An Ad Hoc Network Load Balancing Energy-Efficient Multipath Routing Protocol

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***Abstract*—Multipath routing protocol establishes multiple transmission paths between source node and destination node, which can not only transmit data in parallel, but also one as main path and others as backup paths. The paper proposed a multipath routing protocol PL_AOMDV with power controlling and load balancing based on AOMDV. In order to implement load balancing and prolong network lifetime, it allocates traffic bandwidth based on node remaining power and load status along the path. Appropriate power is used to transmit data packets. As Ad hoc network is complicated and changeable, the proposed protocol conducts periodical routing maintenance to adjust bandwidth allocation of traffic in time. Simulation experiment results show that the improved PL_AOMDV protocol achieves better performance in the aspects of load balancing and average node lifetime.**

***Index Terms*—multipath routing, Ad hoc, power controlling, load balancing**

I. Introduction

Ad hoc has not wireless infrastructure, but runs in the manner of wireless multi-hop relay. For its high flexibility, mobility, self-organizations as well as access anytime and anywhere, Ad hoc has been widely used in various military and civilian fields of emergency relief, smart communications, environmental monitoring and etc. Ad hoc routing protocol has several classification methods. According to transmission path number between source node and destination node, it can be divided into single-path routing protocol and multi-path routing protocol. Single-path routing protocol means there is only one path between source and sink. Common single-path routing protocols include AODV [1], DSR [2], OLSR [3] and etc. The multi-path routing protocol establishes multiple transmission paths from source to destination, which can not only be sued for data transmission, but also one as main path and others as backup. The paper addressed to former situation. Typical multi-path routing protocols include AOMDV [4], SMR [5], MP-DSR [6], TBP [7] and etc. Among them, AOMDV is a kind of on-demand multi-path routing protocol expanded from AODV, the main idea of which is to build multiple independent paths between source node and destination node to implement parallel transmission of data.

The paper brings out a multi-path routing protocol with power controlling and load balancing PL_AOMDV. Similar as AOMDV, PL_AOMDV protocol should firstly establish multiple independent paths. Secondly, in order to balance node load and power as possible, it should allocate traffic among paths to achieve optimal traffic transmission mode. Finally, PL_AODMV protocol needs to control single hop transmission power to save precious energy. Among them, independence of multi-path is the first problem to be solved, which is also the premise to execute other traffic allocation algorithms or QoS resource reservation algorithms [8]. The paper is organized as follows. Section 2 gives establish method of PL_AOMDV independent path. Section 3 introduces implement strategy of protocol. Section 4 designs routing process of PL_AOMDV in detail. Section 5 performs simulation experiments and result analysis. Section 6 concludes our work.

II. Establishment of PL_AOMDV Independent Paths

The independence of path is very important to multi-path routing. Stronger is independence of path, the network resource utilization can be more adequate and the node congestion probability is lower.

In the multi-path routing, independent paths can be divided into node disjoint paths and link disjoint paths [6]. Node disjoint path means there is not two same nodes in these paths. Link disjoint path refers to there is not same link along two paths. The paths not belong to these above two are un-disjoint. Generally, the number of node disjoint paths is less than that of link disjoint. However, the independence of node disjoint is better than that of link disjoint. Therefore, we try to establish node disjoint path. Various disjoint paths are shown from Fig. 1 to Fig. 3. Where, *S* is source node and *D* as the destination. The path *SACD* and *SEFG* in Fig. 1 are node disjoint paths. The *SABCD* and *SEBFD* in Fig. 2 are link disjoint paths. The SABD and SCBD in Fig. 3 are un-disjoint paths. In the Ad hoc, if un-disjoint multipath are used for data transmission, the nodes or links been commonly used by

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paths can easily become a bottleneck, thus effect of traffic division cannot be achieved. If the common nodes failed, multiple paths will simultaneously breaking.

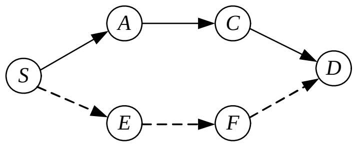

Figure 1. Node disjoint path

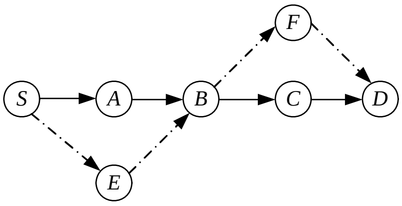

Figure 2. Link disjoint path

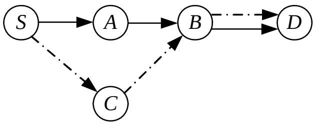

Figure 3. Un-disjoint path

In order to effectively establish multiple node disjoint paths and avoid consuming too much network resources, PL_AOMDV introduce the following theorem [9, 10].

Theorem 1: The path from source node S to destination D along all different adjacent nodes of S is node disjoint.

III. Implementation Strategies

A. PL_AOMDV Flow Distribution Manner

To implement traffic balancing, routing protocol should perform traffic allocation on built multiple paths. The traffic strategy in the paper is as following. In the routing searching, save bandwidth along the path and remaining power to routing reply packet. Source node computes traffic allocation of each path based on these two parameters. Here we will introduce computation method of bandwidth and power as well as traffic allocation strategy below.

The idle time of node in the channel is an important factor to measure effective bandwidth, which is comprehensively determined by traffic of node and its neighbors. Therefore, the effective bandwidth can be computed as follows:

$$B_{available}(i) = B_{\max} \times T_{idle} / T_{interval} \quad (1)$$

Where, $B_{available}(i)$ is available bandwidth of node i; B_{max} is maximum transmission bandwidth of node; $T_{interval}$ is statistics interval; T_{idle} is idle time in channel statistics. We also use linear decreasing model to smoothen changes of bandwidth parameters:

$$B_{real}(i) = (1-\alpha) \times B_{real}(i-1) + \alpha \times B_{available}(i) \quad (2)$$

Where, $B_{real}(i)$ is real effective bandwidth at time i; $B_{real}(i\text{-}1)$ is the real bandwidth at time i-1; $B_{available}(i)$ is effective bandwidth at time i according to (1); α is the adjustable weight in the interval (0,1).

Remaining power of nodes along the path has important effect on path lifelong. The computation of energy bottleneck of path nodes should firstly obtain residual energy of each node, which can be directly obtained by checking battery of nodes.

As numerical level of available bandwidth and energy is magnitude, the paper unifies metric of residual bandwidth and energy before path reliability computation. Available bandwidth and energy were divided into eight different levels. The higher the level, the available resources are more abundant. The level of available bandwidth and energy are computed as follows:

$$L_B = floor(\max\_L \times B_{real}(i) / B_{\max}) \quad (3)$$

$$L_E = floor(\max\_L \times E_{real}(i) / E_{\max}) \quad (4)$$

Where, L_B and L_E are level of node bandwidth and residual energy; $E_{real}(i)$ is residual energy of node at time i; E_{max} is initial node energy; max_L is set 8; floor means floor function been used.

Assume the path from S to D is $(S, S_1, S_2, \cdots, S_i, \cdots, S_j, D)$. The L_B^i and L_E^i are used to represent available and residual energy of node S_i. The bandwidth L_{B_min} and energy bottleneck L_{E_min} can be obtained:

$$L_{B\_\min} = \min(L_B^i, i = 1, 2, \cdots, j) \quad (5)$$

$$L_{E\_\min} = \min(L_E^i, i = 1, 2, \cdots, j) \quad (6)$$

Assume source node S established k paths to destination node, reliability of the i-th path is

$$R_i = (L_{B\_\min} \times L_{E\_\min}) / hopCount \; . \quad (7)$$

Where, *hopCount* is hop number of the path. Allocate traffic on these k paths according to reliability, bandwidth of the i-th path is:

$$B_i = R_i / \sum_{j=1}^{k} Rj \quad (8)$$

It is worth noting disorder of packets of multi-path in TCP flow transmission [8]. We use different method to process different traffic. If some node needs to transmit UDP, it will be divided to be transmitted along different paths, others being backup.

B. PL_AOMDV Transmit Power Control

Ad hoc is a restricted network. Once power energy of node is exhausted, it will directly affect implementation of network functions.

In the case of no power-aware, packet is transmitted with maximum power. If power control is added in MAC and each hop be transited with appropriate power, node energy consumption can be inevitably reduced. Meanwhile, as data packet transmission range being smaller, interference among nodes also inevitable reduces. The messages in MAC can be broadly divided into broadcast massage and unicast message. PL_AOMDV protocol transmits broadcast message with maximum power and unicast message with appropriate power.

For example, if node *A* and *B* are neighbor nodes and *A* needs to transmit to *B*, *A* sends RTS with maximum power P_{max}. After *B* received RTS from *A*, it will send CTS with P_{max}. When node *A* received CTS, it computes data transmission power P_{data_send} according to receiving power $P_{receive}$ and transmitting power P_{max}.

$$P_{data\_send} = \frac{P_{\max}}{P_{receive}} \times P_{threshold} \times c \tag{9}$$

Where, $P_{threshold}$ is the necessary power for correctly receiving; *c* is a constant to prevent too small power to receive data, which is generally set c>1. As P_{data_send} is smaller than P_{max}, it can save data transmitting power by power controlling.

IV. PL_AOMDV Routing Process

A. Routing Discovery

In order to implement node disjoint path and traffic controlling, we should firstly expand format of routing control packet and routing table package of AODV protocol. Firstly, expand format of RREQ. Add next hop node address SN field of source node in RREQ to record first neighbor node address of source node. At the same time, add bandwidth BW field and residual energy LE filed to record bottleneck of forward routing. Secondly, expand routing table. Add source address SA, bandwidth BW, residual energy LE items in routing table. Thirdly, destination node maintain node neighbor list list(sn) to record source node address SA and neighbor node address SN in RREQ. Add fields of BW and LE in RREP to record reverse routing bottleneck.

- RREQ packet processing

When node s needs to communicate but there is not available routing, it initiate routing discovery process to broadcast routing request RREQ to all neighbors. The fields of BW and LE in RREQ packet are initialed values of source node.

After intermediate node i received RREQ packets, it determines whether received repeated packet with same source address, destination address and request ID in source neighbor address field SN in time of path_traversal_time.

After all intermediate nodes received RREQ for first time, compare bandwidth and residual energy of this node with BW and LE in RREQ. If current value is smaller than that in packet, the node may become bottleneck. Update value of current node to RREQ packet. When intermediate node received request packet with same destination address from different source nodes, establish different routing items for different source nodes. Other routing update mechanism and forward mechanism of intermediate node are same as that of AODV.

When destination node received RREQ, it will extract source address SA and neighbor address SN and determine whether SA and SN from packet in list(sn). If so, directly discard the packet. Otherwise, add (SA, SN) into list(sn) and establish reverse path with source node. Send routing reply packet RREP to source node. As to same source node, PL_AOMDV protocol at most establishes three paths.

- RREP packet processing

The BW and LE fields in RREP are used to record bottlenecks from current node to destination node, which is different from bottleneck to destination node. Therefore, the BW and LE fields in RREP are initialized as value of destination node.

The processing method of intermediate node after received RREP packet is substantially same as that of RREQ, namely compare bandwidth and residual energy of this node with BW and LE in RREP. If value of this node is smaller than that in packet, update node value into packet. Otherwise, do not update. All nodes received RREP should establish forward path for source node and record bandwidth and energy bottleneck to destination node. Then, it forwards RREP.

After source node received multiple RREP, it extracts BW and LE fields in order to establish routing items to destination node.

B. Routing Maintenance Process

Ad hoc network has complex characteristics. After source node traffic transmission, nodes along transmission paths may access new traffic or shift to region with poor bandwidth resources. Bandwidth and energy bottleneck of each path will inevitable change as time. If the source node still allocate traffic according to situation in routing establishment, it is obviously very unreasonable. Therefore, PL_AOMDV protocol added periodic routing maintenance on paths to find network congestion or node energy change in time, so as to achieve bandwidth allocation of traffic adjustment.

PL_AOMDV adds periodic routing maintenance process. In the routing discovery phase, destination node builds a timer once receiving first RREQ of source node. The timer is responsible for periodic routing maintenance to this source node. We call it as routing maintenance timer. When the timer expires, if this path still active recently, destination node firstly add ID of this node and then send RREP along multiple paths to source nodes. After source node received RREP, it updates BW and LE information of this packet to routing table. In case of source node sending packets to destination node in next time, if allocates traffic in accordance with new parameters.

We uses destination node to maintain paths. The benefit is that overhead of destination node sending path maintenance information to source node directly is less than source node send to destination and then return. However, it should ensure the path from source to destination is same as that from destination to source. Otherwise, the obtained bandwidth and bottleneck is not real value along transmission path. The references [11-13] have proved that the established path with theorem 1 can meet above conditions.

The processing on path failure of PL_AOMDV is similar to that of AODV. After intermediate node find path failure to destination node, it firstly send path failure message to source node and delete reverse paths to source node. If upper hop of some intermediate node to destination node, it send path failure message to source node and delete reverse paths to destination node. After source node and destination node along this path received message, delete path in routing table respectively. Different from AODV, if there is available path to destination node in the routing table of source node, PL_AOMDV does not perform route recovery operation till there is no available path from source to destination node.

V.SIMULATION EXPERIMENT AND RESULT ANALYSIS

A. Simulation Scenario

We designed simulation experiment on PL_AOMDV protocol with NS-2.33 platform under Linux operation system. In the simulation, the terrain was set plane network of 800m × 800m; node number 20; MAC protocol as IEEE 802.11DCF; signal propagation manner as dual-diameter ground reflection model; node maximum communication range as 250m; channel bandwidth 2Mbps. The initial energy of all nodes was set same value. Data packet length is 512Byte and simulation time as 800s. The constant UDP bit stream was used to simulate real-time traffic and 8 connections were initiated randomly. We select the following performance parameters to evaluate algorithm.

(1) Node number of energy exhausted.

(2) Average lifespan of first half dead nodes.

(3) Control overhead.

In order to validate PL_AOMDV performance, the paper simulated AODV protocol and AOMDV protocol with same moving speed under same conditions. The AOMDV protocol in experiment is transmitted in parallel with multiple paths and at most three decile paths been established. Compared with PL_AOMDV, the simulated AOMDV protocol has not power controlling and traffic allocation.

B. Result Analysis

The relation between dead node number and elapsed time reflects uniformity of the energy consumption of each node. If the image is steeper, it indicates that life cycle of each node in the network has greater difference and energy consumption more uneven. On the contrary, if the image is gentler, each node survival smaller the difference between the consumption of energy is more uniform, network because the node energy is exhausted and the probability of splitting the smaller. At the same time, since the node of the energy consumption and the node load substantially proportional, the node energy consumption also reflects the degree of load balancing in the network, the node energy consumption is more uniform, and the network load is more balanced.

Fig. 4, Fig. 5 and Fig. 6 show relations between dead node number and elapsed time at moving speed of 0m/s, 2m/s and 5m/s. After comparison, we can know that the curves of AODV are relatively steep. The curve of AOMDV is slightly better than that of AODV, they are also very steep. It suggests that node energy consumption of AODV and AOMDV has large difference. The curve of PL_AOMDV protocol is also on the top of that of AOMDV and AODV. Meanwhile, the PL_AOMDV is relatively smooth, which indicates node energy consumption of PL_AOMDV is more uniform than AOMDV and AODV. We can also know from these three images that PL_AOMDV protocol can reach energy and load evenly at different moving speed.

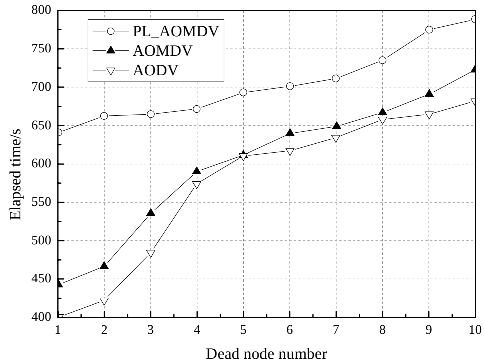

Figure 4. Relationship between dead node and elapsed time at 0m/s

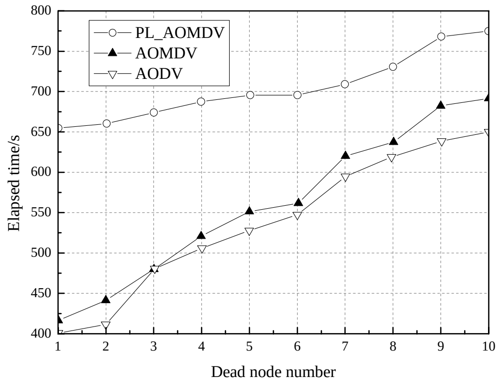

Figure 5. Relationship between dead node and elapsed time at 2m/s

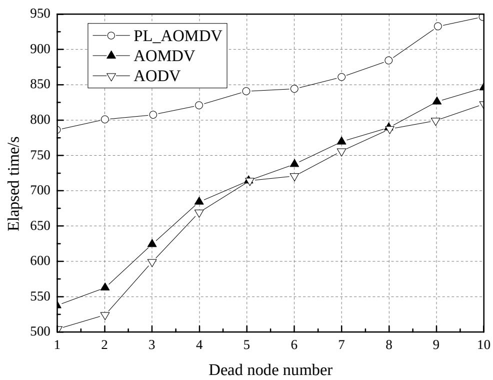

Figure 6. Relationship between dead node and elapsed time at 5m/s

Fig. 7 shows average life of first 10 dead nodes from experiment in Fig. 4 to Fig. 6. Under different moving speeds, average life of first half dead nodes in PL_AOMDV protocol delay 2%-5% than that of AOMDV and AODV, while PL_AOMDV prolongs 12%-18% than AODV, which means PL_AOMDV can also achieves energy saving with power controlling.

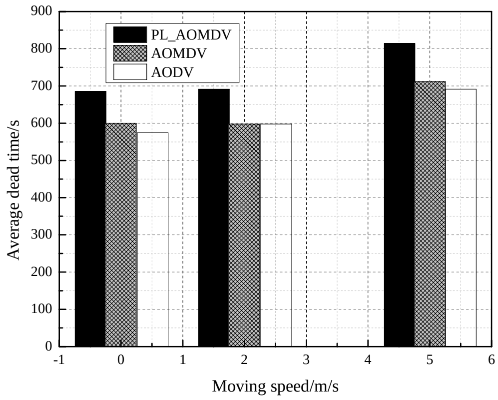

Figure 7. Average life of first 10 dead nodes

Fig. 8 shows comparison of network overhead. As PL_AOMDV adds bandwidth and energy parameters in routing packet as well as periodic network maintenance mechanism, the overhead of PL_AOMDV is slightly increased than AOMDV, but still less than that of AODV. Seen from performance of energy and load balancing, the increased overhead is worthy.

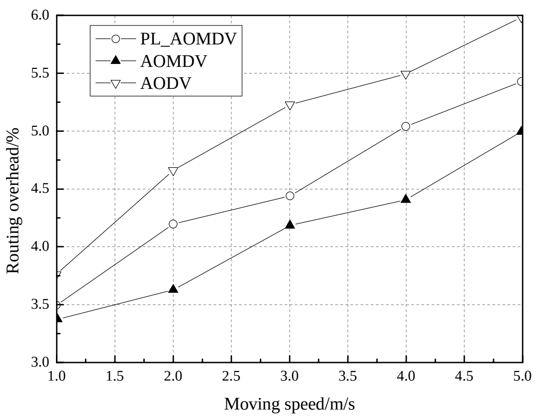

Figure 8. Network overhead comparison

VI. CONCLUSION

The paper improved on AOMDV protocol to bring out a multi-path routing protocol PL_AOMDV with power controlling and load balancing. It established multiple node disjoint paths between source node and destination node to implement parallel data transmission. The protocol allocates bandwidth according to residual energy and load bottleneck so that path load and residual energy balanced roughly, so as to reduce probability of failure caused by node energy exhausted and prolong overall connectivity. As Ad hoc is complex and volatile, the established path may shift to region with poor bandwidth resources and node bottleneck may change, PL_AOMDV adds periodic routing maintenance to adjust bandwidth allocation in real-time. In addition, PL_AOMDV protocol transmits data packets with appropriate energy in case of data transmission to avoid using maximum power and save node energy. Simulation experiment with NS-2 shows that the improved PL_AOMDV protocol better network performance in aspects of load balancing and average node lifespan. In the next working, we will further analyze various traffic allocation algorithms to provide theoretical basis for further improvement.

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