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論文内容の要旨

Currently, Transmission Control Protocol (TCP) is the most widely used transport-layer protocol in the Internet. TCP is the primary transport protocol in use in most IP networks, and supports the major portion of traffic across the Internet. It is typically employed by applications that require guaranteed delivery.

However, data intensive applications, e.g., Content Distribution Network (CDN) and Storage Area Network (SAN), have appeared. These applications use high speed networks to transfer terabyte/pertabyte-sized files over continents. Recent research has shown that current TCP mechanisms can obstruct efficient use of such fast long-distance networks (LFNs). Addressing the problem of TCP used in LFNs, several high-speed protocols are proposed in recent years. These protocols can be classified into two categories. Both of them modify the algorithm of TCP. The first requires modifications at both end-hosts and the routers in between, e.g., eXplicit Congestion control Protocol (XCP), and Variable-structure congestion Control Protocol (VCP). For using them, the mechanism of routers must be reconstructed, for some information gathered by routers need to be fed back to the end-hosts. The second category only needs the modification of the congestion control mechanism of end-host's TCP, e.g., HighSpeed TCP (HSTCP), Scalable TCP, and FAST TCP. Thus, they are relatively easy to be deployed in the current Internet.

To date, these high-speed protocols are still on the way of development and not widely deployed. Moreover, none of them have given a completely solution, for example, HSTCP, which is a representative of high-speed protocols, may provide higher throughput than TCP Reno, but HSTCP flows starve TCP Reno flows when they share the same network links. A more suitable transport protocol, which can provide higher throughput with better fairness against the competing TCP flows, should be designed at present. Thus we solve the problem of fairness by proposing an enhanced transport layer protocol — Gentle HighSpeed TCP (gHSTCP). gHSTCP is based on HSTCP, so it can provide high performance and is easy to be deployed. For fairness, gHSTCP uses two modes — HSTCP mode and Reno mode — in the congestion avoidance phase, and switches between modes

based on the trend of changing RTT. Simulation results show gHSTCP can significantly improve performance in mixed environments. When gHSTCP and TCP Reno flows share the same bottleneck link, compared with the case when HSTCP is used, gHSTCP may provide better utilization and fairness. When TCP SACK option is turned on, gHSTCP can also provide better performance, though HSTCP may achieve almost the same bottleneck utilization as that done with gHSTCP in some case. For instance, when DropTail is deployed, the bottleneck link bandwidth is 2.5 Gbps, and the propagation delay is 50 ms, gHSTCP rises by 15% on utilization, and by 0.1 on fairness (Jain's fairness index) compared with HSTCP. gHSTCP using SACK option rises by 0.16 on fairness compared with HSTCP using SACK option. Then, the performance of gHSTCP is evaluated when gHSTCP flows co-exist with Web traffic. With the help of gHSTCP, the packet drop rate is depressed, and Web responding time is slightly improved.

However, the performance improvement is limited due to the nature of TailDrop router, and the RED routers can not alleviate the problem completely. Therefore, we present a modified version of adaptive RED (ARED), called gentle adaptive RED (gARED), directed at the problem of simultaneous packet drops by multiple flows in high speed networks. gARED can eliminate weaknesses found in ARED by monitoring the trend in variation of the average queue length of router buffer. Our approach, combining gHSTCP and gARED, is quite effective and fair to competing traffic. With the assistance of gARED mechanism, both of utilization and fairness are boosted.

In the above works, the gHSTCP effectiveness has only been demonstrated by simulations. For its applications, it is necessary to evaluate gHSTCP by experiments. Thus, we construct an experimental environment to check the performance of gHSTCP. Based on the experimental results, a refined gHSTCP algorithm is proposed for application to real networks. The refined gHSTCP algorithm is based on the original algorithm, compares two RTT thresholds and determines which mode is used. Then, the performance of the refined gHSTCP algorithm is assessed experimentally, and compared with TCP Reno/HSTCP and parallel TCP mechanisms. The experimental results reveal that gHSTCP can provide a better trade-off in terms of utilization and fairness against co-existing traditional TCP Reno connections, whereas HSTCP and parallel TCP suffer from the trade-off problem.

Addressing the performance issue of TCP Reno in LFNs, parallel TCP mechanism has been proposed and employed by some applications. In this thesis, we attend to investigate the problem of TCP Reno in LFNs and attempt to give some suggestions. Therefore, at the end of this thesis, we use mathematical analysis to explore the performance of parallel TCP. Parallel TCP uses many concurrent TCP connections for one task. So far, using parallel TCP is something of black art. We try to answer this question: Is parallel really effective for LFNs ? The analytical results reveal that it is difficult to use parallel TCP in practice for the sake of approving throughput. That is, parallel TCP is not really effective in LFNs, because the optimal number of TCP connections cannot be easily obtained. Especially, parallel TCP exactly possesses the properties that induce synchronization. While the router has small buffer size, the performance of parallel TCP in synchronization case deteriorates significantly as the number of TCP connections is increased. In contrast, high-speed protocols have the inherent characteristics which are suitable for LFNs. Based on these results, we recommend using high-speed protocols instead of parallel TCP in LFNs in practice.

論文審査の結果の要旨

現在実現しつつある１～10 Gbps 級のリンクを持つ超高速ネットワークにおいて、TCP を用いてデータ転送を行うと、高速リンク帯域を使い切れないことが指摘されている。この問題に対して、HighSpeed TCP が提案されているが、その詳細な性能評価は行われていない。特に、既存の TCP Reno との公平性に関しては考慮されていない。本論

文ではまずHighSpeed TCPの持つ問題点を指摘し、その不公平性を改善するgHSTCP方式を提案している。また、超高速ネットワークにおけるREDの問題点を指摘し、それを解消する方式として、AREDを改善したgARED方式の提案を行っている。その結果、gHSTCPとgAREDを組み合わせることによって、リンク帯域を有効に活用し、かつTCP Renoとの公平性を大幅に改善できることをシミュレーションにより明らかにした。

次に、実験ネットワークを用いた実証実験を行うことで、gHSTCPの実ネットワークでの有効性を検証している。実験の結果、gHSTCPのアルゴリズムに問題点が存在することが明らかとなったため、本論文では改善手法を提案している。また、他の高速TCP方式および並列TCP方式との性能の比較を行い、gHSTCPがスループットおよび既存のTCP Renoとの公平性に関して、優れた性能を示すことを明らかにした。

並列TCP方式はデータ転送スループットを簡易な方法で向上することができる一方、シミュレーションや実ネットワークでの実験などから、TCPコネクション数の決定が難しいことが知られている。さらに、本論文では、並列TCP方式を用いた場合のデータ転送スループットを数学的解析により導出することによって、並列TCP方式の本質的な性質を明らかにした。その結果、理想的なTCPコネクション数はネットワークパラメータなどによって大きく変化し、その設定が困難であることを示している。また、高速TCP方式との比較を行い、ネットワーク環境の変動に対する性質などの点で、並列TCP方式が劣っていることを明らかにした。

以上のように、本論文では大容量かつ長距離ネットワークにおける高速トランスポートプロトコルに関して多くの研究成果を挙げている。よって、博士（情報科学）の学位論文として価値のあるものと認める。