An Effective Scheme for Detecting Articulation Points in Zone Routing Protocol

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Abstract. Zone Routing Protocol (ZRP) is a typical hybrid routing protocol used in Mobile Ad Hoc Networks (MANETs). Hybrid routing protocols are especially suitable for dynamic environments because they combine the best features of proactive and reactive routing protocols. The Gossip-based Zone Routing Protocol (GZRP) uses a gossip scheme, in which the node forwards a packet to some nodes instead of all nodes to further reduce the control overhead. However, GZRP does not perform well when the network includes articulation points since packets will be lost if an articulation node happens not to forward the packet or nodes happen not to forward packets to the articulation point. To raise the packet delivery ratio, the gossip probability of articulation points must be set to 1 and the packets to be forwarded must be sent to the articulation points in peripheral nodes. Accordingly, how to identify articulation nodes in the network becomes a critical issue. This paper proposes an effective scheme, called *articulation point detection* (APD), to find the articulation points. Simulation results show that the proposed APD-GZRP (GZRP with articulation point detection) can improve the packet delivery ratio and reduce both the control overhead and power consumption.

Keywords: Mobile Ad Hoc Network (MANET), articulation point, biconnected component, zone routing protocol, gossiping.

1 Introduction

A *Mobile Ad Hoc Network* (MANET) is a self-configuring network consisting of mobile devices (or nodes), where each mobile device is autonomous and connected through wireless links. In a MANET, the nodes are assumed to be free to move randomly and are able to communicate with each other by multi-hop links without the help of a fixed network infrastructure. With the proliferation of wireless devices, including cellular phones, personal digital assistants (PDAs), laptops, and microsensors, MANETs have become a challenging field of research.

In MANETs, *broadcasting* is a primitive way for a node to emit a message via wireless channels to its neighbor nodes. It is significant in terms of collecting global information and discovering neighbors. Most existing routing protocols,

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such as *Highly Dynamic Destination Sequenced Distance Vector Routing* (DSDV) [1], *Ad Hoc On-Demand Distance Vector Routing* (AODV) [2], *Dynamic Source Routing* (DSR) [3], and *Zone Routing Protocol* (ZRP) [4], rely on broadcasting for route and neighbor discovery. Additionally, broadcasting can also be used for paging a particular host, sending an alarm signal, or determining a route to a particular host [5].

Traditional broadcasting is called *blind flooding*; each node in the network retransmits the message upon receiving the first copy of it or ignores the message if it is a duplicate one. Although blind flooding can obtain high reachability, it generates a large number of redundant messages. Transmitting more redundant messages will consume more system resources, such as bandwidth and battery power. Furthermore, the redundant messages will in turn induce packet collision, reduce the packet delivery ratio and increase the end-to-end delay. To lower redundant transmissions, several methods have been proposed. These methods can be identified as the *probabilistic* scheme, the *counter-based* scheme, the *distance-based* scheme, the *location-based* scheme and the *cluster-based* scheme [5]. These schemes restrain the redundant packet transmission such that the intermediate nodes forward the received broadcasting packets only under specific conditions. In other words, the intermediate nodes do not retransmit the broadcasting packets blindly.

In general, the proactive routing protocol has little delay in data transmission because all routes are in the routing table, while the reactive routing protocol does not make extra overhead in maintaining the routing table but exhibits more delay time in data transmission and route discovery. Either proactive or reactive routing protocol is insufficient for all situations in terms of the node mobility, network size and traffic load. Therefore, the hybrid routing protocol is proposed to combine the advantages of proactive and reactive protocols. Zone Routing Protocol (ZRP) is a typical hybrid routing protocol which uses the proactive routing scheme, *IntrAzone Routing Protocol* (IARP) [6], within a zone domain and utilizes the reactive routing scheme, *IntErzone Routing Protocol* (IERP) [7], for inter-zone routing.

As large overlapping zone in ZRP will cause the maintenance of IARP to incur a high control overhead, Haas *et al.* [8] applied gossiping on ZRP by sending the route request to only part of the peripheral nodes rather than all of them to reduce the control overhead. However, the *Gossip-based Zone Routing Protocol* (GZRP) does not perform well when the network includes articulation points because packets will be lost if an articulation node happens not to forward the packet or nodes happen not to forward packets to the articulation point. In this paper, we propose an effective scheme to detect the articulation points by making use of the information in routing tables and link-state table of ZRP. After the articulation points have been identified, the packet delivery ratio can be enhanced, while the control overhead can be reduced by setting the gossip probability of articulation points to 1 and sending the forwarding packet to the articulation points in peripheral nodes.

The remainder of this paper is organized as follows. Section 2 introduces the related work, including gossiping, Zone Routing Protocol (ZRP) and traditional methods in dealing with the articulation points. Section 3 introduces our proposal for detecting the articulation point in ZRP. Simulation results are revealed and discussed in Section 4. Finally, we offer our conclusions in Section 5.

2 Related Work

2.1 Gossiping

Gossiping is an instance of percolation, which is a method employed to solve the broadcast storm. Gossiping forwards the control packets by a specific probability. Compared with flooding, gossiping has the advantage of broadcasting fewer control messages. The Gossiping scheme can be classified into the *static* gossip and *adaptive* gossip [8,9].

Static gossip, or pure gossip, sends packets with probability 1 for the source node, otherwise forwards packets with probability p for other nodes. The challenge of pure gossip, **GOSSIP1** (p, k), lies in the situation when the source node has only a few neighbors. The adaptive gossip schemes includes **GOSSIP2** (p_1, k, p_2, n), **GOSSIP3** (p, k, m) and **GOSSIP4** (p, k, k_0), which work depend on different factors of Ad Hoc Networks. The readers can refer to [8,9] for the details. **GOSSIP4** (p, k, k_0) is just like **GOSSIP1** (p, k), except that each node has k_0 as its zone radius.

Due to the mobility of MANETs, unpredictable articulation points will decrease the performance when using gossiping in ZRP.

2.2 Zone Routing Protocol (ZRP)

Zone Routing Protocol (ZRP) is a hybrid routing protocol in MANET, which combines proactive (IARP) and reactive (IERP) routing protocols together with the *Bordercast Resolution Protocol* (BRP) [10] with a query-control mechanism.

IARP is used to maintain the topology information of a limited scope, called *zone*. The zone radius of IARP is evaluated relying on how far the source node can propagate. This distance is measured by hops. When the minimum distance from a node to source node is equal to the zone radius, the nodes are called the *peripheral nodes*. Each node in a zone will broadcast routing information to its neighbors, so a larger zone radius may result in more routing traffic.

IERP is adopted to send data when destination nodes are outside the zone, which finds the route by initiating a route discovery process. Instead of flooding, this process uses "bordercasting" with a query control mechanism [11,12]. The query control mechanism can reduce the control traffic by Query Detection (QD1/QD2), Early Termination (ET) and Random Query Processing Delay (RQPD) [11,12].

BRP is a multicast service, which delivers packets efficiently to peripheral nodes. Using BRP in IERP can avoid redundant querying within a routing zone. This service sends the route request outward by the information which IARP provides, via multicast, to the surrounding peripheral nodes.

2.3 Articulation Point

In graph theory, a *articulation point*, also named *cutpoint* or *cut vertex*, is one whose removal increases the number of components [13]. Fig. 1 illustrates the articulation points u and v.

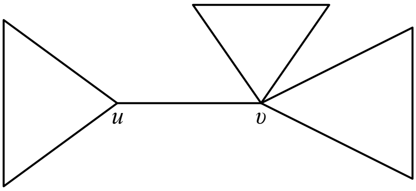


Fig. 1. A simple graph with articulation points u and v

In MANETs, the network topology can not avoid the existence of articulation points because of node mobility and random deployment. How to identify articulation points is an important issue in GZRP for the following reasons. The first is from the point of view of intrazone information. As shown in Fig. 2, the source node S wants to forward packets to nodes u and w via node v. Due to the characteristics of Gossip-based Zone Routing Protocol, if node v does not forward packets, nodes u and w will not receive the packet sent from source node S. This results in outdated local zone information, so the data transmission from one zone to another will be blocked because of wrong zone information.

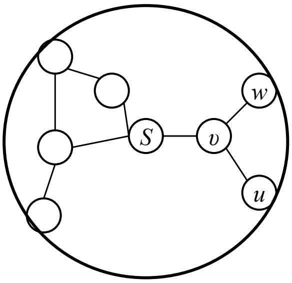


Fig. 2. Intrazone information with articulation point v

The second reason is from the viewpoint of interzone information. Let us look at Fig. 3. The source node S wants to broadcast the *RouteRequest* packet to nodes u and w, which are in other zones, through node v. The route request packets can not find the route in Gossip-based Zone Routing Protocol if v does not forward the packet. And the data transmission will be blocked with route failure.

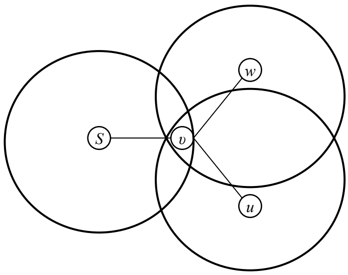


Fig. 3. Interzone information with articulation point v

The third reason comes from interzone routing. When a node sends *RouteRequest* packets to only part of peripheral nodes rather than to all peripheral nodes, the *RouteRequest* message will be blocked if the articulation points of peripheral nodes do not receive the *RouteRequest*. For the example in Fig. 4, since the node S is not an articulation point, it does not have to send *RouteRequest* packets to node v in gossip-based zone routing protocol. If node v does not receive the *RouteRequest* packet, the node S may not find nodes u and w; this also result in route failure.

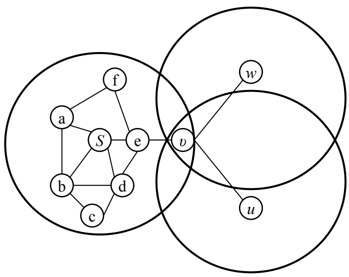


Fig. 4. Interzone routing with articulation point v

Depth-First Search (DFS) [14] is a traditional method to find the articulation point. However, this approach, such as Distributed Depth-First Search (DDFS) and CAM [15] require a communication cost of $O(dn^2)$ where n is the number of nodes and d is the maximum degree of node. In [16], Cut Vertex Detection (CVD) has been proposed for determining the articulation points in *static* Wireless Sensor Networks (WSNs). It needs only $O(dn)$ communication cost. However, it is not suitable for MANETs because the nodes in MANETs are free to move. In this paper, we propose a new method to detect the articulation point by taking advantage of the information in the routing table and link state table in IARP of ZRP. The communication complexity is also only $O(dn)$.

3 Articulation Point Detection

The biconnected graph is a graph that contains no articulation point [17]. Based on the concept, this paper proposes the *articulation point detection* (APD) algorithm to determine whether the local zone is a biconnected graph. The key point of biconnected graph is that any node in a biconnected graph must have more than one way to another node.

Fig. 5 shows a local zone of node S in ZRP, where the peripheral nodes, v and w, have the same 2-hop neighbors t and u which are in the local zone of S, and node v and w and their neighboers include cover all neighbors of node S. This means that all neighbors of node S are in the same biconnected component, so the local zone forms a biconnected graph. By the definition of a biconnected graph, the local zone of source node contains no articulation point.

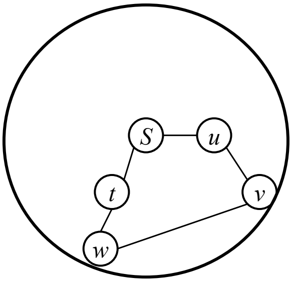


Fig. 5. A local zone topology with one biconnected graph

In Fig. 6, peripheral nodes w, v and y do not have the same neighbor except S. Hence, this graph has more than one biconnected components, $B_1 = \{x, y\}$, $B_2 = \{x, S\}$, and $B_3 = \{S, t, u, v, w\}$. When a node belongs to multiple biconnected components, this node is an articulation point. In Fig. 6, since node S belongs to two biconnected components, i.e. $B_2 \cap B_3 = \{S\}$, so node S is an articulation point.

Fig. 5 and Fig. 6 illustrate that the number of biconnected components in a local zone of S will determine whether S is an articulation point. In other words, the detection of articulation point depends on the number of biconnected components in a local zone.

The proposed APD algorithm is different from other articulation point detection scheme because APD does not build any tree in the local zone. Instead, we make use of the information in routing table and link state table of IARP, without extra overhead, to detect the articulation points. This articulation point detection (APD) consists of two phases: biconnected component identification and articulation point checking.

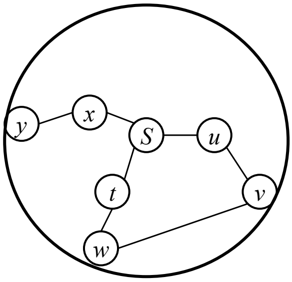


Fig. 6. A local zone topology with two components (connected graph with articulation point S)

Algorithm 1. Articulation Point Detection

Input: Node n, n's Routing Table, n's Link State Table, Zone Radius
Output: n is an articulation point or not

Arbitrarily choose two peripheral nodes of n, v and w
Let S be the set of the common neighbors of nodes v and w in the local zone of n
if $S - \{n\} = \emptyset$ **then**
    return n is an articulation point
else
    Let all the neighbors of n be in set N and all the neighbors of nodes v and w be in set P
    while $N - P \neq \emptyset$ **do**
        Arbitrarily choose a peripheral node u, $u \in N$, and let all the neighbors of u be in set T
        if $T \cap P = \{n\}$ **then**
            return n is an articulation point.
        end if
        $P \leftarrow P \cup T$
    end while
    return n is not an articulation point.
end if

In the APD algorithm, the number of biconnected components in the local zone is determined first. (The details are described in the section of biconnected component identification below.) Then, the algorithm checks whether the node is in the same biconnected component. (The details are presented in the section of articulation point checking below.)

3.1 Biconnected Component Identification

Given the zone information of a node S, we put the neighbors of S into set N, called $N(S)$. We randomly chooses two peripheral nodes v, w from $N(S)$ to check whether the nodes, v and w, have common neighbor nodes which are in the local zone of S.

For example, in Fig. 5, nodes v and w have common neighbor nodes t and u, so the local zone only has one biconnected component, so the node S is not an articulation point.

In certain cases, the local zone might be divided into one *connected* components and one *biconnected* component instead of two *bioconnected* components. The connected component is consisted of biconnected component. If there are two biconnected components and their intersection is $\{S\}$, the node S is an articulation point. In other words, there are two connected components C_1, C_2 and two biconnected components in these two connected components, such that $B_1 \subset C_1$ and $B_2 \subset C_2$. If $C_1 \cap C_2 = \{S\}$, it means that only two biconnected components in these connected components have S as their intersection, i.e., $B_1 \cap B_2 = \{S\}$, so S is an articulation point.

In the example of Fig. 6, the biconnected component identification stage divides the graph into one biconnected component, $B_1 = \{S, t, u, v, w\}$, and one connected component, $C_1 = \{x, y, S\}$. C_1 consists of two biconnected components: $B_2 = \{x, y\}$ and $B_3 = \{x, S\}$. Because $B_1 \cap C_1 = \{S\}$ and $B_2 \cup B_3 = C_1$, the node S belongs to two biconnected components, $B_1 = \{S, t, u, v, w\}$ and $B_3 = \{x, S\}$, and $B_1 \cap B_3 = \{S\}$. So the node S is an articulation point. From this example, we can see that the APD algorithm can also the articulation point even if the graph is divided into two connected components, or one connected components and one biconnected component.

If the local zone has more than one biconnected component, node S is accordingly an articulation point. Otherwise, the next stage, articulation point checking, will be proceeded.

3.2 Articulation Point Checking

Given a biconnected component and unchecked peripheral nodes in the local zone, this stage is to confirm the articulation node. The unchecked peripheral nodes are examined one by one to see whether they are in the biconnected component. For each unchecked peripheral node x, let the neighbor nodes of x be $N(x)$. If there is a node in $N(x)$, except node S, belonging to the biconnected component, then x is also in the biconnected component. Otherwise node x is in another biconnected component. Since the two biconnected components only have one common node S, S is therefore an articulation point.

For example, in Fig. 6, the set of y's neighbor nodes is $N(y) = \{x, S\}$. $N(y)$ only has source node S in the biconnected component. As mentioned above, it is apparently to know that the node y is disconnected with the biconnected component and the source node S is an articulation point. By using the APD algorithm, the node S can determine it is an articulation point.

4 Performance Evaluation

We compare APD-GZRP, ZRP and GZRP by simulation using NS-2 [18]. In the simulation, the MANET environment consists of $50\backslash 100\backslash 150$ mobile nodes which are chosen from a uniform random distribution with initial positions in an area of 1300×1300 $meter^2$. The nodes move based on the *Random-Waypoint* model [19]; the movement starts from the initial position to a random destination with a random speed (uniformly distributed between $0 \sim 14$m/s). This simulation varies the pause time by $0\backslash 80\backslash 180s$. The pause time will affect the relative speeds of the mobile nodes. The transmission range of each mobile node is 250 meters. The simulation time is 180s and constant bit-rate (CBR) traffic sources are used. The source-destination pairs are chosen randomly over the network and data packet size for all is 512 bytes. The simulation parameters are listed in Table 1.

Table 1. Simulation Parameters

Simulator	NS-2
Simulation time	180 s
Simulation area	$1300 \times 1300m^2$
Number of nodes	$50, 100, 150$
Transmission range	250m
Transmission rate	100 kbps
Max speed	14 m/s
Pause time	$0, 80, 180$ s
Data packet size	512bytes
Movement model	Random-waypoint

The following performance metrics are measured: *packet delivery ratio*, *normalized routing overhead* and *power consumption*. The *packet delivery ratio* is the ratio of the number of data packets received at the final destination divided by the number of data packets originated from the source nodes. The *normalized routing overhead* is the number of total transmitted routing packets divided by the number of total delivered data packets. The *power consumption* is the total power consumed in the duration of simulation time. The power consumption will influence the lifetime of the wireless mobile node. With the same power energy, lower power consumption of nodes will extend the lifetime of the node and entire network.

4.1 Packet Delivery Ratio

Fig. 7 compares the packet delivery ratio of APD-GZRP, GZRP and ZRP. For articulation points ZRP and APD-GZRP forward the message with probability 1 but GZRP forwards with probability. So, ZRP and APD-GZRP outperform GZRP. The results reveal that APD-GZRP is nearly the same as ZRP in terms of packet delivery ratio.

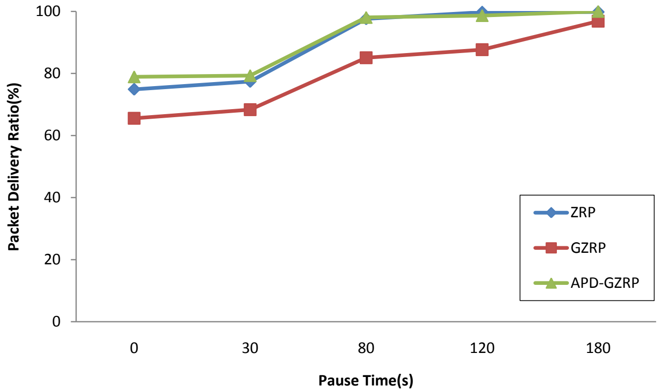
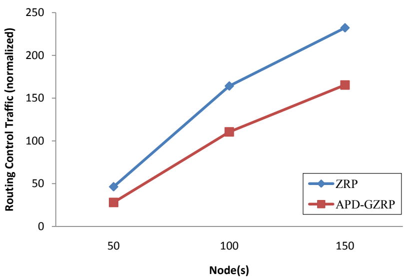
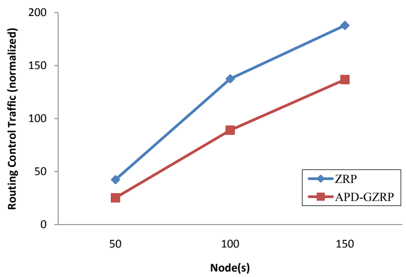


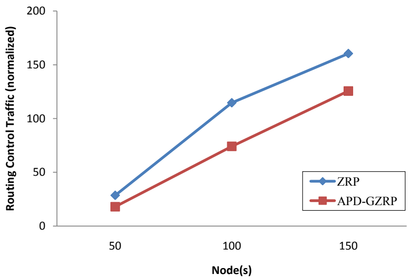
Fig. 7. Packet Delivery Ratio comparison with different pause time



(a) Routing overhead with pause time 0 second.



(b) Routing overhead with pause time 80 seconds.

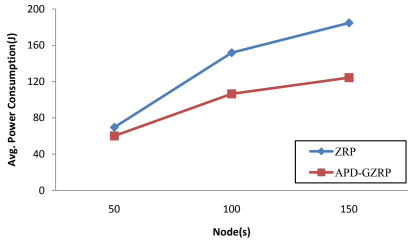


(c) Routing overhead with pause time 180 seconds.

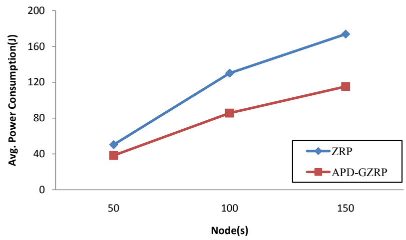
Fig. 8. Routing overhead with different nodes and pause time

4.2 Normalized Routing Overhead

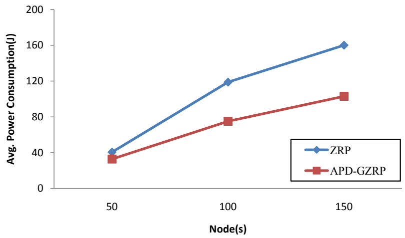
Fig. 8 illustrates the normalized routing overhead of APD-GZRP and ZRP at different pause time in different mobile nodes. These two methods are compared



(a) Power consumption with pause time 0 second.



(b) Power consumption with pause time 80 seconds.



(c) Power consumption with pause time 180 seconds.

Fig. 9. Power consumption with different nodes and pause time

because their packet delivery ratios are about the same. Fig. 8 shows an obvious result that APD-GZRP has less routing overhead than ZRP in all situations.

4.3 Power Consumption

In comparing the power consumption of APD-GZRP and ZRP, the power model and parameters in NS-2 are set as in Table. 2. The initial power of each node is 200 joules (J). A node consumes 2 joules to receive one packet and 5 joules to transmit a packet. When a node is in idle mode, 0.05 joules are consumed.

Table 2. Power model and Parameters

Power Model	Simple
Initial power	200 Joules
Receiving power	2 Joules
Transmitting power	5 Joules
Idle power	0.05 Joules

The power consumptions of APD-GZRP and ZRP are compared in Fig. 9. From the comparison result in Fig. 8, it is reasonable that APD-GZRP consumed less power than ZRP because it incurs lower routing overhead. Both APD-GZRP and ZRP experience low power consumption in sparse regions and comparatively higher power consumption in the dense regions of the network, consistent with the result of Fig. 8 where more control overhead in higher condense network. By further observation, the APD-GZRP saves about 5% of power consumption in low density regions of 50 nodes and saves about 30% of power consumption in high density regions of 150 nodes.

5 Conclusion

This paper presents articulation point detection (APD) with GZRP (APD-GZRP). The proposed scheme utilizes the definition of an articulation point and local zone information to divide subgraphs and confirm the articulation nodes. The articulation nodes will now forward packets with probability 1 in APD-GZRP and general nodes must forward packets to articulation points. Thus, APD-GZRP can effectively improve the packet delivery ratio better than GZRP can.

In the simulation results, three different metrics are measured: *packet delivery ratio*, *normalized routing overhead* and *power consumption*. The packet delivery ratio of APD-GZRP and ZRP is almost equivalent but higher than GZRP. Moreover, the APD-GZRP has lower routing overhead and power consumption than ZRP in a similar packet delivery ratio. Because of that, the APD-GZRP outperforms GZRP and ZRP in MANETs.

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