Scholarly Research Journal for Interdisciplinary Studies
Online ISSN 2278-8808, SJIF 2024 = 8.153,
https://www.srjis.com/issues_data/224
Peer Reviewed, Refereed & Indexed Journal, Nov-Dec, 2023, Vol- 12/80
https://doi.org/10.5281/zenodo.10566413

QUEUE THEORETIC APPROACH TO ANALYZE COMMUNICATION NETWORKS IN INDIAN SMART CITIES

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Paper Received On: 25 Dec 2023

Peer Reviewed On: 28 Dec 2023

Published On: 01 Jan 2024

Abstract

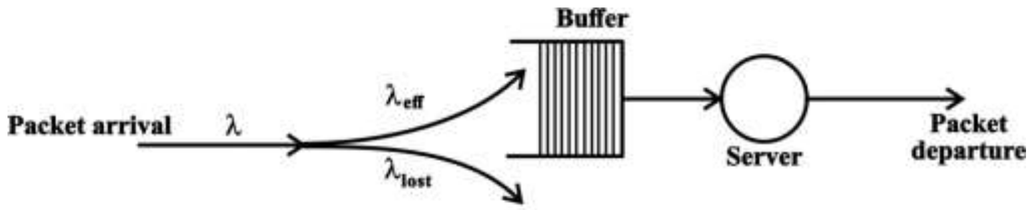
This study aims to analyse the congestion dynamics of the communication networks in the context of the smart cities of India with regard to changing infrastructural / technological scenario. The Indian smart city of Aligarh has been selected for study. The queueing model (M/M/1); a single server model with poisson arrival and exponential processing time distribution, has been used to analyse the communication system at different locations in the city. Various performance measures, such as utilisation, number of packets in the system, time spent by a packet in the system, latency and packet loss, have been determined and analysed.

Keywords: *Communication Network, Smart City, Performance Measures, Latency, Packet loss.*

Introduction

Queueing theory is a branch of mathematics that falls under mathematical modeling. The theory sprang up on the verge of the 20th century, with the application to telephone communication systems. Since then, it has been playing a significant role in studying and analysing a lot of problems that we encounter in our real lives. It understands the congestion phenomenon deeply, interprets models for systematic study, predicts and provides remedial solutions.

A Queue, is referred to a collection or group of customers who arrive at the service facility for a particular type of service.



(Queueing / Communication System)

Communication Network: refers to a collection of multiple queues and each queue consists of data packets waiting for transmission at different terminal nodes, connected via links. Thus, by nature and functioning, the communication network can be identified as a queueing system. With the advancement of science and technology and the population explosion, the data generation rate is going on multiplying rapidly. That's why its management (handling, control, manipulation) requires:

(i) Pace-keeping with emerging technologies

(ii) to be updated, having delved into the phenomenon and then needs optimization in accordance with the changing scenario.

In the context of Indian smart cities, the rapidly evolving landscape of urbanisation and communication technology has raised the question of how to dig into and model a communication network to optimise the different measures related to functional efficiency. Queueing theory can adequately answer this question.

To answer this question, a single server queueing model (M/M/1), with Poisson arrival and an exponential service pattern, has been used to understand the communication system and the related measures.

Essential terms and symbols:

The important terms and symbols used in the study are as under –

λ : data packets arrival / generation rate / throughout

μ : data transmission / processing rate

L_q : average number of data packets waiting for transmission / processing

L_s : average number of data packets in system (in waiting and in processing)

W_q: the average time spent by a data packet in queue (waiting)

W_s: the average time spent by a data packet in system (in queue + in service)

Key Concepts:

The essential concepts used in the study have been described briefly as follows:

Little's formula: This formula is a benchmark in the theory of queues, was propounded by Little in 1961. It interrelates the number of packets in queue / system and the time spent by a data packet in the queue or system. Mathematically, this formula is defined in a precise manner; thus,

$L = \lambda w$

Server utilisation: server utilisation is defined as the product of throughput and packet processing time. It is denoted by ρ, then,

$$\rho = \frac{\lambda}{\mu}$$

Latency: In communication networks, latency refers to the time that a data packet takes to move from the source to the sink (destination).

Data/packet loss: refers to the number of packets sent but not received, i.e., the data packets transferred over the network but could not be processed.

Literature Review:

Queueing theory emerged on the verge of the twentieth century with the applications in telephone communication systems. Since then, it has been a linchpin and backbone of this field and is going on spreading over other numerous fields of our day-to-day lives. It has attracted the attention of scientists, engineers, mathematicians and pioneers in varied fields. A brief survey of relevant and important researches that have been carried out in the field under context, is as follows:

2018 Daradkeh et al. (2018) studied the communication system, emphasising the quality of service. They revealed the fact that the parameters—channel capacity, buffering, routing and load balance—play a significant role in improving the quality of service. That's why their optimisation needs special attention and proper management. **Yang and Zhang (2018)** looked deeper into queueing models in the context of urban communication networks and suggested mechanisms and protocols to fight against the threats that the communication network normally encounters. **Li and Wang (2019)** studied queueing models in the special context of the challenges that we face in smart cities due to the rapid change in their urban landscapes. In this study, they emphasised the need to pay special attention to manage and optimize the factors of traffic load connectivity and emerging technologies while modelling communication systems in smart cities. **Kumar et al. (2020)** delved into urban communication networks and investigated that edge computing technologies are being proven to be more effective in improving different performance measures of the communication network under context. **Chen et al. (2021)** found in their study that the mobility of individuals in smart cities affects the performance of the communication system to a considerable extent. Therefore, they modelled the queueing models as having a dynamic nature and keeping pace with the systems. **Wang et al. (2021)** had a deep insight into the study of how the advent of technologies initially creates hindrances until they are not adopted with technical expertise. They framed the characteristics to keep pace with these technologies, along with internet of things, to optimise the performance measures. **Smith et al. (2022)** studied urban queueing networks and disclosed the fact that queueing models play an important role in congestion control and to manage different performance measures of the communication systems. For the study, they used a single-server system with poisson arrival and an exponential service pattern. **Baik et al. (2023)** used a queueing theoretic approach to study the data centres and explored a policy to control the server speed with the objective of energy saving. **Bogachev et al. (2023)** got insight into a number of complex systems, including information and communication networks and after a deep discussion, they proposed a novel approach to characterise the changing scenario of the complex systems, specifically communication systems. **Vijay et al. (2023)** discussed the Markovian Queueing System and treated the vacation and retention problems of the servers and impatient customers, respectively.

Methodology:- Indian Smart City, Aligarh, has been selected for the study. Data has been collected from varied locations across the city of Aligarh using real-time monitoring and simulation techniques. The executives, operators and other supporting staff helped a lot in data collection. For the study, we have identified four different locations in Aligarh city, these locations are:

Janakpuri (Residential Area)

Centre Point (A smart point of the city)

Railway Road (Busy Market)

Achal Taal (Educational Centre)

Exhibition Region

Data has been collected for the peak and non-peak hours. Their periods have been identified as:

Peak-hours	5.30 pm to 9.30 pm
Non-peak hours	12.30 pm to 3.30 pm

Model Employed: A single server queueing model (M/M/1) with poisson arrival and exponential service time distribution has been used to delve into the communication systems at identified locations across the city.

Table – 1 For Peak hours (5.30 pm to 9.30 pm)

Location	Packet arrival rate, per second: λ	Packet Processing rate, per second: μ
Janakpuri	16	24
Centre Point	12	20
Railway Road	10	15
Achal Taal	8	12
Exhibition area	10	16

Table – 2 Non-Peak hours (12.30 pm to 3.30 pm)

Location	Packet arrival rate, per second: λ	Packet Processing rate, per second: μ
Janakpuri	10	24
Centre Point	9	20
Railway Road	9	15
Achal Taal	8	12
Exhibition area	8	16

Table – 3 Data for latency and Packet loss:

Location	For Peak hours (5.30 pm to 9.30 pm)		Non-Peak hours (12.30 pm to 3.30 pm)	
	Latency (ms)	Packet loss (%)	Latency (ms)	Packet Loss (%)
Janakpuri	25	3.5	16	2
Centre Point	24	3.4	14	1.9
Railway Road	21	3.2	19	3.00
Achal Taal	19	3.0	17	2.9
Exhibition area	18	2.9	12	.9

Calculation of packets in the system and time spent by a packet: These measures have been calculated in Tables 4 and 5 for the peak and non-peak hours, respectively.

Table – 4 For Peak-hours (5.30 pm to 9.30 pm)

Location	Utilization ρ	Average time (second) spent by a packet in system: W_s	Average packets in system: L_s
Janakpuri	.66	.125	2
Centre Point	.6	.125	1.5
Railway Road	.66	.20	2
Achal Taal	.66	.25	2
Exhibition area	.63	.166	1.66

Table – 5 For Non-Peak hours (5.30 pm to 9.30 pm)

Location	Utilization ρ	Average time (second) spent by a packet in system: W_s	Average packets in system: L_s
Janakpuri	.416	.071	.71
Centre Point	.45	.09	.81
Railway Road	.6	.166	1.5
Achal Taal	.66	.25	2
Exhibition area	.5	.125	1

Concluding Discussion :

In Table 4, 5 performance measures—utilisation (ρ), time spent by a data packet in the system, (W_s) and number of packets in the system at any time (L_s) are calculated using the formulae given in the appendix. Table 3 provides the latency and percentage of packet loss. From these tables, it is evident that:

(i) If the processing rate is constant, the time spent by a packet in the system and the number of packets are directly proportional to the arrival rate.

(ii) Achal Taal and Railway Road areas remain overloaded with the deployed servers.

(iii) Janakpuri, the centre point and exhibition areas are overloaded during peak-hours.

(iv) The locations having higher latency have higher packet loss.

(v) The packets spend more time in the system during peak-hours as compared to non-peak hours.

(vi) The number of packets in the system during peak-hours is greater than the number of packets during non-peak hours.

Assumptions/limitations: The study has been made under the following assumptions and limitations:.

(i) The network has been supposed to attain a steady state.

(ii) Packet size is supposed to be uniform.

(iii) The network is supposed to be an M/M/1 queueing model.

(iv) The findings can't be used directly for other locations or cities since different cities have different infrastructure and technologies.

Conclusion:

Communication is a linchpin for the all-round development of our society. It enhances quality of life by increasing capability and the ability of doing better to achieve the expected goals. But it requires good coordination among the planners, executives and executors to develop the appropriate infrastructure while keeping pace with the emerging technologies, i.e., we would have to establish a happy medium between the arrival pattern and the performance efficiency of the system.

Appendix

This Appendix includes the Formulae Employed to calculate different measures

Formulae,

- Server utilization, $\rho = \frac{\lambda}{\mu}$
- Little's formula, $L = \lambda W$
- Average number of packets in the system, $L_s = \frac{\rho}{1-\rho}$
- Average number of packets in buffer (queue), $L_q = \frac{\rho^2}{1-\rho}$
- Time spent by the packet in system, $W_s = \frac{1}{\mu(1-\rho)}$
- Time spent by the packet in waiting, $W_q = \frac{\rho}{\mu(1-\rho)}$

References:-

Bagachev, et al.: *"Approximate Waiting Times for Queueing Systems with Variable Long-term Correlated Arrival Rates", Physica A:Statistical Mechanics and its Applications, 2023, 614, PP. 128513.*

Baik, Seung Min, and Young Myoung Ko. : *"QoS-Aware Energy-efficient Workload Routing and Server Speed Control Policy in Data Centers: A Robust Queueing Theoretic Approach." IISE Transactions (2023), PP. 1-14.*

Chen, Q., et al.: *"Urban Mobility Impact on Communication Network Performance : A Queueing Model Approach", Journal of Urban Technology, 2021, 18(3), 212-230.*

Daradkeh, et al.: *"Development of QoS Methods in the Information Networks with Fractal Traffic", International Journal of Electronics and Telecommunications, 2018, 64 No. 1, PP. 27-32.*

Kumar, S., *et al.: "Edge Computing in Urban Communiction Networks: A Queueing Model perspective," IEEE Transactions on Mobile Computing, 2020, 19(6), PP. 1483-1496.*

Li, Y., & Wang, L.: *"Challenges and Opportunities: Queueing Models in Smart Cities." Smart Cities, 2019, Vol. 5(1), PP. 45-60.*

Smith*, J., et al.: "Queueing Theory Application Urban Communication Networks", Journal of Network Analytics, 2022, Vol. 10(2), PP. 123-145.*

Vijaya Laxmi, P., Girija Bhavani, E. and Andwilile, A. G. : *"Retention of Impatient Customers in a Multi-Server Markovian Queueing System with Optional Service and Working Vacations." Communications in Statistics-Theory and Methods 52, no. 15 (2023), PP. 5195-5212.*

Wang, H., et al.: *"Adapting Queueing Models to Emerging Technologies in Smart Cities", Journal of Emerging Technologies in Urban Planning, 2021, 8(2), PP. 123-140.*

Yang, Y., & Zhang, C.: *"Queueing Models for Secure and Reliable Urban Communication Network", International Journal of Security and Networks, 2018, 10(3), PP. 215-230.*

Cite Your Article as:

Satish Chandra Tiwari & Sanjay Chaudhary. (2024). QUEUE THEORETIC APPROACH TO ANALYZE COMMUNICATION NETWORKS IN INDIAN SMART CITIES. In Scholarly Research Journal for Interdisciplinary studies (Vol. 12, Number 80, pp. 206–212). Zenodo. https://doi.org/10.5281/zenodo.10566413