Multi-attribute Aware Path Selection Approach for Efficient MPTCP-based Data Delivery

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Abstract

With the increasing diversity of wireless access technologies, and the further integration of mobile communication and heterogeneous wireless networks, more and more mobile devices equipped with multiple network interfaces. The mobile devices, which have integrated multi-homing technology, can transmit data through multiple network interfaces to improve the quality of data transmission for users. The advantages of multi-homing technology have contributed to the rapid development of multipath protocols. Multipath Transmission Control Protocol (MPTCP) is an extension of the traditional Transmission Control Protocol (TCP), which can take advantage of the capabilities of multiple network interfaces to simultaneously make use of multiple paths for data transmission, aiming at improving the performance of the data delivery. Although the multi-homing mobile devices configuring MPTCP protocol can obtain a lot of benefits, the current MPTCP path selection mechanism is too simple resulting in some concerns. So, a multi-attribute aware path selection approach for MPTCP (MPTCP-MAPS) is proposed in the paper, which jointly taking the Round-Trip Time (RTT) and the packet loss rate (Loss) of transport layer into account for efficient data delivery. MPTCP-MAPS designs a Multi-attribute path switch Prober (MP) to enhance the efficiency of the path selection mechanism. The results, which are gained from a closing realistic simulation topology, demonstrate how MPTCP-MAPS' path selection approach is superior to the current MPTCP path selection mechanism in terms of continuity of mobile services and performance in heterogeneous wireless networks.

Keywords: wireless access technology, MPTCP, path selection approach, mobile device

1 Introduction

In the background of the rapid development of wireless communication technology such as WiFi, 4G, WiMAX, and LTE [9], large-scale deployment of diversified wireless networks, and the further integration of mobile communication and Internet technology, an increasingly mobile devices [20] and wireless terminals (i.e., smart phones, PADs, etc.) are designed to equip with multiple interfaces and have the ability for simultaneously connecting multiple heterogeneous networks to send packets[6]. According to the above trends, it is possible for the mobile network services to become the most popular service in the future networks [3]. When the multi-homing mobile devices transmit data through attaching multiple heterogeneous accesses, it not only can obtain more throughput, but also can enhance system robustness. In order to make full use of the advantages of wireless access technologies, Internet Engineering Task Force (IETF) has proposed Multipath Transmission Control Protocol (MPTCP) in recent years [17].

Due to being an extension of TCP protocol, MPTCP can be compatible with traditional TCP protocol

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and never need much modifications for today's Internet applications to achieve data delivery by using more than one path. Therefore, the MPTCP can be widely deployed and applied in the realistic network environment. The main idea of MPTCP [12] is making the best use of multiple heterogeneous access capability and resource sharing at the same time so as to distribute data flow to multiple links for implementing simultaneously data transmission. Owing to MPTCP's multipath transmissions and bandwidth aggregation features, a mobile device with multiple heterogeneous access capability can make the best use of multiple network interfaces for data sending and receiving simultaneously to increase performance of data transmission, improve the robustness of system, and maximize utilization of the network resource [12]. At present, Apple has widely applied the principle of MPTCP to the Siri application of Apple's iOS7 and above version [1].

Although many researchers have paid a lot of attentions to the development of MPTCP resulting in many peer-reviewed publications have emerged, there are still many challenges for the deployment and adoption of MPTCP. What's more, the principles of MPTCP have been deployed in a multi-homing mobile device to verify the benefits of impressing on multiple heterogeneous access technology [4]. Unexpectedly, a lot of efforts have been devoted to simultaneously utilizing multiple heterogeneous networks [11], but multi-homing mobile devices still can't access to multiple network interfaces to transmit data. On the other hand, because the current MPTCP path selection mechanism is too simple, it can't make full use of the advantages of MPTCP to carry out multipath transmission data [24]. This will inevitably lead to serious effect on user's Quality of Experience (QoE).

To solve the above concerns, a multi-attribute aware path selection approach for MPTCP (MPTCP-MAPS) is proposed by us. In the WiFi and cellular network environments [21], when a multi-homing MPTCP-based mobile device selects the path to transmit data, the proposed approach takes not only RTT value but also Loss value into consideration. MPTCP-MAPS can implement Soft Hand-over of the network connection to achieve continuity of mobile services and maximize the network resource utilization.

The rest of the paper is structured as follows. The detailed design of MPTCP-MAPS is described in Section 2. Section 3 gives the description of simulation topology and bases on the results to evaluate and analyze performance of MPTCP-MAPS. Section 4 gives conclusion of the paper and our future work.

2 MPTCP-MAPS Detail Design

2.1 Multi-attribute path switch Prober(MP)

In the realistic heterogeneous network environment [10], the Apple's iphones always connect WiFi networks to transmit data, even though WiFi network is in a network congestion condition. In this case, the mobile devises can only switch to cellular networks by manually closing the connection of WiFi network or moving into a place where WiFi networks' signal can't be received [14]. This path switching mechanism has greatly reduced the performance of MPTCP [16]. In order to improve the efficiency of MPTCP path switching mechanism, we propose a Multi-attribute path switch Prober (MP).

According to the discussions of previous work [8], the attributes of transport layer are useful to evaluate the performance of MPTCP. Especially, RTT and Loss values play the most important role to prober whether the path has a network congestion. Therefore, RTT and Loss values of the transport layer are taken into account in our solution as important attributes, detecting path transmission quality. The MP is as follows:

$$MP_i = \alpha \times \varphi_i + \beta \times PLR_i \tag{1}$$

where MP_i is on behalf of the detected transmission efficiency of path i, α and β are weighting factors which use a fair and default value of $1/2$, the RTT value of path i is denoted by φ_i, and PLR_i represents the Loss value of path i. Meanwhile, the path has the best transmission efficiency, which is with the smallest *MP* value. The value of φ can be easily obtained by Eq. (2) .

$$\varphi = \varepsilon \times \overline{\varphi} + (1-\varepsilon) \times (T - time_{send} - \Delta time) \tag{2}$$

where $\overline{\varphi}$ represents the current round trip time, ε is set to 0.875 which is a weighting parameter, the timestamp is represented by T, which denoting the time where the acknowledgment packet has been received at the sender, $time_{send}$ is the packet sending time of timestamp, $\Delta time$ indicates time interval at which the packet is transmitted to receiver, in the light of [8].

To better gaining the value of *PLR*, we have proposed a novel Path Quality-Aware Model (PQM) in our previous work [7]. In order to keep the independence of the paper's contents, we simply introduce the data traffic offload process of PQM algorithm. Let AB_{p_i} , which used in Eq. (3), refers to the available bandwidth of path p_i, obtained by the Mathis model [15], can be calculated by the following equation.

$$AB_{p_i} = \frac{C}{\varphi_{p_i} \times \sqrt{PLR_{p_i}}} \tag{3}$$

which C denotes a constant set to $1.22 \times MSS$, and *MSS* is on behalf of the maximum segment size. In our solution, *MSS* is set to 1500, which is the length of MPTCP MTU (Maximum Transmission Unit).

According to Eq. (3), we can derive *PLR* to express by:

$$PLR_{p_i} = \left(\frac{C}{\varphi_{p_i} \times \sqrt{PLR_{p_i}}}\right)^2 \tag{4}$$

In order to calculate the Loss value in Eq. (4), we can use $\frac{cwnd_{p_i}}{\varphi_{p_i}^{min}}$ (the Vegas model [2], which $cwnd_{p_i}$ denotes the congestion window size of p_i. Due to considering sporadic losses, $\varphi_{p_i}^{min}$ is the minimum RTT value of p_i) to estimate the value of AB_{p_i} .

From the above steps, the value used in Eq. (1) is normalized value of φ, λ, showing in Eq. (5).

$$\lambda = \frac{\varphi_{curr}}{\varphi_{max}} \tag{5}$$

which φ_{curr} refers to the current φ value, and φ_{max} is the maximum value of φ.

Meanwhile, using δ to represent the normalized value of *PLR*, expressed by Eq. (6).

$$\delta = \frac{PLR_{curr}}{PLR_{max}} \tag{6}$$

which PLR_{curr} refers to the current *PLR* value, and PLR_{max} is the maximum value of *RLR*.

With the combination of these two parameters, Eq. (1) should be modified as follows:

$$MP_i = \alpha \times \lambda + \beta \times \delta \tag{7}$$

By taking multiple attributes of transport layer into consideration, the MP model can be more accurate to detect whether a network congestion has occurred or not. By making use of MP model, the multi-homing MPTCP-based mobile devices can enhance the efficiency of path switching mechanism to select a path with better quality for transmission data.

2.2 Multi-attributes Path Switching Model (PSM-M)

Supposed that there are n possible paths $(p_1, p_2, \cdots, p_n)$ in the MPTCP collection. The PSM-M begins to estimate the *MP* value of each path by basing on the above equations, while the multi-homing MPTCP-based mobile devices start to transmit data, and store values [14] into the quality list (denoted q_{list}). The quality list's each element is composed of the index of path i and the value of MP_{p_i}. The pseudo code of PSM-M is shown in Algorithm 1.

Algorithm 1 The algorithm of paths' MP value collection

Definition:

p_i : the i_{th} path of MPTCP transmission paths
MP_{p_i} : the detected transmission quality of path p_i
q_{list} : the quality list for each path

using Eq. (1), (2), (4), (5), and (6) to estimate MP value for each path
set MP_{p_i} = the calculated MP value of each path
for each path p_i within MPTCP transmission paths **do**
  if p_i's status is ACTIVE **then**
    $q_i = (i, MP_{p_i})$
    put q_i into q_{list}
  end if
end for

Algorithm 2 The algorithm of PSM-SP-based path sorting

Definition:

q_{list} : the quality list of all paths
q_i(a pair) : the quality value of i_{th} path
p_{list} : a preferred path list selected from q_{list}

for all pairs q_i within the q_{list} **do**
all paths are sorted in an ascending order basing on the MP value of each path
  set $k = q_i \rightarrow$ path index
  put p_k into p_{list}
  $k = k+1$
end for

2.3 Switching Prober Path Sorting Model (PSM-SP)

An optimized path selection approach is proposed by PSM-SP which based on MP by path's RTT and Loss value, so as to possibly obtain the lowest MP first. After PSM-M has successfully implemented the collection of q_{list}, PSM-SP will sort all paths in ascending order according to each MP value [14] in the q_{list}. The Algorithm 2 shows pseudo code of PSM-SP.

2.4 Multiple Attribute-driven Path Switching Model (PSM-MA)

Under the two models, PAM-MA is able to support packet for arriving orderly. Once fulfilling the sorted paths, PSM-MA will:

1) switch transmit data path to the first path ($d_{list(0)}$) in the d_{list} ; or

2) select second path i in the d_{list} to transmit data, if the $d_{list(0)}$'s cwnd is full [14], and so on.

The pseudo code of PSM-MA is presented by Algorithm 3.

Algorithm 3 The algorithm of PSM-MA-based data transmission

Definition:

d_{list} : a preferred path list obtained by PSM-SP

$d_{list(0)}$: the first path of d_{list}

d_{send} : a candidate path for data transmission

When a packet is sent (d_{list} has been formed in the premise),

1: set $d_{send} = d_{list(0)}$
2: **while** $d_{list(0)}$'s cwnd is full **do**
3: set $d_{send} = d_{list(0)} \rightarrow$ next
4: **end while**
5: transmit the packet by d_{send}

Table 1: Path configuration used in the simulation

Parameters	**Path 1**	**Path 2**
Wireless technology	IEEE 802.11b	IEEE 802.16
Access link bandwidth	11Mbps	10Mbps
Access link propagation delay	10∼20ms	10∼20ms
Access link queue limit	50	50
Access link queue type	Droptail	Droptail
Uniform loss rate	1%∼2%	1%∼2%

3 Simulation And Analysis

3.1 Simulation setup

We explore the performance of MPTCP by making use of the useful Network Simulator version 2.35 (NS 2.35) [23], because the information of MPTCP transmission data can be easily obtained in NS 2.35. Nowadays, with the rapid development of wireless heterogeneous network [22], WiFi networks can be seen in everywhere [13]. What's more, most of mobile devices have multiple wireless network interfaces to connect the Internet [19]. As we can see from Fig. 1, the simulation topology is composed of the sender and receiver of MPTCP, which are attached two paths (denoted Path 1 and Path 2, respectively) at the same time [5]. In order to simulate a more realistic wireless network environment, the packet loss rate for each wireless link is set to uniform. Among them, the bandwidth of path 1 is 11Mbps and 10ms propagation delay with the interface of Wifi/IEEE 802.11b, the bandwidth path 2 is 10Mbps and 10ms propagation delay with WiMax/IEEE 802.16 interface. The total time of simulation experiment is 120s. The detailed parameters of two paths are shown in Table 1.

At present, the optimization scheme for MPTCP protocol lacks consideration of the background traffic. According to our previous work [8] mentioned, the current total Internet traffic is made up by 80%∼83% of TCP traffic and 17%∼20% of UDP traffic [7]. So, we design a realistic simulation topology which uses the combination of TCP traffic, UDP/VBR traffic as background traffic. To obtain 80% TCP and 20% UDP traffic from each wireless link, we add four TCP generators and one UDP generator into each router (as shown in Fig.1: R_1, R_2, R_3, R_4). All connections of all traffic generators

Table 2: Parameters Used In VBR Traffic Generator

Variables	**Values**
Application/Traffic/VBR set rate_	448Kb
Application/Traffic/VBR set random_	0
Application/Traffic/VBR set maxpkts_	268435456
Application/Traffic/VBR set maxSize_	200
Application/Traffic/VBR set minSize_	100
Application/Traffic/VBR set intervaltime_	200

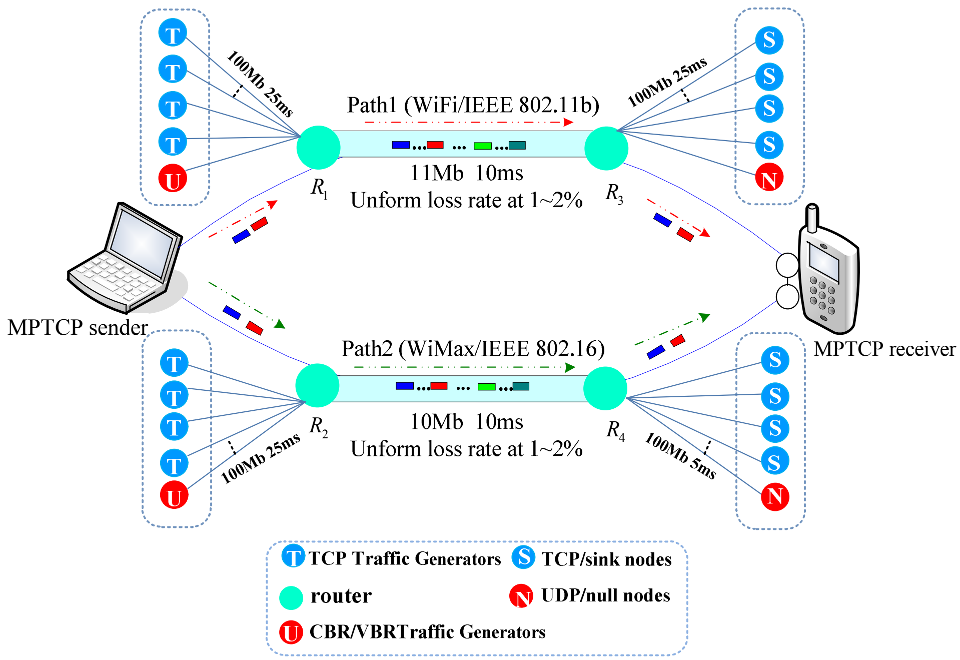

Figure 1: Simulation topology

to each router are set to reasonable bandwidth value of 100Mb and propagation delay of 25ms. In order to be able to set the VBR traffic in the experiment [18], we need to configure the VBR traffic generator in the NS 2.35. We need to add PT_VBR as packet enumeration, and set the value of PT_VBR to VBR in packet information function. Table 2 shows the default values for VBR traffic. The default parameter values of FTP traffic generator is provided by NS 2.35.

3.2 Simulation results

Based on the current MPTCP path selection mechanism, the multi-homing MPTCP-based mobile devices always connect to WiFi network interface in the multiple wireless network environment, regardless of WiFi network with a network congestion condition. In this case, the mobile devises can only switch to cellular networks by manually closing the connection of WiFi network or moving to a place where WiFi network can't be received. However, MPTCP-MAPS can avoid the situation that the mobile devices always use WiFi networks to transmit data when the performance of WiFi networks is worse than cellular

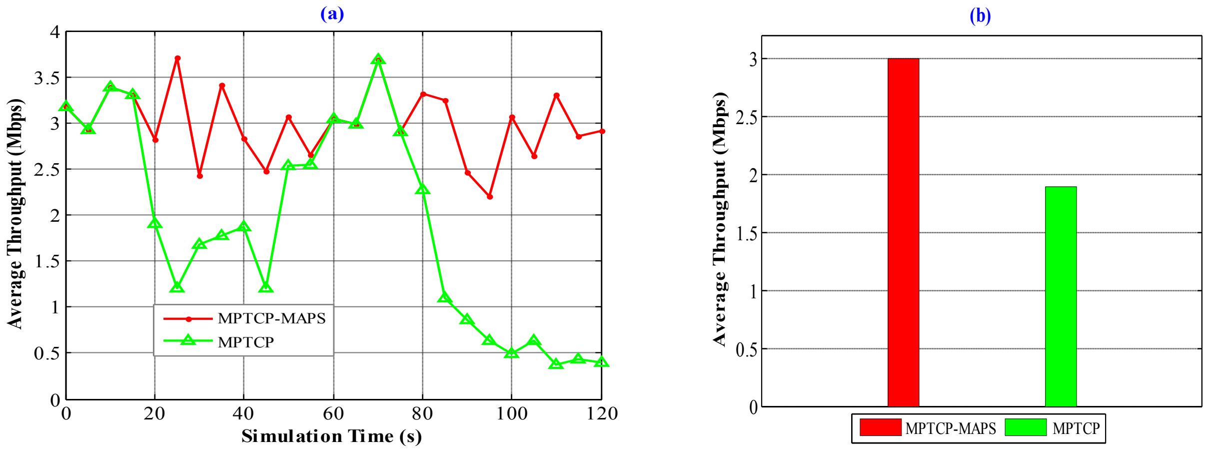

Figure 2: Comparison of average throughput and total average throughput

networks. By considering the value of RTT and Loss at the same time, MPTCP-MAPS can transmit data by a path which has better transmission quality. Those features make the multi-homing MPTCP-based mobile devices can achieve the continuity of mobile services and maximize the network resource utilization. According to the above simulation topology, we calculate and analyze average throughput, average delay, as well as packet sending and receiving times to compare advantages and shortcomings of two path selection mechanisms.

1) Average throughput: The average throughput is one of the important parameters of transport layer. Thus, average throughput can estimate the quality of all paths over multi-homing wireless networks. Fig. 2(a) presents the average throughput which generated by the two mechanisms in 120s. As the red line in Fig. 2(a) shows, the average throughput of WiFi link is smaller than 4G at 20s when the mobile device starts to remove as far as possible from WiFi access device at 10s, resulting in switching the transmission data link to 4G link. And the average throughput of WiFi link is higher than 4G at 60s when the mobile device begins to move near to WiFi access device at 30s, switching the transmission data link to WiFi link. Meanwhile, at 70s, the mobile device begins to stay away from WiFi access device, and the average throughput of WiFi link was smaller than 4G at 75s, which using 4G link to transmit data. However, the blue line shows the changing trend of the current MPTCP path selection mechanism's average throughput when it is away from or approaching to WiFi networks. Meanwhile, Fig. 2(b) estimates the performance of two mechanisms by comparing the average throughput of total simulation time. Compared with the current MPTCP path selection mechanism, the total average throughput of MPTCP-MAPS is 58% higher than the current MPTCP path selection mechanism.

2) Average delay: As we all know, the average delay is usually used to detect the efficiency and stability of the path. In order to better illustrate MPTCP-MAPS can timely switch the transmission data path to a path that has good transmission quality, Fig. 3 makes the comparison of the packet average delay when using the current MPTCP path selection mechanism and MPTCP-MAPS. In terms of the packet average delay, MPTCP-MAPS performs lower than the current mechanism. This is because MPTCP-MAPS takes the RTT and Loss value into consideration to select the path with high-quality for data transmission, it correspondingly reduces the packet average delay of paths. The higher packet average delay makes lots of packets fail to be received on time and submitted to application layer. Therefore, compared with the current mechanism, the better users' quality of experience (QoE) for data transmission services can be provided by MPTCP-MAPS.

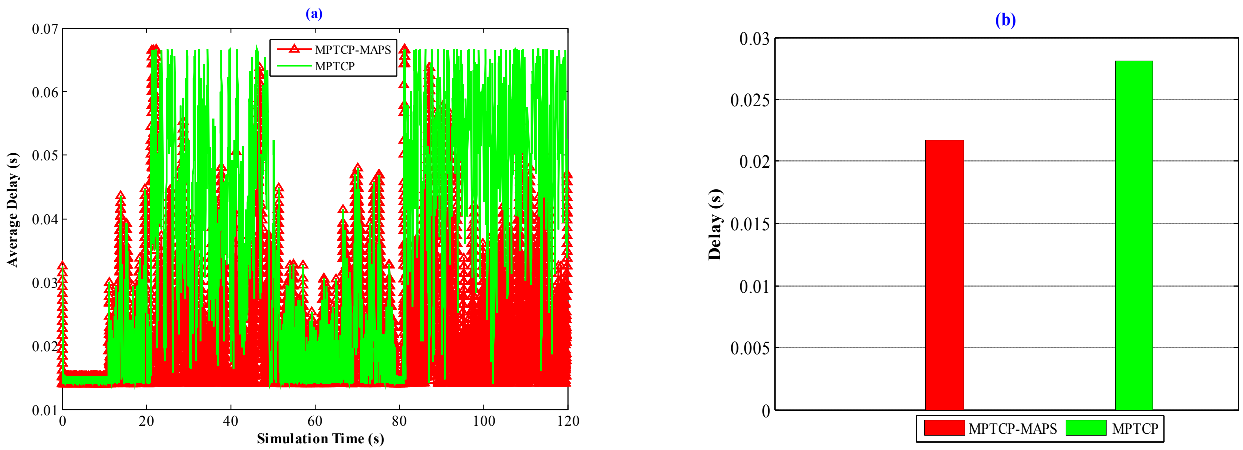

Figure 3: Comparison of average delay and total average delay

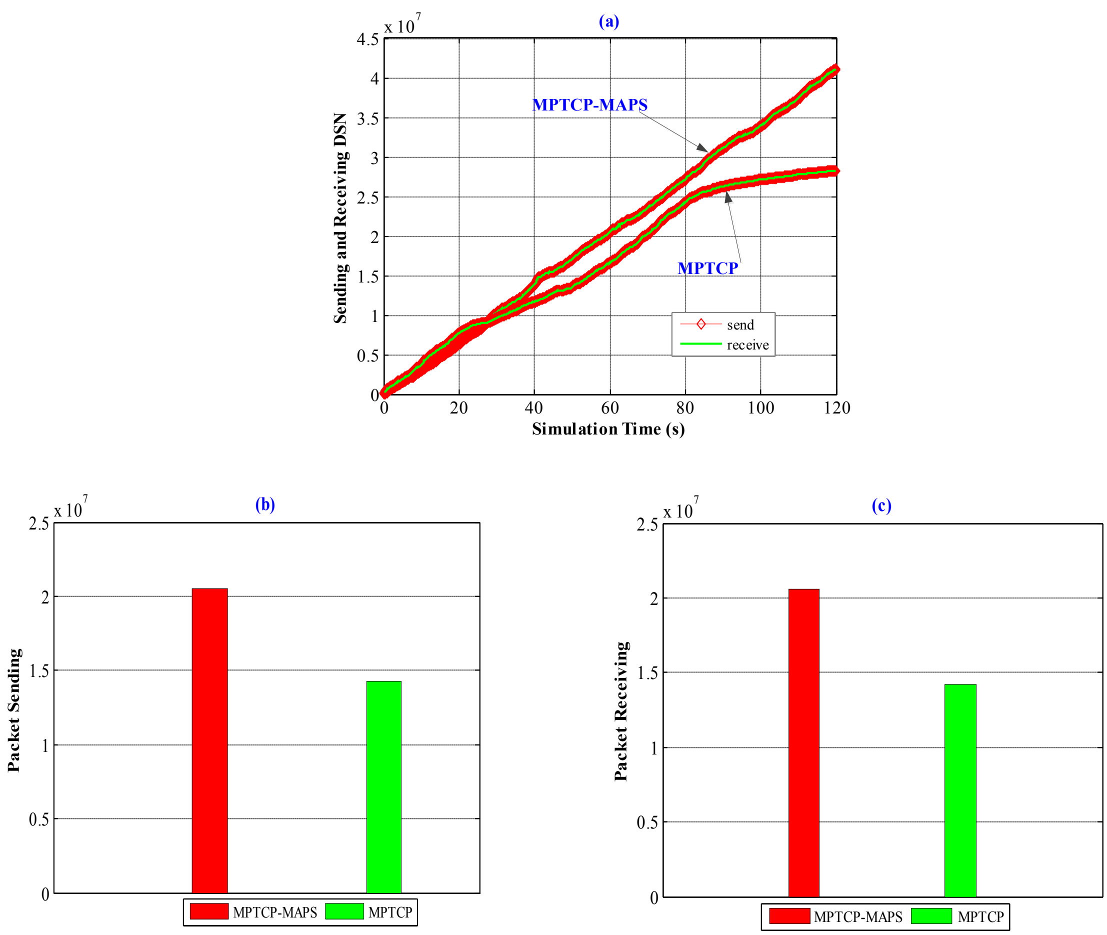

Figure 4: Comparison of sending and receiving time of packets

3) Packet sending and receiving times: Because MPTCP can select any one of multiple paths to send data, and once MPTCP takes advantage of the traditional TCP way to transmit data, there will be a part of packet in a sub-channel and others in another channel, resulting in the condition of serious packet loss. To solve this problem, MPTCP adds the data sequence number (DSN) to manage packet transmission. Since the sequence in each sub-channel continuously, MPTCP can make use of DSN to add up the total segment number. Fig. 4 describes several data packets' sending and arrival times when the current mechanism and MPTCP-MAPS are used, respectively. As can be seen from the figure, MPTCP-MAPS outperforms the current mechanism in regard to sending and receiving DSN. Because of the current MPTCP path selection mechanism, the mobile devices always connect WiFi network interfaces to transmit data, regardless of a network congestion condition. However, not only can we consider RTT value but also Loss value, MPTCP-MAPS selects a path which has better transmission quality to transfer packets. Therefore, MPTCP-MAPS can improve the throughput and reduce the packet loss probability.

4 Conclusion

Considering that the current MPTCP path switching mechanism always selects the WiFi network link to transmit data in the heterogeneous wireless network environments, Multi-attribute path switch Prober (MP) was designed in MPTCP-MAPS, aiming to enhance the path switching mechanism's efficiency. Although many researchers have paid a lot of attentions to the path switching mechanism of MPTCP, and the principle of MPTCP has been widely applied to the Siri application of Apple's iOS7 and above version, there are still many challenges for the development of MPTCP.

By taking the values of RTT and Loss for the transport layer into account, MPTCP-MAPS calculates the MP value, which denotes transmission quality of each path. For making full use of the quality information over each path, MPTCP-MAPS first sorts the paths in an ascending order by MP value of each path, namely, the lowest MP first. After a beneficial path list has been selected, MPTCP-MAPS will intelligently transmit data according to the sorted paths. The results show that how MPTCP-MAPS' path switching mechanism is superior to the current MPTCP path switching mechanism in terms of quality of service and performance in heterogeneous wireless networks. We note that the characteristics of MAC layer play an important role during network selection. In the future work, we will design cross-layer cognitive MPTCP-based path selection solution in multi-homing wireless networks.

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