

# 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 ( $\lambda$ ): average number of packets arriving per unit time
  - Service rate ( $\mu$ ): 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 ( $\rho$ )
- 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.