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A Survey on the impact of Connection-Aware Congestion Identification in RLNC-Based Networks on Quality of Service

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Abstract: Wireless multicast networks, especially in the domains of IoT, 5G, and e-health, are experiencing a growing adoption of random linear network coding (RLNC). Nevertheless, the exponential growth of data can lead to congestion problems. This paper presents a review on novel technique called singular value decomposition (SVD) for the identification of network congestion. When SVD combines with statistical concepts like linear regression can to effectively handle large datasets and conduct comprehensive data analytics. The svd improves network performance and reliability by proactively identifying and mitigating congestion. Additionally, it improves the efficiency of data transmission and delivery in different application scenarios.

Index Terms: RLNC(random linear network coding), congestion, SVD(singular value decomposition), LR(linear regression), detection

1. Introduction

The internet is widely acknowledged as a global communication network that has transformed social, economic, and political landscapes worldwide. The internet has efficiently allocated resources to its stakeholders. When resources are unevenly distributed, it leads to bottleneck conditions known as congestion. First identified by Davies (1972), Rudin (1981), and Nagale (1984). Described network congestion as an internet disruption that can significantly impact QoS parameters [1]. When a computer network is overloaded, queuing latency, packet loss, and the frequency of packet re-transmissions all rise simultaneously. Therefore, congestion indicates a decrease in network performance under heavy network traffic.When looking at congestion, think about a scenario where one user sends packets to another user through multiple network nodes, as shown in Fig. 1. It's clear that packets from user1 might face network congestion due to the unpredictable traffic density caused by other users. It encourages network engineers to monitor the network closely by observing a section of the traffic at the MAC layer to maintain QoS parameters. Researchers have introduced different methods to address this problem, and a few protocols for defining congestion levels have been discussed in [2]. Modern networks with numerous nodes and IoT applications require ongoing monitoring and assessment of necessary QoS parameters and some security considerations[3].

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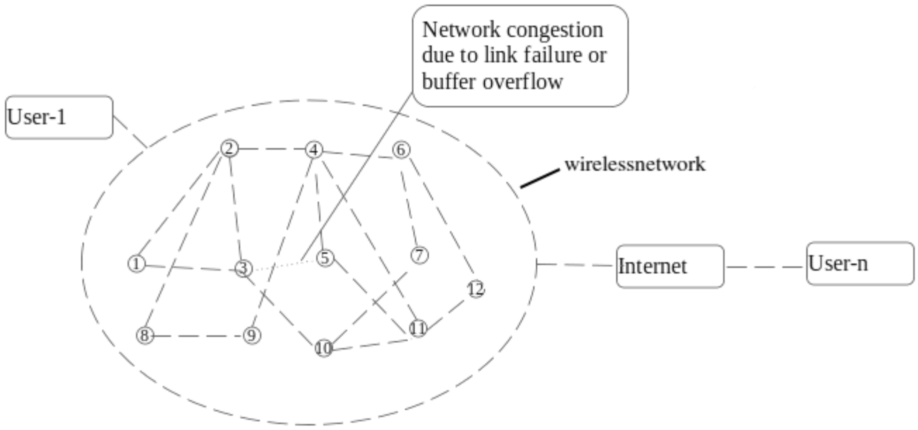

Fig.1. Congestion due to link failure or buffer overflow

In literature,there are two methods for asserting and analyzing network congestion[4]:

1.1 Active Method

This method creates and inserts a probe to gather information on potential network congestion. Observing the impact of this injected probe on performance metrics viz network throughput, packet loss ratio, delay, and so on. This method offers an instantaneous analysis of network performance. For example, when using Linux operating systems, the ping command is used to verify network connectivity and the status of a specific node, as illustrated in Fig.2. Upon receiving the ping command, the destination responds to the host with an acknowledgment. The ping command provides information on the number of hops between the source and destination.

```
PING 192.168.1.156 (192.168.1.156) 56(84) bytes of data.
64 bytes from 192.168.1.156: icmp_seq=1 ttl=64 time=53.7 ms
64 bytes from 192.168.1.156: icmp_seq=2 ttl=64 time=1518 ms
64 bytes from 192.168.1.156: icmp_seq=4 ttl=64 time=696 ms
64 bytes from 192.168.1.156: icmp_seq=5 ttl=64 time=246 ms
64 bytes from 192.168.1.156: icmp_seq=7 ttl=64 time=60.1 ms
64 bytes from 192.168.1.156: icmp_seq=8 ttl=64 time=230 ms
64 bytes from 192.168.1.156: icmp_seq=9 ttl=64 time=6.37 ms
64 bytes from 192.168.1.156: icmp_seq=10 ttl=64 time=90.0 ms
64 bytes from 192.168.1.156: icmp_seq=11 ttl=64 time=181 ms
64 bytes from 192.168.1.156: icmp_seq=12 ttl=64 time=437 ms
64 bytes from 192.168.1.156: icmp_seq=13 ttl=64 time=1233 ms
64 bytes from 192.168.1.156: icmp_seq=15 ttl=64 time=3834 ms
64 bytes from 192.168.1.156: icmp_seq=19 ttl=64 time=5.83 ms
64 bytes from 192.168.1.156: icmp_seq=20 ttl=64 time=12.8 ms
```

Fig.2. Ping command for checking network connectivity

1.2 Passive Method

Passive methods address the real-time traffic situation [5, 6]. For example, fault tolerance. Examining network traffic passively can provide valuable information about network performance, behavior, and security. Instantly capturing packets from any network flow to determine various packet parameters such as source and destination addresses and packet size allows for detailed examination. These analyses are referred to as granular traffic analyses. Examining captured data provides an immediate understanding of network traffic.

1.3 Contributions

The contribution of this work is:

1. Examining different studies on conventional congestion identification works for network congestion and highlighting their differences.
2. Exploring the main features and uses of singular value decomposition in identifying congestion.
3. Exploring the main features and uses of linear regression in analysing data that results from congestion in networks.

2. Litrature Review

Studying the various flows between different nodes provides a thorough understanding of network congestion.The work in [7] discusses the relationship between delays caused by flows in the forward direction and packet loss.Examining various flows that are grouped based on comparison tests as discussed in [7], is further explored and referred to as flow mate in [8].One flow is chosen from each cluster and then compared with a representative flow from a different cluster. Although brief, HTTP causes accuracy issues in FlowMate. The study in [9] detailed topologies involving numerous sources transmitting data to a central destination.Measuring interarrival times at the destination is done using a passive technique. Calculating the average entropy for each flow assumes that all flows are part of the same cluster. The flow is categorised within the cluster with the lowest average entropy.However, this method is most effective when cross flow traffic is minimal. In their study, Rezaei et al. [10] presented a delay link model for encrypted traffic, exploring various classification models based on delay links. The work in [11] discusses a two-phase congestion control:1. Intra-cluster congestion control involves defining nine states to determine congestion at a specific node. 2. When addressing inter-cluster congestion control, the system considers the cluster head priority and adjusts parameters such as back-off timer (BFT), waiting time for acknowledgment (WTTRACK), sequence number (SEQ), and retransmission counter (RC) to prevent congestion. The IoT network has already been mapped to a wireless network. The work in[11] proposed congestion control using two steps:The network is segmented into clusters. Addressing congestion within a cluster involves utilising congestion score and buffer statues in step (1).When dealing with a small and distributed network, congestion issues can be effectively managed by utilising methods such as TCP, which relies on indirect signals like packet loss or delay. The study in[12] has introduced a pacing scheme that relies on the coefficient of variation. Data is sent using a specific rate while considering congestion control and interference delay.The study in [13] discusses the impact of congestion and how to prevent it by analysing the number of visits to each node using multivariate statistics in star topology networks. The study in [14] has explored the source and routing-based technique utilised for congestion control. The approach is based on RLNC, which stands for random linear network coding. This method includes the use of GF(2^p), the combination of source packets in accordance with the generation size that is chosen, and the transmission of coded packets in a safe manner [15].The work in [16],describes limited energy and capacity in long-term interaction in dense networks as the high traffic volume and constant packets increase congestion, which increases energy consumption and network longevity. A Congestion Avoidance Mechanism (CAMA) for AODV reduces congestion, improves packet delivery ratio, and increases throughput, outperforming both Congestion Control AODV and AODV. Some of these studies have also been summarised in tables 1 and 2 below:

3. Conventional Congestion Identification Works and their Differences

Table 1. List of source based congestion control

Year	Title	Approach	Features	Performance Metrics
2004	Binary increase congestion control (BIC) for fast Long-distance networks	Loss based	BIMD, limited slow-start	Throughput, Fairness
2005	TCP-A Reno: Improving efficiency-friendliness tradeoffs of TCP congestion control algorithm	Loss & delay Based with bandwidth Estimation	Adapts the TCP response function according to congestion level estimation through RTT measurement.	TCP friendliness, Efficiency
2006	Compound TCP: A scalable and TCP-friendly congestion control for high-speed networks	Loss & delay based	Integrate a time-based element into the standard TCP reno congestion avoidance algorithm	BW scalability
2007	TCP-fusion:A hybrid congestion control algorithm For high speed networks	Loss based	TCP-Fusion leverages three beneficial characteristics of TCP-Reno, TCP-Vegas, and TCP-Westwood in its congestion avoidance approach.	Efficiency Fairness
2008	CUBIC: A new TCP-friendly high-speed TCP Variant	Loss based	Utilises a growth function that follows a cubic window pattern to enhance	Intra-protocol fairness, RTT-fairness, TCP-Friendliness.
2009	Sync-TCP: A new approach to high speed congestion control	Delay based	Utilises synchronisation and adapts accordingly Delay based on queue Rule for Decreasing Congestion Window, Rule for Increasing Congestion Window Independent of Round-Trip Time	Throughput, TCP Friendliness

2010	TCP Libra: Derivation, analysis, and comparison With other RTT-fair TCPs	Loss based	When increasing the congestion window in TCP, the square of the RTT is multiplied during the additive increase phase.	RTT-fairness TCPfriend liness , Bandwidth
2011	HCC TCP: hybrid congestion control for high-speed networks	Loss ,delay Based	The two approaches (delay, loss) in the algorithm are dynamically transferred into each other based on the network status.	Throughput, TCP Friendliness
2020	Research of Wireless Congestion Control Algorithm Based on EKF	Throughput based	Kalman filtering and bandwidth	Throughput,fairness
2022	A hierarchical congestion control method in clustered internet of things	Packet loss avg energy	Cluster based congestion control	Packet loss avg energy Delay

Utilising source-based methods to address congestion problems in small networks. However, for extensive networks, source-based methods are not effective. Thus, congestion methods based on routing are utilised in such situations.Table2 displays details of several research projects focused on routing.

Table 2. List of router based congestion control

Year	**Title**	**Approach**	**Congestion measure**	**Performance Metrics**
2007	LRED: a robust and responsive AQM Algorithm Using packet Loss Ratio measurement	LRED (propor -tional Controller)	Instantaneous Queue Length Packet loss ratio	Fast response time, Robustness, flexible system Link utilization, low Queuing delay, Low complexity
2007	Active queue management algorithm considering queue And load states Tradeoffs of TCP congestion Control algorithm	PAQM	Queue length input rate response function Based on congestion level estimation Via RTT measurement.	TCP friendliness, Efficiency
2008	Design of a stabilizing AQM controller For large-delay	IMC-PID (control Theoretic)	Stability, robustness, Convergence, High linkutilization And small delay Jitter.	Stability, robustness, Convergence, high linkutilization and Small delay Jitter.
2009	Effective RED: an algorithm to Improve RED's performanceby Reducing packet Loss rate	Queue length (both instantaneous and Average) Input Rate Loss rate	Throughput, packet drops, fully compatible With RED,	
2021	Traffic and Energy Aware Optimization for Congestion Control in Next Generation Wireless Sensor Networks	ant colony Optimization	Entropy	Throughput,delay, Packet delivery ratio
2021	A Centralized and Dynamic Network Congestion Classification Approach for Heterogeneous Vehicular Networks	Deep learning	Throughput,Delay	packetloss ratio
2022	Effect of congestion avoidance due to congestion information provision on optimizing agent dynamics on an Endogenous star network topology	agent based Multivariate Analysis	Delay	Delay
2023	Connection aware congestion Identification In rlnc based networks and it's impact On QoS	Coefficient of Variation	Entropy,delay , jitter	PDR,Delay,jitter
2023	Effect of link failure on QoS Parameters under the influence of field and generation size in wireless Network	link condition	delay,packet Buffered	delay,packet buffered
2023	A machine learning based Distributed Congestion Control Protocol for Multi-hop wireless networks	network load	machine learning	Throughput,packet Delivery ratio

Table 3 presents a succinct overview of the works outlined in Tables 2 and 3. There is a requirement for collaboration by integrating two approaches, specifically RLNC (Random Linear Network Coding) and SVD (Singular Value Decomposition). The current outlook is positive, indicating that it will result in an improved resolution for the issue of congestion.

Table 3. Gaps found in recent approaches

Year	Title	Approach	Gaps
2022	Effect of congestion avoidance due to congestion information provision on optimizing agent dynamics on an Endogenous star network topology	agent based Multivariate Analysis	Measures only delay as performance measure
2023	Connection aware congestion Identification In rlnc based networks and it's impact On QoS	link condition	delay,packet buffered
2023	A machine learning based Distributed Congestion Control Protocol for Multi-hop wireless networks	network load	Throughput,packet Delivery ratio

4. Features and uses of Singular Value Decomposition

The Singular Value Decomposition (SVD) offers numerous futures:

1. Helps in understanding the structure and characteristics of network data
2. Dimensionality reduction enhances processing capabilities and reduces storage requirements.
3. It can be used to quantify the centrality or influence of individual nodes within a network, as well as to identify the community structure or clustering of the network.
4. It has the capability to extract the latent features or attributes of the network, including interests, preferences, behaviours, or roles.
5. It enables the understanding of subgroups or segments present in the network.

One potential use-case involves applying Singular Value Decomposition (SVD) in a free wireless communication scenario that utilises Random Linear Network Coding (RLNC).Fig.3 illustrate how svd can be applied in identifying congestion. Packets generated at source node are sent to next relay node after performing RLNC.It is expected in general sense that there is a fair allocation of network resources to all nodes. But over hungary nodes may cosume network resources in excess thus resulting in shortage of network resources. When a node sends it's traffic on a particular link and finds scarce resource availability,indicating the network nodes has met with congestion. Two different flow of packets which are merged at one paricular node is computed and forwarded to next node.

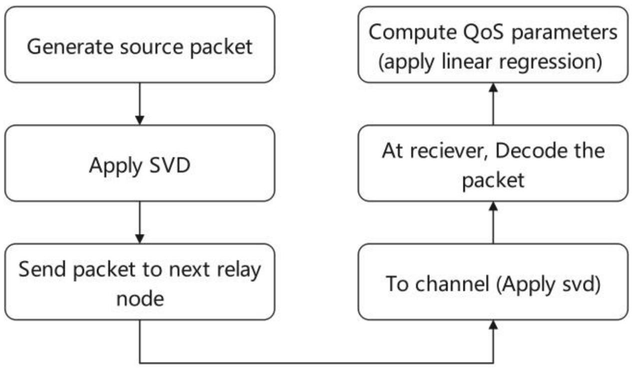

Fig.3. Flow chart depicting the proposed congestion process

5. How SVD works for Congestion Detection

Singular value decomposition(SVD) is mathematical tool that helps in determining matrices structure which represents a channel. Ex: For a mxn matrix A, which represent a channel with rank r, then svd for A can be defined as:

$$A = \sum_{k=1}^{r} \sigma\,(A) u^{(k)} v^{(k)^{T}} \tag{1}$$

where r is the rank of A and it's singular values are: $\sigma 1(A) \geq \sigma 2(A) \geq \sigma 3(A) \geq \ldots . \sigma r(A) > 0$ with $u^{(k)} \in R^m, v^{(k)} \in R^n, t = 1, \ldots r$ be the it's left and right othonormal singular vectors respectively. such that $|A_F^2| = \sum_{i,j} A_{(i,j)}^2 = \sum_{i=1} \sigma^2(A)$ $\Sigma = diagonal(\sigma_1(A), \ldots ., \sigma_r(A))$ is an rxr diagonal matrix containing the singular values of A. As expressed in equation(1),The values in 'A' can be approximated by keeping the principle components and removing the smallest values that are basically nonessential for analysis. A condition called bottleneck occurs when normal packet flows experience delays which is essentially more than the threshold value permitted. When a node surpasses its allocated traffic capacity during transmission, congestion arises because the network cannot manage the higher volume of packets being transmitted. To effectively tackle this issue, it is essential to identify the primary cause of congestion. Past research has mainly concentrated on packet buffering to identify congestion. Furthermore, this argument can be broadened to encompass other QoS parameters like throughput, packet delivery ratio, delay, and jitter. Exceeding the network's capacity can cause delays and packet loss, leading to network congestion.

6. Linear Regression in Analysing Data That Results from Congestion in Networks

Linear regression analysis helps forecast a variable's value by considering another variable's value. The dependent variable is the one we wish aim to predict. The predictor variable for determining the value of another variable is known as the independent variable.A linear relationship is depicted in the graph above between the output(y) and predictor(X) variables. The blue line represents the best-fit straight line. Using the provided data points, we aim to create a line that best represents the data as shown in fig.4

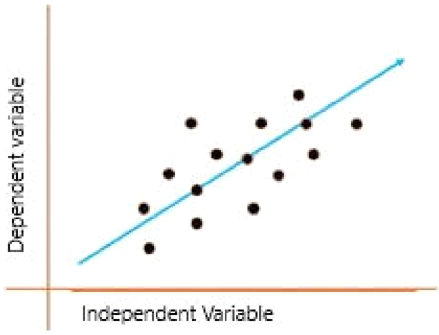

Fig. 4. Linear regression forcasting method

Linear regression can be represented graphically, as shown in fig5. The two types of input data (features), x_1 and x_2 along with certain bais value say=1,is given to the function F(x). The function being fitted involves multiplying each data point by a weight (w_1 or w_2) and then adding them together. The "bias" is similar to the constant term in a linear equation y=mx+b.

$$F(X)=W^T x+b$$

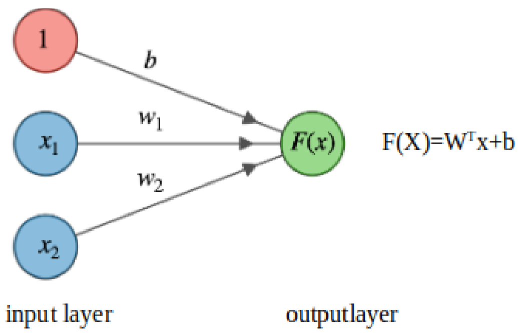

Fig.5. Linear regression process

For creating a model,the values of coefficients(w) and bias (b) should be determined. Various optimization algorithms can achieve this, such as steepest descent or pseudo inverse. Select appropriate values for the weights and bias to establish a functional relationship among the data.

Pseudo-Inverse Method :This method computes the values of coefficients(w) and bias by using moore-penrose pseudo inverse of feature matrix .This results in minimising least square error between the predicted and actual values of selected variable.

The linear regression model can be represented as shown in equation (2):

$$y = Xw + b \tag{2}$$

where X is future matrix, y is target vector, w weight and b bias

To determine optimal values of w and b we use the values shown in equation(3):

$$w = (X^T X)^{-1} X^t y, b = y - Xw \tag{3}$$

The weights (w) in the dataset are determined based on the features and their relative importance in predicting the target variable. The computation of these values is executed utilising the pseudo-inverse formula. The term "bias" (b) denotes a systematic error or deviation in measurements or observations. The bias term is a crucial component in linear regression models as it represents the intercept of the model. The constant term in the equation that relates the independent variables to the dependent variable is accounted for. The value of the variable can be determined by either utilising prior knowledge of the problem or by initialising it to zero. Several explanatory variables may involved in what we called as multiple linear regression. It is extension of linear regression. Mathematically it's expressed by equation (4):

$$y_j = \alpha_0 + \alpha_1 x_j + \alpha_2 x_j^2 + \ldots. + \alpha_k x_j^k \tag{4}$$

where k is the degree of polynomial.

Further insight on this topic is beyond the scope of the article, but one can refer to [17].

7. Conclusion

The work titled "A survey on the impact of connection aware congestion identification in RLNC based networks on quality of service" delves into the realm of network traffic monitoring and analysis, particularly focusing on the utilization of Singular Value Decomposition (SVD) in conjunction with linear regression. Through an extensive literature review, the paper explores the application of SVD and linear regression in understanding and addressing congestion-related issues in network environments.

To provide a comprehensive understanding, the paper discusses both active and passive methods of congestion detection in networks. Active methods typically involve the deliberate generation of traffic to assess network performance, while passive methods rely on observing existing network traffic patterns without introducing additional traffic. By elucidating these methods, the paper lays the groundwork for the subsequent discussion on employing SVD and linear regression for congestion analysis.

The utilization of SVD alongside linear regression for studying Quality of Service (QoS) parameters affected by link congestion is a focal point of the paper. SVD, a powerful mathematical tool for dimensionality reduction, aids in extracting meaningful features from complex network data. When coupled with linear regression, which enables the modeling of relationships between variables, it becomes a potent approach for analyzing the impact of congestion on QoS parameters.

Through this survey, the paper aims to provide insights into how connection-aware congestion identification in networks employing Random Linear Network Coding (RLNC) influences QoS. By leveraging SVD and linear regression techniques, researchers and practitioners can better understand and address congestion-related challenges, ultimately enhancing the overall performance and reliability of networked systems.

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