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High Traffic Flow Management System Based on Queuing Theory

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Abstract: Network traffic monitoring plays a pivotal role in comprehensively analyzing and overseeing network performance. This research endeavor delves into the establishment of a fundamental network traffic analysis model rooted in Queuing Theory. Within this study's scope, two specific queuing models—namely, (M/M/1): ((C+1)/FCFS) and (M/M/2): ((C+1)/FCFS)—have been employed to delineate an anticipatory approach for gauging the network traffic's stable congestion rate.

Through the adoption of these queuing models, the research enables the derivation of both network traffic forecasting methodologies and an analytical formulation for the stable congestion rate. By synergizing these outcomes with widely accepted parameters for general network traffic monitoring, the study facilitates a well-founded process of estimating and vigilantly monitoring network traffic behavior. This integration of Queuing Theory and practical monitoring parameters offers a rational means to comprehend and effectively manage the intricate dynamics of network congestion and performance.

***IndexTerms* - Network traffic monitoring, network performance analysis, Queuing Theory, queuing models, congestion rate, forecasting, stable congestion rate formula, network traffic estimation, monitor parameters.**

I. INTRODUCTION

In the realm of modern communication and information exchange, network traffic monitoring stands as a vital mechanism for comprehending and enhancing network performance. The ever-increasing complexity of network systems necessitates robust methodologies to analyze and manage the flow of data, ensuring efficient operation and optimal user experience. In this context, the present research initiative embarks on a journey to construct a foundational network traffic analysis model, drawing its roots from the principles of Queuing Theory. This study acknowledges the intricate interplay between network traffic dynamics and the principles of queuing, which offers a structured framework for understanding and predicting congestion patterns. Through the lens of Queuing Theory, the project aims to unravel the nuanced behaviors of network traffic, paving the way for informed decision-making in optimizing performance and resource allocation. Specifically, this investigation centers around two distinct queuing models—(M/M/1): ((C+1)/FCFS) and (M/M/2): ((C+1)/FCFS)—chosen strategically to forecast the stable congestion rate of network traffic.

By harnessing these queuing models, the research seeks to accomplish two key objectives. Firstly, it endeavors to establish pathways for predicting network traffic patterns, fostering a proactive approach to congestion management. Secondly, the study seeks to derive a stable congestion rate formula, providing a quantitative framework to gauge the efficiency of the network under varying conditions. To achieve these goals, the research amalgamates the outcomes of queuing theory with essential parameters integral to network traffic monitoring.

In effect, the integration of Queuing Theory into the realm of network traffic analysis promises a holistic and well-rounded understanding of the dynamics that govern network congestion and performance. By aligning theoretical constructs with real-world monitoring parameters, this research venture strives to offer a rational and comprehensive means of estimating, monitoring, and optimizing network traffic behavior. The ensuing chapters will delve into the intricacies of the chosen queuing models, elucidating their applicability in forecasting and managing network congestion, thus contributing to the ever-evolving landscape of network performance enhancement. Furthermore, the significance of network traffic monitoring in today's technology-driven society cannot be overstated. In an era where seamless connectivity and data transfer underpin numerous facets of personal, professional, and societal activities, the efficient functioning of network systems is paramount. Delays, bottlenecks, and congestion not only hinder the smooth flow of information but also lead to suboptimal user experiences, potential economic losses, and compromised operational efficiency.

Against this backdrop, the utilization of Queuing Theory as a foundation for network traffic analysis offers a compelling approach. Queuing Theory, rooted in the study of waiting lines and service systems, provides a rigorous framework to model and understand how entities, in this case, data packets, queue up and progress through a network. The models derived from Queuing Theory facilitate the prediction and quantification of various performance metrics, such as queue lengths, waiting times, and congestion rates, crucial for effective network management.

The two selected queuing models, (M/M/1): ((C+1)/FCFS) and (M/M/2): ((C+1)/FCFS), are deliberately chosen to cater to different scenarios, capturing the inherent complexities of network traffic. These models, based on the number of servers and service time distribution, allow for a nuanced examination of how congestion forms and evolves under varying conditions. Through this approach, the research aims not only to unveil the underlying dynamics of congestion but also to equip network administrators with valuable tools to preemptively address these issues.

Incorporating the outcomes of these queuing models with established network traffic monitoring parameters bridges the theoretical and practical realms of network management. This synthesis facilitates a holistic approach to understanding, estimating, and managing network congestion. Ultimately, the research seeks to contribute to the ongoing discourse surrounding network optimization strategies, providing insights that can empower decision-makers to adopt measures that enhance the efficiency, reliability, and responsiveness of network systems.

As we delve into the subsequent sections of this research exploration, we will delve deeper into the intricacies of the chosen queuing models, elucidating their theoretical foundations and practical implications. Through this journey, we aspire to shed light on the symbiotic relationship between Queuing Theory and network traffic analysis, uncovering strategies that hold the potential to reshape the landscape of network performance management in the face of increasing demands and complexities.

Queueing theory is a research area that studies and develops mathematical models for general queueing phenomena with a broad range of applications. It makes sense that queueing-theoretic methods are a useful tool to analyze delays in road traffic, due to their ability to explain the dynamics leading to congestion. Therefore, the performance analysis of dynamic queueing models is an important step towards the optimization of traffic management policies.

The second complicating factor is the mere fact that several roads meet at an intersection as can be seen in Figure 1.1. Moreover, there might be a vary- ing number of traffic streams from a single direction, potentially heading in different directions; there might be green lights for several (conflicting or not) groups of vehicle streams; there might be cyclists present (on separate lanes or not); pedestrians might cross the intersection (on a pedestrian crossing with a

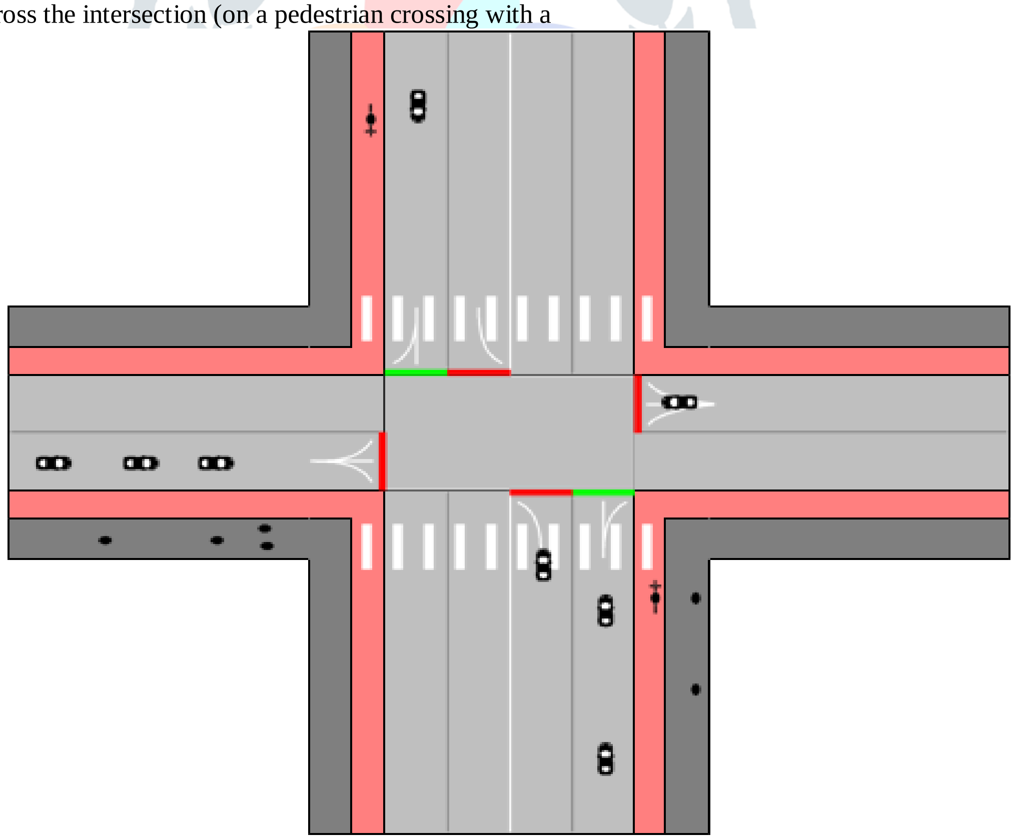


Figure 1: A graphical representation of a general intersection with vehicles, cyclists, and pedestrians. The intersection has six streams of cars, which are all governed by traffic lights. Moreover, there are some pedestrian crossings and also cyclists claim their share of the intersection's capacity.

separate traffic light or not); and many more complications might exist.

Typically, models involving randomness are well-understood as long as we study a single queue (e.g. corresponding to a single road or a single stream of vehicles). For intersections, however, we typically need to study higher- dimensional queueing models to capture queueing phenomena accurately as can be observed from Figure 1. The caveat is that such higher-dimensional stochastic models are much harder to analyze than single-dimensional models.

II. Method

Queuing theory provides a mathematical framework for analyzing and modeling the behavior of waiting lines or queues. It has been widely applied in various domains, including traffic flow management. In the context of traffic flow management, queuing theory offers valuable insights into understanding and optimizing the performance of transportation systems.

Network traffic monitoring is an important way for network performance analysis and monitor. The research work seeks to explore how to build the basic model of network traffic analysis based on Queuing Theory [1]. Using this, we can obtain the network traffic forecasting ways and the stable congestion rate formula, combining the general network traffic monitor parameters. Consequently we can realize the estimation and monition process for the network traffic rationally.Queuing Theory, also called random service theory, is a branch of Operation Research in the field of Applied Mathematics. It is a subject which analyze the random regulation of queuing phenomenon, and builds up the mathematical model by analyzing the date of the network. Through the prediction of the system, we can reveal the regulation about the queuing probability and choose the optimal method for the system. Adopting Queuing Theory to estimate the network traffic, it becomes the important ways of network performance prediction, analysis and estimation and, through this way, we can imitate the true network, it is useful and reliable for organizing, monitoring and defending the network. In network communication, from sending, transferring to receiving data and the proceeding of the data coding, decoding and sending to the higher layer, in all these process, we can find a simple queuing model. According to the Queuing Theory, this correspond procedure can be abstracted as Queuing theory model [2] , like figure-1. Considering this kind of simple data transmitting system satisfies the queue model [3].

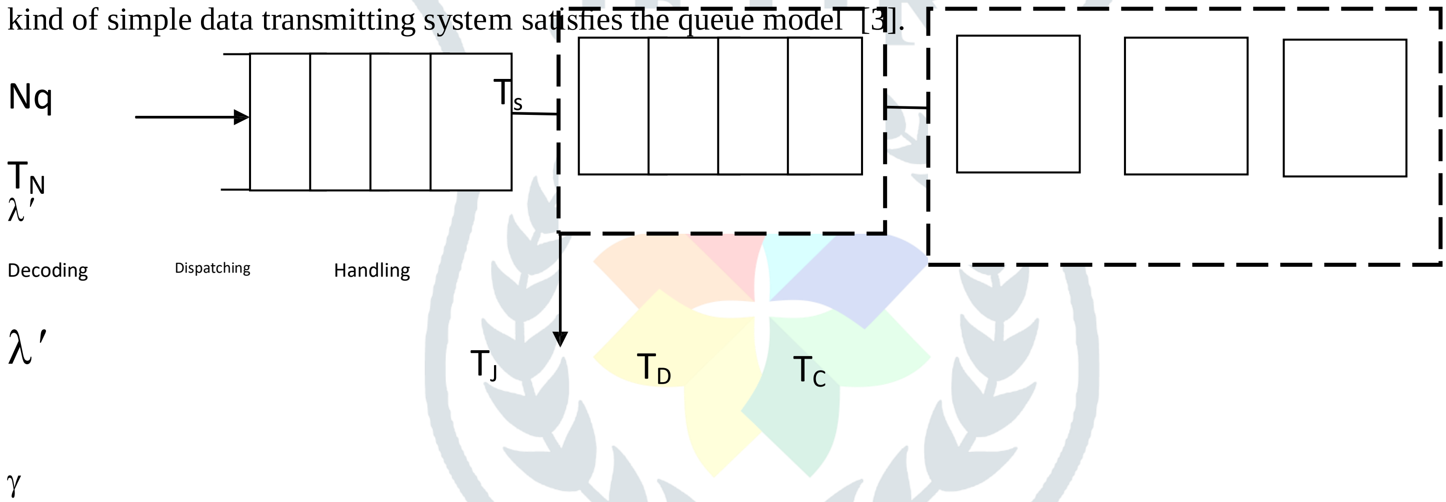


Figure -2:The abstract model of communication process

From the above figure-2,

λ' : Sending rate of the sender.

T_N: Transportation delay time.

λ : Arriving speed of the data packets

N_q : Quantity of data packets stored in the buffer (temporary storage).

Packets rate which have mistake in sending from receiver i.e. lost rate of the receiver.

T_S: Service time of data packets in the server where $T_S=T_J+T_D+T_C$,

T_J: Decoding time

T_D: Dispatching time

T_C: Calculating time or, evaluating time or handling time.

The Queuing model with one server (M/M/1):((C+1):FCFS)

In model M/M/1, the two M represent the sending process of the sender and the receiving process of the receiver separately. They both follow the Markov Process [4], also keep to Poisson Distribution, while the number 1 stands for the channel.
Let N(t)=n be the length of the queue at the moment of t. So the probability of the queue

whose length is n be

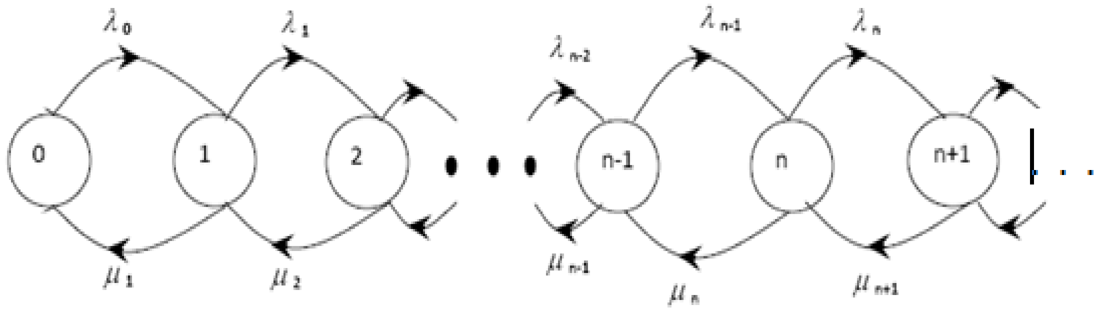
$P_n(t) =$ prob [N(t)= n]

In this model,

λ_n = Rate of arrival into the state n

μ_n =Rate of departure from the state n.

We have the transition rate diagram,



FiFigFigure-3: State transition diagram

The system of differential difference equation is.

$$\frac{d}{dt}\{P_n(t)\} = -\lambda_n P_n(t) - \mu_n P_n(t) + \lambda_{n-1} P_{n-1}(t) + \mu_{n+1} P_{n+1}(t)$$

, for n≥1 *(1)*

And $\frac{d}{}\{P(t)\} = -\lambda P(t) + \mu P(t);$

or n=0 *(2)*

In model M/M/1, we let

$\lambda_n = \lambda$ And $\mu_n = \mu$

Where λ and μ are constants.

Then (1) and (2) reduces to

$$\frac{d}{}\{P(t)\} = \lambda P$$

$(t) + \mu P$
$(t) - (\lambda + \mu)P_n(t)$; for n≥1 (3)
dt
$n-1$
$n+1$ n

And $\frac{d}{dt}\{P_0(t)\} = -\lambda P_0(t) + \mu P_1(t);$
for n=0 (4)

Here, λ is considered as the arrival rate while μ as the service rate. In the steady state condition

$$\underset{t\to\infty}{Lt}\ P_n(t) = P_n$$

And

$$\underset{t\to\infty}{Lt}\frac{d}{dt}\{P_n(t)\} = 0$$

Hence from (2) and (3) when t→ ∞

we get

$$0 = \lambda P_{n-1} + \mu P_{n+1} - (\lambda + \mu)P_n \quad (4)$$

$$P_1 = \left(\frac{\lambda}{\mu}\right)P_0$$

Forecasting the network traffic using Queuing Theory

The network traffic is very common [5], The system will be in worse condition, when the traffic becomes under extreme situation, in which leads to the network congestion [6]. There are a great deal of research about monitoring the congestion at present ,besides, the documents which make use of Queuing Theory to research the traffic rate appear more and more. For forecasting the traffic rate, we often test the data disposal function of the router used in the network. Considering a router's arrival rate of data flow in groups is λ , and the average time which the routers use to dispose each group is $\frac{1}{}$, the buffer of the routers is C, if a certain group arrives, the waiting length of the queue in groups has already reached, so the group has to be lost. When the arriving time of group timeouts, the group has to resend. Suppose, the group's average waiting time is$(1/\mu)$. We identify $P(t)$ to be the arrival probability of the queue length for the routers group at the moment of t, supposing the queue length is i:

$$P(t) = (P_0(t), P_1(t), \ldots, P_i(t)),\ i = 0,1, \ldots, C+1 .$$

Then the queuing system of the router's date groups satisfies simple Markov Process [7], according to Markov Process, we can find the diversion strength of matrix of model 1 as follow:

$$Q=\begin{pmatrix} -\lambda & \lambda & 0 & 0 & \cdots & 0 & 0 \\ \mu & -(\lambda+\mu+v) & \lambda+v & 0 & \cdots & 0 & 0 \\ 0 & \mu & -(\lambda+\mu+2v) & \lambda+2v & \cdots & 0 & 0 \\ 0 & 0 & \mu & -(\lambda+\mu+3v) & \cdots & 0 & 0 \\ 0 & 0 & 0 & \mu & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & -(\lambda+\mu+Cv) & \lambda+Cv \\ 0 & 0 & 0 & 0 & \cdots & \mu & -\mu \end{pmatrix}$$

Network Congestion Rate

Network congestion rate is changing all the time [8]. The instantaneous congestion rate and the stable congestion rate are often used to analysis the network traffic in network monitor. The instantaneous rate $A_C(t)$ is the congestion rate at the moment of t. The $A_C(t)$ can be obtained by solving the system length of the queue's probability distributing, which is called $P_{C+1}(t)$.

Let $P_K(t)(K=0,1,\ldots,C+1)$ to be the arrival probability of the queue length for the routers group at the moment of t by considering the queue length is k .

Then the queuing system of the router's date groups satisfies simple Markov Process. According to Markov Process, $P_k(t)$ satisfies the following system of differential difference equations.

Let,

$P_k(t)$ = prob { k no. of data packets present in the system in time t }

and $P_k(t+\Delta t)$ = prob { k no. of data packets present in the system in time $(t + \Delta t)$ }

Case 1: rk $\geq$ 1

$P_k(t+\Delta t)$ = Prob { k no. of data packets present in the system at time t } $\times$prob {

no data packets arrival in time (Δt) } $\times$ prob {no data packet departure in time Δt }
+ Prob { (k -1) no. of data packets present in the system at time t } $\times$ prob { 1 data packet arrival in time (Δt) } $\times$ prob { no data packet departure in time Δt }
+ prob { (k +1) no. of data packets present in the system at time t } $\times$
prob { no data packets arrival in time (Δt) } $\times$ prob { 1 data packet departure in time Δt }+. . .

$$\Rightarrow P_k(t+\Delta t) = P_k(t) \times \{1-\lambda_k \Delta t + o(\Delta t)\} \times \{1-\mu_k \Delta t + o(\Delta t)\}$$

$$+ P_{k-1}(t)\{\lambda_{k-1}\Delta t + o(\Delta t)\} \times \{1-\mu_{k-1}\Delta t + o(\Delta t)\}$$

$$+ P_{k+1}(t) \times \{1-\lambda_{k+1}\Delta t + o(\Delta t)\} \times \{\mu_{k+1}\Delta t + o(\Delta t)\} + o(\Delta t)$$

$\Rightarrow P_k(t+\Delta t) - P_k(t) = -(\lambda_k + \mu_k)P_k(t) \times \Delta t + P_{k-1}(t)\lambda_{k-1} \times \Delta t + P_{k+1}(t)\mu_{k+1} \times \Delta t + o(\Delta t)$ Dividing both sides by Δt and taking limit as

$\Delta t \rightarrow 0$

$$\Rightarrow \frac{d}{dt}\{P_k(t)\} = -(\lambda_k + \mu_k)P_k(t) + \lambda_{k-1}P_{k-1}(t) + \mu_{k+1}P_{k+1}(t)$$

(5)

III. Conclusion

To Queuing theory and its mathematical models provide valuable tools for Queuing theory and its mathematical models provide valuable tools for Queuing theory and its mathematical models provide valuable tools for understanding and managing traffic flow in transportation systems. The M/M/c queuing model, commonly used in traffic flow management, assumes exponential inter-arrival times, exponential service times, and a specified number of servers or lanes. understanding and managing traffic flow in transportation systems. The M/M/c queuing model, commonly used in traffic flow management, assumes exponential inter-arrival times, exponential service times, and a specified number of servers or lanes. understanding and managing traffic flow in transportation systems. The M/M/c queuing model, commonly used in traffic flow management, assumes exponential inter-arrival times, exponential service times, and a specified number of servers or lanes.

This research program centers around a comprehensive investigation into the dynamics of network traffic by employing principles from Queuing Theory. Queuing Theory, a mathematical discipline, is utilized to model and understand the behavior of waiting lines or queues, making it an apt tool for analyzing network traffic patterns. The focal point of the present analysis is the development of a queuing model rooted in the fundamentals of queuing theory. This model is designed to encapsulate the intricate dynamics of how data packets traverse a network, queue up for processing, and subsequently contribute to overall network congestion. The objective of creating this model is to provide a structured framework that can be used to make sense of the complex interactions between data packets and network resources. Through this carefully constructed queuing model, the researchers derive estimations that shed light on the network's behavior under varying conditions. By subjecting the model to various scenarios and inputs, the researchers gain insights into how the network performs in terms of latency, throughput, and congestion. This, in turn, contributes to a deeper understanding of the network's capacity and limitations.

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