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CONGESTION CONTROL TECHNIQUES FOR SEAMLESS DATA FLOW IN HIGH-SPEED NETWORKS

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ABSTRACT :

The efficient management of data traffic is crucial in today's age of high-speed networks to guarantee a consistent and fluid user experience. Congestion is becoming more of a concern as digital connectivity becomes more essential to our daily lives. The key to overcoming this obstacle is congestion control systems, which coordinate a variety of algorithms, protocols, and methods to eliminate bottlenecks in a network. In this research, we examine many Congestion control strategies for easing congestion in wired communication networks and preventing it altogether, with a focus on High Speed Networks. The evolution of congestion control technologies is influencing the future of network management and keeping information superhighways clear of traffic in a society that is becoming increasingly reliant on them.

Keywords: High Speed, Traffic, Queue, Bandwidth, Nodes

I. INTRODUCTION

In today's interconnected world, high-speed networks have become the backbone of our digital existence. From streaming high-definition videos and online gaming to conducting critical business operations and remote medical consultations, the demand for fast and reliable network connectivity is higher than ever before. However, as the data traffic on these networks continues to surge, the risk of congestion looms large, threatening to degrade the quality of service and disrupt the seamless flow of information. Congestion control mechanisms have emerged as a crucial aspect of managing and optimizing high-speed networks to ensure that data can be transmitted efficiently and without bottlenecks.

In the digital age, high-speed networks have transformed the way we communicate, work, and access information. The rise of broadband internet, 5G, and fiber-optic connections has unleashed unprecedented speeds, allowing us to send and receive vast amounts of data in the blink of an eye. These networks have become the backbone of our digital ecosystem, enabling real-time video conferencing, cloud-based applications, and the Internet of Things (IoT). However, this exponential growth in data consumption and the proliferation of connected devices have given rise to a pressing issue: congestion. Just as traffic jams impede the flow of vehicles on highways, network congestion occurs when the volume of data surpasses the network's capacity to handle it efficiently. This congestion can lead to slower data transfer rates, dropped connections, and overall degraded network performance, which, in turn, can impact everything from user experience to business operations and public services.

Congestion control mechanisms play a pivotal role in mitigating the adverse effects of network congestion, ensuring that high-speed networks continue to function smoothly and efficiently. These mechanisms are a set of protocols, algorithms, and strategies designed to monitor, manage, and alleviate congestion in network infrastructures. They are the unsung heroes working tirelessly behind the scenes to optimize data flow, maintain network stability, and prevent gridlock in our digital superhighways. Without these mechanisms, the dream of seamless, high-speed network connectivity would devolve into a nightmare of dropped calls, buffering videos, and sluggish internet browsing.

To appreciate the significance of congestion control mechanisms, it is essential to understand the challenges they address. High-speed networks face numerous hurdles in delivering data efficiently to their intended destinations. First and foremost is the issue of network oversubscription. This occurs when more devices and users are trying to send and receive data simultaneously than the network can handle. Imagine a busy airport during the holiday season, with more passengers than available seats on planes. Without a system to manage the influx of travelers, chaos would ensue. Similarly, in high-speed networks, congestion control mechanisms ensure that the available bandwidth is allocated fairly among users and applications, preventing data gridlock.

Another critical challenge is the variability in data traffic patterns. Data traffic is not a steady stream but rather a dynamic ebb and flow influenced by various factors, such as user behavior, application demands, and network conditions. For instance, a sudden surge in demand for a popular online game or a breaking news event can lead to spikes in data traffic that strain the network's capacity. Congestion control mechanisms are designed to adapt to these fluctuations, dynamically adjusting the network's behavior to ensure that data is delivered promptly, even during peak usage periods.

Furthermore, congestion control mechanisms must contend with the diversity of network architectures and technologies. High-speed networks encompass a wide array of infrastructures, from wired and wireless connections to satellite and optical fiber links. Each of these technologies has unique characteristics, such as latency, bandwidth, and error rates, which impact how data flows through the network. Congestion control mechanisms must be versatile enough to accommodate these variations and ensure optimal performance regardless of the underlying technology.

In recent years, with the advent of high-speed networks like 5G and the proliferation of IoT devices, congestion control has evolved to meet the demands of these new paradigms. These networks demand even more sophisticated mechanisms to handle the diverse requirements of a wide range of applications, from autonomous vehicles to smart cities. The intersection of congestion control with emerging technologies like edge computing and network slicing promises to usher in a new era of network management and optimization.

Moreover, the development of machine learning and artificial intelligence (AI) has introduced new possibilities for congestion control. AI-driven algorithms can analyze vast amounts of network data in real time, making proactive decisions to prevent congestion before it occurs. These intelligent systems can adapt to changing network conditions and predict future congestion events, allowing for more efficient resource allocation.

Congestion control mechanisms are the unsung heroes of high-speed networks, ensuring that the digital highways remain free of traffic jams and bottlenecks. They address the challenges of oversubscription, traffic variability, and diverse network technologies while upholding principles of fairness and efficiency. Through a combination of feedback loops, packet-level techniques, and adaptive algorithms, congestion control mechanisms are at the heart of network optimization. As we continue to rely on high-speed networks for our daily lives and the digital transformation of industries, the role of congestion control mechanisms will only become more critical. Their ongoing evolution promises to shape the future of network management and enable the seamless flow of data in our increasingly connected world.

II. REVIEW OF LITERATURE

Bazi, Kaoutar & Bouchaib, Nassereddine (2021) In the realm of computer networks, high-speed networks have been crucial in introducing novel approaches while maintaining flexibility, scalability, and dependability. It's a great service in terms of optimality and signal speed. Congestion control algorithms that can maintain network performance while still delivering on the promised high throughput, low latency, and high quality signals are, of course, a necessary cog in the wheel of any network of this caliber. By the way, this work primarily aims to analyze these methods.

Kushwaha, Vandana & Gupta, Ratneshwer (2014) This paper provides a comprehensive review of methods used to manage congestion in high-speed wired networks, including those that focus on either the sources or the routers themselves. Different literature reviews on congestion control have treated the source-based approach and the router-based approach as complementary rather than complementary. For a specific network domain, both lines of inquiry are intertwined and important. Taking a broader perspective and examining both methods together is a sensible notion. The purpose of this study is to stimulate additional research on the topic of congestion control by providing a summary of both approaches and the interaction between them.

Hilmi, Sahrul et al., (2013) Broadband expansion has allowed for the development of numerous new multimedia applications, including live video streaming, IPTV, video conferencing, online gaming, and video surveillance. These video streams typically need a lot of bandwidth yet don't adapt to slow connections. They value promptness more than consistency. Since TCP is designed to guarantee data transfer, it looks unfit for use in real-time applications. Unfortunately, UDP does not have a congestion protocol and there is no assurance that packets will arrive at their destination. DCCP is a novel transport protocol being standardized by the Internet Engineering Task Force (IETF) that offers erratic congestion-controlled data-packet flows. By changing the queue size, link capacity, and packet latency, we may examine how these transport protocols handle congestion. The NS-2 Network Simulator was used to test out various network configurations.

Dangi, Renu & Shukla, Neeraj (2012) The introduction of high-speed networks is a perfect solution to the growing problem of applications requiring instantaneous transport of large amounts of data through networks. Standard TCP is not suitable for high-speed networks as it does not make optimal use of the available bandwidth due to its conservative congestion control mechanism. A novel algorithm for managing congestion in high-speed networks. Whether the window size should be increased or lowered is based on packet loss data, and the amount of change is based on queuing delay data.

Xu, Wenjun et al., (2011) The introduction of high-speed networks is ideally suited to meet the growing demand for applications that require the rapid transport of huge data via networks. Standard TCP is not suitable for high-speed networks as it does not make optimal use of the available bandwidth due to its conservative congestion control mechanism. To get around this issue, numerous high-speed TCP variations have been proposed. Though effective, many protocols nevertheless have performance issues like RTT-fairness, TCP friendliness, etc. that limit their ability to fully maximize available bandwidth. In this research, we suggest HCC TCP, a hybrid congestion management algorithm that takes a combined delay-based and loss-based approach to better handle the challenges of today's high-speed, long-distance networks. The method takes queuing delay as its major signal of congestion and adjusts the window to stabilize near the size that maximizes bandwidth consumption. However, in situations where the delay-based technique operates poorly in networks, packet loss is used as a secondary congestion indication, and a loss-based congestion control strategy is employed to keep bandwidth utilization at a high level. Depending on the current state of the network, the algorithm will switch between its two different techniques dynamically. Finally, we use simulations to test the proposed HCC TCP and confirm its features. The simulation results show that HCC TCP is a good choice for high-speed networks since it provides good throughput, fairness, TCP friendliness, robustness, etc.

Kaura, Shilpi & Vatsa, Avimanyou (2011) Multimedia functions including audio and video transmission are commonplace now. In terms of throughput, lag, and QoS, multimedia transmissions can be categorized. The requirement for increased transmission capacity and bandwidth for multimedia applications has propelled the development of various cutting-edge network technologies. TCP will struggle to keep up with the demands of future high-speed networks because of the unpredictable swings and burstiness of traffic flows within these networks. In this paper, we set out to devise a solution for the issue of frequent congestion occurrence in high-speed networks, specifically a model that has the ability to learn based on round-trip time, node outlink capacity, and average queue size, and then pass a signal to the sender to adjust the rate at which it transmits data. This means that high-speed network congestion issues can be fixed.

III. CONGESTION ALGORITHMS

The following table provides a comparison of all of the congestion algorithms in terms of the parameters that have been addressed.

Table 1: Comparative Analysis of various Congestion Control Protocols

Metrics	**Congestion Algorithms**					
	BCN	**ECN**	**AIMD**	**CHOKe**	**DECbit**	**RED**
Fairness	When TCP and BCN are used together, fairness is achieved. As distance increases, so does unfairness.	Flows of moderate or low strength are treated unfairly. Adaptive ECN (AECN) helps make things more fair.	When sending large amounts of data, it behaves fairly.	Fair uses the queue buffer occupancy of each flow to differentially punish hostile and unresponsive flows.	Congestion signals are only sent to customers who are hogging excessive amounts of bandwidth.	No way to tell the difference between fair and unfair flows.
Latency	Connections at greater distances experience more latency.	TCP connection latency is improved as a result.	The efficiency vs. latency issue is resolved by using a modest backoff factor, which is favored when the queue size is big.	Processing is needed to allow a packet entry via CHOKe.	It regulates the wait time by aiming for an average queue size of 1.	This value could increase if the buffer size is very large.
Jitter	Heterogeneous settings necessitate additional study.	When combined with RED gateways, packet	Buffers of sufficient size can handle	Packet loss increases for UDP sources during	It presupposes that all inputs will be used	There are more packet losses with

		loss is mitigated.	the temporary spikes in traffic.	bursty traffic.	constructively.	bursty traffic.
Packet Loss	The more switches a connection goes through, the higher the probability that packets may be discarded or flagged due to congestion.	Using ECN, a TCP connection will drop less packets.	Losses occur when the total throughput approaches the buffer capacity, shown by the symbol C.	If the average queue length is larger than the maximum threshold, all incoming packets will be discarded.	Packet loss can be prevented if the sources work together to lower their transmission speeds.	The Drop percentage rises as the average queue size approaches the "maxth" threshold.
Throughput	When TCP and BCN are used together, throughput increases.	Less certain are ECN's effects on throughput in the aggregate.	Cuts in half the amount of data being sent across the network when congestion is detected.	To ensure that the entire queue size stays below minth and that TCP flows can achieve high performance, it essentially penalizes the UDP flow.	The "cf" the capacity factor (between 0.5 and 0.9) determines the throughput for several users.	depends on the volume of traffic and other variables.
Link/ Channel Capacity (Bandwidth)	More study is needed for multi-modal traffic.	Bandwidth is effectively distributed due to	If your medium has a high throughput, you shouldn't	Regardless of how quickly or slowly UDP flows are	All users are treated fairly in terms of bandwidth allocation.	The packet losses and the bandwidth-

		ECN's packet-marking capabilities.	use this technique.	arriving, it can limit their share of the available bandwidth to an extremely minimal amount.		hogging flows are both higher for bursty traffic.
Link utilization	When TCP and BCN are used together, link utilization increases.	Despite delays due to propagation and queuing, TCP/ECN is able to achieve nearly 100% connection usage.	In the event that network queues are excessively small, backoff action empties them by decreasing link use.	The responsive sources receive the most bandwidth allocation (Good).	A binary feedback system works well.	The smaller the buffer size, the better (Good).
Queue	When a router's queue fills up, packets are automatically dropped.	The average queue length can be used as a proxy for congestion.	If possible, it should be set so that long stretches of time without any activity in the queue are avoided.	After the average queue size exceeds a threshold, UDP flow is effectively penalized by the random packet selection method.	Regeneration cycles go from empty to full to empty.	The likelihood that a packet will be dropped increases at random as the average queue size grows.

IV. PROPOSED SCHEME FOR CONGESTION DETECTION & CONTROL

This Congestion Detection module will operate on the switch level. This component keeps a constant eye on the queue's current occupancy to identify impending bottlenecks. Here's how it's done:

- Determine the overall queue occupancy rate.
- If the queue's occupancy rate is over 65%, you should take action.
- If the total queue occupancy is greater than 65%, the Control Mode module is activated. This module determines the percentage of queue occupancy for each sending source and notifies those sources that the severity of the congestion necessitates a reduction in their current transmission rates (by a factor of 1, 1, 2, 4, 8,...).
- The module then goes into Wait mode, where it waits for a set amount of time before checking to see if the source has slowed down its transmission rate.
- If a source doesn't behave, the module will invoke the Drop Mode module, which will remove all of that source's packets from the priority queue and add them to the total available bandwidth.
- To add the new sources to the system, the Scale up module is activated.

The following are presumptions for the proposed algorithm:

Network Traffic Classification

- **Traffic from behaving sources:** All the Sender nodes that transmit the packets as per the established terms of Quality of Service (QoS) and during congestion, the nodes which reduce their current sending rates correspondingly after receiving the choke packets from crowded node are termed the Behaving sources.
- **Traffic from Non-Behaving sources:** The non-Behaving sources include any Sender nodes that, despite receiving RM or Choke packets from the crowded node to reduce their current sending rate, continue to transmit packets in violation of the QoS agreement. These misbehaving nodes continuously send out more packets, which might increase network congestion due to a greater demand for bandwidth and a higher percentage of queue occupancy.

Queues

A router or switch's Input Queue is a priority queue, whereas the Output Queue is a standard queue. Priority Queue packets are assumed to be dropped from misbehaving sources when the queue reaches 100% occupancy, whereas regular Queue packets are accommodated in the expectation that they would be processed in due time.

Only under extremely congested conditions will packets from misbehaving sources be DROPPED. The packet transmission rate of the sources must be lowered otherwise.

Bandwidth Management

Assuming that 'n' hosts are eager to join the network and exchange data with one another, we propose utilizing the Dynamic Programming Algorithm to control network bandwidth usage.

In the following case, the dynamic programming-based solution will handle bandwidth management by permitting Scalability (both scaling and de-scaling).

- **From Congestion to No Congestion**

Allowed Source Rate increases for nodes are (1/128, 1/64, 1/32, 1/16, 1/8, 1/4, 1/2, and 1). During this time, additional hosts can ask to join the network, and if the bandwidth and QoS are sufficient, they will be allowed to do so.

- **From No Congestion to Congestion**

Hosts are asked to slow their packet-sending rates (called "Source Rates") down from the default values of (1/128, 1/64, 1/32, 1/16, 1/8, 1/4, 1/2, 1). Until the packets of an already connected node have been dropped for misbehavior, no new nodes may seek to join the network.

Additionally, packets from such sources are dropped based on the criteria of % of queue occupancy for dropping the packets if the currently connected nodes do not comply with the request, until sometime. For as long as there is congestion, packets will be dropped until the situation improves.

V. RESULTS AND DISCUSSION

Bandwidth optimization and making bandwidth available to Behaving sources are two key goals of the proposed paradigm, both in the presence and absence of congestion. Throughput for Behaving sources is maximized in both congested and non-congested conditions. To accommodate the Network Traffic's Quality-of-Service requirements in both congested and non-congested environments. During times of congestion, packets from sources that are behaving themselves are accepted and placed in a queue while those that are not are dropped. Allocate bandwidth to a new host, provided that it behaves by transmitting packets in accordance with the QoS agreement.

VI. CONCLUSION

While the advent of high-speed networks has greatly improved our ability to communicate in the digital realm, this development has also given birth to congestion, a perennial problem that undermines network performance. Congestion control systems are up to the task by effectively regulating data flow. New technology and conceptual frameworks are expanding the possibilities for congestion management in the near future. Congestion control must adapt to the new challenges posed by 5G, IoT, and edge computing. The rise of machine learning and AI has ushered in a new era of proactive network management by making it possible to anticipate and prevent congestion events.

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