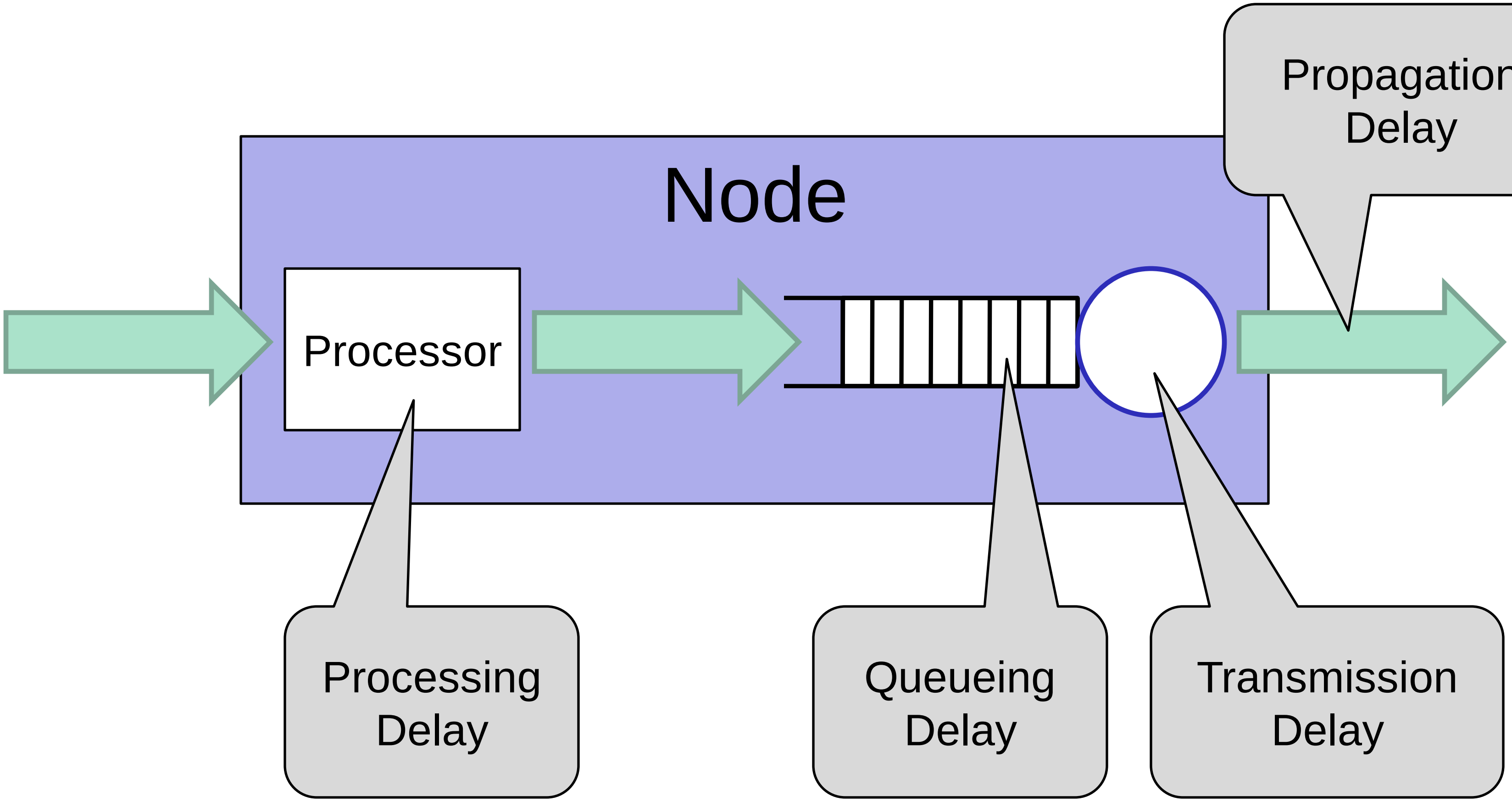
Delay Models in Data Networks

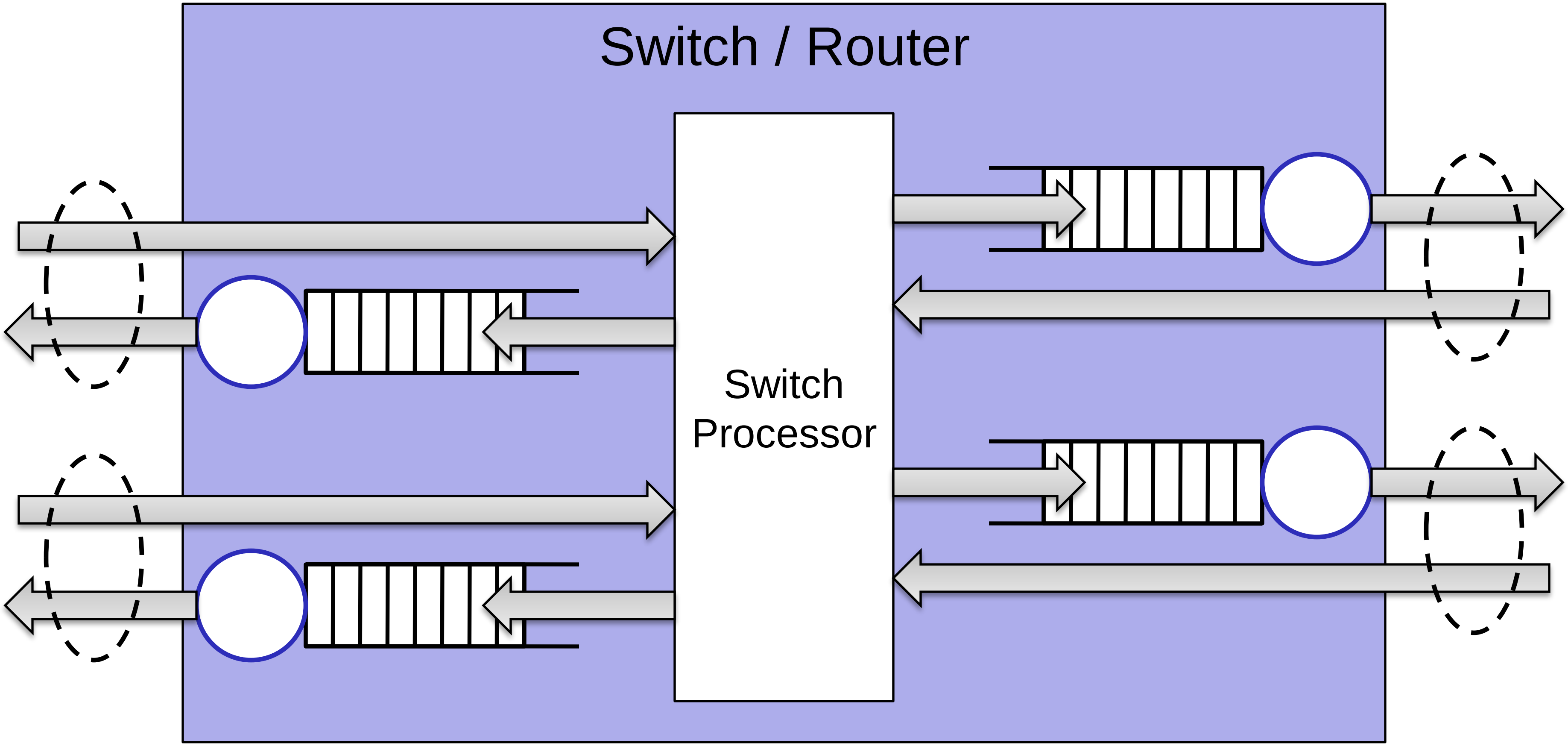
Sources of Delay

- Processing Delay
  - Time between when a packet is received and scheduled on an outgoing queue
- Queueing Delay
  - Time packet spends in the outgoing queue
- Transmission Delay
  - Time between when the first and last bits are transmitted
- Propagation Delay
  - Time it takes for the last bit to leave the transmitter and arrive at the receiver

Graphical Representation



Logical Diagram of Node Internals



Queueing Theory

- Assume customers (packets) arrive at a queue at random times
  - Inter-arrival time: average time between customers
  - Arrival rate: λ = (inter-arrival time)$^{-1}$
- Each customer (packet) takes a random amount of time to service (transmit)
  - Service time: average time to service each customer
  - Departure rate: μ = (service time)$^{-1}$
- Useful Information
  - Average number of customers in the system = N
  - Average number in the queue = N_Q = max(N-1,0)
  - Average total delay per customer = T
  - Average wait time W = T-1/μ

Little's Theorem

- On-Board Derivation
- $N=\lambda T$
- $N_Q=\lambda W$

M/M/1 Queueing System

- Probabilistic queueing system
- M means "memoryless" which means exponentially-distributed arrival and service times
  - Interarrival time ~ exp(λ)
  - Service time ~ exp(μ)
  - Note that $E[\exp(\alpha)] = 1/\alpha$
- Result
  - $\alpha(t)$ ~ Poisson(t; λ)
  - Number of arrivals and departures has a Poisson distribution

Continuous-Time Markov Chains

- Analysis model for M/M/1 systems
- On-board Derivation
- Results:
  - $\rho=\lambda/\mu$
  - $N=\rho/(1-\rho)=\lambda/(\mu-\lambda)$
  - $T=N/\lambda=1/(\mu-\lambda)$
  - $W=\rho/(\mu-\lambda)$
  - $N_Q=\rho^2/(1-\rho)$