# The Impact of Heterogeneous Propagation Delays on Multipath TCP Performance

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## Abstract

In this paper we study the impact of heterogeneous round trip times on multipath TCP (MPTCP) performance via analysis the fluid model and simulation. Using parameter ‘a’ in MPTCP can alleviate poor performance due to divergent RTTs between paths. Moreover, divergent RTTs in MPTCP can affect response to changes in the network conditions.

## 1. Introduction

Multipath TCP (MPTCP) allows multiple TCP connections across multiple paths between a two-end host pair [6]. Two main goals of MPTCP are improvement the performance and resilience. A two-end host pair sees a set of resources on all paths as a single resource, called the resource pooling principle [7]. MPTCP is implemented by a coordinated congestion controller. Such a coordinated mechanism moves the traffic off from most congested paths to a lightly congested path.

Analysis of the impact of diverse RTTs is described in Section 2. The simulation results are introduced in Section 3. Section 4 gives our conclusion.

## 2. Analysis the fluid model in MPTCP

Consider a MPTCP connection has multiple paths r = 1,⋯, N. A flow controller on each path r maintains congestion window size $w_r(t)$ at time t and $RTT_r$. Let $w(t) = \sum_r w_r(t)$ be the total congestion window size, $x_r(t) = w_r/RTT_r$ be data rate of flow r, $x(t) = \sum_r x_r(t)$.

The fluid model of MPTCP [3] on path r corresponds to

$$\frac{d}{dt}x_r(t) = x_r(t)\left[\min\left(\frac{a^{2-\varepsilon}}{w^{2-\varepsilon}(t)}\frac{x_r^{1-\varepsilon}(t)}{RTT_r^{\varepsilon}}, \frac{1}{w_r(t)}\right) - bp_r x_r(t)\right]$$

, (1)

$$a = \hat{w}\frac{\max_r\{\hat{x}_r^{\varepsilon/2-\varepsilon} / RTT_r\}}{\hat{x}^{(2-\varepsilon)/2}} , \qquad (2)$$

where $\hat{w}$ and $\hat{x}$ are the equilibrium value of w(t) and x(t) respectively. b is the decrease factor (sets to ½ in the current implementation). $p_r$ is the packet loss rate on path r. ‘a’ is parameter in order to guarantee MPTCP’s total throughput not in excess of single path TCP on the best path, and compensating for divergent RTTs.

From (1) we derive the data rate on path r $\hat{x}_r$ at the fixed point as follows

$$\hat{x}_r = \left(\frac{a^{2-\varepsilon}}{b\hat{w}^{2-\varepsilon}}\right)^{1/\varepsilon}\frac{1}{RTT_r p_r^{1/\varepsilon}} . \qquad (3)$$

From the above equation, we observe that data rate of each path in the steady state is inversely proportional to $RTT_r$ on its path. When the parameter ‘a’ is fixed, a two-path MPTCP then adversely behaviors for such a case where long RTT path has light congestion and heavy congestion occurs in a short RTT path. This means that congestion window on long RTT path is increased slower than that of expected. Fortunately, choosing dynamically ‘a’ as equation (2) will compensate divergent RTTs among paths [3]. Figure 1 shows that ‘a’ values become larger as difference between two RTTs is larger. ‘a’ value are updated as an ACK received at the sender and are a little difference among two paths in Figure 1. This means

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that aggressiveness on increase of congestion window on both paths is almost same.

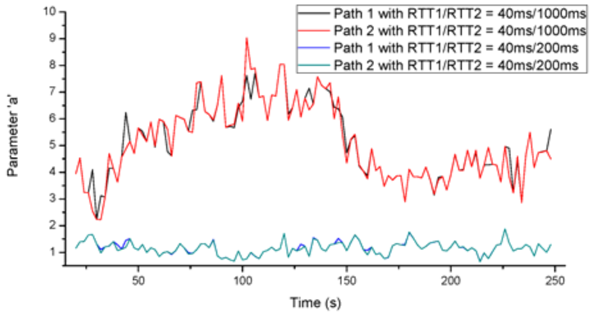

Figure 1. ‘a’ values are dependent on divergent RTTs on two paths. The plot uses two-path MPTCP $S_0$ and $S_1$ as in Figure 2.

## 3. Simulation results

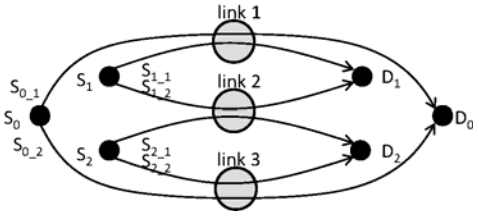

Figure 2. The simulation scenario for MPTCP. Each bottleneck link has a capacity of 2 Mbps, and buffer size to be the delay bandwidth product of its link. The propagation delays for link 1, 2 and 3 are 20ms, 100ms and 500ms respectively.

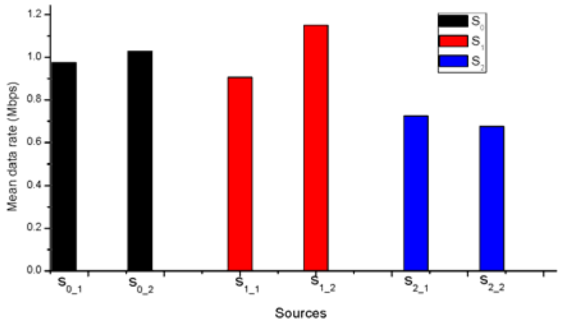

Figure 3. The mean data rate of sub-flows.

In this section, we evaluate the impact of diverse RTTs on MPTCP performance and response to link failure in a simple scenario similar as in [5] (only considering the flow level), which shown in Figure 2. The simulation ran in NS2 [1] with 1000-byte TCP packet and drop tail queueing. Each source $S_i$ spreads data packets across two-path $s_{i-1}$ and $s_{i-2}$. The data rate was sampled once at 2 seconds.

Figure 3 shows that the sums of mean rate of source $S_0$ and $S_1$ are almost identical. While that of $S_2$ gets lower than others. This is due to $S_0$ and $S_1$ share the shortest propagation delay on link 1, ‘a’ value on $S_0$ is largest, and although $S_1$ and $S_2$ have same ‘a’ values (because of same RTT ratio between two paths), RTTs on paths for $S_1$ are always shorter than these for $S_2$.

We evaluate MPTCP response to link failure in term of convergent time to equilibrium rate. Figure 4 shows that due to the impact of largest RTT on source $S_2$, it recovers slowly to a new equilibrium rate. Since sources $S_0$ and $S_1$ share on link 1 (having shortest RTT), they are able to respond more quickly to load changing on their paths.

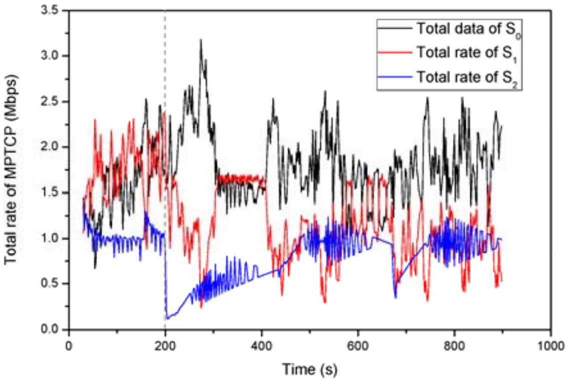

Figure 4. Total instantaneous data rate of sources when the link 2 fails from time of 200 s.

## 4. Conclusion

The congestion controller for each path in MPTCP is not only dependent on packet loss rate but also dependent on RTT on its path. Data rate on each path is proportional to 1/RTT which is similar TCP Reno [4]. Updating parameter ‘a’ in MPTCP can support compensating divergent RTTs. However, this can’t remove completely the impact of RTT.

## References

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