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A MPTCP Path Selection Strategy Based On Improved Grey Relational Analysis

Lan Kou, Sirui Chen, Rui Wang

Department of Software Center

Chongqing University of Posts and Telecommunications

Chongqing, china

chensirui_cqupt@126.com

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Abstract. Multipath Transmission Control Protocol (MPTCP), a transport layer protocol, proposed by the IETF working group in 2009, can provide multipath communication end to end. It also can improve the utilization of network resources and network transmission reliability. However, that how to select multiple paths to improve the end to end overall throughput, and how to avoid the throughput declining by the performance difference, become the focus of this study. We propose a path selection strategy based on improved gray relational analysis, and set the optimal values of the QoS parameters for the selected paths as the reference sequence. According to the value of improved grey relational degree (IGRD) which is compared with reference sequence, we select the paths with better performance, smaller difference for transmission.

I Introduction

With the development of various new applications in the Internet (especial for P2P applications), the users demand for network resources unprecedentedly. But in reality, the related protocol in the terminal and the network greatly limits the utilization of network resources. If the network resources can be used simultaneously, to the end users, the performance will be greatly improved. At the same time, more and more equipment with multiple network interfaces can be equipped with multiple network addresses. In this case, it is possible to make use of multiple network interfaces for communication terminal path parallel transmission to improve the efficiency of network.

MPTCP protocol supports multiple paths to transmit data simultaneously, so it has the features of high fault tolerance, high reliability, high throughput and high security. The protocol added MPTCP layer functions mainly includes: a) packet scheduling; b) path management. Path Management is responsible for paths discovery, available paths selection and unavailable paths deletion. This paper focuses on MPTCP path selection in path management section study, we propose a method for a path selection strategy based on improved grey relational analysis and carried out a simulation test for the strategy. The second part describes MPTCP path selection, and the third part will describe a path selection strategy based on improved grey relational analysis in detail, the fourth part verity the effciency by simulating strategy, the fifth part is the summary of this paper, and states the content of future work.

II MPTCP Path Selection

According to RFC6182 suggestion [1], the sender buffer and the receiver buffer are both set to $2\times sum(B_i)\times RTT_{\max}$, the $sum(B_i)$ is the sum of all the sub-flow bandwidths. $RTT_{\max}$ is the max round-trip time for sub-flows. When the simultaneous transmission of multiple paths, there is a path with poor performance, large RTT, the receiver buffer will require more space than the actual buffer space, and will cause the receiver buffer blocking.

Secondly, data scheduling distribute data according to the information that data path management provided. If there is a path with small bandwidth, and a long time packet delay, that may cause the receiver buffer blocking, it will affect the overall system performance.

If a MPTCP connection lifetime discovers new paths available, and its performance difference is same as the above extreme case, the same problem will occur. There will be a great impact on the overall system performance. At this point, using fewer paths with excellent performance is better than all paths for transmission.

At present, the number of special studies for MPTCP path selection is very less. The studies of path selection are mostly focus on the network layer, such as the routing between nodes. The core issue of path selection is comparing the difference performance between paths. In this paper, we compare three QoS parameters: bandwidth, RTT, and packet loss rate. Then we select the paths which performance is good and the difference between these is less for transmission.

Ⅲ A Path Selection Strategy Based on Improved Grey Relational Analysis

In this paper, we use a method of path selection strategy based on improved grey relational analysis (IGA) to select the paths in the environment of MPTCP for transmission. It aims to improve the throughput end to end.

A. An Improved Gray Relational Analysis

Grey relational analysis (GRA) [3] is an effective method to analyze discrete sequence related grade. The basic idea is to estimate the extent of its degree of relevant tightness by determining the relevant degree of similarity shape between the reference data sequence and the other comparative data sequences. It reflects the degree of association of the curve and can be used to select the best sequence. It is widely used in project selection, factor assessment. The basic principle is to define a reference sequence which represents an ideal situation, the correlation between the reference sequence and other sequences can use gray relational degree (GRD) to calculate, the GRD is larger ,the sequence is better.

GRA is usually divided into three steps:

a. Define the reference sequence and comparative sequences

The optimal value of the corresponding QoS parameters set as the reference sequence,

The reference sequence $X_0 = \left\{ x_0(1), x_0(2), \ldots, x_0(k) \right\}$;

Comparative sequences $X_i = \left(x_i(1), x_i(2), \ldots x_i(k) \right), i = 1, 2, \ldots n$

b. Normalize comparative sequences

If the number of comparative sequences is n, $(X_1, X_2, \ldots X_n)$. Each sequence has k elements, $X_i = \left(x_i(1), x_i(2), \ldots x_i(k) \right), i = 1, 2, \ldots n$. If the normalized value is $x_i^*(j)$, there are two ways to caculate the normalized value of the sequence elements in diffrent cases.

The element value is larger, the sequence is better, such as bandwidth.

$$x_i^*(j) = \frac{x_i(j) - s_j}{l_j - s_j} \qquad \text{(Eq. 1)}$$

The element value is smaller, the sequence is better, such as RTT and packet loss rate.

$$x_i^*(j) = \frac{l_j - x_i(j)}{l_j - s_j} \qquad \text{(Eq. 2)}$$

$l_j = \max\left(x_1(j), x_2(j), \ldots x_n(j) \right)$, $s_j = \min\left(x_1(j), x_2(j), \ldots x_n(j) \right)$.

c. Calculate GRD [4]

Firstly, we calculate $\Delta_i = \left\{ \Delta_i(1), \Delta_i(1), \ldots, \Delta_i(1) \right\}$,

$$\Delta_i(j) = \left| x_0^*(j) - x_i^*(j) \right|, i = 1, 2, \ldots, m \qquad \text{(Eq. 3)}$$

Then, get the value

$$\Delta_{\max}(j) = \max_{(i,j)} \Delta_i(j) = \max_i \max_j \Delta_i(j) \quad \text{(Eq. 4)}$$

$$\Delta_{\min}(j) = \min_{(i,j)} \Delta_i(j) = \min_i \min_j \Delta_i(j) \quad \text{(Eq. 5)}$$

Calculate gray relational coefficient (GRC)

$$GRC_j = \frac{\Delta_{\min}(j) + \varepsilon\Delta_{\max}(j)}{\Delta_i(j) + \varepsilon\Delta_{\max}(j)} \quad \text{(Eq. 6)}$$

$\varepsilon \in (0,1)$, usually $\varepsilon=0.5$.

Finally, calculate GRD

$$GRD_i = \frac{1}{m}\sum_{j=1}^{m} GRC_j \quad \text{(Eq. 7)}$$

The value of GRD is larger, the sequence is better.

Improved gray relational analysis introduced a concept of QoS weights in step c. We use IGRD to take place of GRD.

$$IGRD_i = \sum_{j=1}^{m} Q_j \times GRC_j \quad \text{(Eq. 8)}$$

GRD does not take into account the importance of each element in the sequence, however, according to the importance of the different elements in a sequence, the IGRD use the weight of each element multiplied by the GRC, the value of IGRD is larger, the path is better.

B. Use Analytic Hierarchy Process(AHP) to Calculate QoS Weights

It is proposed in above section, we use improved gray relational analysis to calculate the IGRD between reference sequence and every comparative path sequence. The IGRD is larger, the corresponding path is better. Now, we calculate each weight of bandwidth, RTT and packet loss rate by the way of AHP [5].

In this paper, we will define the importance of the different performance indicators into five levels, 1, 3, 5, 7, 9. The level is higher, the degree is more important. 1 means the same degree of importance, 1/3, 1/5, 1/7, 1/9 and 3,5,7,9 are opposite. In MPTCP multiple parallel transmission environment, packet loss rate is more important than the RTT, RTT is more important than the bandwidth. So we come to the judgment matrix shown in Table 1.

Table 1 Judgment matrix

Performance parameter	Bandwidth	Packet loss rate	RTT
Bandwidth	1	1/5	1/3
Packet loss rate	5	1	3
RTT	3	1/3	1

We use the AHP to calculate the weights of Q1, Q2, Q3.

$$\begin{bmatrix} 1 & 1/5 & 1/3 \\ 5 & 1 & 3 \\ 3 & 1/3 & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} (1\times 1/5\times 1/3)^{1/3} = 0.40545 \\ (5\times 1\times 3)^{1/3} = 2.46621 \\ (3\times 1/3\times 1)^{1/3} = 1 \end{bmatrix} \Rightarrow \begin{bmatrix} 0.40545/3.87165 = 0.10472 \\ 2.46621/3.87165 = 0.63699 \\ 1/3.87165 = 0.25829 \end{bmatrix} \Rightarrow \begin{bmatrix} 0.10472 \\ 0.63699 \\ 0.25829 \end{bmatrix}$$

The conclusion of AHP: Q1=0.10472; Q2=0.63699;Q3=0.25829.
Then, we verify the consistency of the matrix.

$$\begin{bmatrix} 1 & 1/5 & 1/3 \\ 5 & 1 & 3 \\ 3 & 1/3 & 1 \end{bmatrix} \begin{bmatrix} 0.10472 \\ 0.63699 \\ 0.25829 \end{bmatrix} = \begin{bmatrix} 0.31821 \\ 1.93546 \\ 0.78478 \end{bmatrix}^T$$

Largest eigenvalues $\lambda_{\max} = \frac{0.31821}{3\times 0.10472} + \frac{1.93546}{3\times 0.63699} + \frac{0.78478}{3\times 0.25829} \approx 3.03850$

$$C.I. = \frac{\lambda_{\max} - n}{n-1} = \frac{3.0385-3}{3-1} = 0.01925 \quad \text{(Eq. 9)}$$

Table 2 shows the 1-8 order positive and negative matrix was calculated 1000 times to get an average random consistency index.

Table 2 Average random consistency index

n	1	2	3	4	5	6	7	8
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41

The random consistency ratio,

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.01925}{0.58} \approx 0.03319 < 0.1 \quad \text{(Eq. 10)}$$

Thus, we select the judgment matrix with consistency, Q1, Q2, Q3 values theoretically reasonable. The value of IGRD can be:

$$IGRD_i = Q1\times GRD_1 + Q2\times GRD_2 + Q3\times GRD_3 \quad \text{(Eq. 11)}$$

According to equation 11, we calculate the IGRD of each path sequence compared with reference sequence. According to a large number of simulation and experience, we derived IGRD threshold T ∈ (0.55, 0.65), that is, when IGRD> T, choose the path for transmission; When IGRD <T, do not choose the path for transmission.

Ⅳ Simulation

We use NS3 to demonstrate the performance of the proposed strategy. In the simulation, the proposed strategy is able to improve the average throughput end to end.

A. Set up Simulation Scenario

In this paper, we use the network topology shown in figure 1 and set up the simulation environment without bottleneck link to evaluate the performance of IGA strategy.

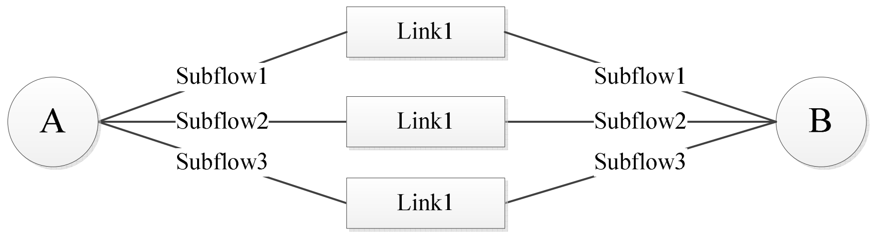

Fig. 1 Network Topology

In order to estimate the performance after using the IGA strategy in the typical network environment, we use different number of sub-flows simulation for performance. In simulation, we set the sender and the receiver buffer to 200 KB, use Round_Robin data scheduling algorithm, congestion control using a Linked Increases algorithm, the receiver data reconstruction using D_SACK algorithm.

B. Simulation Results and Analysis

There are four sub-flows between the sending and receiving ends. The parameters of sub-flows are shown in table 3.

Table 3 Sub-flow Parameters

Sub-flow number	Subflow0	Subflow1	Subflow2	Subflow3
Bandwidth(Mbps)	5	3	2	2
RTT(ms)	30	50	80	80
Packet loss rate(%)	0.2	0.1	0.3	0.2

The simulation results are shown in figure 2 and figure 3.

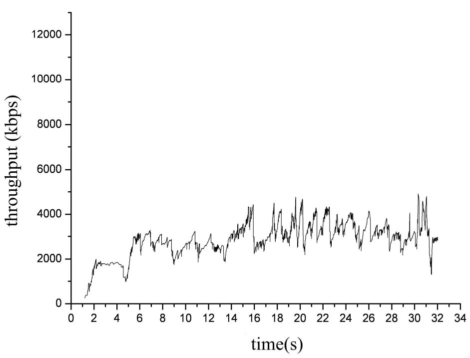

Fig. 2 MPTCP throughput

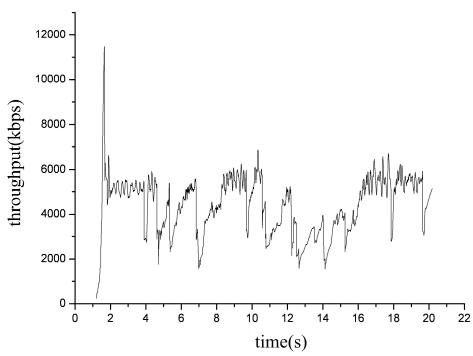

Fig. 3 Throughput after using the IGA

Figure 2 shows the curve of throughput changed with time, and the parameters of sub-flows is shown in table 3. Figure 3 shows the curve of throughput after using the IGA strategy. The average throughput of figure 2 that was calculated is 3.011Mbps, and the average throughput of figure 3 is 4.609 Mbps.

It can be seen, although the standard MPTCP use 4 sub-flows to transmit, but the difference between the sub-flows is large, it is easy to cause packet reordering, and then, result in receiver blocking. After using IGA strategy, it just uses 2 sub-flows for transmission, subflow0 and subflow1, the performance of each sub-flow is best and close. Package reordering effect is relatively small, therefore throughput is higher.

Ⅴ Summary

In this paper, we propose a path selection strategy based on gray relational analysis in the MPTCP environment. It proves by simulation that using this strategy can improve the MPTCP average throughput end to end. Because of the limitation of conditions, we only tested the four paths, the next step we will set up more complex network environment to test the performance of the strategy for further research and analysis.

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