Probabilistic Connectionless Multipath Routing Algorithm for Reliability and Stability Evaluation

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Abstract. Aiming at the dynamic topology characteristics of mobile ad hoc networks, a dynamic multi-path routing algorithm based on improved probability disconnect multiple routing (IDPMR) performance is proposed, which can derive the classification of link cost function by considering real-time parameters, so as to flexibly allocate resources for transmission and reduce the impact between traffic categories. Based on the statistical characteristics of path remaining lifetime, the algorithm takes into account the correlation of adjacent link lifetime, so as to eliminate the theoretical error of existing algorithms in path stability estimation, and uses the optimized stability criterion to realize the multi-path selection of route discovery process and fast route repair based on backup path support. The simulation results show that the algorithm has fast convergence speed, can effectively improve the network throughput, shorten the data transmission delay and reduce the routing overhead, and better ensure the stability of data transmission under high node mobility.

Keywords: Reliability and Stability Evaluation, Probabilistic Connectionless, Multipath Routing, Network Topology, Path Remaining Lifetime

1. Introduction

In order to alleviate the adverse impact of time-varying topology characteristics of mobile ad hoc network (MANET) on mobile transmission, in recent years, link dynamic characteristics analysis based on link or path residual life time (RLL / RPL) estimation and "stability" priority routing strategy have become the focus of MANET research [1]. Although the existing algorithms achieve network optimization to a certain extent, there are still many deficiencies [2]. Firstly, the routing algorithm based on RLL estimation emphasizes the hop by hop routing decision at the link level [3], resulting in a large amount of network resources and node energy consumption; Secondly, RPL estimation [4] in path stability analysis ignores the RLL correlation of adjacent links caused by node sharing; In addition, the above problems also exist in the existing multi-path stable routing strategies [5], which limits the reliability of the algorithm.

In order to make up for this deficiency, this paper proposes a dynamic multi-path routing algorithm based on improved probability disconnect multiple routing (IPDMR) performance under the premise of fully considering the RLL correlation of adjacent links [6]. It has the characteristics of deriving link
cost function classification by considering real-time parameters, so as to flexibly allocate resources for transmission and reduce the impact between traffic categories. Based on the reactive source routing protocol, this algorithm improves the packet format and forwarding mechanism of route request (RREQ) and route reply (RREP) in the process of route discovery [7], and can realize the fast route repair supported by the alternate path.

2. Probability Connectionless Multipath Routing Algorithm

2.1 Improved PDMR Algorithm

For priority service, according to the principle of minimizing the penalty function of each routing cost between the source node and the destination node at the current time, the route is selected from the routing set determined in this paper. In the node cache, packets are queued according to their priority and arrival order to form a multi queue \( M / M / 1 \) queuing system with \( t \) priorities [8]. In different priority queues, regardless of the priority of the arrival time of the packets, nodes give priority to the higher priority groups. According to the \( M / M / 1 \) queuing system, the average delay of priority \( t \) service in the node, that is, the sum of the average queuing delay and the average processing delay of the node \( n_k \) to the packet \( 1/\mu \) is as follows [9]:

\[
\bar{W}_{k,t} = \frac{1}{\mu(1-\rho_{k,1} \cdots - \rho_{k,t})} + \frac{\overline{W}_{\text{res}}^{\text{res}}}{(1-\rho_{k,1} \cdots - \rho_{k,t-1})}
\]

(1)

where \( \rho_{s,j} = \frac{\lambda_{s,j}}{\mu} \) is the traffic intensity of priority \( t \) service in the node \( n_k \), and \( \lambda_{k,j} \) is the average remaining time of priority \( t \) group in node \( n_k \), which can be expressed as:

\[
\overline{W}_{\text{res}}^{\text{res}} = \frac{\overline{X}^2}{2} (\lambda_{k,1} + \lambda_{k,2} + \cdots + \lambda_{k,t})
\]

(2)

where \( \overline{X}^2 \) is the average second moment of the service time of nodes to packets. For the negative exponential distribution with parameter \( \mu \), it is easy to know that:

\[
\overline{X}^2 = \frac{\mu + 1}{\mu}
\]

(3)

Therefore, the following formula is satisfied [10]:

\[
\bar{W}_{k,t} = \frac{1}{\mu - \lambda_{k,1} - \lambda_{k,2} \cdots - \lambda_{k,t}} + \frac{\mu(\mu + 1)(\lambda_{k,1} + \lambda_{k,2} + \cdots + \lambda_{k,t})}{2(\mu - \lambda_{k,1} - \lambda_{k,2} \cdots - \lambda_{k,t})(\mu - \lambda_{k,1} - \lambda_{k,2} \cdots - \lambda_{k,t-1})}
\]

(4)

The propagation delay of packets over the channel is mainly related to the distance between adjacent nodes on route \( p \). The distance between node \( n_k \) on route \( p \) and the next node \( n_{k+1} \) is as follows [7]:

\[
I_{p,k \rightarrow p,k+1} = \sqrt{(a_{p,k} - a_{p,k+1})^2 + (b_{p,k} - b_{p,k+1})^2}
\]

\[ k \in \{1,2,\ldots,z-1\} \]

(5)

The propagation delay of packets between the node \( n_k \) and the next node \( n_{k+1} \) is as follows:
The delay of priority $t$ packets on the link between the node $n_k$ and the receiving computer $n_{k+1}$ is as follows:

$$d_{k \rightarrow k+1}^{\text{link}} = d_{k \rightarrow k+1}^{\text{pro}} + W_{k,j}$$

Therefore, the end-to-end delay $d_{p,t}$ of priority $t$ packets on route $p$ can be expressed as follows:

$$d_{p,t} = \sum_{k=1}^{z-1} (d_{k \rightarrow k+1}^{\text{pro}} + W_{k,j})$$

Since the link reliability mainly depends on the new arrival quality and has nothing to do with the service priority, the reliability of the link between nodes $n_{p,k+1}$ on route $p$ is recorded as $r_{k,k+1}(1 \leq k \leq z-1)$, and the reliability $r_p$ of routing $p$ is marked as:

$$r_p = \prod_{k=1}^{z-1} r_{k,k+1}$$

For route $p$, when the priority $t$ service is transmitted, the penalty function of routing cost is constructed as follows:

$$U_{p,t}^{\text{route}} = \alpha_i (1 - \frac{d_{p,t}}{D_j})^{-1} + \beta_i (1 - \frac{R_i}{r_p})^{-1}$$

Where, $\alpha_i$ and $\beta_i$ denote the weight coefficient of routing effectiveness and reliability in priority $t$ service, satisfying $0 \leq \alpha_i, \beta_i \leq 1$, and $\alpha_i + \beta_i = 1$. The weight coefficient here is used to meet the QoS requirements of different services when constructing routing. $D_j$ and $R_i$ are the end-to-end delay and reliability index of packet transmission of priority $t$ service respectively. Accordingly, the link cost penalty function between the node $n_k$ and the next node $n_{k+1}$ can be expressed as follows:

$$U_{k \rightarrow k+1,t}^{\text{link}} = \alpha_i (1 - \frac{d_{k \rightarrow k+1,t}^{\text{link}}}{D_j})^{-1} + \beta_i (1 - \frac{R_i}{r_{k,k+1}})^{-1}$$

In order to minimize the routing cost penalty function of the total traffic between the source node and the current node, the sub-optimization problem can be expressed as follows:

$$\min \left\{ \sum_{p=1}^{p_{\max}} \sum_{t=1}^{T} \frac{U_{p,t}^{\text{route}}}{\lambda} \right\}$$

subject to:

- $d_{p,t} \leq D_j, r_p \geq R_i$
- $p \in \{1, 2, \ldots, p_{\max}\}, t \in \{1, 2, \ldots, T\}$

The workflow of the improved PDMR (IPDMR) algorithm proposed in this paper is as follows: the multimedia traffic is divided into delay sensitive applications and the rest of the traffic; the two types
of multimedia traffic are forwarded to two separate FIFO queues according to the categories in the packet header field; different packet forwarding strategies are considered for each queue.

2.2 Improved PDMR Algorithm in Multipath Routing Calculation Process
In this paper, an improved PDMR algorithm is constructed. Figure 1 shows the flow chart of the improved PDMR algorithm in multipath routing. The calculation process of the algorithm in multipath routing includes the following steps [11]:
1. Multimedia traffic is divided into delay sensitive applications and other traffic;
2. The packet forwards the two types of multimedia traffic to two separate FIFO queues according to the category in the header field;
3. Considering different packet forwarding strategies for each queue;
4. Processes all queues starting from the priority queue.

![Flow chart of improved PDMR algorithm in multipath routing calculation](image)

**Figure 1.** The flow chart of improved PDMR algorithm in multipath routing calculation

3. Simulation Experiment and Result Analysis

3.1 Experimental Environment and Initialization
MATLAB R2018a simulation platform is used to realize the modeling of MANET, and the IPDMR algorithm is compared with the other two stable routing algorithms PRMLE [12] and LEBR [13]. Firstly, the convergence time of the three algorithms is compared, and then the throughput (TH), average data transmission delay (TD) and routing overhead (R_OH) are compared. Simulation results show the effectiveness and superiority of the proposed algorithm. Among them, LEBR is based on on-demand distance vector routing protocol (AODV). The RREQ and RREP packets of AODV only contain one hop of information on forwarding nodes. PRMLE local route repair mechanism means that when the stability of a link in the data transmission path decreases, the intermediate node can cache the data and start the route discovery mechanism to establish a new path with the destination node, while the routing repair of IPDMR algorithm is centrally controlled by SN [14].

3.2 Simulation Comparison of Algorithm Convergence Time
Figure 2 (a) shows the comparison results of $T_c$ with $N_{num}$ when $V_{max} = 5m/s$. As can be seen from the figure, the convergence time of each algorithm decreases with the increase of $N_{num}$. This is because the average distance between nodes decreases with the increase of node density, and the link stability is improved, which is conducive to the establishment of high-quality routing. In addition, when $N_{num}$ is small ($\leq 60$), the results of IPDMR algorithm $T_c$ are significantly smaller than those of the other two algorithms. Figure 2 (b) shows the comparison results of three algorithms with $V_{max}$ when $N_{num} = 60$. It can be seen from Figure 2 (b) that the increase of $V_{max}$ reduces the link stability, resulting in the rise of $T_c$ of each algorithm. However, the CT curve of the algorithm in this
paper rises most gently, and the $T_c$ value after $V_{\text{max}} \geq 5m/s$ is significantly lower than that of the other two algorithms.

(a) Number of nodes                         (b) Node moving speed

Figure 2. Simulation results of TC when the number of nodes and the moving speed of nodes change

To sum up, when the network state is good ($N_{\text{num}}$ is large, $V_{\text{max}}$ is small), the convergence speed of the three routing algorithms is equivalent; when the connectivity of network nodes decreases or mobility increases, the convergence time of IDPMR algorithm in this paper is shorter, which has certain advantages.

3.3 Simulation and Comparison of Network Performance Indicators

In the simulation, if the data transmission is still unable to complete after the process is restarted three times, the data is lost. In addition, the sending period of HELLO message used by PRMLE algorithm for power sampling is 1 (timeslot).

Table 1. Network performance simulation parameter settings

| Name of parameters | Parameters setting | Name of parameters | Parameters setting |
|--------------------|--------------------|--------------------|--------------------|
| Simulation area    | 400 m * 400 m      | Sending speed      | 2 packets / time slot |
| Node number        | 600-800            | Routing protocol   | IDPMR/PRMLE/LEBR   |
| Simulation cycle   | 100 time slot      | Time of routing select | Timer = 2 (time slot) |
| Simulation time    | 100 T0             | Node sending radius | 50 m               |
| Data form          | CBR                | Node minimum speed | 0                  |
| Single data size   | 100 packets        | Node maximum speed | 1-6 m / s          |

In Figure 3 (a), Figure 3 (b) and Figure 3 (c) respectively show TH, TD and R_OH obtained by the three algorithms when the node mobility $V_{\text{max}} = 3$ (m / timeslot) and the number of nodes ($N_{\text{num}}$) changes simulation results. In general, when the simulation area is fixed, increasing $N_{\text{num}}$ is equivalent to increasing the density of nodes, and the routing opportunities and connectivity between nodes are increased, so the network performance tends to be optimized.

As shown in Figure 3 (a), the TH of IDPMR algorithm is about 10% higher than PRMLE algorithm and LEBR algorithm respectively, and the optimization effect is most obvious when $N_{\text{num}} \in (660, 700)$. As can be seen from Figure 3 (b), compared with LEBR algorithm, IDPMR and PRMLE algorithm can reduce the average delay of data transmission by about 15%, especially when $N_{\text{num}}$ is small (the ratio is about 24% when $N_{\text{num}} = 600$). The root cause of this result is: IDPMR and PRMLE algorithm have fast routing repair mechanism, which can effectively avoid multiple route discovery and data retransmission caused by link break between $N_S$ and $N_D$, so as to better ensure the communication continuity. In Figure 3 (c), the algorithm R_OH is significantly lower than PRMLE algorithm: when $N_{\text{num}}$ is 600 and 800, the latter R_OH is about 1.6 and 2 times of the former. The results show that PRMLE has the same effect as our algorithm in shortening TD, but it has higher
R\textsubscript{OH} as a price. This is because the former R\textsubscript{OH}, in addition to RREQ, RREP and RERR messages, it also includes periodic Hello messages used for RLL estimation among neighbor nodes, which increases resource consumption to a certain extent.

Figure 3. TH, TD and R\textsubscript{OH} when the number of nodes changes simulation results

Figure 4 (a), FIGURE 4 (b) and Figure 4 (c) show the simulation results of each index obtained by the three algorithms when $N\textsubscript{max} = 700$ and $V\textsubscript{max}$ change respectively. In general, the network performance decreases with the increase of $V\textsubscript{max}$. It can be seen from Figure 4 (a) that the TH obtained by PRMLE and LEBR algorithms is basically the same, while the TH obtained by IDPMR algorithm is about 10% higher than that of the former two algorithms, and it is obvious under each $V\textsubscript{max}$ value. In Figure 4 (b), the TD value obtained by IDPMR algorithm is the smallest and the corresponding curve rises most gently. TD of PRMLE and LEBR algorithm increases significantly after $V\textsubscript{max} = 5$ and $V\textsubscript{max} = 4$ respectively. The average TD of LEBR algorithm is about 1.1 times of that of IDPMR algorithm when $V\textsubscript{max} = 1$ and 1.5 times of that of IDPMR algorithm when $V\textsubscript{max} = 6$. Figure 4 (c) shows the comparison results consistent with Figure 4 (b), and it is obvious that the R\textsubscript{OH} obtained by IDPMR is lower than the other two algorithms, especially when $V\textsubscript{max} = 1$ and $V\textsubscript{max} = 6$, PRMLE algorithm R\textsubscript{OH} is about 1.8 times and 2.2 times of IDPMR algorithm, respectively.

Figure 4. TH, TD and R\textsubscript{OH} with node moving speed changes simulation results

To sum up, the simulation results in Figure 3 and Figure 4 fully verify the effectiveness and superiority of the proposed algorithm: compared with the existing algorithms, IDPMR algorithm fully considers the RLL correlation of adjacent links, and can establish more accurate and reliable stability evaluation criteria, so that data transmission depends on the path with longer lifetime, and effectively reduces the adverse impact of high-speed node movement on data transmission, it has stronger adaptability, and improves network TH, shortens data TD and ensures lower R\textsubscript{OH}, to achieve a reasonable balance between stability and resource utilization.

4. Conclusion

In this paper, based on the analysis of the statistical characteristics of path RPL and considering the RLL correlation of adjacent links, an optimized path stability evaluation criterion is proposed, and then a dynamic multi-path routing algorithm with IDPMR performance is proposed, which can derive
the classification of link cost function by considering real-time parameters, so as to flexibly allocate resources for transmission and reduce the impact between traffic categories. The simulation results show that: compared with the existing stable routing algorithms, the proposed algorithm can provide more reliable path stability evaluation criteria, and can still maintain a faster convergence speed in the case of high network topology dynamics, and can effectively reduce the adverse impact of node mobility on data transmission, and improve the throughput of MANET network and shorten data transmission. It is of great significance to reduce the routing overhead.

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