CONGESTION CONTROL IN WIRED COMMUNICATION USING REINFORCEMENT LEARNING

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Abstract:
In the congestion avoidance phase, where multiple flows constantly transmit data across a shared network connection, traditional TCP-like congestion management algorithms equally manage all the flows. Congestion control strategies are becoming increasingly relevant as the internet and network technologies rapidly evolve. The router experiences congestion when its buffer cannot hold all incoming packets. Consumers expect a high level of service quality from traditional congestion control protocols. Congestion control techniques that function across various networks are essential for improving performance. This restriction results from the rule-based design paradigm, which requires a fixed mapping between the observed state of the network and the corresponding actions to ensure optimal performance. These protocols need to be able to modify their actions based on their surroundings or gain insight from past experiences to improve their efficiency. To resolve this problem, we present QTCP, a method that combines the TCP design framework with a Reinforcement-based Q learning framework. The QTCP protocol allows senders to learn the best online congestion management policy over time. Because it does not rely on predetermined rules, QTCP can be applied to many network configurations. The current study discusses the procedures, processes, and algorithms employed in wired networks and integrates the findings and suggestions of prior research.

Key words;Congestion control, wired communication, Reinforcement learning

INTRODUCTION

Today's businesses require hybrid networks that combine wired, wireless, and satellite connections. Moreover, assessing how a network will behave is quite challenging because its actions depend on so many unknown factors. Reasons like these make it exceptionally challenging to create reliable analytical models of networks. However, [1] orderly computer networks call on the creation of effective control mechanisms and the rapid adjustment of these approaches to new technologies. Therefore, data mining and machine learning are crucial tools for expanding our understanding of networks and enabling the creation of efficient control techniques. Data for these methods can be easily gathered through observing existing systems or modeling fake ones, as networks are computer-based systems.[2] When TCP is allowed to coexist on a shared network with another TCP, both protocols are able to attain throughputs that are comparable to those reached when operating with an independent TCP under the identical conditions. The new protocol would be fair to the Internet's de facto standard if it had to adhere to this limitation. When we classify congestion losses frequently, we are unfair to TCP, since other protocols must slow down to avoid constraints, while TCP's congestion window remains constant. [3] A global misinterpretation of congestion losses will cause the network to go dark even if the competing protocols use the same one because no one will lower their congestion window. Therefore, one should not utilize a classifier that frequently fails to detect losses due to congestion for its advantage and the benefit of the community. It is not worthwhile to evaluate a classifier that correctly identifies all congestion losses but incorrectly identifies numerous link error losses.

TCP congestion control:

Network congestion occurs whenever routers cannot process the data that arrives at them, leading to buffer overflows at certain routers and the subsequent loss of some data packets. Taking some of the strain off the network is the only way to reduce congestion. The Transmission Control Protocol (TCP) employs a congestion window (abbreviated cwt) to regulate the rate at which packets are transferred from a sender to a receiver and a means of dynamically adjusting this window's size in response to changes in network conditions. [4] When things are going well, the rate can go up gradually, but when a loss happens, it can go down more quickly. Every time a packet is delivered from a sender to a receiver via TCP, the recipient must send back an acknowledgment packet. A sender's maximum packet queue length is limited by the congestion window. Then, after receiving confirmation, it will send out a new packet. [5] Once it receives confirmation that the last packet in the preceding cwnd packets has been received, it will increase cwnd by 1, and it will send out two packets in a burst instead of one. A packet's round-trip-time (RTT) is measured from the moment it is sent until the moment the sender receives an acknowledgment of its received.

The three phases that make up TCP's overall policy for dealing with congestion are as follows:

- Slow start
- Congestion avoidance
- Congestion detection

The sender initiates transmission at a low rate and rapidly raises it until it reaches the threshold during the slow start phase. When the data rate reaches a certain point, it slows down to prevent congestion.

Goals and Metrics of Congestion Control

- In order to optimize bandwidth use.
- Combine for the objective of achieving justice quickly and efficiently.
- With the objective of reducing oscillation amplitude.
- Keeping a high level of responsiveness.

Scope of the work:

Furthermore, we describe that machine learning may be used to enhance the congestion control protocol of hybrid wired/wireless telecommunications networks. Computer networks require

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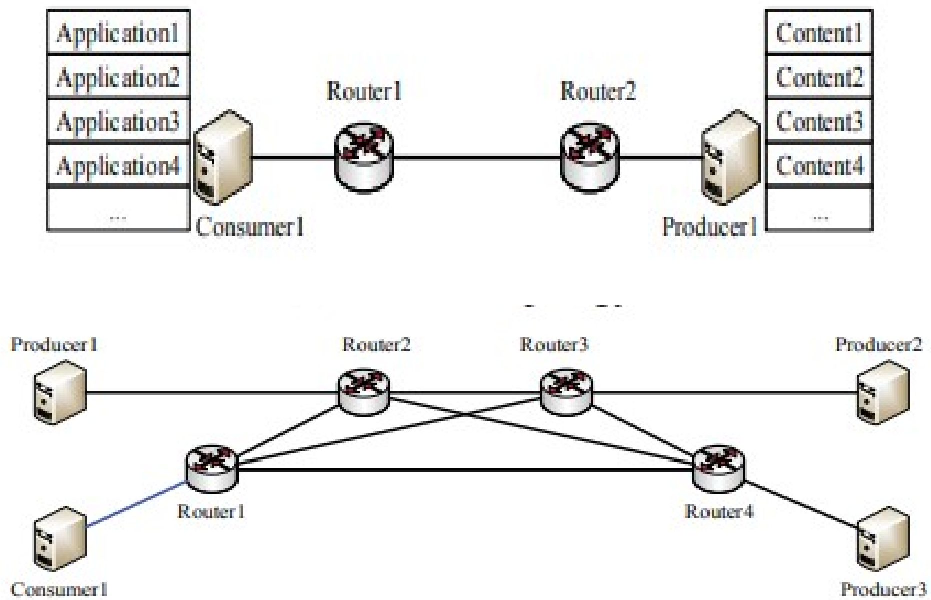
ISSN: 1005-0930

congestion control to prevent congestion collapse and ensure that all users receive an equal amount of bandwidth. Since TCP carries the majority of internet traffic nowadays, it is also responsible for controlling congestion. The congestion control method of this previously deployed protocol is not suitable for the networks of today, which increasingly make use of wireless connections.



Differentiation between baseline and multi-source and multi-path topology

objective

- Content-based optimal congestion control is well-suited to the characteristics of NDN and is more flexible to user requirements.
- The consumer-focused integrated congestion-control goal will be developed with input from users regarding their requirements for content, the quality of the user experience they require, etc.

2.0 LITERATURE REVIEW

H. Dubo Ferries et.al [6] presented an Associated with maintaining clustering technique for maintaining different sink nodes. This Voronoi algorithm assigns a single "sink" to each cluster, which is responsible for collecting data from all of the sensors within that cluster. Each node remembers the distance in the network to its nearest sink and stores that information. After receiving a message from a sink, the receiving node ensures that the packet's round-trip distance is smaller than the nearest sink distance estimate. If so, the node will resend the message after updating its nearest sink and parent entries. If the message originated at the closest sink and the distance travelled is equal to the closest distance, the node will relay the information. The algorithm has the issue of not taking into account the remaining energy of the sensor node. TCP Reno-2, a cross-layer congestion control method, was discussed by B. Mamalis [7]. Here,

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congestion control is a team effort between the TCP and PHY layers. Congestion is controlled by the TCP layer's Reno-2 window-based flow management, while the PHY layer adapts transmission power in response to changes in channel condition, interference, and wire network congestion. Throughput and sensitivity to changes in window size are two areas where our simulations reveal an improvement thanks to the cross-layer congestion control method. J. W. Chung [8] As a result of digital convergence's booming growth in audio-visual traffic, this has become the case. Real-time or on-demand content transmission is essential for many network applications, including video streaming and conferencing, voice over IP (VoIP), and video on demand (VoD). With more and more individuals using these network apps, congestion is inevitable. Throughput, fairness, stability, performance, bandwidth usage, and responsiveness are only few of the performance criteria that Reddy et al. [9] have used to analyse several congestion control methods developed for the High-Speed Network.

Congestion control methods:

When a network is overloaded, traditional congestion management methods provide an alarm to the source, giving it the option to slow down its packet transmission rate or switch to a less desirable path. In addition, because they all use TCP, all congestion management solutions can signal back to the source about the congestion problem. [10] Communication between the sensor node and the sink is based on a multi-hop message relay. Battery life will be shorter for sensor nodes that are closer to the sink than for those that are further away from the sink. [11]. This is due to the increased message relay burden for nearby sensors and the increased number of possible pathways from sensor to sink, both of which lead to higher overall power consumption. Inefficiency in the network as a result of energy gaps brought on by exhaustion. Energy models have been built by a number of scholars, and while they do provide some explanation, they may be improved. [12] To extend the reliability and lifespan of a network, clustering techniques are used in routing protocols. With the wired network's clustering method, you can talk directly to other nodes in the network. With this method, we can increase network packet overhead while decreasing energy use. Ideally, the cluster heads would share the network's load in a balanced fashion to provide the best possible performance of the underlying wire architecture. [13] Whenever there is a disparity in the network's load, the cluster heads' power consumption rises, which in turn shortens the duration of the network. Congestion in the network might cause a load imbalance condition to occur. [14] The Transmission Control Protocol (TCP) is a highly efficient and dependable transport protocol for wired networks that is used mostly for data services. However, studies and tests demonstrated that TCP's congestion control mechanism fails miserably in Wireless Ad Hoc Networks, resulting in lower throughputs and significant disparity among flows. [15] Existing work established the path using a minimum hop count and a newly generated sequence number. An adaptive congestion control method is developed to address the bottlenecks that occur in wired and hybrid wireless networks. [16] The suggested mechanism, unlike existing variants that use the AIMD strategy in updating the cwnd, dynamically evaluates the available network bandwidth using the received acknowledgments and modifies the

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congestion window (cwnd) of TCP sender correspondingly based on the available capacity of the network. With this, we predict a rise in TCP connection throughput and efficiency.

Congestion Control Algorithms:

Drop Tail Algorithm: To discuss how the drop Tail (DT) algorithm, which removes packets from the very end of a full queue buffer, is the most popular, simplest, and accurate algorithm in use today's networks. [17] The key benefits of this algorithm are its ease of use, tolerance for difference, and decentralised structure.

Random Early Detection Algorithm: RED (Random Early Detection Algorithm) was mentioned as a potential primary algorithm for Active Queue Management (AQM) implementation [18]. When a packet arrives, the average queue size is calculated using an Exponential Weighted Moving Average (EWMA). The next move is decided by contrasting the calculated average queue size with both the minimum and maximum values.

CHOKE Algorithm: The proposed CHOKE algorithm compares newly arriving data with data drawn at random from the FIFO buffer of the overworked gateway router. If the packets are all part of the same network flow, they are dropped simultaneously; otherwise, the packet is preserved intact and the next arriving packet is allowed into the buffer with a probability that changes with the congestion.

Blue algorithms: [20] The objective of the RED queue management system is to identify the onset of congestion as early as possible, notify the affected parties of the condition, and then let them to reduce their sending rates accordingly.

Random Exponential Marking Algorithm: [21] The Random Exponential Marking Algorithm (REM) is a novel method for congestion control that seeks to maximise bandwidth usage while simultaneously minimising delay and loss in transmission of data.

Fair Queuing Algorithms: Multimedia integrated services networks favour the proposed Fair Queuing Algorithms and Stochastic Fair Queuing Algorithms due to their reliability and ability to limit delays in the flow of data.[22]

Virtual Queue Algorithm: This approach proposes a novel method called the Virtual Queue Algorithm (VQ), in which a fictitious queue is kept in sync with a real queue, each with the same arrival rate. [23] The capacity of a virtual queue, however, is less than that of an actual structure.

Adaptive Virtual Queue Algorithm: The link's virtual queue is kept at a constant length based on the link's capacity and the targeted usage, both of which are detailed in the Adaptive Virtual Queue method. [24] The virtual queue has the exact same capacity and buffer size as the physical queue. The capacity of the virtual queue is adjusted with the arrival of each packet.

Congestion Control in Wired Networks

From a control theoretic perspective, there are two broad classes into which all possible answers fall. The two types are open loop and closed loop congestion control. Congestion is avoided entirely with the use of open loop solutions, which focus on implementing sound engineering practises. The system can't be tweaked in the middle [25]. The principle of the feedback loop is the foundation of closed-loop solutions. As a whole, this strategy consists of three stages.

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- Constantly checking for points of congestion is important.
- In other words, get this data to the people who can do something with it.
- Identify the problem and make the necessary adjustments to the system's operation.

Algorithms for open-loop congestion control can be further categorised into two groups. They are the "which acts at source" and "which acts at destination" clauses. [26] Similarly, there are two types of closed-loop algorithms. Two types of feedback are implicit and explicit. When congestion occurs, explicit feedback sends packets back to the source to alert them. Congestion is detected in implicit by the source, who does so via observational studies of the immediate area. For instance, the length of time required for responses such as acknowledgments. If there is congestion, it's because demand is higher than supply. To manage the traffic, we can either allocate additional resources or reducing the demand. [27].

Recent advances on ML based congestion control

As future networks grow more dynamic, traditional rule-based congestion control solutions are likely to become inefficient, if not completely ineffectual. Inspired by the tremendous success that machine learning (ML) has achieved in solving large-scale and complex difficulties, researchers are starting to shift their focus from rule-based method to ML based approach. In this work, we provide a selective overview of current ML applications in the area of end-to-end congestion control. First, we take a glance back at how congestion management and ML are related in the past to set the stage for this analysis. A standard TCP congestion control operates as follows, and we then analyse the latest research that apply ML to congestion control. When first activated, the endpoint's transmission rate should ramp up rapidly in order to maximise the use of available network bandwidth. If ML-based congestion control is taught in a competitive environment, it may learn to periodically cause packet loss to force competing TCP protocols to back off so that it can take more network resources. The difficulty lies in figuring out how to work in harmony with pre-existing protocols. Also, a worst performance guarantee is often necessary for network protocols due to the requirements of network systems. Congestion management using machine learning must be adaptable to new circumstances. Lastly, the model needs to be able to change to novel situations inside the network without requiring constant re-training. This requires the generalization capacity of the ML method.

Reference	Study	Methodology	Conclusion
Huiling Jiang [28]	A Survey and Comparison of Machine Learning Meets Congestion Control	We analysed that how RL-based CC algorithms perform, and we describe the issues that exist in the world in this field. We describe issues and directions for learning-based CC	However, unsupervised learning-based CC algorithms have seen less adoption than their supervised learning counterparts. Primarily, they are

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		algorithms.	used to group together observables like latency and loss.
Ticao Zhang [29]	First, we take a look back at how congestion management and ML are connected in the past and present. Later, we take a look at the most recent research that has used ML for traffic control.	to make use of ML methods in order to develop efficient traffic-control algorithms.	analysis of the most significant progress made in end-to-end congestion reduction using machine learning. We also talked about research gaps that exist in both networking and ML.
Author K Xiao et al [30]	Generally speaking, TCP-Drinc refers to Transmission Control Protocol Deep Reinforcement Learning-based Network-based Congestion Control.	proposes a novel and intelligent congestion control technique that makes use of Reinforcement Learning	method for modifying the congestion window size that takes into consideration current network conditions. Superior product in all respects to TCP-New Reno (59.5%) and QTCP Baseline (35.2%). When compared to New Reno, the RTT performance here is slightly improved.
Mythiliboopathi etal [31]	TCP does not generalise well under a large number of network circumstances since it adapts the central congestion-control strategy based on unique network designs or applications.	data transport context, which places fresh demands on congestion management protocol development.	These performance records serve as the raw material for Reinforcement Learning. Real-time data collection and aggregation and remote monitoring are both provided by data Collector.
S. NagaMallik	Improve wireless	Wireless networks	ML Algorithms, as

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Raj et al [32]	network safety with machine learning methods	can vary in performance depending on distance covered, the number of users connected, the type of devices being used, and the amount of force exerted on the network.	well as many Wireless Network Security Issues. It is made evident how ML Algorithm Techniques can be used to address security issues.
Shirong Lin et al [33]	To improve TCP performance in anticipation of congestions on wireless networks, by launching the appropriate rate control locally on the access points (APs) before congestions develop.	When comparing throughput, delay, and jitter performance, the aforementioned techniques are at least 16.5%, 25%, and 12.6% more effective than the bottleneck bandwidth and RTT (BBR) protocol and the recently proposed protocol Vivace.	To implement our strategies, we use the highly compatible Software Development Workbench (SDWN). Our platform is guaranteed to perform better thanks to these three benefits.
An Kyu Hwang [34]	TCP Performance Enhancement Algorithm Using Machine Learning for Networks with Low-Performance Connections	A machine learning system with a single hidden layer is used to differentiate between network congestion and wireless packet loss.	The suggested strategy does not shorten the congestion window when it is absolutely necessary, even if machine learning predicts that the loss will be predictable.
B. Subramani [35]	This paper provides a comprehensive overview of the most major congestion control mechanisms, a classification of their defining characteristics,	These conducts research the state-of-the-art of congestion management algorithms designed for networks, classifies their	In Theory of Congestion, the authors investigate what leads to congestion as well as its negative outcomes and

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	an elaboration of the Protocol concept, and finally a state-of-the-art analysis of congestion control mechanisms created specifically for networks.	distinctive features, elaborates on the TCP-friendliness idea, and analyzes their performance.	potential solutions.
Vandana Kushwaha [36]	In this study, we provide a comprehensive review of congestion control strategies for high-speed wired networks.	When discussing congestion control strategies, several reviews papers in the literature treat the source-based approach and the router-based method as complementary rather than competitive.	The objective of this study is to provide a concise summary of both approaches, to analyse their mutual effects, and to pinpoint the most pressing problems and obstacles in distribution networks.
Hanaa Torkey [37]	To determine the optimal size for a congestion window (cwnd) Goals include optimizing resources and increasing End-to-End TCP throughput.	Simulation studies are conducted with the popular Network Simulator NS-2 to assess the effectiveness of the proposed mechanism in a variety of network configurations.	To prevent a total breakdown of the network, the system constantly makes estimates of the available bandwidth and adjusts the transmission rate at the TCP sender appropriately.

Congestion Control using Reinforcement Learning

Congestion control RL formulation requires action, state, reward, etc. specification. Responses are rate of propagation adjustments. Our approach emphasizes the fact that the agent is the traffic source, and that her activities result in varying transmission rates. For this purpose, we use the concept of monitor intervals (MIs) from [6, 7]. Time is divided up into discrete chunks. As each MI t begins, the sender has the opportunity to change the transmission rate Xt, which will remain constant for the duration of the MI. Our group tried a few different approaches before settling on the concept of action being represented by a shift in the present rate.

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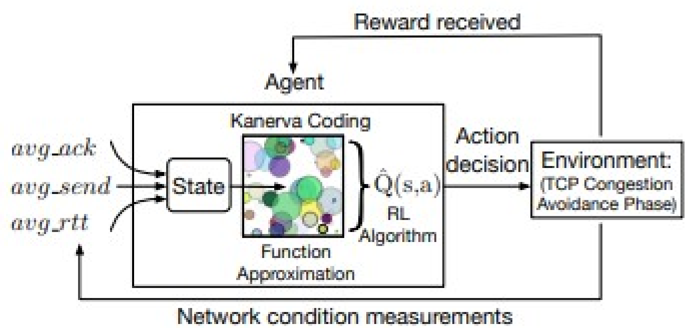
The history of sending rates and the related statistics is bounded in states. After settling on rate xt at MI t, the sender monitors the outcome of her transmissions and derives statistics like goodput, packet loss rate, average delay, etc. from the packet-acknowledgements she receives. Using the transmission rate at MI t, we may calculate a vector of statistics denoted by Vt. In what follows, we focus only on statistics vectors that have the following components: I rate of transmission at the MI, (ii) rate of average reception, (iii) rate of average losses, (iv) latency on average, (v) latency gradient [7], and (vi) received the largest with the latency on average.

Generally speaking, congestion control protocols can be broken down into two groups: (1) "special purpose" protocols developed to excel in a narrow range of environments (such as mobile networks, satellite networks, data-center networks, etc.) and (2) "general purpose" protocols designed to perform well in a wide variety of settings. Protocols in the first group may have great performance when the network conforms to their expectations, but they may be severely hindered when the network is not ideal. On the other hand, a protocol developed for a particular type of network environment may naturally outperform a general-purpose protocol that isn't optimised for that environment [15].



CONCLUSION:

This research aimed to survey all the most up-to-date work on TCP-friendly congestion management methods. Since non-TCP-based unicast traffic and multicast communication require TCP-friendly congestion management, we have presented an overview of the design space for such congestion control methods. The paper briefly discusses many methods for easing traffic congestion. Internet congestion management and other computer networks seem to need a fool proof algorithm. Possible alternatives to the current congestion control methods could be implemented with router support that hides their shortcomings. Even if TCP friendliness is a good measure of network fairness in the present day, newer network designs may settle on or demand different fairness metrics. Improving the TCP network traffic models employed by some rate-based congestion control methods is another active topic of study. Several key assumptions made in existing TCP equations are rarely realized in practice. The ability to deal with temporary

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traffic spikes is an important part of congestion management methods that are only loosely related to the traffic categories addressed in this study (i.e., traffic associated with streaming media). The approximation approach for Kanerva coding functions minimizes the computational complexity of value functions and the extent of the state space that can be searched. We need to use QTCP because it exceeds the standard rule-based TCP by delivering over 59.05% more throughput at the same or lower transmission latency.

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