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具位置知覺之無線隨意行動網路的設計與實作

子計畫二：具位置知覺之無線隨意行動網路的繞徑協定

Design & Implement Location-Aware of Mobile Ad Hoc Networks
Sub-Project(2): Location-Aware Routing Protocols for Mobile Ad Hoc Networks

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摘要：

A *mobile ad-hoc network (MANET)* is formed by a cluster of mobile hosts, without the infrastructure of base stations. To deal with the dynamic changing topology of a MANET, many routing protocols have been proposed. In this paper, we consider the route maintenance problem, which includes two parts: *route deterioration* and *route breakage*. In a MANET, a route may suddenly become broken because only one host roams away. Even if a route remains connected, it may become worse due to host mobility or a better route newly being formed in the system. Existing protocols, however, will stick with a fixed route once it is discovered, until it is expired or broken. In this paper, we show how to enhance several existing protocols with *route optimization* and *local route recovery* capability. So the routing paths can be adjusted on-the-fly while they are still being used for delivering packets and can be patched in minimum wireless bandwidth and delay while route errors occur.

關鍵詞：mobile ad hoc network (MANET), mobile computing, routing, route recovery, wireless network.

1. Introduction

Routing protocols for a MANET can be classified as *proactive* and *reactive*, depending on how they react to topology changes [4]. Observing that a proactive protocol may pay costs to constructing routes even if mobile hosts do not have such need, thus wasting the limited wireless bandwidth, many researchers have proposed to use reactive-style protocols, where routes are only constructed on-demand. Many reactive protocols, such as Dynamic Source Routing (DSR) [5], Signal Stability-based Adaptive Routing(SSA) [3], and Ad Hoc On Demand Distance Vector Routing (AODV) [8], have been proposed based on such on-demand philosophy. Recently, a hybrid of these two approaches, called the Zone Routing Protocol (ZRP) [4], is also proposed.

Routing in a reactive protocol typically consists of three parts: *route discovery*, *data forwarding*, and *route maintenance*. This paper considers the route maintenance problem in a reactive protocol. When a mobile host wants to communicate with another host, it first tries to discover a good route to the destination, on which the data packets are forwarded. Route maintenance, under our definition, should address two issues: *route deterioration* and *route breakage*. Route deterioration refers to the situation where an existing route becomes worse than other routes due to host mobility. However, in existing protocols, such as [3,4,5,8], a sending host will stick with the discovered route until it is expired or broken, even if some better routes are newly being formed in the system. One straightforward solution is to run the route discovery procedure more frequently to detect such possibility. However, this is very costly as route discovery is typically done by network flooding [7]. This observation has motivated the first work in this paper: we propose to use *route optimization* to refine or improve the routes *on-the-fly* while they are being used for transmission. Not only can the data packets be sent with less hops and latencies, but also may the chances of route breakage be reduced, lowing the number of times the costly route discovery process being called.

To deal with the route breakage problem, most existing protocols will send a route error packet back to the source node from the position where breakage is found, which will then invoke another route discovery procedure. However, since route discovery is very costly (in terms of both bandwidth and delay), it should be used with caution. Several recent works have targeted in the direction of reducing the cost of one route discovery [2,6,7]. In this paper, we propose to exploit the *locality* of a route to reduce the number of times that route discovery is activated. We observe that it is very likely that a route is broken because only one relay node leaves its neighbors. This is very similar to the "spatial locality" discussed in [2], which uses prior routes to rebuild new routes. In this paper, we suggest to use a *local route recovery* to patch a broken route before a route error packet is sent back to its source node.

2. The Enhancements of Existing Routing Protocols

2.1. Route Optimization for DSR

In DSR, since source routing is used, the routing paths are only kept two places: those source nodes that are currently active in sending messages, and data packet headers. As a result, route optimization should be achieved based on information therein.

As the MANET topology changes, it is possible for a source node to find out a better route for another source. For instance, consider the scenario in **Fig1**. Suppose there is a route from a to e: $a \rightarrow\rightarrow b \rightarrow c \rightarrow\rightarrow d \rightarrow\rightarrow e$. Under a promiscuous mode, node f may hear the packets from b to c. If f has a route $f \rightarrow\rightarrow d \rightarrow\rightarrow g$. If the hop count from c to d is longer than f to d, then f can suggest a better route $a \rightarrow\rightarrow b \rightarrow f \rightarrow\rightarrow d \rightarrow\rightarrow e$ to the source node a.

The route optimization protocol is formally developed below.

It is executed by any node f receiving a data packet from node b to node c such that $c \neq f$.

1. Let the route in the packet header be $P = a \rightarrow \cdots \rightarrow b \rightarrow c \rightarrow \cdots \rightarrow e$.
2. Let $Tmp = P$.
3. **for** (each path P' in f's routing cache) **do**

    for (each $d \in P'$ such that d is a downstream node of c) **do** in P

        Let P'' be the path obtained from P by replacing the subpath from c to d by the path from f to d in P'.

        If the length of P'' is less than Tmp, then let $Tmp = P''$.

    end for;

   end for;

4. If $Tmp \neq P$, then send a ROUTE_REPLY packet to the source node a with Tmp as the suggested new route.
5. When a receives the ROUTE_REPLY, it replaces the entry P in its routing table for destination node e by Tmp.

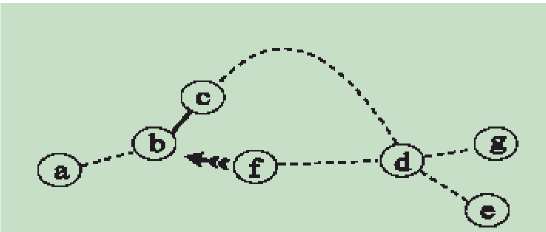

Figure 1. An example of route optimization in DSR.

2.2. Route Optimization for SSA

There are two directions to optimize routes in SSA: (i) to find a route of a less hop count, and (ii) to find a route of higher quality (such as from SC to WC).

To achieve these goals, we modify the routing table used in the SSA to one as shown in **Fig2**. The *hop-count* field is the length to the corresponding destination. The *route quality* field indicates the quality of the route. These two fields can be filled when the ROUTE_REPLY packet returns from the destination to the source, using the hop_list and PREF fields.

Also, to help finding a shorter route, each data packet must indicate the remaining hops that it has to traverse. Thus, we modify the data packet format as shown in **Fig3**, by adding a hop_count field. Through this information, it is possible for other nodes to tell if they can suggest shorter routes or not.

Destination	Next Hop	Hop Count	Route Quality
t	o	5	SC
m	x	3	WC

Figure 2. The modified routing table used in SSA. The modified part is shown in gray.

<table>
<tr><td rowspan="2">DA</td><td rowspan="2">SA</td><td rowspan="2">SEQ</td><td rowspan="2">TTL</td><td rowspan="2">TYPE</td><td rowspan="2">PREF</td><td rowspan="2">LEN</td><td rowspan="2">CRC</td><td rowspan="2">Hop Count</td><td>Hop List</td></tr>
<tr><td>Data</td></tr>
</table>

Figure 3. The new format of data packet used in SSA.

For instance, suppose there are data packets being transmitted along the path: $a \rightarrow\rightarrow b \rightarrow c \rightarrow d$ (refer to **Fig4**). When a node, say f, hears a data packet sent by b and it has a better route from f to d, node f can send a packet to recommend node b to forward its data packet destined for d to it instead of to node c. The protocol is formally developed as follows. It is executed by any node f when receiving a data packet from node b to node c such that $c \neq f$.

1. Retrieve the hop count (say i) and the PREF (say s) from the packet header.
2. Let i' and s' be the hop count and route quality, respectively, to node d recorded in f's routing table, if any.
3. **if** $(i > i' + 1) \wedge (s \leq s')$ **then**

    if ($s \leq$ the signal strength from b to f) **then**

        Broadcast a packet ROUTE_REPLY with hop_limit=1 to indicate that "node f has a route of length i' and with quality s' to node d."

    end if;

   end if;
4. Any node (including node b), on receiving the ROUTE_REPLY packet, updates its routing table for destination d (including hop-count and route quality) if the route is better than its current one. Note that to follow the on-demand route discovery notion, only those routes that are currently active are updated. If there is any update on its routing table, the node should in turn broadcast anohter ROUTE_REPLY to indicate that it has a route of length $i' + 1$ and quality s' to node d.

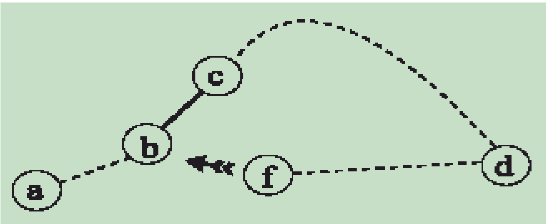

Figure 4. An example of route optimization in protocols using next-hop routing such as SSA and AODV.

2.3. Route Optimization for AODV

The AODV protocol also follows the next-hop routing style. So the route optimization is similar to the SSA protocol. Both the routing table and the data packet need to have a hop-count field. The only difference is that the AODV does not have the link quality information, but it has a destination-sequence-number field. A larger sequence number means a fresher route, so this may also mean a route of less chance being broken.
The protocol shown below is a slight modification of the one for SSA.

1. On f receiving the data packet from b destined for node d, it will retrieve the hop count (say i) and the destination sequence number (say s) from the packet header.
2. Let i' and s' be the hop count and the sequence number for node d recorded in f's routing table.
3. **if** $(i > i' + 1) \wedge (s \geq s')$ then

    Broadcast a packet ROUTE_REPLY to indicate that "node f has a route of length i' and with destination sequence number s' to node d."

   end if;
4. Any node (including node b), on receiving the ROUTE_REPLY packet, updates its routing table for destination d (including hop-count and destination sequence number) if the route is better than its current one. Note that to follow the on-demand route discovery notion, only those routes that are currently active are updated. If there is any update on its routing table, the node should in turn broadcast anohter ROUTE_REPLY to indicate that it has a route of length $i' + 1$ and destination sequence number s' to node d.

2.4. Route Optimization for ZRP

In ZRP, a node always knows the best route to any node in its local zone, so no route optimization is needed for intra-zone routing. On the inter-zone part, a modified DSR protocol is used.
For instance, consider a MANET using ZRP with radius = 2. Suppose there is a route from a to e : (refer to **Fig5**). Note that only border nodes are registered in a route, so in **Fig5** node c is a border node of b's zone. Suppose there is another route $f \rightarrow i \rightarrow ... \rightarrow d \rightarrow ... \rightarrow g$, and the border count from f to d is less than that from c to d. If f hears the packets from b to e, f can figure out a better route $a \rightarrow ... \rightarrow b \rightarrow f \rightarrow i \rightarrow ... \rightarrow d \rightarrow ... \rightarrow e$ and recommend the route to the source a.

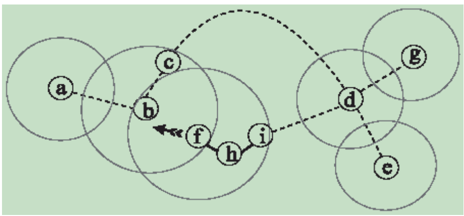

Figure 5. A route optimization example for the ZRP protocol

Although the new route known by a can

successfully deliver data packets to the destination e, the route has violated the original ZRP protocol's definition because node f is not a border node of node b(the hop count is 1, which may be less than the radius). This can be resolved as follows. Node a still transmits data packets using the new route recommended by f. When f receives a data packet from b with itself as the border, it will find out from its intra-zone routing table that h should be a border node of b leading to i. So f can replace itself by h in the packet header and forward the data packet to h (now the new route will become $a \to ... \to b \to h \to i \to ... \to d \to ... \to e$). Then intra-zone routing will be used to forward the data packet to h. On h receiving the data packet, the similar scenario will be discovered by h, who will further modify the route in the data packet. This will keep on going until the packet arrives at e. Now the route already follows the ZRP style, so node e will send a ROUTE_REPLY with this modified route to a.

We now formally present the protocol. The protocol is executed by any node f receiving a data packet from b to c destined to e such that $c \neq f$.

1. Let the route in the packet header be $P = a \to \cdots \to b \to c \to \cdots \to d \to \cdots \to e$.
2. Let $Tmp = P$.
3. **for** (each path P' in f's inter-zone routing table) **do**

    for (each $d \in P'$ such that d is a downstream node of f in P) **do**

        Let P'' be the path obtained from P by replacing the subpath from c to d by the path from f to d in P'.

        If the length of P'' is less than Tmp, then let $Tmp = P''$.

    end for;

   end for;
4. If $Tmp \neq P$, then send a ROUTE_REPLY packet to the source node a with Tmp as the suggested new route.
5. When a receives the ROUTE_REPLY, it replaces the entry P by Tmp in its inter-zone routing table for destination node e.
6. The following operations should be added to the data forwarding part when any node f receives a data packet from node b.

    if (f is not a destination node and f is not a border node of b) **then**

        Find out from the route in the data packet the next border node, say i.

        Compute from f's intra-zone routing table the path from f to i (let the path be P').

        Compute the border node of b on the path P' (let the result be h).

        Replace the entry f in the route of the data packet by h.

        Forward the data packet to node h.

    endif;

3. Conclusions

In this paper, we have shown how to perform route optimization for four MANET routing protocols, namely DSR, SSA, AODV, and ZRP. The original protocols will use a fixed route between a pair of node to deliver data packets, until it is broken. We show how to enhance these protocols with route optimization such that better routes can be formed on-the-fly while the original route is being used for transmission. So data packets will not experience delays even under route optimization. Our route optimization may lead to unstable routes due to host mobility (e.g., going back and forth between two routes), thus wasting the wireless bandwidth. Hence one direction that deserves further investigation is to perform route optimization only when the new route is shorter as well as more stable (which may be determined from, say, signal strength). Recently, an independent work [1] also suggests a similar approach. As a route becomes broken, route recovery can be performed. Since such an event will be sent to the source host, the source host will initiate a route optimization request when some criteria is satisfied.

4. References

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