A Study Congestion Control for Wireless Networks (無線通信網における輻輳制御に関する研究)

著者	内海 哲史
号	14
学位授与番号	436
URL	http://hdl.handle.net/10097/42621

氏名（本籍地）	内海　哲史（うつみ　さとし）
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論文審査委員	（主査）東北大学教授　白鳥　則郎 東北大学教授　加藤　寧　　東北大学教授　安達　文幸（工学研究科） 東北大学准教授　菅沼　拓夫

論文内容の要旨

Chapter 1 Introduction

In recent years, the Internet has been expanding at a rapid pace. Different types of networks (e.g., wireless network, high-speed network) are being incorporated, and many new devices are getting connected to this world wide network. At the same time, the concept of ubiquitous information society has been becoming a popular next generation topic. In the ubiquitous information society, wireless networks in particular, are very important in term of the usability. This, in turn, is resulting in the evolution of a number of applications with different requirements. Ultimately, the need for optimizing major applications to perform satisfactorily over the Internet becomes a dominating concern.

At present, almost eighty percent of Internet applications run on TCP (Transmission Control Protocol). This dominance of TCP applications is likely to continue in the years to come. Therefore while accommodating a fast expansion both in scale and diversity over the Internet, TCP concerns deserve special attention.

The purposes of this research is to device schemes for improving the performance of TCP congestion control in wireless networks (e.g., cellular phone networks, satellite networks), and their evaluations.

Chapter 2 Conventional TCP Congestion Control in Wireless Networks

TCP (Transmission Control Protocol) is a connection-oriented and reliable protocol in the 4th layer (the transport layer). A TCP sender sends data in blocks of data segments. Then, it recognizes that a TCP receiver received the data segment by receiving an acknowledgement (ACK) corresponding to the data segment from the TCP receiver. Because TCP provides a reliable connection, at the detection of a data segment loss the TCP sender retransmits the data. Conventional TCP protocols

detection of a data segment loss the TCP sender retransmits the data. Conventional TCP protocols assume to be used in wired networks. In wired networks almost all segment losses are due to overflow on a node in the network, that is due to network congestion. Thus conventional TCP protocols assume that the segment losses in networks are being caused by network congestion. If network congestion continues long, performance in the entire network declines. Conventional TCP protocols make the sending rate lower at the segment loss detection to make network congestion weaker. There are some versions of the congestion control mechanisms in TCP. Here I describe about one of the versions called TCP NewReno. TCP NewReno behaves following using two parameters (*cwnd* and *ssthresh*). *cwnd* is the parameter expressing the congestion window size (whose unit is segment(s) here), and *sshresh* is the threshold of *cwnd*. TCP NewReno has slow start algorithm, congestion avoidance algorithm, fast retransmit algorithm and fast recovery algorithm. Whenever a TCP segment is lost, the conventional TCP sender interprets it as an indication of congestion and lowers its transmission rate. Hence TCP segment losses due to link error are also interpreted as signals of congestion. This results in slowing down of the transfer rate unnecessarily. Since wireless links are highly prone to link errors, the ultimate consequence is drastic degradation of throughput.

Chapter 3 TCP Congestion Control for Wireless Networks with Data Link Layer ARQ

I propose a new TCP congestion control I named as "TCP Identification & Revivable Window (TCP-I&RW)" to improve TCP performance in wireless networks supporting data link layer automatic repeat request (ARQ) for link errors in wireless links. The TCP sender in TCP-I&RW places an identification tag decided by using random number for every data segment. Like conventional TCP protocols, if a segment loss is detected, it first infers congestion, lowers the sending rate and retransmits with a different identification tag. The TCP sender figures out the actual cause of segment loss depending on identification reply in the acknowledgement corresponding to the retransmitted data. If the segment loss is not due to congestion, the TCP sender revives its transmission rate to the value prior to the retransmission. As such, erroneous detection of congestion is avoided. This ensures an improved throughput for TCP over wireless links supporting data link layer ARQ. Experiments show my proposed new scheme can achieve better performance than existing well established schemes in the cellular network and also in the satellite network as Fig. 1. Also, TCP-I&RW incorporates a mechanism to nullify any attempt by aggressive TCP receivers hoping to occupy unfairly high shares of link bandwidth.

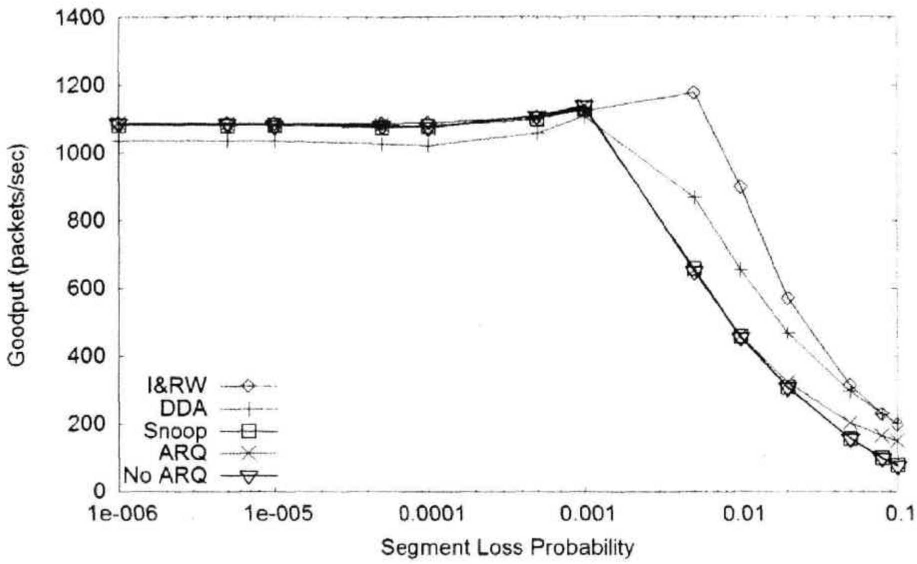

Figure 1 Goodput of TCP-I&RW on the satellite network.

Chapter 4 TCP Congestion Control for Satellite Networks

Performance of conventional TCP congestion control is vulnerable to long delays and errors over satellite links despite their potential for ubiquitous coverage. I therefore propose a new TCP congestion control mechanism, TCP-Cherry, to improve TCP performance over satellite IP networks. The basic idea is to probe the network for available resources using data segments that do not put the network into congestion. To this goal, TCP-Cherry deploys a new type of low-priority data segments, namely, supplement segments that in addition to probing the available network capacity, carry data not yet transmitted as regular data segments. My major contributions in this work include two new algorithms, Fast-Forward Start and First-Aid Recovery, for congestion control in the presence of data segments belonging to two different levels of priority. Another unique feature of my scheme is the mechanism for selection of supplement segments which keeps the overhead of duplicate transmission minimum. I also propose a simple scheme for avoiding gradual decrease of TCP congestion window owing to recurring loss of probing segments. Simulation results show that my proposed TCP-Cherry yields up to a maximum improvement of more than 150% in goodput compared with other existing schemes as Fig. 2. I also observe that TCP-Cherry maintains a fair share of bandwidth among competing TCP connections. In addition, the supplement segments used for probing the network induce the minimal network overhead.

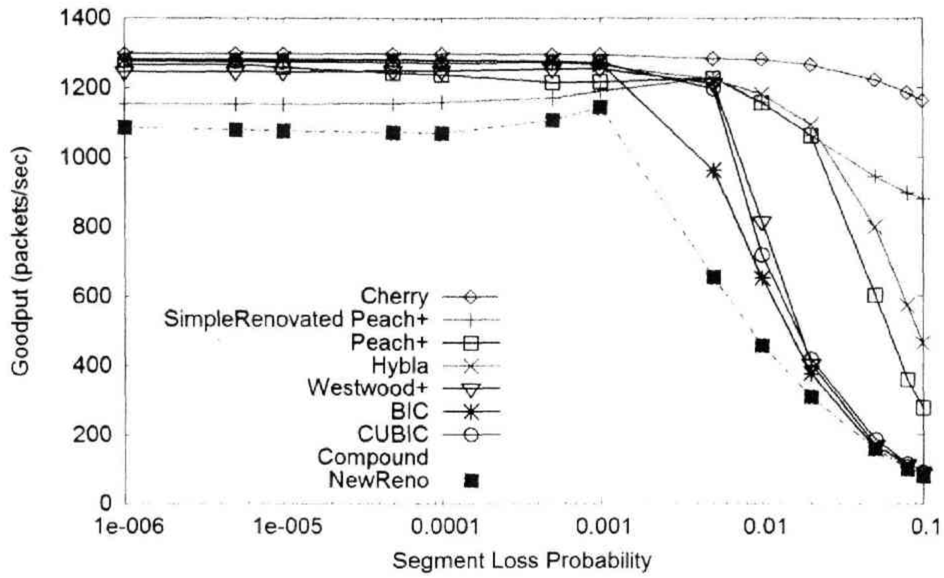

Figure 2 Goodput of TCP-Cherry on the satellite network.

Chapter 5 Conclusion

My research, as presented in this thesis, aims at efficient TCP operations through effective end-to-end congestion control. It is known that for window based connection oriented protocols like TCP, congestion control mechanism is affected by segment loss. Hence my objective effectively translates to a thorough investigation of different types of TCP segment loss and devising measures to minimize their negative impact on TCP congestion control. TCP segment losses occur due to either congestion or link error.

Congestion losses can be minimized if TCP congestion control mechanism can be informed of the situation before congestion actually occurs. For an appropriate early indication of incipient congestion, assistance from the network is needed. I therefore consider network assisted approaches for handling congestion loss and associated performance problems.

Losses due to link error are difficult to identify. For a proper distinction between losses due to link error and that due to congestion, some appropriate mechanism should be deployed at TCP end hosts. I therefore consider devising end host based solutions for handling segment losses where link errors are highly probable and thus minimizing associated congestion control problems.

I proposed two new TCP congestion controls.

- TCP Identification & Revivable Window (TCP-I&RW)
- TCP-Cherry

- TCP-I&RW

TCP performance over wireless links suffers severely because of misinterpretation of segment losses due to link errors. Proposals that count on retransmission support over wireless links are promising to overcome this problem. These solutions, e.g., Snoop scheme or DDA scheme, however suffer either from implementation problems or from performance drawbacks or both. In this thesis I therefore propose a new variant of TCP, I name as TCP-I&RW. This variant of TCP with data link layer ARQ effectively differentiates between segment losses due to congestion and those due to link error. That is, my scheme can detect spurious retransmission in wireless links. In addition to providing improved performance than these existing most effective schemes, TCPI&RW is free from implementation problems. Experiments show that TCP-I&RW with data link layer ARQ can get higher performance than the existing schemes in the cellular network and in the satellite networks. Again, TCP implementing the Eifel algorithm that somewhat resembles TCP-I&RW is vulnerable to aggressive TCP receiver malpractices. To the contrary, my proposal incorporates a mechanism to nullify any such attempt by an aggressive TCP receiver.

- TCP-Cherry

I introduce a new congestion control protocol for satellite IP networks, i.e., TCP-Cherry. My major contributions include the idea of low-priority supplement segments, which, along with probing the available bandwidth in the network, carry new data blocks. I propose two novel algorithms, Fast-Forward Start and First-Aid Recovery, for congestion control in the presence of data segments belonging to two different levels of priority. Another unique feature of my scheme is the mechanism for selection of supplement segments which keeps the overhead of duplicate transmission minimum. I also propose a simple scheme for avoiding gradual decrease of TCP congestion window owing to recurring loss of probing segments. I evaluate the effectiveness of my scheme through simulations using network simulator. Results show that my proposed TCP-Cherry yields up to a maximum improvement of more than 150% in goodput compared with other existing schemes. I also observe that TCP-Cherry maintains a fair share of bandwidth among competing TCP connections. In addition, the supplement segments used for probing the network do not induce any considerable network overhead.

I have contributed to make performance of the information communication on the information society better by proposing the improvements of TCP congestion control and evaluating them.

The future works of this research are:

1. Development of the proposed TCP congestion controls (TCP-I&RW and TCP-Cherry) in an actual operation system, e.g., Linux kernel.
2. Popularization of the proposed TCP congestion controls.

論 文 審 査 結 果 の 要 旨

ネットワークアーキテクチャにおいて、TCP（Transmission Control Protocol）はトラフィックの輻輳制御をしつつ、アプリケーションに論理的通信路を提供するためのプロトコルである。従来の TCP の輻輳制御法は、有線ネットワークでの利用を想定して設計されているため、TCP が伝送するデータの単位であるセグメントの損失をネットワークでの輻輳によるものであると想定していた。しかし、無線ネットワークのように、リンク上でデータが欠損するリンクエラーによるセグメントの損失が発生するとき、不必要にセグメントの送信レートを低下させるｔめ、スループットが低下する。このようなスループットの低下は、無線ネットワークにおける輻輳制御法の大きな問題となっている。さらに、衛星ネットワークのように、遅延が大きな無線ネットワークの場合、この問題はさらに顕著となる。著者は、無線ネットワークにおいて、効率的な伝送を実現する TCP 輻輳制御法に関する研究に取り組んできた。本論文は、その成果をまとめたもので全編５章からなる。

第１章は序論である。

第２章では、無線ネットワークにおける従来提案されているいくつかの TCP 輻輳制御法について、性能の観点から整理している。従来の TCP 輻輳制御法では、無線リンクにおけるリンクエラーの発生確率が高くなるに従い、不必要にセグメントの送信レートを低下させるため、スループットが低下するという問題が重要な課題となっている。

第３章では、ネットワークアーキテクチャの下位層にあたるデータリンク層で再送制御機能を備えた無線ネットワークにおいて、TCP 輻輳制御法の性能を改善する方法を提案している。具体的には、TCP における往復遅延時間測定機能であるタイムスタンプオプションを利用した識別子を用いることで TCP の性能を改善する TCP 輻輳制御法を提案している。シミュレーションによる評価の結果、無線ネットワークにおける TCP スループットが向上することを確認した。これは、無線ネットワークにおいて、効率的な伝送を実現するための基盤となる重要な成果である。

第４章では、衛星ネットワークにおいて、TCP 輻輳制御法の性能を改善する技術について提案している。具体的には、新しい低優先度のセグメントを用いることで、衛星ネットワークにおいて TCP の性能を改善する TCP 輻輳制御法を提案している。シミュレーションによる評価の結果、衛星ネットワークにおける TCP のスループットが大きく改善されることを確認した。これは、衛星ネットワークにおいて、効果的な伝送を実現するための重要な知見である。

第５章は結論である。

以上要するに本論文は、無線ネットワークにおいて効果的な伝送を実現する TCP の輻輳制御法を提案し、シミュレーションによってその効果を明らかにしており、ユビキタス情報社会を支える無線ネットワークにおける基盤技術の基礎を与えたものであり、情報基礎科学の発展に寄与するところが少なくない。

よって、本論文は、博士（情報科学）の学位論文として合格と認める。