

Evaluating TCP-friendliness in light of Concurrent Multipath Transfer

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ABSTRACT

In prior work, a CMT protocol using SCTP multihoming (termed SCTP-based CMT) was proposed and investigated for improving application throughput. SCTP-based CMT was studied in (bottleneck-independent) wired networking scenarios with ns-2 simulations. This paper studies the TCP-friendliness of CMT in the Internet. In this paper, we surveyed historical developments of the TCP-friendliness concept and argued that the original TCP-friendliness doctrine should be extended to incorporate multihoming and SCTP-based CMT.

Since CMT is based on (single-homed) SCTP, we first investigated TCP-friendliness of single-homed SCTP. We discovered that although SCTP's congestion control mechanisms were intended to be "similar" to TCP's, being a newer protocol, SCTP specification has some of the proposed TCP enhancements already incorporated which results in SCTP performing better than TCP. Therefore, SCTP obtains larger share of the bandwidth when competing with a TCP flavor that does not have similar enhancements. We concluded that SCTP is TCP-friendly, but achieves higher throughput than TCP, due to SCTP's better loss recovery mechanisms just as TCP-SACK and TCP-Reno perform better than TCP-Tahoe.

We then investigated the TCP-friendliness of CMT. Via QualNet simulations, we found out that one two-homed CMT association has similar or worse performance (for smaller number of competing TCP flows) than the aggregated performance of two independent, single-homed SCTP associations while sharing the link with other TCP connections, for the reason that a CMT flow creates a burstier data traffic than independent SCTP flows. When compared to the aggregated performance of two-independent TCP connections, one two-homed CMT obtains a higher share of the tight link bandwidth because of better loss recovery mechanisms in CMT. In addition, sharing of ACK information makes CMT more resilient to losses. Although CMT obtains higher throughput than two independent TCP flows, CMT's AIMD-based congestion control mechanism allows other TCP flows to co-exist in the network. Therefore, we concluded that CMT is TCP-friendly, similar to two TCP-Reno flows are TCP-friendly when compared to two TCP-Tahoe flows.

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1. Introduction

A host is *multihomed* if the host has multiple network addresses [1]. We are seeing more multihomed hosts connected to the networks and the Internet. For instance, PCs with one Ethernet card and one wireless card, and cell phones with dual Wi-Fi and 3G interfaces are already com-

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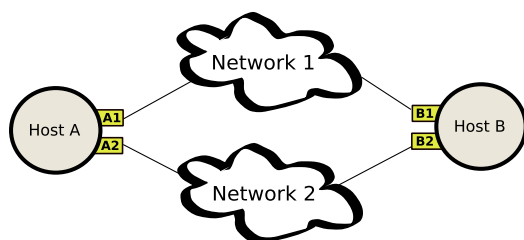


Fig. 1. Example of multihoming (with disjoint paths).

mon realities. Nodes with multiple radios and radios operating over multiple channels are being deployed [2,3]. In addition, Wi-Fi wireless interface cards are now so inexpensive that nodes with multiple Wi-Fi cards and wireless mesh networks (or testbeds) with multiple radios are practical [4,5].

A transport protocol supports multihoming if it allows multihomed hosts at the end (s) of a single transport layer connection. That is, a *multihome-capable transport protocol* allows a *set* of network addresses, instead of a single network address, at the connection end points. When each network address is bound to a different network interface card connected to a different physical network, multiple physical communication paths become available between a source host and a destination host (Fig. 1).

A multihome-capable transport protocol can accommodate *multiple paths* between a source host and a destination host within a *single* transport connection. Therefore, technically, a multihomed transport protocol allows simultaneous transfer of application data through different paths from a source host to a destination host, a scheme termed *Concurrent Multipath Transfer (CMT)*. Network applications can benefit from CMT in many ways such as fault-tolerance, bandwidth aggregation, and increased application throughput.

The current transport layer workhorses of the Internet, TCP and UDP, do not support multihoming. However, the *Stream Control Transmission Protocol (SCTP)* [6,7] has built-in multihoming support. Since SCTP supports multihoming natively, SCTP has the capability to realize CMT for the network applications. In this paper, we study TCP-friendliness of SCTP-CMT in the Internet.

TCP is the de facto reliable transport protocol used in the Internet. Following the infamous Internet *congestion collapse* in 1986, several congestion control algorithms were incorporated into TCP to protect the stability and health of the Internet [8]. As a direct response to widespread use of non-TCP transport protocols, the concept of *TCP-friendliness* emerged [9]. Briefly, TCP-friendliness states that the sending rate of a non-TCP flow should be approximately the same as that of a TCP flow under the same conditions (RTT and packet loss rate) [10]. In addition, a non-TCP transport protocol should implement some form of congestion control to prevent congestion collapse. Since the 1990s, new developments, such as multihoming and CMT, challenge this traditional definition of TCP-friendliness which was originally introduced for single-path end-to-end connections. For instance, recently, there is substantial activity in the Internet Engineering Task

Force (IETF) and the Internet Research Task Force (IRTF) mailing lists (such as *tmrg*, *tsvwg*, *iccr*, and *end2end-interest*) discussing the definition of TCP-friendliness and other related issues (such as compliance with TCP-friendly congestion control algorithms, what can cause congestion collapse in the Internet, Internet-friendly vs. TCP-friendly algorithms, fairness of “flow rate fairness”).

In this paper, we survey the historical development of TCP-friendliness and argue that the existing definition should be extended to incorporate SCTP CMT and multihoming. Since SCTP CMT is based on (single-homed) SCTP, we first investigate TCP-friendliness of single-homed SCTP.¹ We then study TCP-friendliness of SCTP CMT according to the traditional definition of TCP-friendliness [9] using QualNet [12] simulations. Note that we developed SCTP and SCTP-based CMT simulation modules in QualNet [13]. We also verified the correctness of our SCTP QualNet module against SCTP ns-2 module [14] before we ran our simulations (see [15] for details).

This paper is organized as follows. Section 2 presents a primer on SCTP and CMT. Section 3 presents the historical development and the formal definition of TCP-friendliness. Section 4 elaborates on the TCP-friendliness of single-homed SCTP. Section 5 evaluates the TCP-friendliness of CMT. Section 6 concludes this paper with summary of our results and future work.

2. Primer on SCTP and CMT

SCTP was originally designed to transport telephony signaling messages over IP networks. Later on the IETF reached consensus that SCTP was useful as a general purpose, reliable transport protocol for the Internet. SCTP provides services similar to TCP’s (such as connection-oriented reliable data transfer, ordered data delivery, window-based and TCP-friendly congestion control, flow control) and UDP’s (such as unordered data delivery, message-oriented). In addition, SCTP provides other services neither TCP nor UDP offers (such as multihoming, multistreaming, protection against SYN flooding attacks) [16]. In the SCTP jargon, a transport layer connection is called an *association*. Each SCTP packet, or *SCTP protocol data unit (SCTP-PDU)*, contains an SCTP *common header* and multiple data or control *chunks*.

2.1. SCTP multihoming

One of the innovative features of SCTP is its support of multihoming where an association can be established between a *set* of local and a *set* of remote IP addresses as opposed to a *single* local and a *single* remote IP address as in a TCP connection. In an SCTP association, each SCTP endpoint chooses a *single* port. Although multiple IP addresses are possible to reach one SCTP endpoint, only one of the IP addresses is specified as the *primary* IP address to transmit data to the destination endpoint.

¹ Note that, although SCTP has “similar” congestion control mechanisms as TCP, subtle differences exist between (single-homed) SCTP and TCP.

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