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Intelligent Congestion Control System to Control Computer Traffic by using various techniques - A Survey

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Abstract
Network Congestion due to heavy data traffic has been known to disrupt seamless and timely transmission of data. This problem has been exacerbated in recent times owing to exponential increase in data usage. At times, the message traffic flow exceeds the capacity of the network layer to handle the traffic which results in slowing of network response time, sometimes also resulting in dropping of packets and requiring re-transmission of data. In this paper, we explore how machine learning techniques can be used to improve congestion control and what are the challenges in adopting these techniques for congestion control. Machine learning is an application of Artificial Intelligence (AI) using which the network / system can be programmed to solve the issues arising in network performance on real time basis using the past experience / historical data. The network's learning evolves over time and the system refines its algorithm with each new experience thereby becoming more efficient. Such Machine Learning based Intelligent Congestion Control system provides real time connection and efficient management of network traffic for high quality data transmission.
Keywords: *congestion control, intelligent, network traffic, machine learning*

1. Introduction

In recent times, rapid expansion has been witnessed in computer networks in terms of their number, size, data volumes & bandwidth. As illustrated in Fig. 1 below, large number of computers/devices, located across the globe, can now be connected over a network and transmit/receive data. [1]

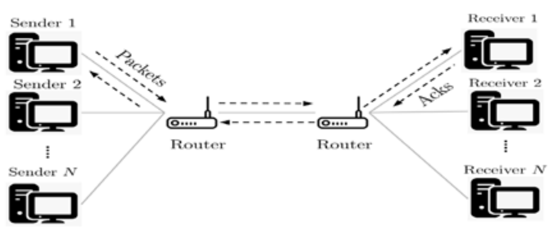

Fig. 1. Multiple packet flows sharing medium

Wide ranging technologies have now been developed which enable handling of large sized data to perform multitude of tasks and analysis of that data. Such technologies include Cloud computing, wireless networks, hybrid networks, Internet of Things (IoT), Serverless Computing, etc. Performance of these networks depends upon a variety of factors including network traffic, network's capacity as well as requirements / behavior of the network user [2]. Network infrastructure and network technology must be designed by taking these factors into account since if the network configuration is not aligned to challenges posed by these factors, it may result in network congestion which in turn would impact network's ability to serve its desired purpose.

If the network congestion issue is not addressed, it may result in loss of data during transmission or it may even result in the entire network collapsing. To address this issue, steps for congestion control have to be taken. Congestion Control is necessary to ensure transmission of data in a safe and timely manner while also ensuring optimum utilization of network

resources. In simple terms, Congestion Control is a tool using which the system controls entry as well as transmission of data in a network so as to allow the network to perform efficiently while also ensuring desired transmission of data.
Network congestion causes drop of data packets on account of buffer overflow which leads to data loss and unreliable network connection. Congestion Control is an important network layer issue which is used to control the data flow through a network with ultimate aim of keeping the data traffic at sustainable level so as to avoid data loss. For ensuring congestion control thereby reducing the network load, it is necessary to monitor the rate at which packets are transmitted by a sender to a receiver over the network [3]. Through effective congestion control measures, it is possible to achieve network stability, optimum utilization of resources and also ensure acceptable packet ratio [4]. Two main steps necessary for effective congestion control are: (1) Packet drop detection and (2) Rate control. This survey paper focuses on Intelligent Congestion Control using Machine Learning (ML) techniques so as to avoid loss of data packets. This paper reviews fundamental reasons why ML can be used for effective Congestion Control.

ML is now finding increasing application in a variety of fields. Some examples of ML application include self driving cars, medical diagnosis, online fraud detection, etc. Essentially, ML is a technique whereby the algorithm developed based on ML improvises / upgrades itself based on its past experience thereby learning new things in the process and improvising / upgrading itself on a continuous and real time basis. ML also has the potential to recognize inherent linkages between input and output in complex network environment and learn from these linkages to develop a model which can address the issue of Congestion [11]. This paper reviews how this aspect of ML can be utilized to develop Intelligent Congestion Control.

2. Why Intelligent Congestion Control?

With ever increasing data traffic and limited network infrastructure resources, it is desirable that techniques are developed which ensure efficient & optimum utilization of available network resources to handle the increasing data traffic thereby avoiding further expansion of network infrastructure which also entails greater costs. To do this, efficient congestion control system is required which measures the data traffic flowing through the network. Such congestion control system is applied in the Transport Layer using established protocols like Transmission Control Protocol (TCP) and Stream Control Transmission Protocol (SCTP) [5].

Machine Learning (ML) and Artificial Intelligence (AI) are amongst the most widely discussed concepts today which are finding increasing applications in a variety of fields. ML is a computer science concept which finds its roots in mathematics and statistics. Basic concept of ML is that a large amount of data is fed to the machine based on which the machine develops its own ability to predict future data patterns. Further, as actual future data patterns are received, the machine compares them with data patterns which it had predicted and improvises its own prediction algorithm based on the difference between actual and predicted data patterns. This is an ongoing process which happens on real time basis and with passage of time, the machine improvises itself and its data prediction capability improves. ML algorithms focus on allowing the machine to develop its own brain which learns directly from the data. Performance of ML systems improves with increase in the quantum of data fed to the system [6].
There are 3 main techniques of ML which are described below:

2.1 Supervised Learning

In Supervised Learning, a known set of input data and a known set of output data is fed to the machine which develops a model which enables the machine to generate predictions regarding what would be the response or output data for any new (unknown) data set that is fed to the machine. In Supervised Learning, classification techniques are deployed to predict discrete responses by the machine whereas regression techniques are deployed to predict continuous responses. Some of the most widely used techniques / algorithms for Supervised Learning include Neural Network, Decision Trees, Logistic Regression, Linear and Non Linear Modelling, etc. Fig 2 below illustrates Supervised Learning.

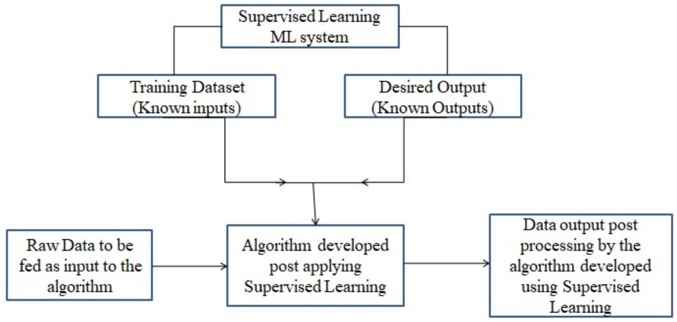

Fig. 2. Supervised Learning

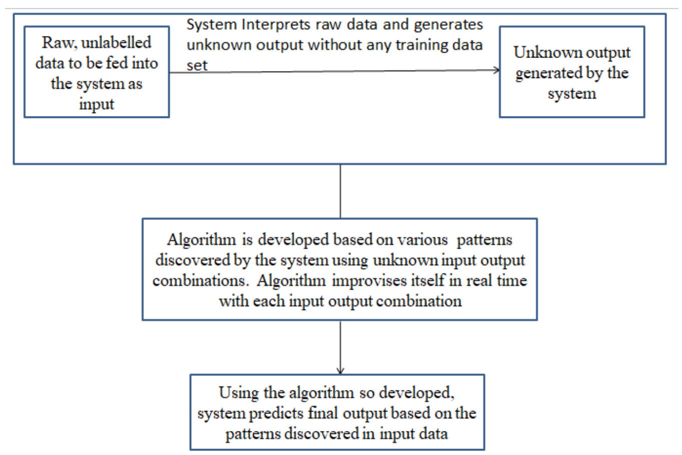

Fig. 3. Unsupervised Learning

2.2 Unsupervised Learning

In case of Unsupervised Learning, no known data set for input / output is fed to the system. Instead, in unsupervised learning, the machine is allowed to perform complex tasks to discover data patterns which were not hitherto discovered. The machine works on its own on unlabeled data, discovers patterns as mentioned above and based on these patterns, the machine tries to generate predictions for future responses. Commonly used algorithms like hierarchical clustering; K-Means, Principal Component Analysis, etc. are widely used for Unsupervised Learning. Fig 3 above illustrates unsupervised learning.

2.3 Reinforcement Learning

In Reinforcement Learning (RL), the machine learns continuously from its environment by continuously interacting with the environment with its target being maximization of cumulative reward. In reinforcement learning, the machine responds to situations that it confronts by using a trial and error method (no labeled set of input / output data is fed to the machine). In some responses, the machine gets rewards whereas in some (where the responses are not appropriate), the machine gets penalties. With each reward and penalty, the machine improvises its own intelligence with the ultimate objective of maximizing rewards. The reward mechanism helps the machine to better understand the problem and the environment thereby enabling it to make better decisions. Q Learning and Markov Decision Process are techniques used for Reinforced Learning.

Conventional techniques for congestion control have limited focus on factors like packet loss/drop or queuing delay. Conventional techniques rely on adjusting the transmission rate in the network to address aforesaid factors. To make congestion control more effective, upgrading / improving the congestion control policies to handle packet buffering for resolving connectivity issues is imperative. Machine Learning (ML) has the ability to achieve considerable improvement in congestion control vis-à-vis conventional methods by modelling the inherent linkages between network inputs & outputs and improvising the congestion control system based on this modeling to achieve improvised and intelligent congestion control [1].

3. Machine Learning for Network Traffic

Due to rapidly rising data usage coupled with wide variety of multimedia data being shared increasingly over the internet, there has been significant increase in internet traffic due to which congestion control has become exceedingly important. Experts have developed various methodologies for implementing effective congestion control for internet traffic using ML. These methodologies can be broadly classified into two categories viz. (1) Offline Learning and (2) Online Learning

Examples of Offline Learning ML based methods for congestion control include (1) Remy (2) Indigo (3) CUSTARD and (4) Aurora. Examples of Online ML based methods for congestion control include (1) PCC and (2) Vivace. These methodologies are summarized below:

3.1 Offline Learning methodologies for ML based congestion control

3.1.1 Remy:
Remy is a computer program which controls cooperation amongst various computers which share a network to ensure how these computers can best cooperate to handle network traffic. Remy uses Transmission Control Protocol (TCP) and applies ML techniques to develop an algorithm for congestion control which can develop better performance (at achieving effective congestion control) and more fairness (in resource utilization) than a manually developed code for congestion control. Remy is designed to be effective in handling congestion control issues in a variety of network infrastructures whereby its main objective is to find out best possible congestion control solution with optimum utilization of available network resources to manage congestion window size (i.e. number of packets allowed to be transmitted)[4]. Remy is an example of Supervised Learning technique.

3.1.2 Indigo:
ML is a technology whereby the machine develops its own mind / logic / algorithm by observing millions of iterations which could take a very long time from hours to weeks. Due to this, it is difficult for ML techniques to be deployed on real time over internet network environment as real time scenario changes much faster vis-à-vis the time taken by the ML technique to develop its algorithm in a manner suited to handle real time scenario. In Indigo methodology, Pantheon based emulators replicate the real time online environment[7]. Based on these emulations, the system can observe network responses to a variety of congestion scenarios which closely resemble real time scenarios. In Indigo, the system develops its own congestion control algorithm by observing the network's response to each iteration churned out by the Pantheon emulators. While observing the network response, Indigo updates its internal state and adjusts the congestion window each time an ACK is received. Indigo is a deep learning method used to train a congestion control algorithm to better adapt for real world online environment [8].

3.1.3 Custard (Customized and Robust Decision) and Aurora:
Custard and Aurora techniques use deep RL to develop congestion control policies by observing network performance to generate network data like packet loss rate, total round trip time, etc. Based on such data generated, Custard / Aurora techniques develop congestion control policies which can work effectively even in very different network domains [1]. Despite being an offline learning technique, Custard / Aurora methods have the ability to converge fast i.e. they develop their congestion control policies fast enough to adapt to real time internet network situation.

3.2 Online Learning methodologies for ML based congestion control

3.2.1 Performance-oriented Congestion Control (PCC):
In PCC, the system transmits packets at a particular rate for a short period of time. Then, the system observes the performance metrics of such transmission like throughput, loss rate, latency, etc. Based on the observation of such performance metrics, the system adjusts its transmission rate with its aim being to improve performance metrics i.e. to generate higher throughput and to minimize loss rate. Again, the system transmits at revised rate for some time, observes the performance metrics and re-adjusts the transmission rate. This process continues in a loop and with each iteration, the system adapts itself to improve its performance. As this system observes real time performance and adjusts itself on real time basis, this is an example of online learning.

3.2.2 Vivace:
Vivace is a new learning theory framework for utility derivation that incorporates crucial parameters such as TCP friendliness & latency minimization. Also, Vivace helps to achieve high utilization of network capacity, swift reaction to changes and fast & stable concurrence. Vivace importantly outperforms traditional TCP form [9].

4. Challenges

Some of the key challenges faced in Congestion Control using ML are as below:

4.1 Fairness

Fairness is an important factor to be considered while designing Congestion Control system using ML. Internet is a dynamic environment wherein multiple CC systems coexist and interact with each other. Such multiple systems may be based on different protocols like TCP / PCC / BBR, etc. In such an environment, it is necessary that the ML based CC system functions in a fair manner thereby ensuring that there is no data loss in its quest to establish its primacy over other systems. ML based CC systems must be designed so that they coexist with other systems, especially legacy TCP systems. CC systems which are trained in environments wherein they compete with TCP have also shown instances whereby they cause packet loss in the network only to force TCP based system to back off and free up network capacity. Such behavior of ML based CC system would be unfair and it is critical that ML based CC systems are designed to ensure Fairness in a dynamic environment [2].

4.2 Multiple objectives in a complex environment

A Congestion Control (CC) system can have different end results as its ultimate objectives. These could be minimizing latency, maximizing throughput or minimizing packet loss. In a relatively simpler and static environment, ML based CC systems can be designed so as to achieve multiple objectives listed above while striking a fine balance between these multiple objectives. However, while such system may work effectively in a less complex environment, it becomes very challenging to design an ML based CC system which could work in a dynamic, Internet based environment with huge data traffic and still deliver the multiple objectives defined for the system. To design ML based CC systems which can deliver on multiple objectives in a complex environment with huge data traffic is a challenging task [1].

5. Conclusion

Exponential growth in data usage and Internet has resulted in networks becoming increasingly complex in today’s world. Such increase in data flow / Internet usage has resulted in significant increase in packet requests over one central server due to which the risk of network congestion has increased considerably [10]. In such complex networks with large data volumes, congestion control in the network becomes very important. ML based techniques can be deployed to develop effective congestion control algorithms which can resolve the issue of congestion in today’s complex networks. In this survey paper, we analyzed why Intelligent Congestion Control is necessary and how ML based techniques are used for Intelligent Congestion Control. This paper also summarizes various ML techniques as well as online and offline learning methodologies to achieve Intelligent Congestion Control.

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