

Probabilistic Models and Assumptions

- In our project, packet arrival at the router is modeled using probability distributions.
- We assume packet arrivals follow a **Poisson process**, which is commonly used in network traffic studies.
- Packet service time at the router is assumed to follow an **exponential distribution**.
- These assumptions help us model the router as an **M/M/1 queue**, where the first **M** denotes a Markovian (Poisson) arrival process, the second **M** denotes a Markovian (exponential) service process, and **1** denotes a single server (router).
- We assume that:-
 - Packet arrivals are independent of each other
 - Service time of one packet does not affect others
- These assumptions are reasonable because:-
 - In real networks, packets arrive randomly
 - Routers usually process packets one by one
- **Key variables used in the model:-**
 - Arrival rate (**λ**): average number of packets arriving per unit time
 - Service rate (**μ**): average number of packets processed per unit time
 - Packet delay (**D**): total time spent by a packet in the system

Probabilistic Reasoning and Inference Logic

- Uncertainty exists because:-
 - Packet arrival time is random
 - Packet service time is random
- This uncertainty affects:-
 - Waiting time in the queue
 - Total packet delay
- Probabilistic reasoning helps us:-
 - Estimate average packet delay
 - Predict average queue length
 - Decide whether the router is becoming congested
- For stable operation, the router must be able to process packets faster than packets arrive on average. Otherwise, the queue grows continuously, leading to very large delays.
- This gives the **stability condition**:-
$$\lambda < \mu$$
- **Conceptual Steps:-**
 1. Packets arrive randomly at the router
 2. Router serves packets one at a time
 3. Some packets wait in the queue
 4. Delay is calculated using probability formulas
 5. Results help us understand router performance

Operationalizing Probabilistic Reasoning in the Project

- The probabilistic reasoning is applied using:-
 - Mathematical formulas from queueing theory
 - Simple simulations of packet arrival and service
- We measure:-
 - Average packet delay
 - Average queue length
 - Router utilization

- **Equation 1: Traffic Intensity**

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

- Traffic intensity represents how busy the router is and plays a key role in determining congestion and delay.
- **Evaluation metrics:-**
 - Mean delay shows expected performance
 - Probability of high queue length indicates congestion risk
- **Simplifying assumptions made:-**
 - Single router only
 - Infinite buffer size
 - No packet loss
 - These assumptions make the model easier to analyze.

Current Limitations and Conceptual Gaps

- The model assumes:-
 - Constant arrival rate, which may change in real networks
 - Infinite buffer size, so packet loss is not considered
- Real networks may have:-
 - Burst traffic
 - Multiple routers
 - Priority-based packet handling
- Some assumptions are not verified using real traffic data.
- The model considers congestion **only at a single router (queueing congestion)** and does not consider end-to-end network congestion.
- The model also does not consider different packet sizes.

Planned Refinements and Role Coordination

- In the next milestone, we plan to:
 - Add finite buffer size
 - Consider packet loss probability
 - Study varying arrival rates
- Future modeling tasks include:
 - Extending the model to an **M/M/1/K** queue
 - Comparing analytical results with simulation results
- **Role of reviewer / GitHub manager:**
 - Check correctness of formulas
 - Maintain code and documentation
 - Coordinate updates from all group members

Summary of Group-Level Understanding

- Packet delay in a router is random in nature due to random packet arrivals and service times.
- Probabilistic models help us:
 - Understand packet delay behavior
 - Predict average system performance
- **Equation 2: Average Packet Delay (Mention Only)**
$$E[D] = \text{Expected packet delay}$$
- One of the main goals of this project is to estimate the expected packet delay using probabilistic models and simulation.
- **Queue Length (Conceptual):**
 - Queue length is modeled as a random variable
 - Its behavior depends on traffic intensity (ρ)
- The objective of this project is **not to design a router**, but to analyze and quantify packet delay behavior under random traffic using probabilistic models.
- Although simplified, the model:
 - Explains basic router behavior
 - Acts as a foundation for analyzing more complex networks
- **Papers / References Used :-**
 - **L. Kleinrock**, *Queueing Systems, Volume 1: Theory*, Wiley, 1975.
 - **D. Bertsekas and R. Gallager**, *Data Networks*, Prentice Hall, 1992.
 - **J. Walrand**, *An Introduction to Queueing Networks*, Prentice Hall, 1988.