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Multi-path TCP performance evaluation in dual-homed (wired/wireless) devices

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ABSTRACT

Multipath TCP is a major extension of TCP, designed for leveraging the increasing availability of multiple interfaces in end hosts, on one side, and the existence of diverse Internet paths between hosts, on the other. This paper proposes a measurement methodology and provides a first evaluation, based on real Internet experiments, of the user benefit of using MPTCP instead of TCP in devices with multiple wireless/wired networking interfaces. We focus on bandwidth utilization and file transfer delays. Our experiments, on a testbed with two disjoint paths connecting a server and a dual-homed probe, indicate that MPTCP is able, in most cases, to take advantage of additional bandwidth with limited cost in terms of delay, but also show that the MPTCP bandwidth benefit substantially degrades when the interfaces have very different bandwidth capacities.

1. Introduction

In the TCP/IP architecture, a transport connection is a single path between two host interfaces. This was adapted to the original situation in the Internet, in which end devices were mostly connected to the Internet via a single networking interface. This has however changed in the last decades: more and more end devices are multi-homed hosts, meaning that they have multiple networking interfaces. Popular examples include smartphones (3G/4G and WiFi interfaces), laptops (Ethernet/WiFi interfaces) and multi-homed servers in datacenters. Even for single-interface hosts, transport throughput is not usually limited by the host interfaces, and therefore throughput could be increased by leveraging path diversity in the Internet, e.g. by way of ECMP inside ISPs. In this context, the use of a single transport path often entails an underutilization of network resources.

Multipath TCP (MPTCP) (Paasch et al., 2014) is a major extension of TCP that leverages at the transport layer the existence of multiple Internet paths (typically available over multiple networking interfaces) between end devices. MPTCP has been standardized at the IETF (RFCs 6182, Ford et al., 2011; 6824, Ford et al., 2013) and, unlike other multipath transport proposals, e.g. SCTP, it is transparent for applications and backwards-compatible with regular TCP. This eases its wide adoption by users and its incremental deployment in the Internet. MPTCP has been adopted, for instance, by Apple in iOS7-based devices. The growth of multipath opportunities in the Internet and the rise of MPTCP as a feasible and increasingly deployed extension to single-path TCP has attracted considerable attention in the research community to the performance evaluation of Multipath TCP in multiple scenarios.

1.1. Contributions

This paper focuses on the study of the potential benefit of using Multipath TCP instead of regular TCP, from a final user perspective, for devices with both wired and wireless (WiFi) networking interfaces. While several works have recently focused on multipath transport evaluation, the WiFi/Ethernet case in the Internet edge has not been properly explored.

The contribution of this paper is thus three-fold. First, it discusses and proposes basic user-experience metrics for evaluating transport performance and specifies two new bandwidth and delay aggregation benefit metrics for MPTCP. Second, it derives a consistent measurement methodology from these two metrics;

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this measurement methodology is implemented and publicly available, and can be used or extended for more demanding purposes. Third, the paper explores the benefits of using MPTCP instead of TCP in a real Internet networking testbed with multi-homed (wireless/wired) devices.

This is the first paper that addresses, in a real networking scenario, the performance of multipath transport for multi-homed devices connected to (partly) separate paths via WiFi and Ethernet interfaces. This is a situation that can be found in laptops and is also a feasible scenario for IoT-based sensor deployments in which sensoring devices support wired and wireless connectivity. Based on the result of 3000 experiments distributed along several weeks, the paper investigates how MPTCP leverages the existence of multiple (wireless/wired) Internet paths between endpoints of a transport connection and explores the interaction between multipath transport and the most relevant congestion control mechanisms. The analysis of performed experiments shows that the use MPTCP can be beneficial, but it degrades substantially when available paths have very different bandwidth capacities. Also, differences in path latency may lead MPTCP to perform worse than TCP, if transmission duration is not sufficient to take advantage to utilize several paths.

1.2. Paper outline

The remainder of the paper is organized as follows. Section 2 reviews and discusses existing literature related to MPTCP performance analysis. Section 3 presents the aspects of MPTCP performance that are studied in the paper, specifies the considered metrics, the procedure and the experimental scenarios in which measurements are performed. Section 4 describes the main observations from the performed experiments. Finally, Section 5 concludes the paper.

2. Related work

Several tools have been proposed in the literature for bandwidth and network performance estimation purposes (Jain and Dovrolis, 2003). Prasad et al. (2003) provide an extensive survey on metrics and standard available tools for bandwidth estimation. The measurement tool proposed and used in this paper focuses on the estimation of end-to-end capacity and transport delay. It is partly inspired by *Iperf* (NLANR/DAST) and *NetPerfMeter* (Dreibholz et al., 2011), but its design is simplified and adapted to the specificities of MPTCP/TCP measurements and comparison.

We examine the performance of Multipath TCP by way of two user metrics: the Bandwidth Aggregation Benefit and the Delay Benefit. The first metric relies on a definition originally proposed by Kaspar (2011) and later adopted by Paasch et al. (2013). We adapt it in this paper to support non-disjoint transport paths. The second metric is also inspired by the same intuition of Kaspar. In both cases, the objective is to provide a bounded estimation of the relative benefit (or penalty) when using MPTCP instead of TCP.

Evaluation and optimization of TCP have been extensively addressed in the last decades, but the interest for Multipath TCP is more recent. MPTCP performance evaluation has only attracted attention in the last years. Raiciu et al. (2012) describe the main design choices on MPTCP implementation in Linux kernel, and provide a first evaluation of their impact, both in simulated environments and with real dual-homed wireless/wireless (3G/WiFi) scenarios.

The wireless/wireless scenario (with 3G or LTE and WiFi) has been widely explored in other works. Results obtained in this scenario, however, cannot be mechanically extrapolated to other scenarios involving wired paths, partly due to the specific characteristics of cellular and wired networks (Sommers and Barford, 2012; Zhang and Arvidsson, 2012). Raiciu et al. (2011c) provide the first evaluation, both by way of simulations and by indoor mobility experiments, of the potential bandwidth benefits of MPTCP in 3G/WiFi scenarios. Paasch et al. (2012) use the kernel implementation to examine, through real experiments, the ability of MPTCP to handle handovers between WiFi and 3G networks. Chen et al. (2013) and Chen and Townsley (2014) analyze the performance of MPTCP in real mobile wireless/wireless scenario, with dual-homed devices (smartphones) with 3G/4G and WiFi interfaces. Their work focuses on the user benefits in terms of bandwidth and delay in these scenarios (Chen et al., 2013), and the modeling and understanding of some of the main issues that arise, in particular the delayed startup of the second subflow and bufferbloat (that is, the excessive variation of delays due to over-dimensioned buffers, typically observed in cellular and WiFi scenarios), and their impact on MPTCP performance (Chen and Townsley, 2014). They observe that MPTCP achieves similar latencies to those obtained by the best available path alone, can outperform it for sufficiently large downloads and is able to reduce latency variability. More recently, Deng et al. (2014) compare the performance of WiFi and LTE paths and examine the potential gains of MPTCP in this case.

Raiciu et al. (2011b) explore the performance of MPTCP in datacenters and show that the use of MPTCP can leverage efficiently the existence of multiple redundant paths in this situation, and allows further optimizations of datacenters topology. From a wider evaluation perspective, Paasch et al. (2013) introduces the notion of "experimental design" and applies it to perform an extensive MPTCP performance evaluation in a broad range of emulated environments, with dual-homed devices, via Mininet.

This paper complements the previous literature on MPTCP performance, but introduces a novel measurement methodology/metric approach and fills a gap in the space of MPTCP measurement studies. To the best of our knowledge, it is the first to investigate user benefits, behavior and limiting factors of MPTCP with real experiments in the edge of the Internet, over scenarios with separate wireless (WiFi)/wired paths, both local and in the Internet. Aside from specific contributions, presented results confirm previous observations in simulation-based experiments and are consistent with real testbed observations in other scenarios explored by the literature – in particular, 3G/WiFi scenarios.

3. Measurement methodology

Experiments are performed by way of a specific software, designed to define and launch sequences of experiments between probes (Measurement Agents, MAs) and a centralized server (Measurement Server, MS). Source code is publicly available (Cordero). The MA determines the experiments setup, scheduling and performs metric computation; measurements are reported to the MS. This section details the main focus of the MPTCP performance analysis (Section 3.1), presents the measurement architecture and experimental procedures (Section 3.2), and describes the testbed and additional scenarios in which measurements have been performed (Section 3.3).

3.1. Metrics

Multipath TCP performance is studied from the perspective of the final user. The evaluation compares basic performance indicators such as bandwidth (transport goodput) and file transfer delay in MPTCP and standard TCP. Two metrics are identified: a slight variation of the Bandwidth Aggregation Benefit metric, proposed by Kaspar (2011) and already used in MPTCP analysis by