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A Comprehensive Review of Reactive and Proactive Congestion Control Methodologies

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ABSTRACT
Congestion control is a preventive method associated with computer networks operated at high load conditions. The congestion is a severe issue which requires considerable attention, as internet performance is largely governed by data traffic fluctuations which are usually burst in nature. Therefore, a survey of different congestion control protocols comparing various parameters is essential to come up with new proposal to avoid congestion problem in computer networks. In this paper, we review progress made in the field of reactive and proactive congestion methodologies, which explicitly compute rates independently of congestion signal in decentralized fashion. Finally, the review brings to notice the application of various protocols along with their advantages and disadvantages.

Keywords
Congestion control, TCP, ECN, VCS, RTT, AIMD.

1. INTRODUCTION
Computer networks or data networks primarily called as digital communication network which allow sharing of resources through different nodes. These nodes in a network are connected through by cable media or a wireless media. Data Link is used by computing devices to exchange data. Sometimes during the exchange of data among various networks leads to congestion. It usually occurs when network node is carrying more data than it can handle. Delay packet loss [1], queuing [2] reduces the quality of services in data networks and queuing theory. Network protocols are used for compensating for a packet loss due to congestion, it uses aggressive retransmission scheme [1-3]. Congestion is a state occurring in network layer which slows down network response time and bandwidth response when message traffic is so heavy in it [4]. Congestion control is a technique to keep the load below capacity using various mechanisms and techniques. Performance of the system is degraded if the number of packets pumped in the system increases [5]. For streaming a class of audio and video applications non-linear congestion control algorithms are used [6]. With initiation of Transmission Control Protocol TCP Peach control scheme for satellite networks [7] in terms of good output has outperformed other TCP network schemes. The blocking of new connection at high speed networks are typical effects of congestion [8] with increase in delay the performance decreases [8] and if the delay further increases, retransmission occurs worsening the situation [9]. Occurrence of congestion shows a lack of balance among various networking equipment [10-11].

Several schemes have been introduced so far, to do away with this problem. TCP congestion control scheme is based on congestion window [12] where multiple devices are said to be networked together for exchanging information among themselves either through direct connection or not [13]. For this several protocols have been introduced as Application specific communication protocols for their reliability [14]. Moreover, admission control is used for explicit allocation of network resources to specify the flow [15]. There are several problems associated with networks, major among them is congestion. Such networks have two stable states: 1) Congestion Collapse- A state with low throughput and 2) Congestion avoidance- A state to avoid collapsing of networks [14].

To overcome this problem various methods are being implemented such as cross layer routing schemes for transmitting some packets of higher priority than others [16]. Also feedback strategy [10] can be used as dynamic approach for sensing the presence of congestion and then either increasing the subnet capacity (routers) or decreasing the traffic offered to subnet [16]. Varied transmission signals which carry their signals and transmission protocols to organize network traffic [4], network size topology [17] and organization intent makes difficult in computer networks. Mac scheduling [8] and routers [13] assist the back-pressure congestion control in multi-hop wireless networks [8]. So, for the fair queuing in routers, exponential back off in protocols such as CSMA/CA [19] is 802.11 is used. In which a subnet may be able to handle an average 10M packets in an hour, but it can’t handle an average 10M packets in a minute and doing nothing for next fifty-nine minutes [20]. Therefore, TCP congestion control scheme proposed by Jacobean with current specification in Request for Comments (RFC) 568[21] was introduced. TCP relies in Additive Increase and Multiplicative Decrease (AIMD) [6]. To overcome the routing issue Cluster based Hierarchal routing is put forward for effective utilization of energy at nodes [23]. Inherent loading of computer traffic is one cause of congestion [17]. To smoothens or alter traffic as the function of time using Radio Frequency Identification (RFID) tag [24] traffic shaping is proposed. The size of queue in network flow-map distribution of traffic between different source and destination is used in multipath routing scheme [25].

The flow control mechanism can be used for handling congestion to reduce the traffic put on the net by different host and solving the packet loss problem by Policy feature Card (PFC) [26].

Congestion control methods can be categorized broadly in to two following categories:

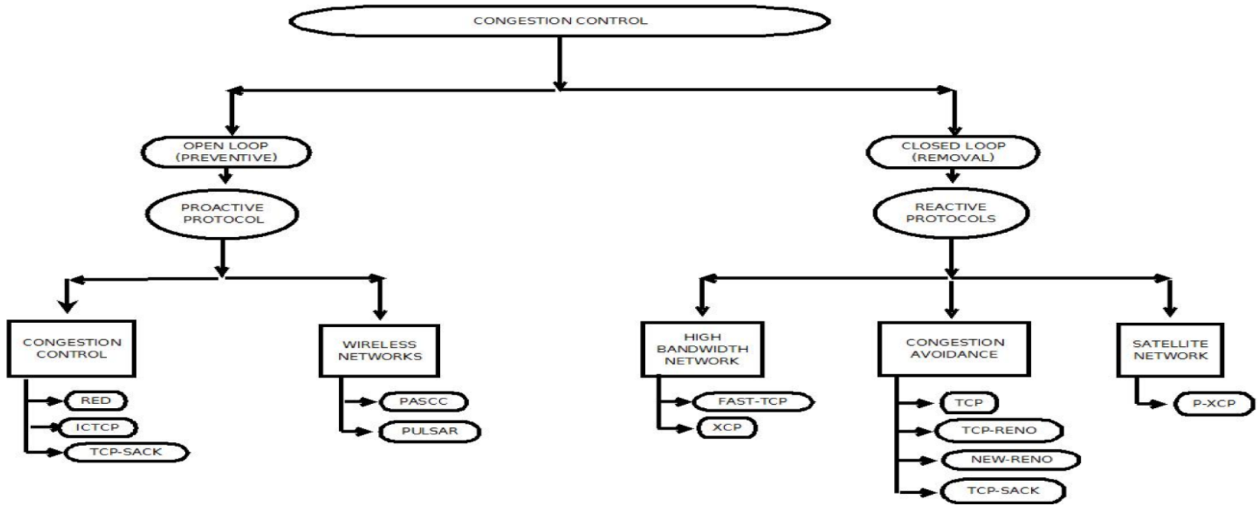
- *Open loop congestion control (prevention)*

In open-loop congestion control, policies are applied to prevent congestion before it happens. In these mechanisms, congestion control is handled by either the source or the destination [13, 26]

- *Closed loop congestion control (removal)*

Closed-loop congestion control mechanisms try to alleviate congestion after it happens. Several mechanisms have been used by different protocols [1, 9].

A detailed categorization of various congestion control methods reported over the years is presented in Fig. 1 as follows:



- **Fig 1: Categorization of congestion control methods**

2. PROACTIVE CONGESTION CONTROL PROTOCOLS

The maximum-minimum rate of the flows is directly calculated through Proactive Congestion Control Algorithm. This differs from reactive congestion in two ways:

Firstly, rate calculation is done independently and it is only limited by the time it takes for the network to register change in the set of active flows such as flow arrival or departure which is itself proportional to delay [1, 12].

Secondly, rates are calculated explicitly based on which flows are active, thus avoiding gradual adjustments that a reactive algorithm needs to converge to target rates. The lack of a measurement phase and fast explicit rate calculations helps protocol algorithm quite quickly [7, 9].

2.1 Random Early Detection (RED):

It is synchronization of TCP flow and correlation of drop event with an improvement over traditional drop tail queue within TCP flow [5]. Binomial algorithm [6] interacts with TCP across RED gateway for controlling traffic. RED detects incipient congestion early and conveys congestion notification of end-hosts in queue management. While doing this RED allows them to reduce their transmission rate before queue of the network overflow [16] and packets are dropped [1]. To detect congestion RED maintains an exponentially weighted moving average of queue length [8, 25].

2.2 Priority Based Applications Specific Congestion Control Clustering (PASCC)

This cluster based hierarchal routing protocol works well for wireless networks [18] and used efficiently to utilize the limited energy of nodes [24] for different types of application, thus different set of priorities [26] and timeliness [14] requirement are maintained for the packet transfer. PASCC integrates the mobile utility and heterogeneity [26] of nodes to detect congestion in networks.

2.3 Periodically Updated Load Sensitive Adaptive Rate Control (PULSAR)

Periodically updated load sensitive adaptive rate control (PULSAR) [22] used for determination of different maximum and minimum transmission rate intervals and transmission ranges. This data adaption oriented protocol is design methodology for Vehicle Safety Communication (VSC) [24].

2.4 Incast Congestion Control for Transmission Control Protocol (ICTCP)

TCP incast congestion happens in high- bandwidth [4] and low latency networks when multiple synchronized servers send data to same receiver in parallel. Designing an incast congestion control for TCP (ICTCP) scheme on receiver side helps to study relationship between throughput and Round-Trip Time (RTT) [1, 12] and receiver window [22]. ICTCP adjusts the TCP receiver window proactively before packet loss occurs. Frequency of receiver window based congestion control should be made according to pre-flow delay independently. The performance collapsed of these many to one TCP connections as these overflows the Ethernet switch buffer [26] in small time causing packet loss and this TCP Re-Transmission [3] time out is called TCP incast congestion.

3. REACTIVE CONGESTION CONTROL PROTOCOLS (RCP)

The basic RCP algorithm, router maintains a single link rate R (t) for every link. The router “stamps” R (t) on every passing packet, receiver sends the value back to sender informing it about slowest (bottleneck) rate along the path. There is efficient and fair network usage in the presence of a few high-bandwidth transfers [4]. The biggest plus of RCP is the short flow completion times under a wide range of network and traffic [24] characteristics—which are in fact quite close to what flows would achieve if they were processor-shared. There is no per-flow state or per-flow queuing [26].

3.1 Transmission Control Protocol (TCP)

Provides a communication services at an intermediate level between application program and the internet protocol as well as host-to-host connectivity is provided at transport layer. Study of TCP segment undertook interpacket limit adaption based on Round Trip Time (RTT) [10] delay, based on solving small packet problem and source Quench problem [1-17]. It eliminated congestion within sensor networks with fair delivery of packets to central node and base station [12]. TCP is designed to work with any MAC protocol in data link layer [12] achieving fairness and stability [15]. Whereas, for streaming audio and video application Binary Algorithm [6] generating TCP style Additive Increase and Multiplicative Decrease (AIMD) [21] for fair and stable operating point, provided Jacob son's algorithm found in current TCP. This algorithm interacted well with TCP at RED [5] gateway. Multipath TCP [21] presents congestion control algorithm that allows one TCP connection to be spread across multipath.

3.2 TCP- RENO

It is standard version of TCP congestion control protocol in high speed networks [17]. RENO suggested algorithm called Fast Re-transmission [3] it worked after waiting for the time out to take place. For small packet loss it performs better than TCP. But for high packet loss it performs almost equal to TCP Tahoe.

3.3 New-RENO

In the event of multiplicative packet loss, NEW-RENO a modified version of TCP-RENO is much more efficient. The only difference between TCP-RENO and NEW-RENO is that advanced version does not exit fast recovery until all data is acknowledged which was outstanding at time it was entered [17].

3.4 TCP-SACK

TCP with selective acknowledgement is an extension of NEW-RENO. SACK retains slow start and Fast Re-Transmission parts of RENO [3]. It works efficiently for multiple lost packets, and retransmission of more than one lost packet per RTT [12]. The major problem of SACK is selective acknowledgement which is currently not provided by receivers.

3.5 Fast TCP

Basically used for High Bandwidth protocol network [2, 3]. FAST TCP is always linearly stable with single bottleneck link which captures the queue dynamics when congestion window of TCP sources changes [25]. It works productively for both homogeneous [11] and heterogeneous delay [26].

3.6 Explicit Control Protocol (XCP)

This is a multilevel network feedback mechanism for congestion control of Internet Transport Protocols. It outperforms TCP in both conventional and High Bandwidth [9] generating Explicit Control Number (ECN) proposals [12]. Therefore, allows more flexible and analytical tractable protocol designs.

3.7 Satellite Network Protocol (XCP)

TCP Peach a congestion control scheme was specifically introduced for satellite network [7]. It is basically based on two Algorithms- Congestion Avoidance and Fast Re-Transmission [3, 17]. This scheme while operating in satellite network has to face flow challenge as low throughput high link error rate. So, the advanced version P-XCP is used to overcome these existing challenges.

3.8 Datagram Congestion Control Protocol (DCCP)

It is basically based on two mechanisms- acknowledgement mechanism and optional mechanism. Both these mechanisms make use of ECN [12] for communicating packet loss. This Transport Protocol provides bidirectional unicast connection of congestion controlled unreliable datagram [15].

Further, the progress made in the field of congestion control by employing proactive as well as reactive strategies is summarized in Table 1 as follows:

Table 1. Progress in the field of congestion control strategies.

Protocols	Author Name	Reliability	Retransmission & Recovery	Congestion Avoidance	Throughput & Latency	ECN/RTT
TCP	Liu S. et al. (2008) [17], Nagle J. (1984) [1]	Fair reliability of packets	TCP takes time to realize lost packet and to take action	When congestion window exceeds threshold. it enters congestion avoidance phase	Average throughput rate	TCP congestion window is doubled for each RTT
TCP-RENO	Liu. S. et al. (2008) [17]	Better reliability than TCP for single packet loss but behaves similarly for multiple packet loss	Fast retransmission and enters fast recovery	Halves the congestion window	Better throughput rate than TCP	_
NEW-RENO	Liu. S. et al. (2008) [17]	Improves TCP RENO packet for burst number of packet loss	Fastest retransmission with improvement in fastest recovery algorithm	Avoids congestion by acknowledging all packets outstanding at start of recovery period	High throughput rate	_

TCP-SACK	Liu. S. et al. (2008) [17]	Highly reliable even for multiple packet loss	It maintains record at which received packet is missed and only retransmit only lost one's	When all outstanding packets are acknowledged it enters congestion avoidance	_	_
TCP-FAST	Hoe J. C. (1996) [3]	Linearly stable for single packet loss	Fair transmission for long distance network	TCP congestion avoidance algorithm maintains constant no. Of packets in queues	High latency link and fairness in system throughput	No. Of packets measured by difference between throughput and base RTT
XCP	Katabi D. et al. (2002) [9].	Uses feedback mechanism by low reliability rate	__	High link error rate with ineffective congestion avoidance	Low throughput	Generates ECN proposal
P-XCP	Akyildiz I. F. et al. (2001) [7]	Better reliability link	High transmission rate	Congestion avoidance scheme for satellite network	_	Generates ECN proposal
DCCP	Kohler, E. et al. (2006) [15]	Communicate packet loss, hence fair reliability	Provides bidirectional connection for unreliable datagram	Unicast connection of congestion controlled	Fair throughput for end to end network connection	_
RED	Firoiu, V. and Borden, M. (2000) [5], Bansal, D. and Balakrishnan, H. (2001) [6]	Improvement over drop tail queue in TCP flow	Reduced transmission and recovery rate	RED power controls traffic through queue management	Decreased throughput	_
PASCC	Jan, M. A. et al. (2014) [23]	Reliable for wireless networks	Slow transmission rate	Integrated mobility and heterogeneity of network to detect congestion in network	Low throughput as it utilizes more energy during processing and transmission	_
PULSAR	Tielert T, et al. (2011) [20]	Increased level of reliability for short range communication	Maximum transportation of packets	_	Efficient throughput rate	_
ICTCP	Wu, H. et al. (2013) [22]	_	Fair transmission rate for packet loss	Adjust receiver window before packet loss occurs to avoid congestion	Low latency	Study relationship between TCP flow and RTT

4. DISCUSSION

TCP basically has fair reliability of packets as it takes long time for selecting the packet loss and to retransmit it. Therefore, it has an average throughput. TCP-RENO [17] adds some intelligence over TCP as lost packets are detected earlier and it enters fast retransmission [3] and fast recovery algorithm, showing better reliability for single packet lost. NEW-RENO [17] is slight modification over TCP. It can detect well multiple packet losses and enters into fastest retransmission with improvement in fast recovery algorithm with selective acknowledgement is an extension of TCP-RENO. The various problems faced between TCP-RENO and NEW-RENO namely as detection of multiple packet loss and retransmission of more than one lost packets per RTT [12] are over connected by TCP-SACK [17]. FAST-TCP a linearly stable network for single packet loss helps to maintains fair number of packets in a queue. It has high latency rates and improvement in system throughput. The review also introduces P-XCP [7] to address the low throughput under high link error-rate condition of XCP protocol in satellite network.

Whereas for both wired and wireless networks DCCP provides efficient congestion control mechanism [15]. Before overflowing of queue in network the transmission rates are decreased in RED protocol. Therefore, there is problem in detecting congestion for wireless [18] network. In order to overcome this existing congestion problem PASCC protocol a highly reliable one is recommended. But it has low throughput due to large utilization of energy during transmission. Whereas for short range communication PULSAR [22] protocol has increased level of reliability with efficient throughput. To avoid congestion in network ICTCP adjusts the receiver window [22] before packet is lost.

5. CONCLUSION

In this paper, recent advancement in the field of congestion control network has been reviewed along with various protocols in a categorized manner. TCP-RENO [17] and its modified standard version NEW-RENO of TCP congestion control scheme works effectively for high speed networks with better reliability [3]. Discussions about promising features of TCP-FAST and XCP for high bandwidth networks have been elucidated [2, 3]. It has been reviewed that XCP outperforms TCP in more flexible designing of protocols. But, due to its high link error rate and low throughput P-XCP has been introduced a TCP Peach congestion control scheme for satellite network [7]. The article also brings to light the cluster based hierarchical routing [23] protocols PASCC and PULSAR featuring enriching performance for wireless networks [18]. Particularly, PULSAR has been designed for Vehicle Safety Communication (VSC) [21]. The paper even reflects on RED proactive protocols an effective improvement over traditional drop tail queue [5] with biggest plus of traffic shaping [17]. Lastly, highly designed incast congestion control for TCP (ICTCP) scheme on receiver side helps to study relationship between throughput and Round-Trip Time (RTT) [1, 11]. Upcoming networking techniques tend to support the massive number of connected devices with diverse bandwidth requirements and minimum content retrieval latency. This review paper has come up with an exhaustive survey and comparison of different classes of congestion control protocols which will offer significant advantages in processing high bandwidth data signals.

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