Scholarly Research Journal for Interdisciplinary Studies,
Online ISSN 2278-8808, SJIF 2024 = 8.153
https://www.srjis.com/issues_data/227
Peer Reviewed & Refereed Journal, Jan-Feb 2024, Vol- 12/81
https://doi.org/10.5281/zenodo.10931744

AN ANALYTICAL STUDY OF QUEUE MANAGEMENT TECHNIQUES; DROPTAIL, RED AND CODEL

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Paper Received On: 20 JAN 2024
Peer Reviewed On: 28 FEB 2024
Published On: 01 MAR 2024

Abstract

This research article delves into three conventionally used adaptive queue management techniques / strategies; DropTail, RED and CoDel, underscores their role, significance and effectiveness in special context of QoS of communication network. The theoretical and simulation results obtained as findings suggest the suitability of a particular strategy under changing scenario and varying network conditions.

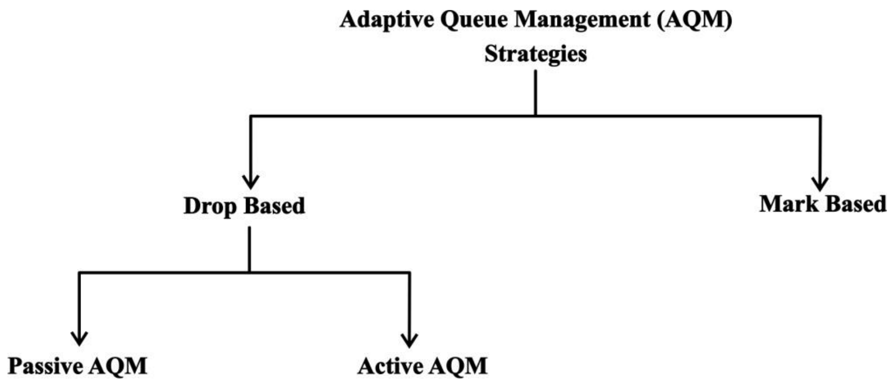
Keywords: *Adaptive Queue Management (AQM), Network, Quality of service (QoS), Strategy.*

Introduction

No scientific or technological development is meaningful without proper communication and utilization. With the advancement of science and technology and exponential population growth, the data generation rate and number of users are increasing very rapidly. That's why data congestion is a natural issue that every user faces very often. Specifically at the TCP level; network latency, throughput, buffer utilization and packet loss are affecting the quality of services (QoS). Pioneers in the concerned field have been trying to deal with the problem. Queueing theoretical models play a significant role in studying and handling congestion-related problems. Adaptive Queue Management (AQM) Techniques are the outcomes of the optimum-seeking efforts of the pioneers to mitigate or smooth out the problem.

1. Adaptive Queue Management (AQM) Techniques refer to the techniques that provide an optimal solution for QoS by dropping or marking the packets selectively. They are categorized as

(i) Drop-based; (ii) Mark-based



1.1. Drop based queue management techniques/algorithms refer to the techniques / strategies under which the packets are dropped selectively when the buffer is saturated and congestion occurs. These techniques are further subdivided as passive and active queue management techniques.

1.1.1 Passive Queue Management (AQM) techniques are the techniques under which packets are dropped as the buffer reaches saturation. **DropTail, HeadDrop and Pushout** are the techniques, to quote but a few. These techniques are easy to implement but provide a larger delay, are suitable to control the congestion but not to avoid it.

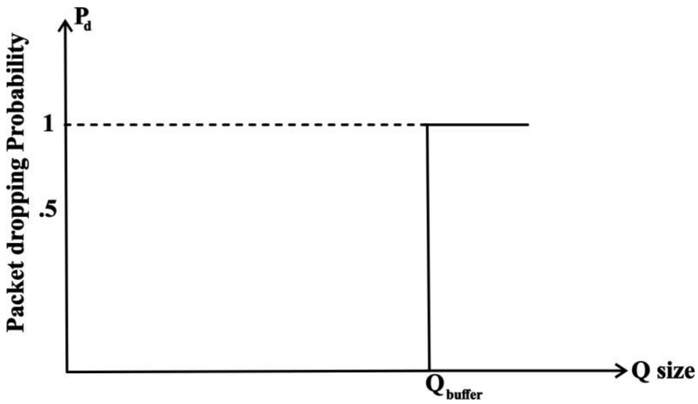
DropTail Technique: It is a passive adaptive queue management algorithm. Under this algorithm, when the buffer gets full, the newly arriving packets are dropped. It remains passive until the buffer has some space. Thus, the dropping probability is either zero or one. When the queue length exceeds the buffer size, the packet dropping probability is ‘1’ otherwise, it remains ‘0’. If P_d be the dropping probability, it can be given as

$$P_d = \begin{cases} 0 & Q_{inst} \le Q_{buffer} \\ 1 & Q_{inst} > Q_{buffer} \end{cases}$$

Where,

Q_{inst} is the instaneous queue length

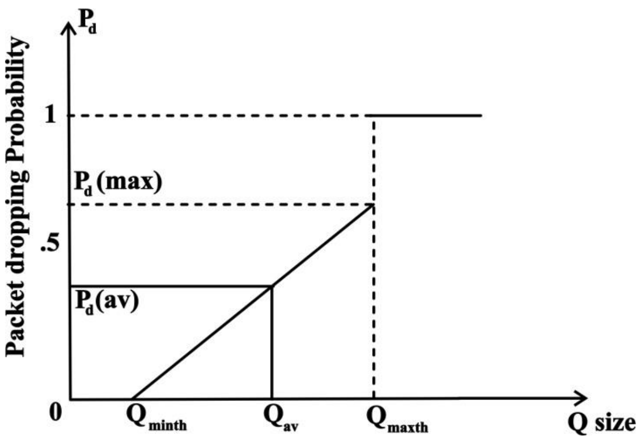
& Q_{buffer} is the buffer size of the queue



This technique is easy to implement and suitable to control delay but not to avoid and provides larger end-to-end delay.

1.1.2 Active Queue Management (AQM) Techniques These algorithms are used for congestion avoidance. Under these strategies/algorithms, the congestion control begins as early as the queue length attains its minimum threshold length. Before getting the buffer saturated, the packets are dropped gradually and proportionately with the rise in average queue length. Random Early Detection (RED) and Controlled Delay (CoDel) are examples of this type.

RED (Random Early Detection): It is an active queue management algorithm and may be thought of as a modified DropTail. In DropTail, there is sudden packet loss as soon as the buffer gets full, which causes congestion to collapse. while in this algorithm the packet drop is smooth and begins as early as the decided minimum queue threshold is attained. The packets are dropped proportionately as the queue rises. The dropping probability up to the minimum threshold is '0' and thereafter increases with queue size until its maximum threshold and becomes '1' as the queue size crosses this limit. Thus, there is a smooth increase in packet loss, which avoids congestion collapse.



If Pd be the probability of dropping then.

$$P_d = \begin{cases} 0 & Q_{av} \leq Q_{minth} \\ P_{max} \dfrac{Q_{av} - Q_{minth}}{Q_{maxth} - Q_{minth}}, & Q_{minth} < Q_{av} < Q_{maxth} \\ 1 & Q_{av} \leq Q_{maxth} \end{cases}$$

$$\mathbf{Q_{av} \leftarrow w' \, Q_{av} + w \, Q_{inst}}, \qquad \mathbf{w' = 1 - w}$$

where,

w is the weight assigned to Q_{inst}

Q_{av} is the average queue size.

Q_{minth} is the minimum threshold of queue size.

Q_{maxth} is the maximum threshold of queue size.

CoDel (controlled delay) This algorithm may be considered a modified RED. It is an active queue management technique that was developed by Jacobson and Nichols to dial with buffer bloat. In this algorithm, the packet delay is controlled to optimal limits. This technique improves the performance of RED, mitigating its perceived shortcomings.

1.2 Mark-based AQM: Under this type of technique, the packets are marked selectively when congestion takes place. ECN (explicit congestion notification) is an example of marked-based AQM. In this technique, packets are selectively marked with an ECN bit, which warns the TCP of congestion occurring instead of dropping the packets.

Since our concern is to study DropTail, RED and CoDel techniques, it's unnecessary to dive deep into these types of algorithms.

Review of the Literature:

The AQM algorithms have attracted the attention of the users recently to improve the quality of service (QoS) of the broadband networks. Various AQM techniques/algorithms have been developed during the recent past. A brief review of the existing literature in this context is as follows:

Bhashkar et al. (2009) made a comparative study of the AQM techniques; DropTail and RED. In the study, they discussed throughput and fairness analytically and found that RED performs better than DropTail in these metrics. **Sharma and Behra (2016)** dived deeper into active queue management techniques through an analytical survey and found that active queue management techniques have better performance than passive queue management techniques. Under these techniques, the network achieves higher throughput, and higher fairness with a lower latency and lower packet loss. **Wang et al. (2017)** used simulation methods to study the performance of the queue management techniques adopted in broadband networks. In the study, they found that the theoretical results and the results obtained by simulation resemble a closer approximation. **Johnson and Smith (2018)** delved into broadband networks and highlighted the demand of the users and the related problems they face. They suggested adaptive management techniques to improve various measures of the network. **Patel and Gupta (2019)** dug deeper into broadband network-related studies and discussed the effect of adaptive queue management on the quality of service (QoS) of the network. They revealed the fact that QoS is the top priority of network users. **Huang and Liu (2019)** dealt with software-defined networks (CDN) using queue management techniques and underscored the role and capability of these techniques in the study of broadband networks. **Zha and Liu (2020)** dealt with queue management strategies and discussed performance as well as security measures. **Chen et al. (2020)** studied broadband communication networks deeply and underlined the need and significance of QoS, which is multifaceted and includes metrics such as throughput, latency, packet loss, degree of fairness, etc. **Lee and Kim (2021)** examined the effectiveness of various adaptive queue management techniques as well as the dynamics and behavior of the networks. In the study, they found that these strategies are capable of establishing a happy medium between utilisation and QoS under real-time queue parameters. **Fli et al. (2023)** developed a queue management method to prevent the congestion. This method is fully adaptive and provides better throughput with a tolerable delay.

3. Methodology:

The first and foremost step in methodology is the identification of the communication network. The communication system under study has been identified as (M/M/1) queueing system, where data packets' generation and processing rates follow poisson and exponential distributions, respectively. The theoretical results have been determined using well-established formulas for the model. The study is followed by simulative studies under adaptive queue management techniques. The adaptive queue management techniques; **DropTail, RED and CoDel** have been employed to study the dynamics of the communication system during routine and special event (exhibition) peak hours and after analytical/mathematical discussion, their performances are compared.

4. Location, scenario and data collection: under these strategies, the simulative studies have been made in two scenarios of the urban landscape of Aligarh city.

(i) Routine peak hours,

(ii) Peak hours, of the special event (during the exhibition).

The approximate data has been collected from the exchange connecting different centers.

5. System Parameters and Measures :

Packet arrival rate, λ = 75 packets / sec

Processing rate, μ = 100 packets / sec

Processing time per packet = 1/100 sec = 10 ms

Utilization, $\rho = \lambda/\mu = 75/100 = .75$

Average queue length, $Q_{av} = \frac{\rho^2}{1-\rho} = \frac{(.75)^2}{1-.75}$

= 2.25 packets.

6. Results obtained from simulation studies without using AQM

Table – 1

Strategy	Latency (ms)	Packet loss (%)	Throughput (Mbps)	Latency (ms) with packet loss adjustment
Routine Peak hours	24	3	90	24.30
Special Event Peak hours	32	4.5	75	32.45

7. Results obtained from simulation studies on using AQM

Table - 2

(Study for the routine peak hours)

Strategy	Latency (ms)	Packet loss (%)	Throughput (Mbps)	Latency (ms) with packet loss adjustment
DropTail Strategy	20	2.4	94	20.24
RED Strategy	16	2.0	102	16.20
CoDel Strategy	14	1.6	112	14.16

Table – 3

(Study for the peak hours of the special event)

Strategy	Latency (ms)	Packet loss (%)	Throughput (Mbps)	Latency (ms) with packet loss adjustment
DropTail	28	3.6	84	28.36
RED	18	2.4	98	18.24
CoDel	20	2	102	20.20

Pertinent facts drawn from the results tabulated above:

i. All three techniques are capable of reducing latency and packet loss, enhancing throughput and thus providing good QoS.

ii. CoDel Strategy is a good performer in the routine peak hours scenario, in comparison to the other DropTail and RED strategies.

iii. In special event peak hours where the load crosses the limits often, RED has been proven to be more successful in mitigating and smoothing out the problem, maintaining optimal limits of the different metrics.

8. Assumptions: The study has been carried out under the following assumptions;

(i) The communication system has been assumed to behave approximately as an M/M/1 queueing system.

(ii) The theoretical and simulation studies have been made assuming the system is in a steady state in each scenario about network conditions, data generation and processing patterns.

(iii) Packet size is assumed to be uniform.

9. Limitation :

(i) Findings are based on the previous studies and approximate data obtained from the data centre.

(ii) Due to the dynamic nature of the network and the possibility of mismatching the assumptions with reality, the numerical values may differ.

(iii) In the study, the focus has been given to a comparative study of the AQM algorithms, which can't be applied as such to any broadband/network.

10. Conclusion:

The study agrees with the findings of previous studies carried out exploring the fact that AQM algorithms; DropTail, RED, and CoDel are well capable of reducing latency, packet loss, delay and enhancing throughput to optimal limits and thus can improve QoS considerably. Thus, QoS needs the selection of an appropriate algorithm after understanding the network conditions, data generation and processing patterns accurately, together with the efficient and appropriate use of supporting devices.

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Cite Your Article as

Satish Chandra Tiwari & Sanjay Chaudhary. (2024). AN ANALYTICAL STUDY OF QUEUE MANAGEMENT TECHNIQUES; DROPTAIL, RED AND CODEL. 12(81), 311–318. https://doi.org/10.5281/zenodo.10931744