A Routing Algorithm Based on Cross-layer Power Control in Wireless Ad Hoc Networks

Haojun Huang, Guangmin Hu, Fucai Yu
Key Laboratory of Broadband Optical Fiber Transmission and Communication Networks UESTC of China, Ministry of Education
Chengdu, China, 611731
Email: {hhj0704, hgm, fcyu}@uestc.edu.cn

***Abstract*—Applying power control into routing protocols in wireless ad hoc networks has become a hot research issue, because rational use of power control in routing protocols can not only reduce network energy consumption but also improve network throughput, packet delivery ratio and other performance of ad hoc networks. In this paper, we propose an on-demand routing algorithm based on cross-layer power control termed as CPC-AODV (Cross-layer Power Control Ad hoc On-demand Distance Vector). This algorithm builds different routing entries according to the node power levels on demand, and selects the minimum power level routing for data delivery. In addition, CPC-AODV uses different power control policies to transmit data packets, as well as control packets of network layer and MAC layer. Simulation results show that our algorithm can not only reduce the average communication energy consumption, thus prolong the network lifetime, but also improve average end-to-end delay and packet delivery ratio.**

I. Introduction

Wireless ad hoc networks are self-organizing networks without the use of any exiting network infrastructure or centralized administration, which can be useful in a variety of applications including one-off meeting networks, disaster, military applications, and the entertainment industry and so on. Each node in ad hoc networks performs the dual task of being a possible source or destination of some packets while at the same time acting as a router for other packets relay. Traditional routing protocols can not be applied to ad hoc networks directly because ad hoc networks inherently have some special characteristics and unavoidable limitations such as dynamic topologies, bandwidth-constrained, variable-capacity links, and energy-constrained operations compared with traditional networks. Consequently, research on routing protocols in ad hoc networks becomes a fundamental and challenging task [1-3].

The existing popular routing protocols in ad hoc networks such as Dynamic Source Routing (DSR) [1], Destination Sequenced Distance Vector (DSDV) [2] and Ad hoc On-demand Distance Vector (AODV) [3] are all the shortest paths, that is, the minimum hop count routings. Although these algorithms are easy to be implemented, they do not consider the network energy consumption. The minimum hop count routings could not guarantee that the packet reaches the destination node using minimum energy consumption [4-5]. Designing an effective power control strategy to reduce network energy consumption is very important and useful in some application environments such as battlefield, where node battery recharging is usually impossible. The power control in ad hoc networks determines the quality of physical layer link, MAC layer bandwidth and degree of spatial reuse, while at the same time affects the network layer routing, transport layer congestion control and QoS of application layer, etc [4-11].

In recent years, research on routing protocols based on power control in ad hoc networks has received increasing attention. Power aware routing schemes try to find routes which consist of links consuming low energy or prolong the network lifetime. In [4], Tan CW and Bose SK introduced a cost function based on AODV to find a path consisting of minimum number of intermediate forwarding nodes between a source and a destination. Considering that AODV using IEEE 802.11 CSMA/CA MAC protocol could not guarantee to find a minimum energy route, Lee SH et al. in [5] added a wait time to RREQ packets to set up a more energy-efficient path than the shortest hop routing energy consumption, thus reducing the network energy consumption. In [6], Kyungtae Woo et al. improved the route discovery process of DSR where each node decides whether to participate in route discovery process according to its own residual energy, and thus extend the network lifetime. In [7], Narayanaswamy S et al. built and maintained more than one routing tables at different transmission power level. By comparing the entries in different routing tables, each node in network can determine the smallest common power that ensures the maximal numbers of nodes are connected. The authors argued that if each node uses the smallest common power required to maintain the network connectivity, the traffic carrying capacity of the entire network is maximized, the battery life is extended, and the contention at the MAC layer is reduced. Considering that the network communication power may be very large if nodes in uniform in [7], Vikas Kawadia and P. R. Kumar in [8] forwarded a packet at minimum power level to the next node which has a route to the destination node to save energy consumption. In [9,10] Li Bing et al. based on AODV dynamically adjusted the transmission power of nodes using the data link layer information to save the network energy consumption.

However, these studies in [4-10] have a major drawback that only considered network layer energy consumption without considering corresponding MAC layer energy consumption, which can not farthest reduce network energy consumption,

CHINACOM 2010, August 25-27, Beijing, China
Copyright © 2011 ICST 973-963-9799-97-4
DOI 10.4108/chinacom.2010.30

some cross-layer routing protocols based on power control can be better to solve this problem. In [11], Javier Gomez and Andrew T. sent DATA/ACK packets at minimum power level with the goal of reducing the overall transmission power needed to deliver packets in the network, which increasing the relay nodes between the source-destination nodes based on the relationship between transmission power and distance of nodes.

Most of approaches in routing protocols based on power control in ad hoc networks present their own aspects of interest. Although the existing research has made some progress, there is no accurate and efficient description and solution between routing protocols and power control in ad hoc networks. For example, some studies try to reduce the energy consumption [4-11], but just partly or even have not take into account the energy consumption of the other layers [11]. Furthermore, numerous studies [4-5, 9-11] require geographical coordinates given by GPS for the power controlled connection with nearby nodes accurately and the distance between nodes.

To address the abovementioned problems, we propose an on-demand routing algorithm based on cross-layer power control called CPC-AODV. CPC-AODV differs from the above protocols in the following important respects. First, unlike the other protocols, it does not require geographical coordinates of nodes accurately and the distance between nodes to dynamically adjust transmission power. Second, it changes transmission power in a few discrete power levels, at the same time considers energy consumption of network layer and MAC layer. This is an important feature and has a profound effect on energy consumption which could sustain the network mobility favorably. It is an available approach to incorporate routing protocols with power control in ad hoc networks.

The rest of the paper is organized as follows. Section II presents network model and definition for the proposed algorithm. Section III describes algorithm idea, route discovery and maintenance in details, and analyses its characteristics. Section IV presents the simulations and analytical comparisons of our algorithm with AODV and CLUSTERPOW [8]. Finally, conclusion and future works are given in section V.

II. Network Model and Definitions

In this section, we introduce the network model and some essential definitions for description our algorithm in this paper.

A. Network Model

Power control is a very complex issue, Kirousis et al. simplified it into assignment of transmission ranges, short to as RA problem (Range Assignment) [12], and analyzed its computational complexity in details.

Let $N = \{u_1, \cdots, u_n\}$ be a set of n points in the d-dimensional Euclidean space(d=1,2,3), denoting the positions of the network nodes and $r(u_i)$ be the transmission radius of node u_i, the network transmission power $f[r(u_i)]$ can be expressed as:

$$f[r(u_i)] = \sum_{u_i \in N} [r(u_i)]^\alpha \tag{1}$$

Where: $2 \leq \alpha \leq 5$.

RA problem is to minimize $f[r(u_i)]$ while maintaining the network connectivity, that is:

$$f[r(u_i)]_{min} = min \sum_{u_i \in N} [r(u_i)]^\alpha \tag{2}$$

In the one-dimensional case, (2) can be solvable in $o(n^4)$ time, while it is shown to be NP-hard in the case of the two-dimensional [13] and three-dimensional [12] networks. The actual power control problem is more complex than RA problem. For the RA problem, in this paper we try to reduce packets transmission power based on cross-layer to reduce network energy consumption.

Assume that the link is symmetric and the maximum transmission power $P_{t_{max}}$ is known and the same to all nodes which are capable of changing their transmission power below it, and the relation between the power P_t used to transmit packets and the received power P_r can be characterized as:

$$cP_t d^{-\alpha} = P_r \tag{3}$$

Where, c is a constant, and α is a loss constant between 2 and 5 that depends on the wireless medium. For Free Space propagation model and Two-Ray Ground propagation model, α is 2 and 4 respectively.

Suppose that in order to receive a packet, the received power must be at least γ, i.e.,

$$cP_t d^{-\alpha} \geq \gamma \tag{4}$$

From (4) it comes out that:

$$P_t \geq \frac{\gamma}{c} d^\alpha \tag{5}$$

In order to effectively support node mobility and reduce network energy consumption while simplify the network model, we only adjust the node's transmission power in a number of different discrete power levels (see definition 1). The corresponding support hardware are Cisco Aironet 350 and 1200 series Cards [14] and so on, in which 350 series has six power levels (1,5,20,30,50 and 100mw) and 1200 series has three power levels(5,10 and 30mw). Equation (3) and inequation (5) show that: different transmission power level covers nodes of differing distances.

B. Definitions

In order to facilitate expression, we make the following definitions:

Definition 1(Power Level) Power levels(termed as PL)are defined as the discrete grades of node transmission power. The power level between node A and node B is expressed as PL(A,B), the minimum power level between node A and node B is expressed as $\textbf{PL}_{\text{min}}$(A,B), and the power level for a node to send data packets and MAC layer control packets are expressed as PL_{Data} and PL_{MAC} respectively.

Definition 2 (routing selection rules 1) If node S have k routes $\text{RT}^{(\text{S,D})}_{(\text{PL,h})}$ at different power levels to destination node D, then node S select a route at smallest power level to transmit data packets.

Definition 3 (routing selection rules 2) If node S have more than one routes $\mathrm{RT}^{(S,D)}_{(PL,h)}$ at the same power levels to destination node D, the node S select the route with the minimum hop to transmit data packets.

III. CPC-AODV ALGORITHM

In this section, we detailedly introduce the operation of CPC-AODV based on AODV routing protocol. First, we describe algorithm idea, route discovery and maintenance in details, and then analyse its characteristics.

A. Algorithm Idea

CPC-AODV is an on-demand routing protocol, the essential idea is that it:

• building different routing entries at different power levels on demand, and a node selects the route according to routing selection rules 1,2;

• using different power control policies to transmit data packets as well as control packets of network layer and MAC layer .

CPC-AODV consists of two main phases: route discovery and route maintenance. We assume that each node uses the MAC protocol specified by IEEE 802.11 Distributed Coordination Function (DCF) which mainly uses three kinds of MAC layer control packets including RTS (Request To Send), CTS (Clear To Send) and ACK (Acknowledge). Our algorithm uses different power control strategies to transmit date packets, and control packets of network layer and MAC layer, that is, use different PLs to send network layer control packets, and the transmission power to send actual data packets is set according to the routing table entry. Furthermore, the transmission power to send MAC layer control packets is set and varied according to transmission power to send network layer control packets and actual data packets.

B. Route Discovery and Maintenance

1) Route Discovery: CPC-AODV extends AODV by adding a power control metric.

There are four main steps as follows in our algorithm.

Step 1 Determining whether there is a route to the destination node.

When a node S desires to send a message to destination node D, it searches the routing table firstly. If there is a valid route to the destination node D, then executes step 4, otherwise executes step 2.

Step 2 Establish a route to the destination node at different power levels.

If source node S has data packets to send and no route is known to destination node D. it immediately forwards RREQ packets at different $\mathrm{PL} = i(i = 1, 2, \cdots, n)$to establish a route to destination node D, where n is the total amount of power levels. Thus form m routes $\mathbf{RT}^{(S,D)}_{(PL,h)}$ $(m \le n)$at different power levels $\mathrm{PL} = i(i = n - m + 1, \cdots, n)$ from the source node S to destination node D. The transmission power of the same PL route discovery is unified, and it is identical with transmission power level $\mathrm{PL_{MAC}}$ to send the corresponding MAC layer control packets, that is:

$$\mathrm{PL_{MAC}} = \mathrm{PL} \tag{6}$$

The transmission power of route discovery at different PL is not the same. The differences between single power level route discovery of COC-AODV and that of AODV are summarized as follows:

• we add PL to RREQ, RREP, ERROR and HELLO packets respectively. The transmission power level of packets is identical with their corresponding PL, while AODV has not considered power control;

• intermediate nodes forward RREQ packets is determined on (ID, Broadcast ID, PL), while AODV is determined on (ID, Broadcast ID);

• COC-AODV has taken into account power control of MAC lay control packets, while AODV not.

Step 3 Select a route to destination node according to routing selection rules 1,2.

Let $u_{j-1} \xrightarrow{u_j} \mathrm{D}$ denote a selected route by node u_{j-1} to the destination node D according to routing selection rules 1,2. Where: node u_j is the next hop of the node u_{j-1} on the route from the node S to the destination node D, $1 \le j \le k \le d$, k is the total number of routing hops, d is network diameter, u_0 is source node S, and u_k is destination node D.

The nodes select routes to the destination node D according to routing selection rules 1,2, namely:

$\mathrm{S} \xrightarrow{u_1} \mathrm{D}$ $(\mathrm{S} \in \mathrm{RT}^{(S,D)}_{(PL,h)}, u_1 \in \mathrm{RT}^{(S,D)}_{(PL,h)})$,

$u_1 \xrightarrow{u_2} \mathrm{D}$ $(u_1 \in \mathrm{RT}^{(u_1,D)}_{(PL,h)}, u_2 \in \mathrm{RT}^{(u_1,D)}_{(PL,h)})$,

$\cdots\cdots\cdots\cdots\cdots\cdots$,

$u_{k-2} \xrightarrow{u_{k-1}} \mathrm{D}$ $(u_{k-2} \in \mathrm{RT}^{(u_{k-2},D)}_{(PL,h)}, u_{k-1} \in \mathrm{RT}^{(u_{k-2},D)}_{(PL,h)})$,

$u_{k-1} \xrightarrow{\mathrm{D}} \mathrm{D}$ $(u_{k-1} \in \mathrm{RT}^{(u_{k-1},D)}_{(PL,h)}, u_2 \in \mathrm{RT}^{(u_{k-1},D)}_{(PL,h)})$,

Where: $\mathrm{PL_{min}}(\mathrm{S}, u_1) \ge \mathrm{PL_{min}}(u_1, u_2) \ge \cdots\cdots\cdots\cdots\cdots$ $\ge \mathrm{PL_{min}}(u_{k-3}, u_{k-2}) \ge \mathrm{PL_{min}}(u_{k-2}, u_{k-1}) \ge \mathrm{PL_{min}}(u_{k-1}, \mathrm{D})$

Thus form a route of non-increasing and minimum power levels from the source S to the destination node D.

Step 4 Use different power control policies to transmit data packets and MAC layer control packets.

After the route is established, the nodes u_j on the active route start to send data packets according to their respective routing tables, and furthermore the power level $\mathrm{PL_{Data}}$ to send packets is set as the same as PL of its routing table, that is:

$$\mathrm{PL_{Data}}(u_i, u_j) = \mathrm{PL} \tag{7}$$

Where: node u_{j+1} is next hop of node u_j whose Power levels express as PL in its routing table, $0 \le j \le k \le d$, k, d, u_0 and u_k are the same as abovementioned parameters. Moreover, the power level $\mathrm{PL_{MAC}}$ to send corresponding MAC layer control packets is consistent with PL of its routing table, that is:

$$\mathrm{PL_{MAC}}(u_i, u_j) = \mathrm{PL} \tag{8}$$

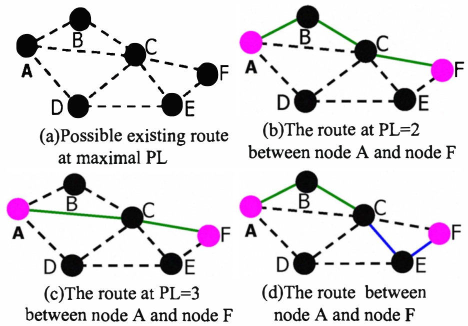

Fig. 1. Sample analysis figure

Node A Routing Table

Dest	Nexthop	Hops	PL
F	B	3	2
F	C	2	3

Node C Routing Table

Dest	Nexthop	Hops	PL
F	B	1	2
F	F	1	3

Node B Routing Table

Dest	Nexthop	Hops	PL
F	C	2	2

Fig. 2. Routing table for all nodes on the route

2) Route Maintenance: The route maintenance of CPC-AODV is only suitable for active routes and is similar to AODV which uses of Hello packets and RERR packets. The differences in process with AODV are that:

- when a node on the route monitors the route is not available, it will notify the source node S to repair the route;
- the transmission power level of the node to send Hello packets and RERR packets is set as the same as PL of the existing effective routing table, at the same time the corresponding MAC layer control packets with the same transmission power level.

C. Sample Analysis

As shown in Fig.1.(a), the minimum PL among nodes are as follows: $\mathbf{PL}_{\min}$(A,B) = 1, $\mathbf{PL}_{\min}$(B,C) = 2, $\mathbf{PL}_{\min}$(C,D) = 3, $\mathbf{PL}_{\min}$(A,D) = 3, $\mathbf{PL}_{\min}$(A,C) = 3, $\mathbf{PL}_{\min}$(C,E) = 1, $\mathbf{PL}_{\min}$(C,F) = 2, $\mathbf{PL}_{\min}$(D,E) = 3, $\mathbf{PL}_{\min}$(E,F) = 3. When the nodes have data to send, we try to establish three routes at PL = 1,2,3 to analyze the route discovery and route maintenance as well as data transmission process.

(1) In Fig.1.(a), node A is source and node F is destination. Node A first searches whether there is route to the node F in its routing table, if it is node A immediately forwards actual data packs, and that the transmission power to send MAC layer control packets is the same as transmission power to send network layer control packets and actual data packets. Otherwise, node A must find a route to node F at PL=1 or 2 or 3 respectively. Because PL = 1 $<$ $\mathbf{PL}_{\min}$(B,C) = 2 and PL = 1 $<$ $\mathbf{PL}_{\min}$(A,D) = 3, node A could not find a route to node F at PL = 1. The routes at PL=2,3 are shown in Fig.1.(b),(c).

According to the routing selection rules 1,2, A$\xrightarrow{B}$F, B$\xrightarrow{C}$F, C$\xrightarrow{F}$F, nodes A, B, C and F choose a route at PL=2 to send

Node A Routing Table

Dest	Nexthop	Hops	PL
F	B	4	2
F	C	2	3

Node C Routing Table

Dest	Nexthop	Hops	PL
F	E	2	1
F	F	1	2

Node B Routing Table

Dest	Nexthop	Hops	PL
F	C	3	2

Node E Routing Table

Dest	Nexthop	Hops	PL
F	C	3	2

Fig. 3. Routing table for all nodes on the route

data packets, the routing tables of nodes A, B and C are shown in Fig.2, whose valid routes are indicated in bold font. Throughout the transmission process in sending data packets and network layer control packets, nodes A, B, C and F use power level PL = 2, furthermore the power level $\mathbf{PL}_{\mathbf{MAC}}$ to send corresponding MAC layer control packets is 2.

If in the route discovery process at PL = 2, node C has learn the route to node F at PL = 1, then the route to send data packets from node A to node F consists of two parts according to the routing selection rules 1,2, as shown in Fig.1.(d). And the routing tables of node A, B, C and E are listed in Fig.3, whose valid routes indicated in bold font.

The entire route from node A to node F is A-B-C-E-F. The nodes A, B and C send data packets and network layer control packets at PL = 2 in the first part, and send corresponding MAC layer control packets at PL = 2. And yet, the nodes C, E and F send data packets as well as network layer control packets at PL = 1 in the last part, and send corresponding MAC layer control packets at PL = 2.

When any one of nodes B, C, E and F monitors the route failed, will notify the source node A to repair it.

(2)When the source nodes find no any route at PL = 1,2,3, then will discard the data packets.

IV. Simulation and Analysis

In this section, we evaluate the performance of CPC-AODV by Simulations. We first describe the simulation environments and performance evaluation metrics, then evaluate the performance with given environments and parameters. Finally, we show the comparisons between our scheme, AODV and CLUSTERPOW [8].

A. Simulation Conditions

In the simulation, we randomly selected source node and destination node to simulate our scheme, AODV and CLUSTERPOW on NS2 (Network Simulator) [15], 100 nodes have initial energy of 200J respectively and randomly distribute in a 1000 $\times$ 1000 square region. Detailed simulation parameters are listed in Table I.

B. Performance Metrics

The following metrics are used to evaluate the different protocols:

- **Packet Delivery Ratio** -This is defined as the ratio of the number of data packets received by the destinations to those sent by the sources.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
NS version	2.34
Number of nodes	100
Terrain range (m^2)	1000×1000
Mobility model	Random way point
Propagation model	Two-ray ground reflection
Number of transmission power levels	5
Ranges corresponding to the PL (m)	90,130,170,210,250
Average node degree	5
Node's mobility speed (m/s)	0-20
Rate of channel (Mbps)	2
Type of traffic	TCP
Number of FTP flows	10-36
Packet size (Bytes)	1400
MAC IEEE	802.11
Simulation time (s)	1000

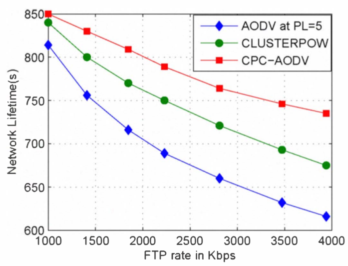

Fig. 4. Network liftime under various loads

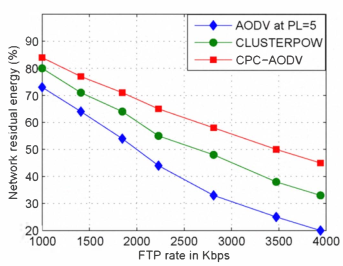

Fig. 5. Network residual energy under various loads

• **Average End-to-End Delay** -This is defined as the delay between the time at which the data packet was originated at the source and the time it reaches the destination. Data packets that get lost en route are not considered. Delays due to route discovery, queuing and retransmissions are included in the delay metric.

• **Network Lifetime** [16,17]-This is defined as the time at which the first node failure occurs, that is, the time at which some node's energy reserve is reduced to zero.

• **Network Residual Energy** [18]-This is defined as the total number of residual battery power of all nodes in network at the time when the communication terminates.

C. Simulation Results

In our simulation scenarios, each result on the curve is the average of 50 simulation runs.

Network Lifetime and Residual Energy Fig.4 and Fig.5 show the network lifetime and the residual energy of three algorithms at different traffic load respectively. When there is only small traffic load, three protocols almost achieve the same the network lifetime and the residual energy. As increase in network average load, all the protocols show significantly degradation in both network lifetime and residual energy. The results in Fig.4 indicate that the network lifetime of CPC-AODV is higher than of CLUSTERPOW and AODV under the same conditions. At the same time, the results in Fig.5 indicate the residual energy of CPC-AODV is more than of CLUSTERPOW and AODV in the same circumstances. This is because AODV does not take measures to network energy consumption, and just uses the default maximum power to transmit data will consume more energy. Some nodes of burdening heavy flow excessively consumed their energy, thus the corresponding residual energy is less and the network lifetime is shortened due to uneven energy consumption. However, CPC-AODV and CLUSTERPOW consume less energy because of using power control scheme. Comparing with CLUSTERPOW, CPC-AODV further reduces network energy by integrating with MAC layer power control. By this way, CPC-AODV can gain 15% average energy savings, thus prolonging the network lifetime. These results show that CPC-AODV can save the network energy consumption and prolong network life.

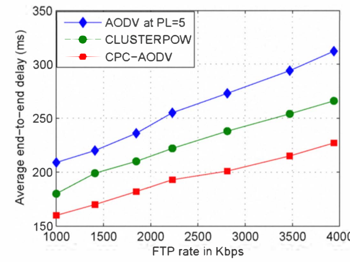

Fig. 6. Average end-to-end delay under various loads

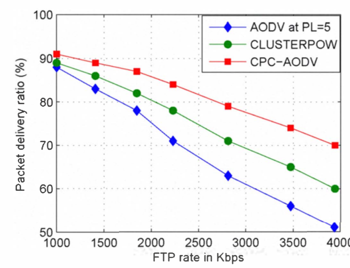

Fig. 7. Packet delivery ratio under various loads

Average End-to-End Delay Fig.6 displays the average end-to-end delay of three algorithms with varying average traffic load. As increase in network average load, the average end-to-end delay of three algorithms will increase. In Fig.6, we can see that CPC-AODV provides an obvious lower network delay compared with AODV and CLUSTERPOW. Under the same conditions, CPC-AODV can reduce the delay from 9ms to 125ms compared with other protocols. This is due to the fact that CPC-AODV uses smaller transmission power to send data packets along the route. In wireless Ad Hoc network, uses smaller transmission power to send data packets can reduce interference and collision which benefit to decrease the retransmission, thus reduce the responding queue and transmission delay. In addition, CPC-AODV can update the routing table in time in mobile environment, thus reduce the queue delay. While CLUSTERPOW updates the routing table relatively slowly and causes a larger data transmission delay. These imply that CPC-AODV can improve the network delay.

Packet Delivery Ratio Fig.7 indicates the packet delivery ratio of three algorithms for the case when the average load is varied from 1000Kbps to 4000Kbps. For all approaches, there is a decrease in packet delivery ratio when the load increases. The results shown in Fig.7 indicate that packet delivery ratio of CPC-AODV is higher than of AODV and CLUSTERPOW under the same conditions. The key contributing to this significant improvement in packet delivery ratio is the fact that CPC-AODV and CLUSTERPOW consider power control, while AODV just uses the default maximum power to transmit data. Since the larger the transmission range is, the serious the local conflicts become, thus maximum power transmissions result in degradation in packet delivery ratio. As the network load increases, the probability of one successful transmission will drastic reduced. CLUSTERPOW and CPC-AODV exploit a power control scheme, and each node tries to send data packet at a lower power level, this can reduce local conflict and improve the packet delivery ratio. By comparison with CLUSTERPOW, CPC-AODV additionally improves the packet delivery ratio because it also considers MAC layer power control. In addition, in mobile environments, CLUSTERPOW updates routing table more slowly, while CPC-AODV updates the routing table in a real time manner, thus CPC-AODV can further improve the packet delivery ratio. From these we can see that CPC-AODV can increase the network packet delivery ratio, and reduce the network packet loss ratio.

V. Conclusion and Future Work

In recent years, research on routing protocol in ad hoc networks based on power control has received more and more attention. In this paper, we propose an on-demand routing algorithm based on cross-layer power control. This algorithm builds different routing entries according to the node power levels on demand, and selects the minimum power level routing for data delivery. In addition, CPC-AODV uses different power control policies to transmit data packets, as well as control packets of network layer and MAC layer. Simulation results show that our algorithm can not only reduce the average communication energy consumption, thus prolong the network lifetime, but also improve packet delivery ratio and average end-to-end delay. It is an available approach to incorporate routing protocols with power control in ad hoc networks.

In the future, our research will be improved based on the abovmentioned results. Power control is therefore a prototypical cross-layer problem affecting all layers of the protocol stack from physical to transport, and affecting several key performance measures, including the trinity of throughput, delay and energy consumption. We will incorporate it with delay, and packet loss ratio and so on to optimize network performance. We hope that in the future studies we could not only provide multiple routings that meet the QoS requirements, but also use the compound routing that meets the QoS requirements when the single routing is not available.

Acknowledgment

This research has been supported by National Science Foundation of China (No. 60872033) and Program for New Century Excellent Talents in University(No. NCET070148)

References

[1] Johnson DJ, Maltz DA, and Hu YC. IETF RFC4728, The dynamic source routing protocol for mobile ad hoc networks (DSR). http://www.ietf.org/rfc/rfc4728.txt, 2007.
[2] C.E. Perkins, and P. Bhagwat, Highly dynamic destination-sequenced distance vector routing (DSDV) for mobile computers. ACM SIGCOMM 94,London,UK, Oct 1994: 234-244.
[3] Perkins CE, and Royer EM. IETF RFC3561, Ad hoc on-demand distance vector routing (AODV). http://www.ietf.org/rfc/rfc3561.txt, 2003.
[4] Tan CW, and Bose SK, Modifying AODV for efficient power-aware routing in MANETs. TENCON 2005, Melbourne, Australia, 2005,1-6.
[5] Lee SH, Choi E, and Cho DH, Timer-Based broadcasting for power-aware routing in power-controlled wireless ad hoc networks. Communications Letters, 2005, 9(3):222-224.
[6] Kyungtae Woo, and Chansu Yu, Non-blocking localized routing algorithm for balanced energy consumption in mobile ad hoc networks. IEEE International Workshop on Modeling,Analysis,and Simulation of Computer and Telecommunication Systems 2001, MASCOTS 2001, Ohio, USA, 2001:117-124.
[7] Narayanaswamy S, Kawadia V, and Sreenivas RS, Power Control in Ad Hoc NetworksTheory,Architecture,Algorithm and Implementation of the COMPOW Protocol. European Wireless Conference 2002, Florence, Italy, 2002:156-162.
[8] Vikas Kawadia, and P. R. Kumar, Principles and protocols for power control in wireless ad hoc networks. IEEE Journal on Selected Areas in Communications, January 2005, 23(1):76-88.
[9] Li Bing, JinZhigang, and Shu Yantai, Cross-layer design of energy-saving AODV routing protocol Transactions of Tianjin University, October 2009,15(5):343-349.
[10] Li Bing, JinZhigang, and Shu Yantai, CEMAODV: Cross-layer design of energy-conserving multicast AODV routing protocol. 3rd International Conference on Communications and Networking in China, ChinaCom 2008, Hangzhou, China, 2008:743-747.
[11] Javier Gomez, and Andrew T. Campbel, PARO: Supporting Dynamic Power Controlled Routing in Wireless Ad Hoc Networks, 2003, 9(5):443-460.
[12] Kirousis LM, Kranakis E, and Krizanc DPelc A, Power consumption in packet radio networks. Theoretical Computer Science, 2000, 243(1-2):289-305.
[13] Clementi A, Penna P, and Silvestri R, On the power assignment problem in radio networks. ACM/Kluwer Mobile Networks and Applications (MONET), 2004, 9(2):125-140.
[14] http://www.cisco.com,2010.
[15] The Network Simulator-ns-2:http://www.isi.edu/nsnam/ns,2010.
[16] Hossain M. Julius, Dewan M. Ali Akber,and Chae Oksam, Maximizing the effective lifetime of mobile ad hoc networks. IEICE Transactions on Communications, 2008, 91(9):2818-2827.
[17] Arvind Sankar, and Zhen Liu, Maximum Lifetime Routing in Wireless Ad-hoc Networks. INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies, Hong Kong, China, March 2004, 2:1089-1097.
[18] R.Asokan, and A.M.Natarajan, Performance evaluation of Energy and Delay Aware Quality of service (Qos) routing Protocols in Mobile Adhoc Networks, International Journal of Business Data Communications and Networking (IJBDCN), 2008, 4(1):52-63