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Literature Survey on Congestion control for high-speed wired network

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Abstract

This paper presents a survey of congestion control approaches in high speed wired network by taking into account directions of router based congestion control. Various survey papers reported in the literature, regarding congestion control approaches, have considered router based approach independently. The research directions is considered for a particular network domain. It is a practicable idea to take a holistic view and study router base congestion control approach. The main motivation of this work is to summarize router base congestion control approach, and identify major issue and challenges in congestion control.

Key Words: Congestion control; High speed network; Router based approach

Introduction

The number of internet users as well as the number of applications using internet have increased drastically due to the emergence of high speed network, which in turn increased the amount of traffic in the internet. The main side effect of this increased load is the problem of congestion in the network. Congestion control is considered as a problem of distributed nature, which requires a solution distributed at intermediate routers (network layer) to handle network congestion. Consequently researchers have considered aspects of research for congestion control. Labrador and Banerjee (1999), Chatranon et al. (2004), Ryuetal.(2003) and Adams (2013) have presented a detailed survey of various router based congestion control algorithms.

The purpose of this literature survey is to review the congestion control research for high-speed network and characterize the router base congestion control approach to congestion control design, by considering advantages and limitations. Unlike previous studies, we tried to collect, categorize, and analyzed major congestion control approaches for high speed network by considering the aspects of router base congestion control design. In this way this survey will naturally strengthen with regard to the directions of router base congestion control research and traces a better picture of major issues, challenges and possible solutions of network congestion problem in high speed network.

Related work

In the literature, the problem of congestion has been studied widely in the context of high speed network. Substantial survey work has been reported regarding congestion control. Some significant survey works related to the topic areas follows. Yang and Reddy (1995) have first proposed ataxonomy of congestion control approaches in packet switched network, based on the control theory. This taxonomy contributes a frame work which helps in the comparative study of the existing approaches and set a path toward the development of new congestion control approaches. Labrad or and Banerjee (1999) have given a comprehensive survey of selective packet dropping policies for the best-effort service of ATM and IP networks. They discussed three router based congestion control schemes for IP networks, namely RED, RED In/ Out (RIO) and Flow RED (FRED). They compared RED and RIO in terms of fairness. Ryuetal. (2003) have presented a review of AQM algorithms for congestion control. They also had done a survey of control-theoretic analysis and design of end-to-end congestion control with a router based scheme. As alternatives to AQM algorithms, they also surveyed architectural approaches such as modification of source or network algorithms, and economic approaches including pricing or optimization of allocated resources. Chatranonetal.(2004) have discussed the state-of-the- art in router-based mechanisms to address the TCP-friendliness problem and present a description of the most important algorithms, design issues, advantages and disadvantages in their survey. They have done a qualitative comparison of all the existing AQM schemes and a quantitative performance evaluation is performed to show the advantages and disadvantages of only those schemes that do not require full per-flow state information since they are more likely to be implemented in practice.

Ryuetal. (2004) have presented a review of recently proposed active queue management (AQM) algorithms for supporting end-to-end transmission control protocol (TCP) congestion control with a focus on recently developed control theoretic design and analysis method for the AQM based TCP congestion control dynamics. Finally, they surveyed two adaptive and proactive AQM algorithms, PID-controller and Pro-Active Queue Management (PAQM), designed using classical proportional-integral-derivative (PID) feedback control to overcome the reactive congestion control dynamics of existing AQM algorithms. A comparative study of these AQM algorithms with existing AQM algorithms is also given by them. An exhaustive survey is made by Thiruchelvi and Raja (2008) on the recent advances in the area of AQM techniques. Further they classified the AQM mechanisms according to the type of metrics they used as congestion measure. From the survey they found that the performances of rate based AQM schemes are better than that of queue based schemes and existing rate based schemes such as AVQ and EAVQ may result in better performance in terms of, throughput, packet loss, and link utilization by the inclusion of more number of congestion measures.

Chandra and Subraman(2010) have presented a brief survey of major congestion control approaches and categorization characteristics, and elaborates the TCP-friendliness concept and then a state-of-the-art for the congestion control mechanisms designed for network. V.Kushwaha, R.Gupta/Journal of Network and Computer Applications 45(2014)62–78 63 They pointed out the major pros and cons of the various congestion control approaches and evaluated their characteristics.

Adams (2013) has done a survey attempting to travel the trajectory of AQM research from 1993 with the first algorithm, Random Early Detection (RED), to the work in 2011. In her survey she has discussed the general attributes of AQM schemes, and the design approaches taken such as heuristic, control-theoretic and deterministic optimization. Kushwaha and Ratneshwer (2013b) have performed a performance parameter analysis of congestion control approaches in high speed network by taking in to account both direction of research: source based and router based congestion control. They have also presented a review of router supported congestion control approaches (Kushwaha and Ratneshwer, 2013a).

Congestion control in high speed networks

The internet is a global infrastructure for information exchange that has revolutionized the social, economic, and political aspects of our lives. One of the most crucial building blocks of the internet is a mechanism for resource sharing and controlling congestion on the internet .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 (Papadimitriou, 2011). At the time of congestion in a computer network there will be a simultaneous increase in queuing delay, packet loss and number of packet retransmissions. In other words congestion refers to a loss of network performance when a network is heavily loaded. Keshav (2007) has defined it as “A network is said to be congested from the perspective of a user if the service quality noticed by the user decreases because of an increase in network load.”

Since congestion causes data loss and large delays in data transmission therefore controlling or avoiding congestion is a critical problem in network management and design. Without proper congestion control mechanisms there is the possibility of inefficient utilization of resources, ultimately leading to network collapse (Haider,2004). Hence congestion control is an effort to adapt the performance of a network to changes in the traffic load without adversely affecting user's perceived utilities. Congestion control requires quick remedial measures both at the end host and at the routers. At the time of congestion the end host needs to decreases their data sending rates (or congestion windows) and routers need to drop packets until the congestion state is relieved.

Congestion control refers to techniques and mechanisms that can either prevent congestion, before it happens, or remove congestion, after it has happened. Yang and Reddy (1995) have divided congestion control mechanisms in to two broad categories: congestion avoidance (open-loop congestion control) and congestion recovery (closed-loop congestion control).The strategy of congestion avoidance is preventive in nature; it is aimed to keep the operation of a network at or near the point of maximum power, so that congestion will never occur. Whereas, the goal of congestion recovery is to restore the operation of a network to its normal state after congestion has occurred. Without a congestion recovery scheme, a network may crash entirely whenever congestion occurs. Therefore, even if a network adopts a strategy of congestion avoidance, congestion recovery schemes would still be required to retain throughput in the case of abrupt changes in a network that may cause congestion. Congestion control is a (typically distributed) algorithm to share network resources among competing traffic sources.

A network with a large bandwidth-delay product is commonly known as a high-speed network or long fat network (shortened to LFN and often pronounced “elephant”). As defined in RFC1072 (Braden and Jacobson, 1988), a network is considered an LFN if its bandwidth-delay product is significantly larger than 10^5 bits (12,500bytes). In data communications, bandwidth-delay product refers to the product of a data link's capacity (bits/s) and its end-to-end delay(s). The result, an amount of data measured in bits (or bytes), is equivalent to the maximum amount of data on the network circuit at any given time, i.e. data that has been transmitted but not yet received. Some important examples of systems where the bandwidth-delay product is large are high-capacity packet satellite channels e.g. DARPA's Wideband Net, a DS1-speed satellite. Terrestrial fiber-optical paths will also fall in to the LFN class; for example, across-country delay of 30ms at a DS3 bandwidth (45Mbps) also exceeds 10^6 bits.

Router based congestion control

Router based congestion control methods are proactive in nature. Router continuously measure the traffic load and if there is any symptoms of traffic overload which causes congestion, it sends a signal to source host to slow down its transmission speed before congestion occurs. Router based methods sends incipient congestion signal by marking packets with a mark probability. Based on the mark probability calculation criteria router based methods are categorized as Queue length based, Rate based and Hybrid approach. Based on the nature of solution, router based approach is classified as Heuristic approach, Optimization approach and Control Theoretic approach (Adams, 2013).

Heuristic approach.

Heuristic approach was followed by earlier router based methods like RED proposed by Floyd andJacobson (1993). RED detects incipient congestion by computing the average queue size and control the average queue size before the gateway queue over flows. They considered it an effective mechanism for congestion avoidance at the gateway; in cooperation with network transport protocols because it is unbiased against bursty traffic and avoid global synchronization. Pan etal. (2000) stated that earlier methods for congestion control are either easy to implement or able to achieve flow fairness, but not both simultaneously and they proposed an active queue management method, called CHOKe (CHOose and Keep for responsive flows; Choose and Kill for unresponsive flows) that is simple to implement (since it is stateless) and provide fairness by differentially penalizing misbehaving flows by dropping more of their packets. Kunniyur and Srikant (2001) have given a virtual queue based AQM method Adaptive Virtual Queue (AVQ) which uses a rate based marking approach and it can achieve low loss with high link utilization, more robust to the presence of extremely short flow or variability in the number of long flow in the network. Fengetal.(2001) proposed SFB which scalably detects and rate-limits non-responsive flows through the use of a marking probability derived from the BLUE queue management algorithm and a Bloom filter. Chan and Hamdi (2003) found that most of the existing AQM schemes cannot provide accurate fair bandwidth sharing while being scalable because of per flow state management. They proposed a novel AQM scheme, called Capture–Recapture (CARE) which requires small bounded number of states but can provide fair bandwidth sharing similar to those that can be provided with per flow mechanisms. Thus CARE can simultaneously achieve high quality-of-service (QoS), highscalability, and robustness which are necessary for high speed implementation.

Kamraetal. (2004) stated that with the emergence of new applications with diverse Quality-of-Service requirements over the internet, the need for mechanisms that provide differentiated services has become increasingly important and they proposed FABA a rate control based AQM discipline that is well suited to network edges or gateways(e.g., the ISPs). Long etal.(2005) demonstrated the inherent weakness of current rate-based active queue management algorithms and proposed a new AQM method "Yellow" with key design goals to predict incipient congestion timely and accurately with controlled queuing delays, stability, and robustness to variation in traffic load. Liu etal. (2005) introduced and analysed a decentralized network congestion control algorithm which has dynamic adaptations at both user ends and link ends, a so-called general primal-dual algorithm and introduced an AQM scheme Exponential-RED (E-RED) which out performs RED with larger throughput and lower queuing delay and is inherently stable when combined with TCP-Renoorits variants for high-speed networks. Wangetal. (2005) proposed rate-based algorithm "RAQM" which uses the aggregated traffic input rate to iteratively compute the packet drop probability according to an exponential rule, in order to regulate the input rate to an expected value. RAQM obtains good stability and fast response under diverse network environment and can regulate the queue length to an expected value and achieve a better trade-off between good put and queuing delay. Hongetal. (2007) proposed a new AQM algorithm "PAQM" that considers both the average queue length and the estimated packet arrival rate together in order to detect incipient congestion. The proposed algorithm predicts the average queue length and controls it to maintain a certain reference value to achieve high linkutilization and low queuing delay and has low complexity and easy configuration. Abbasov and Korukoglu(2009) proposed effective-RED a refinement to classic RED scheme with aims to reduce packet loss rates in a simple and scalable manner. Kim etal. (2011) stated that flow fairness and queue-length stability are the two major goals of queue management; however most prior work dealt with these goals in dependently. They proposed a new scheme "P-AQM" which consists of a multilevel caching technique to detect high-bandwidth flows accurately with minimal overhead; and a drop policy for achieving both flow fairness and queue-length stability at the same time.

Optimization approach.

Lapsley and Low (1999) first proposed an optimization approach to congestion control method REM which was derived from earlier work on the Optimization Flow Control (OFC). REM uses Proportional Marking and Online measurement techniques for congestion control which results in fairer bandwidth sharing and allows for the provision of differentiated services between users.

Control theoretic approach.

Aweyaetal. (2001) stated that it is difficult to parameterize RED queues to perform well under different congestion scenarios and further considered router queue length stabilization as one of the goal of queue management methods. They commented that traditional RED does not succeed in this goal because the equilibrium queue length strongly depends on the number of active TCP connections and first proposed a simple control theoretic approach, DRED randomly discard packets with a load-dependent probability when a buffer in router gets congested and is able to stabilize a router queue occupancy at a level independent of the number of active TCP connections which results in high resource utilization, bounded delays, more certain buffer provisioning and traffic-load-independent network performance. Hollotetal.(2002) analysed a combined TCP and AQM model from a control engineering stand point and uncovered limitations of the averaging algorithm in RED. Further they proposed and designed two alternative AQM controllers, first one was "proportional controller" which showed good transient response but suffered steady-state errors in queue regulation, and second one was “PI controller” which exhibited better performance under all cases considered. Renetal.,(2005) found that almost all the existing AQMs schemes neglected the impact of large delay on their performance and they first showed an unexpected dramatic oscillation appear in the queues controlled by several popular AQM schemes, including RED, PI controller and REM, in large delay networks. With appropriate model approximation, they design a robust AQM controller “DC-AQM” to compensate for the delay using the principle of “internal mode compensation” in control theory and found that DC-AQM algorithm is superior to other algorithms for large delay and small reference queue length.

Chang and Muppala (2006) proposed aqueue-based adaptive PI controller “Q-SAPI” for AQM with an aim to improve the transient performance of the fixed-gain PI controller while maintaining its steady-state performance over a wide range of uncertainties and showed its versatile ability in addressing the trade-off between responsiveness and small steady-state error under the dynamic network and traffic conditions. Wangetal. (2007) proposed a novel AQM method “LRED” which first incorporated packet loss ratio as a complement to queue length for congestion estimation and further they found that the use of packet loss ratio enables LRED to catch network dynamics in time, thus achieving fast control response and better performance in terms of good put, average queue length, and packet loss ratio.

Wang etal. (2008a) have focused on the problem of the stability of congestion control for networks with large round- trip communication delays and commented that nearly all the existing AQM schemes neglected the impact large communication delay has on system behaviour, such as stability, robustness and convergence which results in low link utilisations and/or high delay jitters. To address the congestion control stability issue they proposed a congestion controller, called “IMC-PID” which was able to restrict the negative impact on queue stability caused by large delay. Wang et al.(2008b) sfurther proposed a novel AQM based on the “optimized-second-order-system” model, called Adaptive Optimized Proportional Controller(AOPC) which is more responsive to time varying network conditions than other algorithms and achieve the best trade-off between utilization and delay.

Kim etal. (2011) have proposed a novel scheme which consists of a multilevel caching approach which detect high- bandwidth flows accurately with minimal overhead; and a drop policy for achieving both flow fairness and queue-length stability simultaneously. Santi andFonseca (2011) first introduced a novel optimal AQM approach to operate in large bandwidth-delay product networks which uses HSTCP as its transport protocol.

Network Performance Parameter for Router based congestion control

Three performance parameters packet loss rate, queue length and queuing delay have considered most important parameters while designing router based congestion control algorithms. Queuing delay and packet loss rate are the performance metrics which affect the QoS of multimedia traffic. There is a direct relationship between the queue length and packet loss rate as larger the average queue size higher the packet loss rate. Loss rate is defined as the number of dropped packets divided by the total number of packets arrived at the router's input ports. Router output queue length variation is examined over time, in order to measure the average queuing delay and its standard deviation. Minimizing average queuing delay is an important goal for real-time applications. On the other hand, the standard deviation gives a measure of the jitter at the destination hosts which is considered as an important metric for audio/video play back applications.

The metric good put reflects the best use of the available router resources and can be defined as the bandwidth delivered to all the receivers, excluding duplicate packets. Fairness against nonresponsive flows plays an important role while evaluating a AQM approach. Since an AQM mechanism is a sort of congestion control mechanisms, it needs to have robustness over network failures. Namely, even if a network failure occurs, it is desirable for an AQM mechanism to continue its operation. Generally, it is also desirable for congestion control of an AQM mechanism to be decentralized and distributed. Since, for example, other network devices may break down, control information that an AQM mechanism uses may not arrive on time. Even in such a case, the AQM mechanism should operate without serious trouble.

Queue stability is a desirable feature of an AQM policy since it helps in minimizing the packet loss rate. From the view point of Internet service providers, maintaining queue-length stability is also important for maximizing link utilization with reduced buffer requirements(Kim etal.,2011). Maintaining stable queue length at a link is critical for improving service quality as well as increasing utilization and decreasing buffer cost. With a stable queue, a flow may exhibit a stable delay with a low jitter as well as a stable loss rate.

Conclusion

This work explores the literature review of congestion control algorithms in the context of high speed wired networks. This survey covers the directions of router based congestion control. A demonstration of various approaches for router based congestion control approach has been mentioned in order to find out strengths and weaknesses of those approaches. The above discussion clearly suggests that there is a need to analyse the interaction between AQM and TCP as both are used to solve the problem of congestion in a distributed computing environment. A comparative study of performance of existing methods based on different performance metrics has been mentioned. Three performance parameters packet loss rate, queue length and queuing delay have considered most important parameters while designing router based congestion control algorithms**.**

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