Revisiting the Current State-of-the-art Multipath Routing in Ad Hoc Networks

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Abstract. Ad Hoc network is one of the popular wireless multi-hop networks. Nodes or Users in Ad Hoc network can move randomly and freely to maintain communication without the control of the fixed infrastructure. Due to the limited transmission power and wireless coverage of the terminal, if two terminals that are beyond their respective transmission radius need communicate, they must use other intermediate or relay nodes for packet forwarding, so that a wireless Ad Hoc network is formed among these nodes. In this paper, the current state-of-the-art multipath routing protocols for Ad Hoc networks are reviewed. Particularly, the pros and cons of them are analyzed. Finally, they are summarized and compared.

1. Introduction
In Ad Hoc mobile network, due to the features of open wireless channels, multi-hop, free movement, arbitrary joining or changing dynamically, which causes the entire network topology to change dynamically, the routing problems become extreme difficulties for affecting efficiency and reliability.

As shown in Figure 1, the circle is the transmission range that each node could access which means that the nodes in Ad Hoc networks are bounded in power resources and the battery power is limited. If the most left node wants to communicate with the most right node, a route needs to be discovered by node themselves. This is called self-configuring[9].

However, it is because these routing protocols generally only use a single path and cannot effectively utilize the entire network information, resulting in some disadvantages such as large routing overhead, increased delay, low throughput, low robustness and stability, which cannot be well adapted to the requirements of the Ad Hoc mobile network, thus multipath routing is needed.
The rest in this paper is scheduled as follows: In Section 2, related works of multipath routing protocols for Ad Hoc networks are reviewed. Section 3 present the current three state-of-the-art multipath routing protocols. Finally, Section 4 concludes this paper and compares the aforementioned routing.

2. Related work

Currently, routing protocols exist different taxonomies depending on different viewpoints. According to the routing mechanism, they are categorized into three types. The first one is Table-driven routing which is also called proactive routing. Proactive routing is a traditional table-based routing method in which nodes update routing information by periodically exchanging routing tables. For example, the Destination Sequence Distance Vector (DSDV) is one of the proactive routing protocols[1]. Another type is On-demand (reactive) routing, reactive routing is an on-demand routing based on request/response. Dynamic Source Routing(DSR) and Ad hoc On-demand Distance Vector(AODV) Routing are the paradigms of the reactive routing protocols[2]. The third type is Hybrid routing which contains both proactive and reactive routing. Some proactive route will be established. Additionally, the route will be discovered based on demand.

Considering some special features of ad hoc networks, such as the limited power, mobility, and limited bandwidth. The on-demand protocol reduces the overhead packets and it could automatically work when the node moves[3]. DSR is a popular on-demand protocol. Each packet header in the DSR protocol contains the entire sequence from the source node to the destination node. The node on the path just needs to send the packet to the next node based on the information of the packet header. DSR protocol contains two part: route discovery and maintenance.

Further, the clustering also could help to reduce the latency, save energy and prolong the life cycle of networks. The cluster in the ad hoc network could be understood as the nodes are separated and form clusters. The cluster usually contains the cluster Head (CH) or gateway and ordinary nodes. The cluster head is the neighbor of other cluster heads. The cluster head could work as base station within the zone or clusters, performing communication between nodes, sending information between clusters[8]. For example, in figure 2, there are four clusters formed. The black nodes are the gateways since they are the neighbors between different clusters.

![Figure 3. Node-disjoint multiple paths](image3.png)

![Figure 4. Link-disjoint multiple paths](image4.png)

In addition, to increase the stability and the throughput of the network, the multipath routing is also proposed, which can be divided into the node-disjoint and link-disjoint that are shown in figure 3 and 4, respectively [5]. Thus, when nodes or links exist failure or down, other nodes or links can assist to finish the transmission. However, multipath routing also brings some problems, such as energy balance and multipath cooperation, etc.

For example, S means source node, in figure 3, D means destination node, A, B, and C are nodes in the network. There are three paths in this figure 3 which are SAD, SBD, SCD. Three paths do not share any common node except the source and destination nodes. Thus, three paths are node-disjoint multiple paths. If the main route fails, for example, assuming B is the main route in the main path SBD, the B
node is out of battery, the backup node could be used to send information since they do not have the node B in their route.

3. Three Current State-of-the-art Multi-path routing protocols

Multipath routing protocols focus on how to increase network load balancing, reduce network latency, and increase network transmission rates, which can establishes multiple routes between source and destination nodes[5].

Hesham A. Ali raised up an enhancement of DSR scheme using the cost function to establish load-aware multiple paths and compared it with pure DSR in the simulation[4].

In another paper[6], the fitness function is applied to multipath distance vector (AOMDV) routing protocol. The new multipath routing protocol is FF-AOMDV. The fitness function is applied to find the optimal path from different nodes and backup paths during the discovery phase[6].

In addition, in the paper [7], energy aware and stable cluster-based multipath routing (ES-CMR) is presented to increase the Quality of Service (QOS) of the network.

3.1. On-demand power and load aware node disjoint multiple paths routing

In this section, we will focus on the detail of the new protocol which has the features of on-demand, power-awareness and load-awareness. Since the protocol is based on the DSR protocol, it has a similar function as DSR, but it could find the optimal path by calculating the cost function from the source node to destination node[4]. The new protocol has three mechanisms which are power load function, on-demand multipath routing, and node-disjoint path compared to the basic DSR.

3.1.1. Power and load aware cost function

In the discovery phase, the cost function will calculate a cost value for nodes in the route path, then the node will be selected according to this value. In addition to the traditional DSR protocol, According to the paper, If the cost is the lowest and the cost of bottleneck node is higher, then this path is the optimal path and will be selected. The equation 1 means "the cost of node j at time t"; equation 2 means "the estimated lifetime of node i at time t"; equation 3 represents for battery capacity [4]. The equation 4 and 5 are used to calculate at all the nodes (except for the source) that participate in the available paths[4].

$$F(c_j(t)) = 1/Lt_j(t)$$  \hspace{1cm} (1)

$$Lt_j(t) = E_j(t)/ETR_j(t) \times P_{j,i}(t)$$  \hspace{1cm} (2)

$$ETR_j(t) = (1 - e^{\frac{timeGap}{k}})(pktSize/timeGap) + (e^{\frac{timeGap}{k}})estRate$$  \hspace{1cm} (3)

$$C(p_i) = \max_{j=1} F(c_j(t))$$  \hspace{1cm} (4)

$$C(p_i) = \sum_{j=1}^{m} F(c_j(t))$$  \hspace{1cm} (5)

Equation 4 means the bottleneck cost of the intermediate nodes from the path[4]. Another cost(Pcost) is calculated by formula 5. After receiving the modified RREQ packet with the cost values at the destination node, it will compare and select the optimal path with the minimum Pcost and maximum Mcost.
3.1.2. Route discovery and maintenance  Different from the traditional DSR protocol, the intermediate nodes have no ability to send RREP message to the source node, because the new scheme want node-disjoint. Only the destination node has the ability of the selection of optimal and node-disjoint route.

Figure 5 shows the source node phase of discovery of the new protocol. The intermediate node will create the Route Request Table (RRT) to store the RREQ packet information and drop the duplicate RREQ packet according to their Mcost which is calculated by equation 4. Then the duplicated RREQ packet will be stored in RRT and broadcast the packet after updating the packet detailed information[4].

When the packet arrives at the destination node, the destination address will be append to the RREQ packet and it will wait for more RREQ packets from the source node[4]. After a set time, the destination node will compare different path that it received. The computation is based on the formula 5 to select the lowest cost and destination node will set this path as the primary path. Other paths will be store in the cache in the sequence of the cost from low to high. The final RREP message which contains the primary path will be sent back to the source node[4]. The detailed phase is shown in figure 6.

The maintenance phase is the same as the traditional DSR. When the link is fail, the source node will search for a new route in its cache table or initiate the route discovery phase after receiving the error message.
3.1.3. Pros and Cons  The disadvantage of enhanced DSR protocol may be too many information contained in the head packet if the network is very big and the source node and destination node are far away from each other. Unluckily, the author only compares the PLA-DSR with the pure DSR in the NS2 simulator.

3.2. Energy Efficient Multipath Routing Protocol Using the Fitness Function
In this section, the FF-AOMDV protocol will be introduced.

3.2.1. AOMDV ROUTING PROTOCOL  First of all, the basic AOMDV protocol will be introduced. AOMDV is based on ad hoc on-demand distance vector (AODV) which is a single path protocol[6]. However, different from the AODV, the node could maintain multiple path to source or destination, and every copy of RREQ is processed in AOMDV. The duplicated copy will be dropped in AODV.

The protocol is similar as the DSR protocol which has the route discovery and maintenance phase. DSR has the problem when the route becomes bigger since the data packet carries the route information. AODV saves the route information in the nodes’ table when they receiving and forwarding data packets.

In the route discovery phase, the protocol has the ability to find node-disjoint route[10]. AOMDV could maintain loop free multiple path which means that the reverse path has the feature of loop-free and disjointedness[6].

3.2.2. Fitness Function and FF-AOMDV  In the research of AQEEL TAHA1, the fitness function is a "part of particle swarm optimization (PSO) algorithm[6]. Fitness function could also find primary routes when the optimal route fails.

![Figure 7. Optimum route selection in FF-AOMDV [6]](image)

The fitness function will first perform the scanning of the nodes with higher energy. For example, in figure 7 , the red nodes are the result of applying the fitness function. Then the protocol will choose the path with the highest energy level and least route distance as the primary path[6]. It could also choose two other path as backup if the short distance and energy level meet the requirement.

3.2.3. Pros and Cons  The AOMDV has the ability to find loop-free multipath routes. The fitness function is applied to choose the optimal path to improve the path choosing. The result shows that FF-AOMDV is performed more outstanding than the traditional AOMDV.
3.3. Energy-Aware and Stable Cluster-Based Multipath Routing Protocol

In this section, we will go into the details about Cluster-Based Multipath Routing Protocol in this paper [7]. In this scheme, there are three types of nodes which are cluster head, gateway and ordinary nodes. These nodes have been introduced in the introduction section. K-hop clusters need to be established for the routing in the ad hoc network[7]. K means the radius of the cluster and it determines the number of the cluster. The larger the k the less number of cluster.

3.3.1. Cluster creation and maintenance

The selection and creation of the cluster head are based on Entropy-based Weighted Clustering algorithm [11]. The election of cluster head is according to the stability and energy level.

The movement of the nodes may leads to the gateway failure, thus the Request Error Link Gateway (RRLG) message will be generated[7]. The RRLG contains the updated information of gateway nodes.

3.3.2. Intra-cluster and inter-cluster routing

The protocol has two parts which are inter cluster routing and intra cluster routing[7]. The intra-cluster routing is shown in the figure 8. Node 3 is the cluster head. The source node want to communicate with the destination node within the same cluster. The node s will first send the RREQ packet to the cluster head. Then the cluster head will response with the information RREP of the route to destination d since the cluster head knows all the information.

The inter-cluster is the routing between different clusters. The process is done by the management of cluster head and gateway nodes. For example, in the figure 9, the node 8 is the source node and it send the packet to the cluster head, then the cluster head broadcast the packet to the gateway when the destination node is not inside the cluster. The gateway forward the packet to the neighbour gateway and then forward to the cluster head. The path sequence is inserted in the RREQ message[7]. When the packet reach the destination node, it will reply RREP message with the route information.

3.3.3. Route selection

The timer is set to receive multiple RREP messages and then select the best path based on the energy consumption and path stability[7].

The energy consumption is calculated by the energy function \(f_{ep_j}(t)\). And the path stability is calculated by Link stability aware function. The link stability is measured by the coordinates of the nodes. We will not go into the details of these functions.

\[
f_{ep_j}(t) = \min_{j=1}^{n-1} f(e_{n_j,t}(t))
\]  

(6)

The equation 6 means the minimum residual energy of nodes. The left side of equation means the the cost of node i in the path j which is shown in the following equation 7 [7].

\[
f_{en_i,j}(t) = \frac{E_{lev_i,j}(t)}{D_{R_i,j}(t)} w_{i,j}
\]  

(7)
3.3.4. Pros and Cons  The ES-CMR is the clustering routing method which is different from the other two protocols. The nodes are formed in cluster. The gateway and cluster head are assigned. The protocol use energy aware function and link stability function to choose the path. The protocol contains the inter and intra cluster routing method.

| Table 1. Comparison of the aforesaid multi-path routing |
|---------------------------------------------------------|
| **Type**       | **Enhanced DSR** | **FF-AOMDV** | **ES-CMR**    |
|----------------|------------------|--------------|---------------|
| **Based on**   | On-demand routing| On-demand routing| Hybrid routing |
| **Evaluation Function** | power and cost function | fitness function | link and energy function |

4. Conclusion
In this paper, we review the current state-of-the-art multipath routing protocols for Ad Hoc networks, and discuss their advantages and disadvantages. The purpose of all these three protocol is to establish routes that could extend the life time of the network, improve the throughput and minimize the delay of node to node. As is shown in Table 1, the enhanced DSR and FF-AOMDV are on-demand protocols which could establish different routes from source to the destination on demand. Enhanced DSR (PLA-DSR) modified the traditional single route DSR to make it multi-path and node-disjoint. The main goal is to extend the battery life time because the multipath protocols can balance or optimize the energy consumption[4].

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