal power and calculates the excess power transmitted using its signal to noise ratio threshold and the received signal power. Then while responding with the CTS packet, it piggybacks the excess power value. That helps the sender on receiving the CTS packet to tune its transmit power for data packet transmission to the required reduced level. The transmission power for other type of packets is set to the maximum level. The reduced power transmission of data packets will certainly save power which is a critical resource for battery operated mobile devices.

Power control algorithm: The steps involved in the proposed algorithm to perform transmit power control for data packets are listed below.

- Power level P_R of received RTS control signal is measured
- Excess received power P_{ER} is calculated as,

$$P_{ER} = P_R - P_{min} \quad (1)$$

where, P_{min}, the minimum power needed to capture any signal is given by,

$$P_{min} = SNR_{th} * P_{noise} \quad (2)$$

where, SNR_{th} is the receiver SNR threshold and P_{noise} is the accumulated interference/ noise power.

- Excess transmitted power, P_{ET}, can be calculated from the general relationship between the received and transmitted powers given below:

$$P_R = P_T \ (\lambda / 4\pi d)^n \ G_T G_R \quad (3)$$

where, λ is the wavelength of the carrier, d is the distance between transmitter and receiver, n is the path loss co-efficient and G_T and G_R are the transmitting and receiving antenna gains. Normally λ, G_T and G_R are constants. The path loss co-efficient 'n' may vary between 2 and 6, which depends the physical environment. As the data packet transmission duration is very short, 'n' and 'd' can also be considered as constants. Even if, the above parameters are unknown, the excess power transmitted can be computed from the following relationship: $P_{ET}/P_{ER} = P_T/P_R$:

$$\text{Therefore, } P_{ET} = P_{ER} * (P_T/P_R) \tag{4}$$

where, P_T is the transmitted power value piggybacked in the RTS packet, P_R is the measured power value of received RTS packet and P_{ER} is the excess received power value calculated using Eq. 1.

- The new power (reduced) for data packet transmission is calculated by the sender when it receives the CTS packet piggybacked with the excess transmitted power using the following equation.

$$P_{New} = P_T - P_{ET} \tag{5}$$

As the new power calculated is highly influenced by the distance between the sending and receiving nodes, the performance of this transmit power control algorithm is studied by varying the speed of nodes and the results are presented in the next section.

SIMULATION ENVIRONMENT AND RESULTS

The GloMoSim library, a scalable simulation environment for wireless network systems using the parallel discrete event simulation capability provided by PARSEC is used to model multi-hop ad-hoc network[13]. In our simulation 36 numbers of nodes are initially placed in a grid pattern over a terrain range of 500m x 500m. The random way point mobility model is used. In this model each node selects a random destination and moves at a random speed uniformly between 0 and max-speed. Upon reaching the destination the node remains stationary for a fixed pause-time and repeats the cycle by selecting another destination. In the simulation, the pause-time used is 600 sec and the maximum speed is varied from 0 to 35 m sec^{-1}. Four constant bit rate traffics with 4200 packets each are used in the experiments. The accumulated noise type radio channel is used. The source and destination node pairs are assigned randomly. The size of each data packet is 512 bytes. Other important simulation parameters are listed in Table 1. Each experiment is done for multiple simulation runs with different seed values and collected data is averaged over those runs.

To analyze the performance of our transmit power control algorithm experiments are done by choosing AODV and NTP routing protocols. AODV is chosen because it is the standard on demand routing protocol. NTP is chosen because it is recently proposed and claimed as good alternative for AODV with respect to control overhead, scalability and mobility. Total transmit power consumed by all nodes in the network is calculated with and without transmit power control through separate

Table 1: Simulation parameters

Radio frequency	2.4 GHz
Radio bandwidth	2 Mbps
Radio Tx-power	12 dBm
Rx. sensitivity	-91 dBm
Rx. threshold	-81 dBm
Antenna gain	0 dB
MAC protocol	802.11, Modified 802.11
Routing protocol	NTP, AODV
Network protocol	IP
Transport protocol	TCP
Application	CBR
Inter packet interval	1 sec

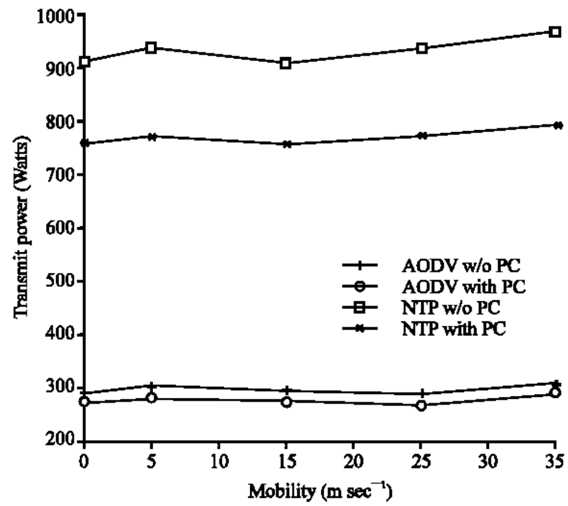

Fig. 4: Transmit power consumption

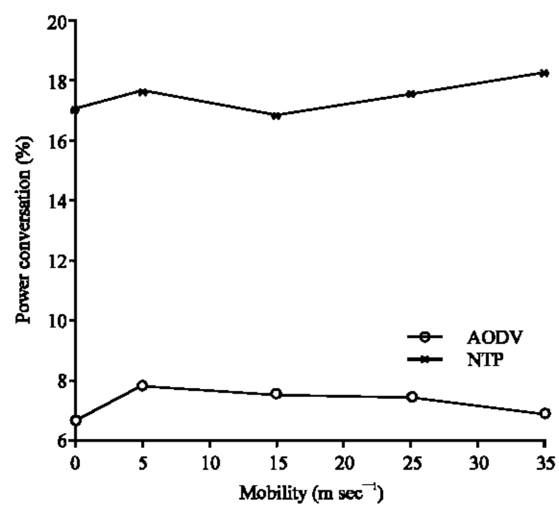

Fig. 5: Power conservation

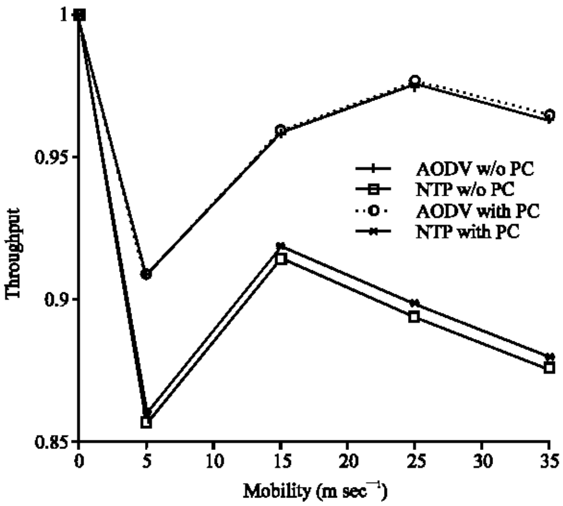

Fig. 6: Throughput performance

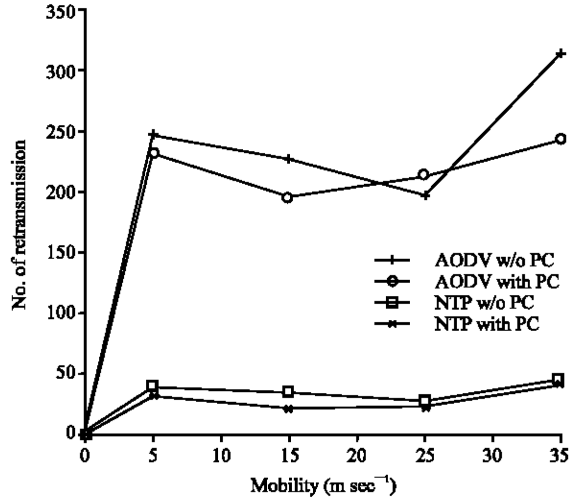

Fig. 8: Retransmission counts

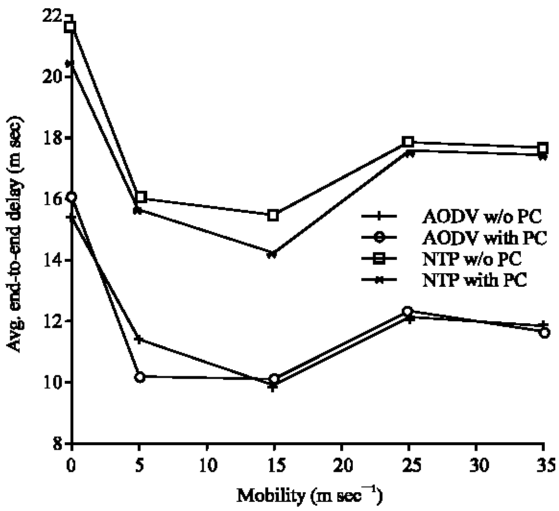

Fig. 7: Delay performance

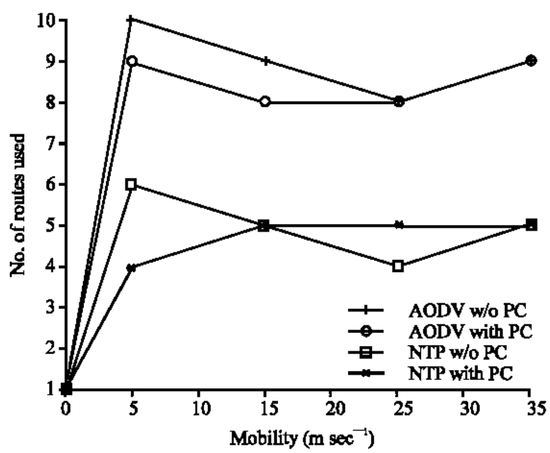

Fig. 9: Route failures

experiments. Note that transmit power is the power spent on transmission alone, i.e not including power spent by nodes to listen, receive and process packets. From Fig. 4 we could understand that NTP consumes excess transmit power as it uses more number of hops. We could also see that the proposed power conservative cross layer design has produced sufficient reduction in transmit power consumption with both AODV and NTP based routing protocols. Fig. 5 shows the percentage of transmit power conserved due to power control for data packets transmission. It is around 7% with AODV protocol and 17.5% with NTP based routing protocol. The additional power conservation is achieved with NTP based protocol because it uses more number of short hops. To study the effect of transmit power control on throughput, delay, retransmissions and route failures, experiments are done. From Fig. 6 and 7, we could infer that the throughput and delay performances are not degraded due to transmit power control and in fact, there are small improvements found. Fig. 8 shows that the number of retransmissions and the overall contention among nodes in sharing the common channel is slightly reduced due to overall interference reduction in the network because of reduced transmit power utilization. But the amount of improvement in the throughput and delay performances achieved is not good enough because except data packets, other control packets are transmitted using maximum transmission power which does not allow sufficient reduction in interference. Because the proposed power control algorithm very much make use the accumulated interference/noise level while calculating the new power for data transmission, the route failures due to mobility are not further fueled by power control as shown in Fig. 9. As the transmit power control works on packet by packet basis in the point to point MAC layer data transmission, the transmission duration involved is very short for small size data packets. This is also a reason for the success of this power control algorithm. Hence, the proposed power control algorithm using cross layer interaction between the PHY and MAC layers conserve sufficient percentage of transmit power both in low and high mobility environments without any compromise on the overall performance of the wireless ad-hoc network.

CONCLUSIONS

The power control algorithm incorporated through the cross layer interaction between PHY and MAC layers provides around 17.5% transmit power conservation with NTP based routing and 7% transmit power conservation with AODV routing in mobile ad-hoc network. As the number of retransmissions due to CTS and ACK timeouts are slightly reduced by transmit power control, the throughput and delay performances are slightly improved. Moreover, route failures are not created by transmit power control. The general drawbacks of power control such as higher error rate and weaker connectivity are suppressed in our work as transmit power control is done in packet by packet manner for data packets of small size. The other aspect of power control is achieving increased network capacity due to reduced interference is possible only when power control is done for control packets also, which will actually reduce the transmission range of nodes and result in network topology changes. The cross layer interaction among PHY-MAC-Network layers towards designing an efficient routing protocol with the sense of power conservation, reliability and network capacity for wireless mobile ad-hoc networks is the scope of our future work.

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