Power Conservation in Wireless Networks: Cross Layered Approach

N.Kasiviswanath[1], Stephen Charles[2], P.Chandra Shekar Reddy[3]

Abstract

This study proposes a simple cross layer design between physical and medium access 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 data packets. This simulation is implemented using Global Mobile Information Systems Simulator (GloMoSim) and its performance studied using on-demand routing protocols such as Dynamic source routing (DSR). Around 7% power conservation is obtained with DSR routing protocol.

Keywords: Mobile ad-hoc networks, power conservation, CSMA/CA, cross layer design, DSR.

1. Introduction

Ad-hoc wireless network is a collection of mobile nodes that self-configured 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 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.

It is well known that power is a precious resource in wireless networks due to limited battery life. This is further aggravated in ad hoc networks since all nodes are mobile terminals of limited weight and size. In addition, power control is of paramount importance to limit multiuser interference and hence maximize the spatial re-use of resources [2]. So, power conservation is a key objective in the design of ad hoc networks. Power control has been studied extensively in the context of channel zed cellular systems [3], [4] and in a general framework [5]. The main objective of this study is to develop a power control-based multiple access algorithm for contention-based wireless ad hoc networks.

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 [6]. But this collision avoidance MAC

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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 within 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.

2. Assumptions

i. A wireless ad hoc network consisting of n nodes. There is no wireline infrastructure to interconnect the nodes, i.e., they can communicate only via the wireless medium.

ii. All nodes share the same frequency band. And time is divided into equal size slots that are grouped into frames. Thus, part of the study is conducted in the context of TDMA.

iii. The nodes have low mobility patterns, that is, they are typical pedestrians. This, implies that the network topology changes slowly and the class of shortest-path routing algorithms is applicable.

iv. The transmit power of any mobile node is upper bounded by a maximum power level. This limited size and weight of the mobile terminal dictate this constraint.

v. The transmit power of any mobile node is lower bounded by a minimum power level. This constraint is essential to avoid partitioning the network into isolated islands.

vi. The control packets are sent at fixed transmission power and only the data packets are sent at reduced transmission power.

vii. The nodes are expected to send their transmission powers used to send control packets.

The received power at any node has to be greater than a minimum power level. This is crucial in order to ensure reliable communication between the transmitter and the receiver. This value helps to determine the power level at which a node has to transmit in order to directly reach a neighboring node.

3. Cross Layer Protocol Design

Future wireless networks are expected to accommodate a wide variety of nodes with different power constraints, bandwidth capabilities, and vastly different QoS requirements as dictated by a large set of applications. One of the main hurdles toward designing protocols is the dynamic and volatile nature of the underlying wireless link, which is characterized by time-varying quality due to fading, shadowing, in addition to multiuser interference. A major limitation in the design of wireless ad hoc networks is that research efforts has been devoted to introducing protocols in a specific layer of the International Standards Organization (ISO) Open Systems Interconnection (OSI) protocol stack (Fig. 1) Moreover, these protocols have been designed independently without considering their interaction or impact on the design choices at other layers of the stack [7]. Recent work has provided overwhelming evidence of the need to couple physical layer design with other aspects of the system design in the link and network layers (Fig. 2).

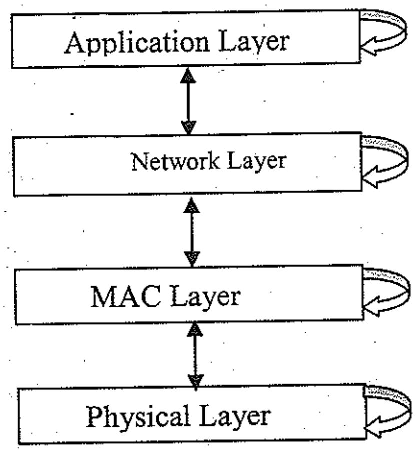

Figure. 1 OSI model

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 neighborhood and thus defines the context 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.

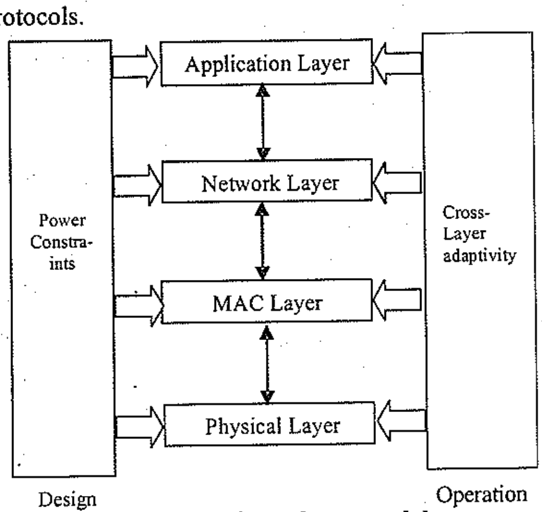

Figure 2 Cross layer model

3.1 Power Conservation

Power control refers to the technique of tuning stations transmission power to the proper range. Power conservation protocols can be divided into two categories: (1) transmitting power control mechanism and (2) power management algorithms in MAC, network and higher layer implementations. Power control has mainly two advantages: (1) it can conserve battery energy and (2) it can reduce interference and thus increases the network capacity.

3.2 3.2 Ieee 802.11 Standard

Distributed co-ordination function (DCF) of 802.11 WLAN standards that uses CSMA/CA medium access mechanism [8] supports ad-hoc network operation. In order to avoid collision avoidance, the 802.11 protocol uses a four way handshake mechanism with a positive acknowledgement scheme.

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 acknowledgement (ACK) transaction. All the other neighboring 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 retransmissions.

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

3.2 Power Conservative Cross Layer Design

To increase the number of simultaneous transmissions in a shared channel wireless network, a pair of communication nodes must use a 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 which allows the nodes to advertise their tolerance to interference by manipulating the transmit power of control signal to achieve more spatial re-use of the shared channel is discussed by monks et al [9]. 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.

A. Cross Layer Design

Layered structure designed for wire line networks is inflexible as various layers can only communicate in a strict manner. Also the layers are designed to operate over worst conditions, rather than adapting to changing conditions. This leads to inefficient use of energy. Many techniques have been developed to support efficient transmission over wire line networks.

Unfortunately they are not applicable to wireless networks due to adverse channel conditions and limited battery life of the mobile devices. Due to dramatic difference between wire line 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. 3 and the steps involved are presented in the flow diagram (Fig. 4).

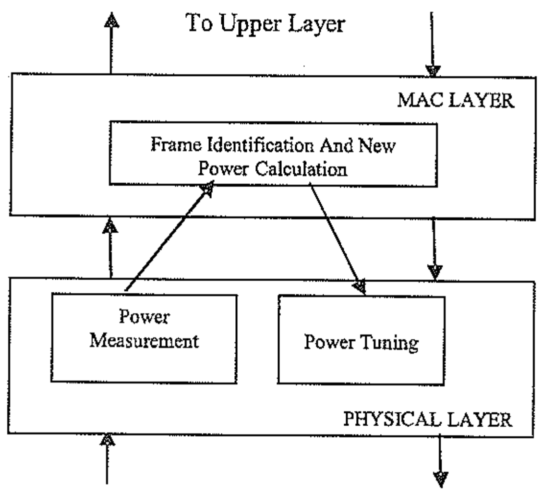

Figure 3 Cross layer interaction

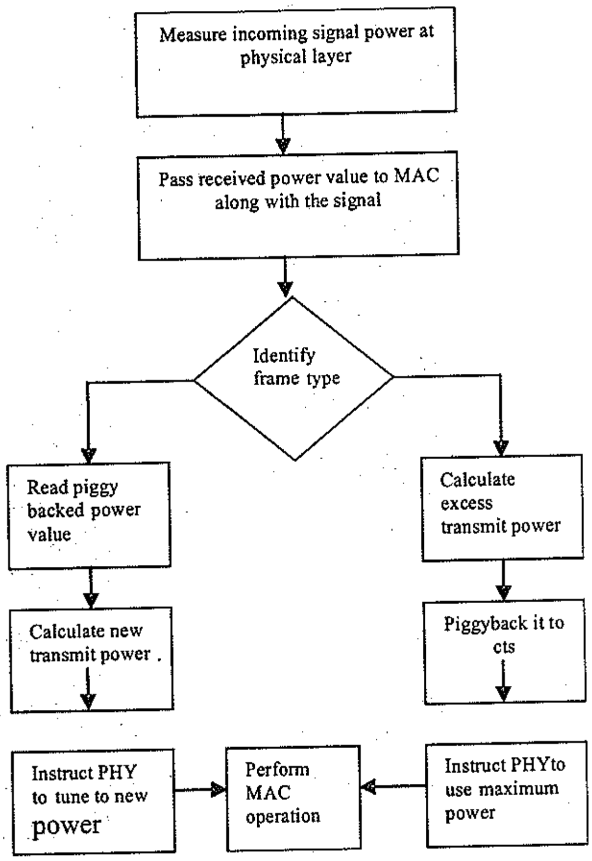

Figure 4 Flow diagram for power tuning

When a sending node is 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 it's transmit power for data packet transmission to the required reduced level. The transmission power for other types 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.

B. 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 Per is calculated as,

$P_{ER} = P_R - (SNR_{th} * P_{noise})$................ (1)

Where, SNR_{th} is the receiver minimum power 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 as given below:

$P_R = P_T * (x/4*pi*d)^n *G_T *G_R$........... (2)

Where, x is the wavelength of the carrier, d is the distance between the transmitter and the receiver, n is the path loss coefficient and G_T and G_R are the transmitting and receiving antenna gains. Normally the x, G_T and G_R are constants. The path loss coefficient 'n' may vary between 2 and 6, which depends on the environment. As the data packet transmission duration 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: $P_{ET}/P_{ER}=P_T/P_R$

Therefore, $P_{ET} = P_{ER} * (P_T/P_R)$................ (3)

Where, P_T is the transmitted power value piggybacked in RTS packet, P_R is the measured power level of the 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 APTS packet piggybacked with the excess transmitted power using the following equation:

$P_{NEW} = P_T - P_{ET}$ .... (4)

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

4. 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 [10]. In this simulation 36 nodes are initially placed randomly over a terrain range of 500m * 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 600sec and the maximum speed is varies from 0 to 35 m/sec. Four constant bit rate traffics with 4200 packets each are used in the experiments. The accumulator 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 table1.Each experiment is done for multiple simulation runs with different speed values and an average of the collected data is computed.

Table 1: Simulation Parameters

Radio frequency	2.4GHz
Radio bandwidth	2Mbps
Radio Tx-power	12dBm
Rx. Sensitivity	-91dBm
Rx. threshold	-81dBm
Antenna gain	0 dB
Routing protocol	DSR
Network protocol	IP
Transport protocol	TCP
Application protocol	CBR

To analyze the performance of the transmit power control algorithm experiments are carried out by choosing DSR protocol. DSR is chosen because it is standard on demand routing protocol.

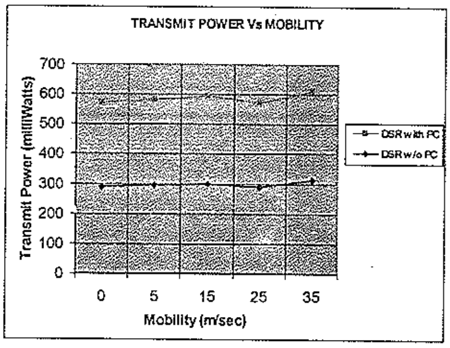

Figure 4 Transmit power consumption

Total transmit power consumed by all nodes in the network is calculated with and without transmit power control through separate 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.

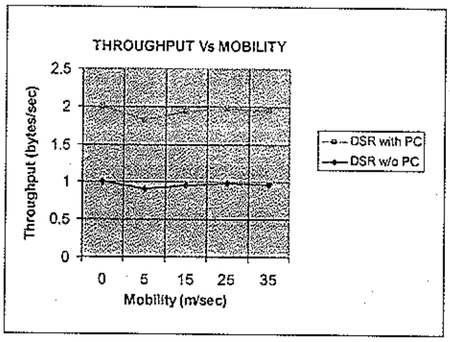

Figure 5 Throughput performance

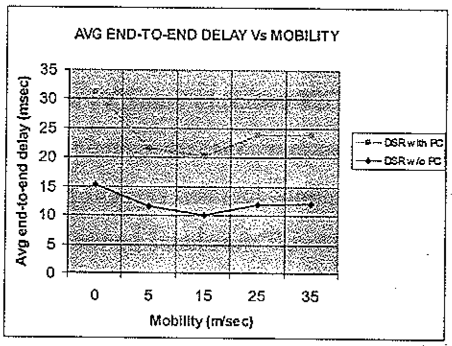

Figure 6 Delay performance

From Fig.4 it is observed that the proposed power conservative cross layer design has produced sufficient reductions in transmit power consumption with DSR routing protocol. To study the effect of transmit power control on throughput and end-to-end experiments are conducted.

From Fig. 5 and 6, It can be infered that the throughput and delay performance are not degraded due to transmit power control and in fact, there are small improvements found. 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 transmissionpower which does not allow sufficient reduction in interference. As the transmit power control works in 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.

5. Conclusion

The power control algorithm incorporated through the cross layer interaction between PHY and MAC layers provides transmit power consumption with DSR routing in mobile ad hoc network. Also, the throughput and delay performances are slightly improved. The general drawbacks of power control such as higher error rate and weaker connectivity are suppressed in this 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 to achieve increased network capacity due to reduced interference which 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 effective 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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