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Research Issues in TCP based Congestion Control for High Speed Network

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Abstract

The Congestion control methods used by the traditional TCP is not applicable to the current high-speed long delay networks due to rapid increase of link bandwidth and end to end delay specifically on wide area networks. The packet drop rate requirement for full utilization of long bandwidth-delay link is not achievable by the traditional TCP. There is large number of congestion control methods for high speed network used by TCP have been proposed. These high-speed TCP's are efficient in utilizing the high bandwidth link. Still there are various new issues and challenges have been emerged while design and implementation of these high-speed TCP's.

1. Introduction

Congestion can be defined as a network state in which the total demand for resources, e.g. bandwidth, among the competing users, exceeds the available capacity leading to packet or information loss and results in packet retransmissions[1]. Congestion control refers to techniques and mechanisms that can either prevent congestion, before it happen, or remove congestion, after it has happened.

Traditional TCP like TCP Reno is the major protocol used for congestion control used by applications like HTTP and FTP. There is a rapid increase of high bandwidth demanding applications like web streaming, bulk data transfer and computational grid infrastructure used by the wide area networks. A network with a large bandwidth-delay product is commonly known as a high-speed network or long fat network like satellite channels e.g., DARPA's Wideband Net, a DS1-speed satellite. Terrestrial fiber-optical paths will also fall into the LFN class. For such network traditional TCP's are inefficient as they are not able to fully utilize the available high bandwidth.

The packet drop rate required to fill a LFN link using the traditional TCP protocol is beyond the limit of achievable high bandwidth link error rate.

There are large number of proposals have been emerged to improve the performance of TCP in high speed network. These high-speed TCP's are efficient in utilizing the high bandwidth link due to dynamic nature. Still there are various major issues and challenges like Scalability, TCP friendliness, RTT fairness and Responsiveness have been emerged while design and implementation of these high-speed TCP's.

In this paper, various major issues and challenges while design and implementation of TCP in high speed network have been discussed.

The paper is organized as follows: In Section 2 of this paper, a brief review of TCP for high speed Internet congestion control, has been mentioned. The major issues and challenges for high speed TCP is briefly defined in Section 3. Finally Section 4 concludes the paper.

2. TCP based Congestion control in high-speed Network

TCP congestion control methods are reactive in nature i.e. Source host reacts after getting congestion signals from the networks, by reducing its transmission speed. TCP uses *implicit* congestion signals: packet loss or delay or the combination of both. Based on the types of congestion signals, source based approaches are further categorized as: Loss based approach, Delay based approach and Hybrid approach.

2.1. Loss based approach

The earliest loss based source based solution for congestion control in high speed network, '*High Speed- TCP*' was proposed by Floyd [2] (2003). He commented that congestion control mechanisms of the Standard TCP limit the congestion windows that can be achieved by TCP in actual environments which results in poor utilization of network bandwidth. Therefore a new mechanism is required which effectively utilize a wide range of available bandwidths, and competes with Standard TCP more fairly in congested environments.

Kelly [3] (2003) considered 'better utilization of network bandwidth' and 'fairness with Standard TCP' as two major challenges while designing TCP congestion control for high-speed network and proposed *'Scalable TCP'*. Leigh et al [4] (2004) raised the issue of backward compatibility of high speed TCP with Standard TCP while deployment of high speed TCP. He proposed '*H-TCP'* with focus on fairness, friendliness, responsiveness and throughput. Xu et al [5] (2004) commented that previous High speed TCP approaches only solved the bandwidth scalability and TCP friendliness problems. He pointed out another important issue termed as RTT (round trip time) unfairness for high speed congestion control and proposed *'BIC TCP'* as its solution.

Wang [6] (2005) considered dynamic bandwidth utilization as another challenge for high speed TCP and proposed a sender side enhancement method '*TCPW-A* TCP' by using the concept of agile probing. Ha et al [7] (2008) proposed *'CUBIC TCP'* by using a cubic window growth function and focused on improving the 'TCP-friendliness' and 'RTT-fairness' characteristic by making window growth rate RTT independent. Kliazovich et al [8] (2008) uses logarithmic increase function and proposed '*LogWestwood+ TCP*' having low sensitivity with respect to RTT value, while maintaining high network utilization in a wide range of network settings. Marfia et al [9] (2010) considered RTT-fairness a severe problem because it adversely affect the long-RTT flow performance and proposed 'TCP Libra' which ensure fairness and scalability regardless of the RTT, while remaining friendly towards legacy TCP.

2.2. Delay based approach

Due to continuous advancement in computing, communication and storage technology, Jin et al [10] (2003) considered poor bandwidth scalability of standard TCP, as a key challenge for TCP congestion control in high-speed network. He proposed a first **delay based** source based method *'FAST TCP' for congestion control in high speed network* and considered throughput, fairness, stability and responsiveness as key issues for High-speed TCP. Wo et al [11] (2009) have proposed *'Sync-TCP'* a delay based solution for congestion control in high speed environment and proposed a concept of flow level coordination for handling congestion. 'Sync-TCP' guarantees a better tradeoff between throughput and friendliness which is a serious issue while deploying new high speed TCP.

2.3. Hybrid approach

King et al [12] (2005) have proposed a first **hybrid method** *'TCP- Africa'* for high speed congestion control and raised a major issue of maintaining a careful balance between the increased aggressiveness and the fairness and safety while developing TCP for high bandwidth delay product network. Shimonishi et al [13] (2005) considered TCP-Reno efficiency –friendliness tradeoff as a most important issue in high speed TCP design because TCP-Reno unfriendliness is the major hurdle in the way of high speed TCP deployment in current Internet. They proposed *'TCP-AR'* (Adaptive Reno) to ensure friendliness to TCP-Reno, as well asefficiency in high speed networks. Tan et al [14] (2006) emphasized that pure delay-based approaches may not work well if they compete with loss-based flows and proposed a hybrid approach *'Compound TCP'* which provides very good bandwidth scalability and at the same time achieves good TCP-fairness. Kaneko et al [15] (2007) proposed *'TCP fusion'* which exploits three useful characteristics of TCP-Reno, TCP-Vegas and TCP-Westwood in its congestion avoidance strategy and can obtain the highest throughput among existing TCP variants when there is unused residual capacity while its friendliness to the TCP-Reno is sufficiently satisfied, otherwise, it shares the same bandwidth to coexisting flows. Baiocchi et al[16] (2007) stated while designing high speed TCP, we should consider not only the full link utilization characteristic but preserve also the primary characteristic of congestion avoidance as it causes network instability and non-negligible degradations. They raised new issues like 'induced network stress' and 'robustness to random losses' for TCP in high speed environment. They proposed *'YeAH TCP'*aa heuristic attempt to strike a balance among different opposite requirements. Xu et al [17] (2011) commented on existing high speed TCP, although these protocols perform successfully to improve the bandwidth utilization, they still have the weakness on the performance such as RTT-fairness, TCP-friendliness, etc. They stated that none of the existing approaches is overwhelmingly better than the other protocols and has the convincing evidence that could be generally deployed; the development of new high-speed TCP variants is still needed. They proposed *'HCC TCP'* which satisfies the requirements for an ideal TCP variant in high-speed networks, and achieve efficient performance on throughput, fairness, TCP-friendliness, robustness, etc.

3. Major Issues for High speed TCP

TCP friendliness, *Fairness* and *efficiency* have considered most important issues while designing TCP based congestion control algorithms. TCP friendliness means maintaining fairness among the traditional TCP connections and High speed TCP connections. Hasegawa et al [18] pointed out that traditional TCP has already been used widely in the current Internet, it is difficult for the new high speed protocol to be accepted if it is not downward compatible to the existing TCP. A number of protocols, such as High Speed TCP and Scalable TCP, have been proposed, however, their lack of friendliness to existing protocols has hampered their wide deployment in public networks [19].Thus *TCP friendliness* is a key issue while deployment of High speed TCP in current internet. Throughput-efficiency and fairness are considered as major design issues because in high speed network large amount of bandwidth is available which should be exploited efficiently in a fair manner. *RTT unfairness* and *bandwidth scalability* have also considered as important issues for TCP based congestion control algorithms. RTT unfairness problem arises when multiple flows with different RTT delays are competing for the same bottleneck bandwidth. *RTT unfairness* is considered as a severe problem on the way of deployment of source based congestion control approaches in high speed networks [5]. The *fairness* issue was considered by various researchers for the evaluation of high speed TCP.

The main goal of fairness is to share the network resource in a fair manner. The fairness issue has two dimensions, one is inter-protocol fairness and another one is intra-protocol fairness. In case of high speed network bandwidth scalability is also considered as an important issue because source based approach having scalable window increasing rule that not only can efficiently probe the link capacity, but also reacts early to congestion by sensing the changes in RTT.

Faster convergence to a fair bandwidth share is also considered as a vital issue because source based approach must adapt to changing network conditions on reasonable timescales. Convergence times deal with the time for convergence to fairness between an existing flow and a newly starting one, and are a special concern for environments with high-bandwidth long-delay flows. Convergence times also concern the time for convergence to fairness after a sudden change such as a change in the network path, the competing cross-traffic.

Responsiveness is one of the key concerns in the design of congestion control mechanisms which concern with the response times to sudden congestion in the network. On the one hand, congestion control mechanisms should respond reasonably promptly to sudden congestion from routing or bandwidth changes or from a burst of competing traffic. At the same time, congestion control mechanisms should not respond too aggressively to transient changes, e.g., to a sudden increase in delay that will dissipate in less than the connection's round-trip time. Evaluating the response to sudden or transient changes in bandwidth-delay product can be of particular concern for slowly responding congestion control mechanisms. One goal is that of stability, in terms of minimizing oscillations of queuing delay or of throughput. In practice, stability is frequently associated with rate fluctuations or variance. Rate variations can result in fluctuations in router queue size and therefore of queue overflows. These queue overflows can cause loss synchronizations across coexisting flows and periodic under-utilization of link capacity, both of which are considered to be general signs of network instability. Thus, measuring the rate variations of flows is often used to measure the stability of transport protocols.

Xu et al [20] (2011) have first considered *Robustness* of TCP against reverse traffic as a performance parameter in High speed TCP design. Because throughput performance in forward path is significantly affected by the reverse traffic, and the throughput of the source traffic decreases as the queuing delay increases on the reverse path. In other words as the congestion on the reverse path increases, the throughput of the flows degrades although there is available bandwidth on the forward path.

In addition to that one critical challenge while designing High speed TCP is to tackle the trade-offs among various issues. The trade-offs observed by various researchers are: Responsiveness and throughput efficiency trade-off[4],RTT fairness and scalability trade-off [5],Efficiency and friendliness trade-off[9,11,13,15],TCP friendliness and scalability trade-off[21] etc.

3. Conclusion

This work explores the major issues and challenges of TCP based congestion control algorithms in the context of high speed networks. Friendliness, fairness, responsiveness and convergence are some of the major design and implementation issues for high speed TCP.We understand that the identified issues and challenges regarding the high speed congestion control algorithms may help in future research in this area.

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