Research on routing method of Multipath D2D Communication based on forward cellular network

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Abstract. Traditional communication route selection methods find the shortest communication path based on graph theory, ignoring the influence of communication parameter changes on routing selection, resulting in excessive consumption of communication resources. In order to solve the above problems, a multi-channel D2D communication routing method based on Forwarding cellular network is proposed. Based on the establishment of D2D cooperative forwarding mechanism in cellular network, the mathematical model of multi-channel D2D routing is constructed by adding QoS index. In D2D, the multi-channel routing of D2D is calculated by mathematical model. The results show that the proposed routing method not only has low transmission delay, but also can control the resource loss within 15% with good reliability.

1. Introduction
Multipath D2D communication technology can meet the communication needs of multiple communication devices simultaneously, while multipath D2D communication technology has higher requirements for routing selection[1]. The traditional communication routing method mainly uses the principle of network graph theory to establish the shortest path tree and seek the route that can make the communication path shortest. However, when this method is applied to multi-channel D2D communication, it cannot consider the change of routing strategy under different communication states, which leads to excessive consumption of communication resources and affects communication quality [2].

Cellular network is a kind of wireless communication network widely used at present. The forward cellular network can improve the data distribution efficiency of the original network while covering all the base stations in the communication area. In order to improve the data transmission efficiency of multipath D2D communication, this paper will study the routing selection method of multipath D2D communication based on forward cellular network on the basis of the above analysis content.

2. Research on routing method of Multipath D2D Communication based on forward cellular network
2.1. Establish D2D cooperative forwarding mechanism of cellular network
In multichannel D2D communication, the data transmission rate depends on the worst path of the communication channel. Therefore, this paper will establish D2D cooperation mechanism of...
forwarding cellular network to improve D2D communication rate. If the D2D communication collaboration cluster is \( V_N = \{1, 2, \cdots, N\} \), when multiple communication terminals transmit data to other device terminals in the collaboration cluster, the information source terminal set is \( V_f \), and the receiver terminal set \( V_r \) is defined as the residual set of the source terminal set in the D2D communication collaboration cluster. The initial threshold value \([3]\) is calculated according to the following formula:

\[
T_0 = f_{\max}(U, i) = \max_{x \in U} d(i, x)
\] (1)

In formula (1), \( U \) is any non-empty subset; \( i \) and \( x \) are non-empty subspace elements; \( d \) is the distance between two communication terminals. The set of forwarding candidate relays in cellular network is calculated and the threshold value is iterated \( n \) times. In this paper, we need to calculate the resource consumption of each relay node in the communication process, and count the total resource consumption of D2D communication under the current path \([4]\). Among all the recorded resource consumption, a forwarding relay collaboration scheme with the lowest resource consumption is found to complete the establishment of D2D collaborative forwarding mechanism \([5-6]\). According to the multi-path D2D collaborative forwarding mechanism, the mathematical model of multi-path D2D routing selection is built with the goal of minimizing resource consumption.

2.2. The mathematical model of multipath D2D routing is constructed

In addition, QoS indicators are added to the multipath D2D communication under the forwarding cellular network, and the indicators are taken as the optimization target of the communication routing problem to establish the mathematical model of routing as shown below.

\[
\begin{aligned}
\min M_D(E_{\rho}) &= E \left[ \sum_{y \in E_{\rho}} k_y x_y \right] \\
\min M_E(E_{\rho}) &= E \left[ 1 - \prod_{y \in E_{\rho}} (1 - e_y) \right]
\end{aligned}
\] (2)

In formula (2), \( s \) is the end-user of D2D communication request; \( k \) is a D2D communication receiver user; \( \theta_{thr} \) is the threshold value of communication channel bandwidth demand; When \( x_y = 1 \), it means that the undirected path is on the routing path of multipath communication service \( E_{\rho} \); \( e_y \) is the packet loss rate of communication link; \( M_E \) is the maximum transmission rate of communication data when transmitted at both ends of D2D communication, which is numerically equivalent to the minimum bandwidth on the communication link; \( M_D \) is the duration of D2D communication data from the source end to the receiver, which is equivalent to the sum of all communication delays on the communication link numerically; \( \ell \) is the parameter, which represents the business cycle of D2D communication. The above equation requires that the maximum available communication bandwidth on the D2D communication path should be greater than the threshold value of D2D communication service bandwidth demand, so as to avoid the influence of resource loss on communication quality during the communication process \([7]\). After constructing the mathematical model of multipath D2D route selection, the selection weight of the route to be selected is calculated.

2.3. Calculate the routing selection weight

The combination of D2D communication and cellular network can improve the communication transmission rate to some extent, but the interference of D2D communication on the communication base station will also be affected, so it is necessary to calculate the selection weight of communication
network routing after D2D communication is connected [8]. The formula for calculating the total interference power of D2D routing to base station communication is as follows:

\[
\eta(v_i) = \left[ R_i^D - \mu PD \cdot g_{ib} \cdot \frac{\partial R^C}{\partial (PD \cdot g_{ib})} \right]
\]

In formula (3), \( R_i^D \) is the sum of the interference power of the forward cellular network to D2D communication users; \( \frac{\partial R^C}{\partial (PD \cdot g_{ib})} \) represents the negative gradient of the interference power received by D2D users in cellular network; \( PD \cdot g_{ib} \cdot \frac{\partial R^C}{\partial (PD \cdot g_{ib})} \) is the value that the interference power of D2D user results in the decline of cellular communication network usage rate; \( \mu \) is the proportion parameter; \( R^C \) is the communication rate; \( \eta(v_i) \) is the selection weight of route \( v_i \) to be selected. In the case of multi-channel D2D communication, the routing should be the one with the least channel fading and the least interference to network communication, and the routing weight should be as large as possible. According to the calculated route weight, the mathematical model as shown in formula (2) is solved to complete the selection of multipath D2D communication routes.

2.4. Realize multi-way D2D communication routing
Greedy algorithm is used to select the path with the least forwarding times of the distance data receiving node and establish the initial route. The initial cluster is formed according to the established initial routes. The cluster heads of the cooperative cluster are evenly distributed between the source node and the receiving node at the equivalent distance of signal transmission. Based on the path initially established, collaborative routing messages are sent according to the specified forward collaboration mechanism. When the cooperative routing message arrives at the receiving node, the receiving node generates the cooperative routing confirmation information. The confirmation information includes data transmission path, collaborative cluster header information, etc. From the receiving node to the source node, the path information in the data transmission process is stored. According to the calculated routing weight, in the path information of reverse transmission, after deleting the path whose bandwidth value does not meet the requirements of D2D communication bandwidth, the relay node with the highest weight is selected as the D2D communication path in turn. Update the D2D communication and transport node routing table according to the selected path, and then transmit the data in a point-to-point straight way. After the single data transmission, the cooperative cluster is dynamically updated and waits for the next communication.

3. Simulation verification and performance evaluation

3.1. Experimental process
The comparison group of simulation verification is the traditional communication routing method, and the verification group is the multipath D2D communication routing method based on forward cellular network studied in this paper. The data communication monitoring software was installed in two computer simulation platforms, and the monitoring software was used to record all the data in the simulation verification process. MATLAB was used to process the monitoring data recorded by the monitoring software, analyze the data and draw conclusions, and complete the preset objectives of simulation verification.

3.2. Simulation verification results
After applying the routing selection method of verification group and comparison group, the data
delay record table of experimental communication network is as follows.

| Table 1 Network communication data transmission delay /ms |
|-------------------------------------------------|
| The serial number | Method of this paper | Traditional method |
|                   | Maximum delay        | Minimum delay     | Maximum delay | Minimum delay | Delay differential | Maximum delay | Minimum delay | Delay differential |
| 1                  | 1.78                 | 1.16              | 0.62          | 2.48          | 1.65             | 0.83          |
| 2                  | 1.63                 | 1.09              | 0.54          | 2.55          | 1.53             | 1.02          |
| 3                  | 1.61                 | 1.03              | 0.58          | 2.63          | 1.66             | 0.97          |
| 4                  | 1.74                 | 1.04              | 0.70          | 2.58          | 1.72             | 0.86          |
| 5                  | 1.74                 | 1.05              | 0.69          | 2.76          | 1.71             | 1.05          |
| 6                  | 1.77                 | 1.26              | 0.51          | 2.47          | 1.67             | 0.80          |
| 7                  | 1.75                 | 1.28              | 0.47          | 2.75          | 1.61             | 1.14          |
| 8                  | 1.87                 | 1.19              | 0.68          | 2.59          | 1.53             | 1.06          |
| 9                  | 1.64                 | 1.34              | 0.30          | 2.67          | 1.54             | 1.13          |
| 10                 | 1.68                 | 1.20              | 0.48          | 2.52          | 1.61             | 0.91          |

By analyzing the above table, it can be seen that the maximum and minimum delay of the communication data transmitted by the experimental network using this method is far less than that of the experimental network using the traditional method. The difference between the maximum and minimum delay of data transmission in the experimental network using this method is also smaller than that in the experimental network using the traditional method. According to the definition of delay difference, the experimental network communication route selected by this method has better communication reliability.

The experimental network carries out data transmission according to the routing nodes selected by two groups of routing methods. By recording the signal energy received by the receiving end and the signal energy sent by the sending end, the resource consumption ratio of network communication transmission after applying different methods is obtained. The higher the proportion of resource consumption, the more unsuitable the route given by the routing method for data transmission. The figure below shows the proportion of resource consumption in the experimental network data transmission using the two methods after software processing.

![Comparison of resource consumption proportion of network transmission data](image)

(a) Method of this paper  
(b) The traditional method

It can be seen from the above figure that under the background of different communication needs of users, the resource consumption proportion of the communication route selected by the proposed method in the experimental network is significantly lower than that selected by the traditional method. The information in the overall analysis figure and the communication route selected by the method in this paper are all used for communication, and the proportion of resource consumption is less than 15%, and the influence of different D2D communication distances on the proportion of resource
consumption is not obvious. The proportion of resource consumption varies with the change of D2D communication parameters when using the communication route selected by the traditional method. The above data indicate that the routing method studied in this paper can select the best communication route, reduce the consumption of data transmission resources, and improve the quality of D2D communication.

4. Conclusion

The extensive use of mobile devices, the explosive growth of business demand and the investment and construction of 5G communication technology make users have higher and higher requirements for communication quality. Multi-channel D2D communication can reduce base station load and equipment power consumption, gradually becoming one of the key technologies of 5G communication. This paper studies the routing selection method of multipath D2D communication based on forward cellular network. Through the comparison experiment with the traditional routing selection method, it is verified that the method studied in this paper can reduce the communication delay, reduce the communication resource loss and improve the communication service quality.

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