On Modeling Feedback Congestion Control Mechanism of TCP using Fluid Flow Approximation and Queuing Theory

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Background

- TCP (Transmission Control Protocol)
  - Transport layer protocol
  - Congestion control mechanism

- Analysis of the TCP until today
  - Assuming a constant packet loss probability
  - Statistical behavior

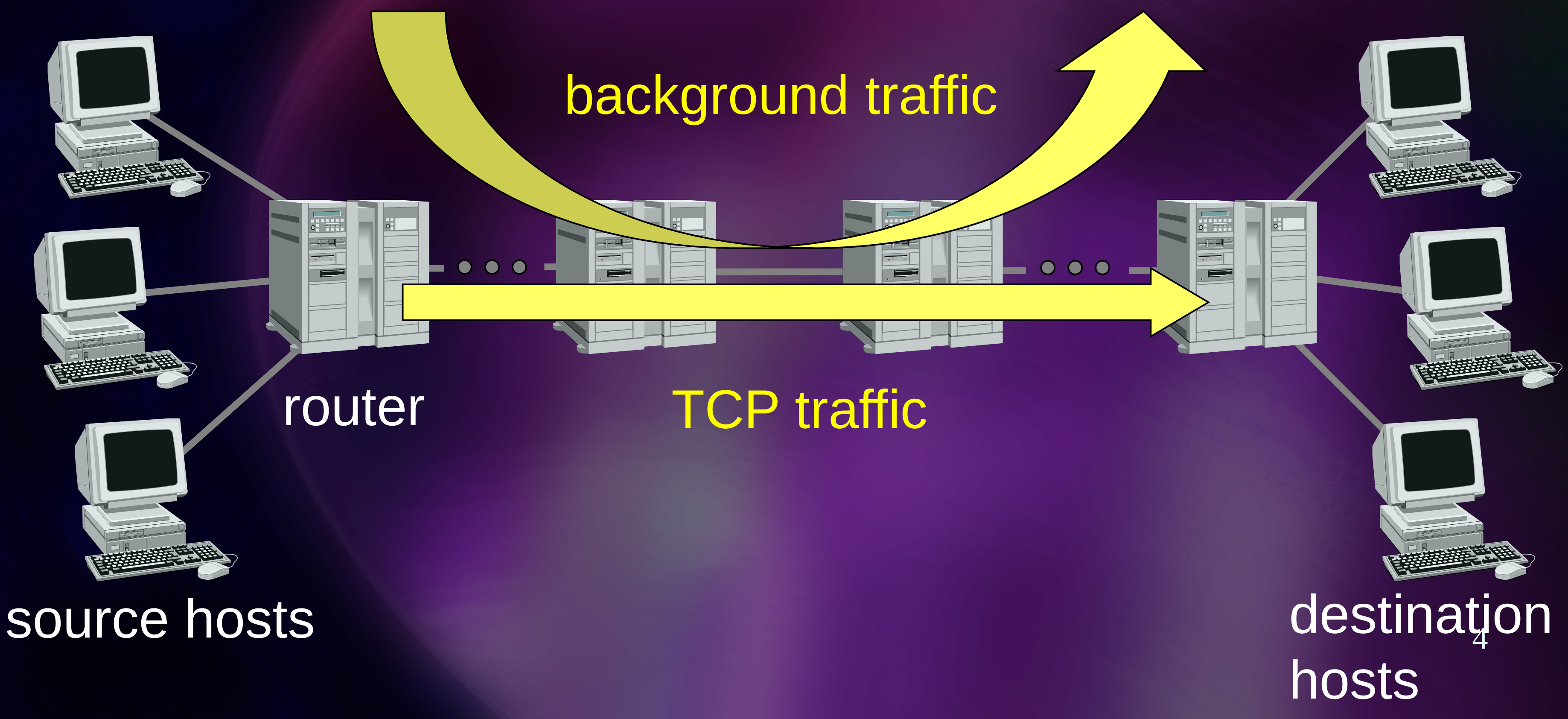
- Real Network
  - Packet loss probability has changed according to packet transmission rate

Objective

- Model the interaction between two systems as a feedback system
  - Network seen by TCP
    - M/M/1/m queuing system
  - Congestion control mechanism of TCP
    - Fluid flow approximation
- Background Traffic are also taken account of

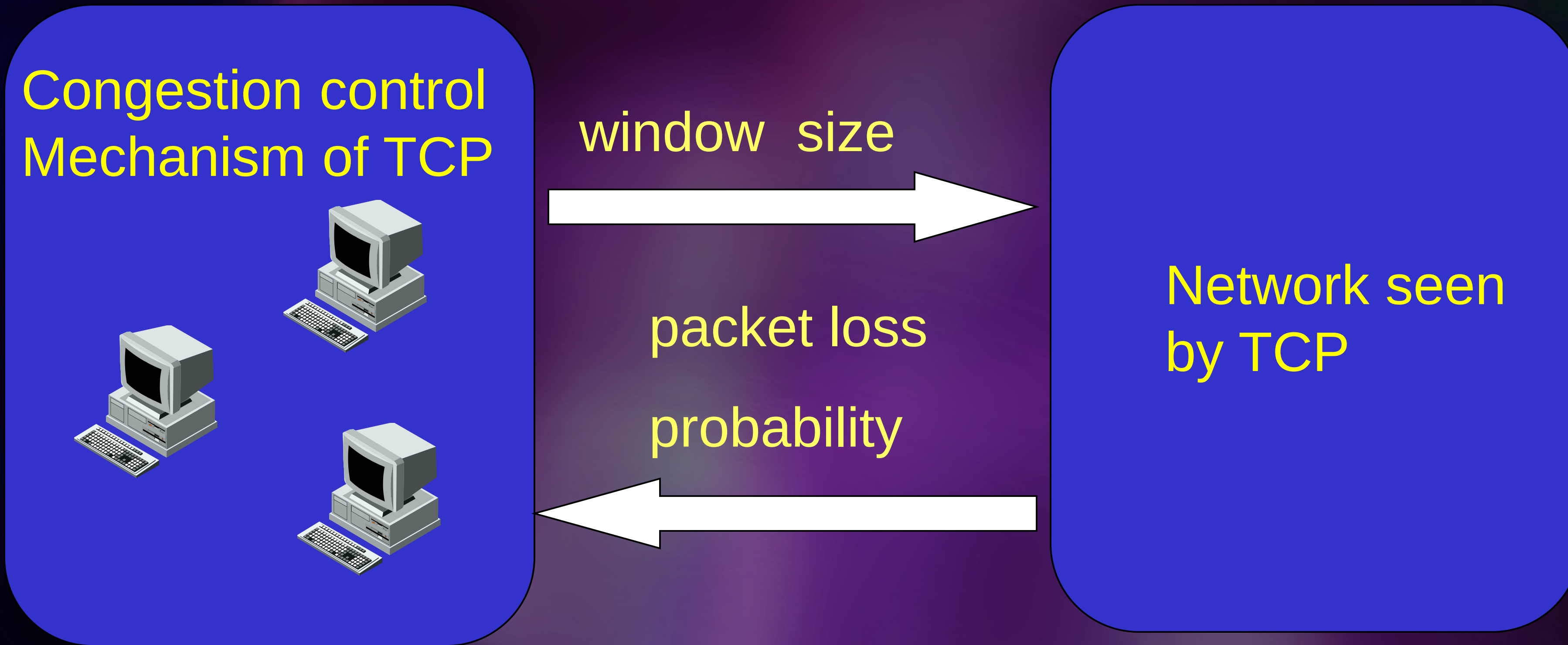
Analytic Model

- TCP connections
- Take account of background traffic



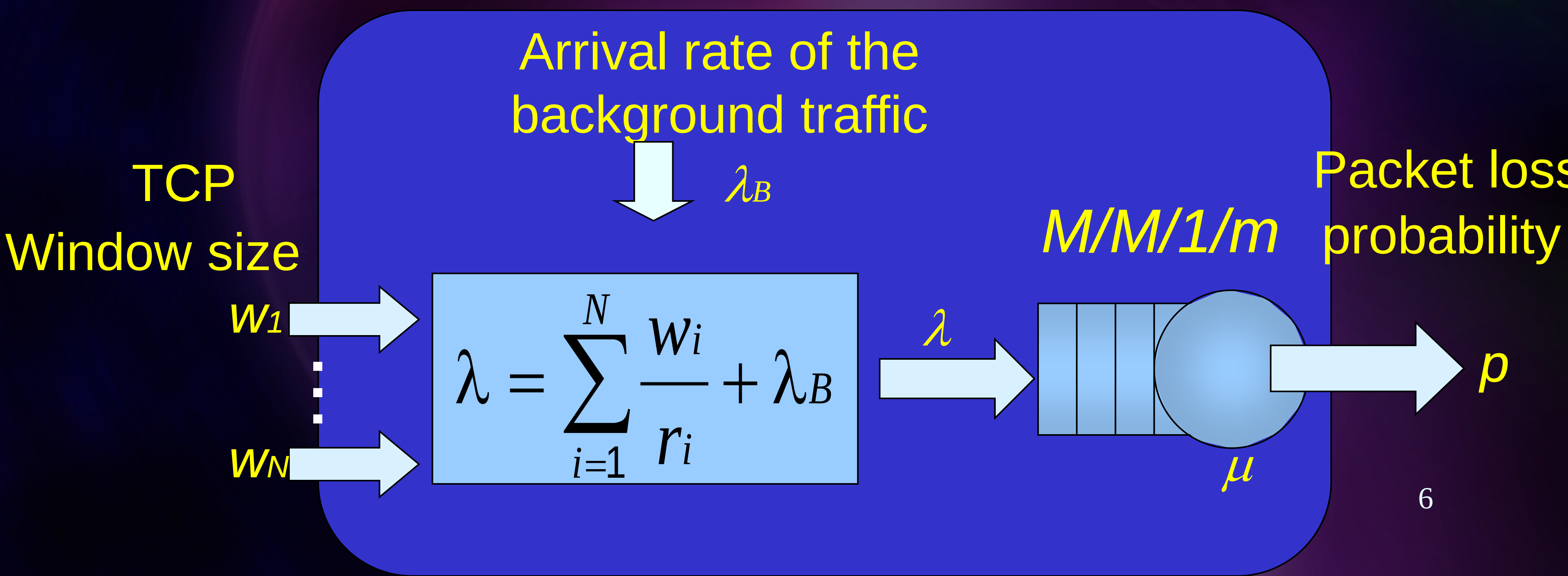
Modeling total TCP and Network

- Modeling Network as a feedback system
  - Network seen by TCP
  - Congestion control mechanism of TCP seen by network



Modeling Network using Queuing Theory

- Assume bottleneck router is a Drop-Tail router
- Model by M/M/1/m queue
- Incoming traffic
  - TCP traffic
  - background traffic



Changes of TCP Window Size

- Congestion avoidance phase
  - Increase window size at every receipt of ACK packet

$$w \leftarrow w + \frac{1}{w}$$

  - Decrease window size at every detection of packet loss
    - Detect from receipt of duplicate ACKs

$$w \leftarrow \frac{w}{2}$$

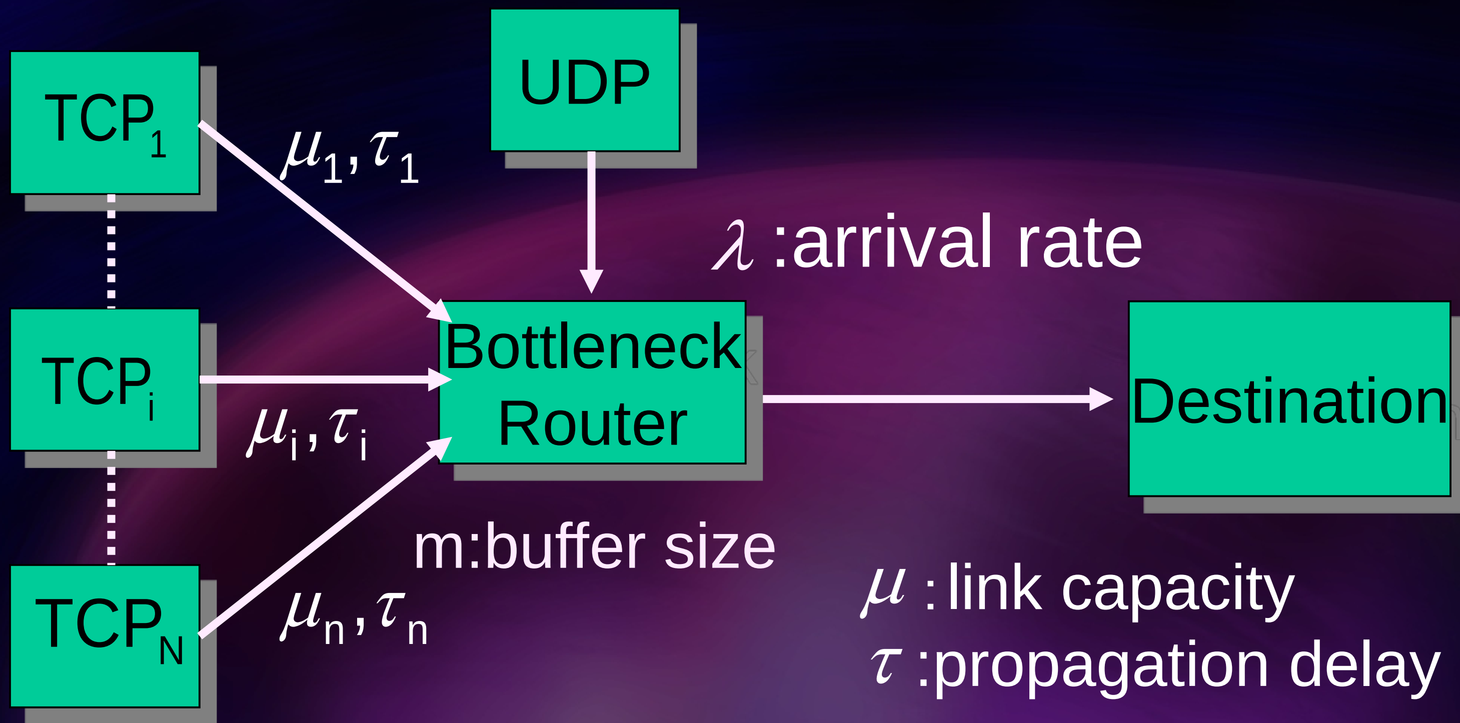
    - Detect from time-out mechanism

$$w \leftarrow 1$$

Modeling TCP using Different Approaches

- 4 analytic models
  - Model A1 :
    - Assume a constant packet loss probability
    - Derive window size of TCP connection in steady state
  - Model A2 :
    - Approximate A1 when packet loss probability is very small
  - Model B :
    Window size change at every receipt of ACK packet and detection of packet loss
  - Model C :
    - Evolution of window size between two succeeding packet loss

Simulation Model



μ_i :5+0.5i [packet/ms]

τ_i :5+i [ms]

λ :2 [packet/ms]

m :50 [packet]

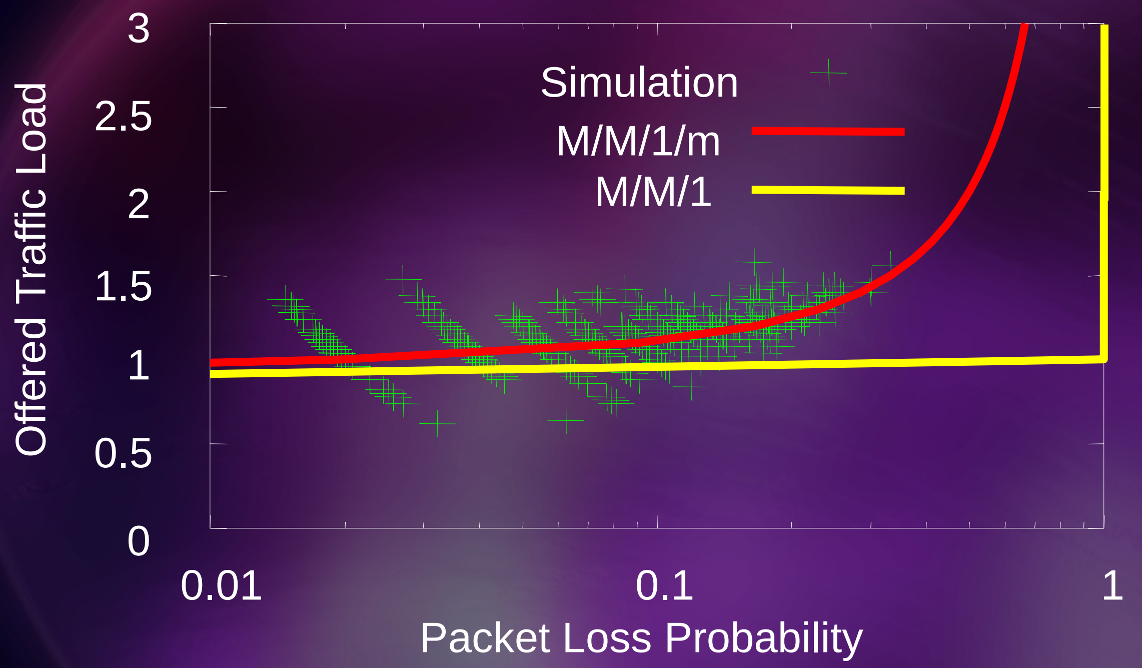
μ :5 [packet/ms]

τ :5 [ms]

N :10

Network Model

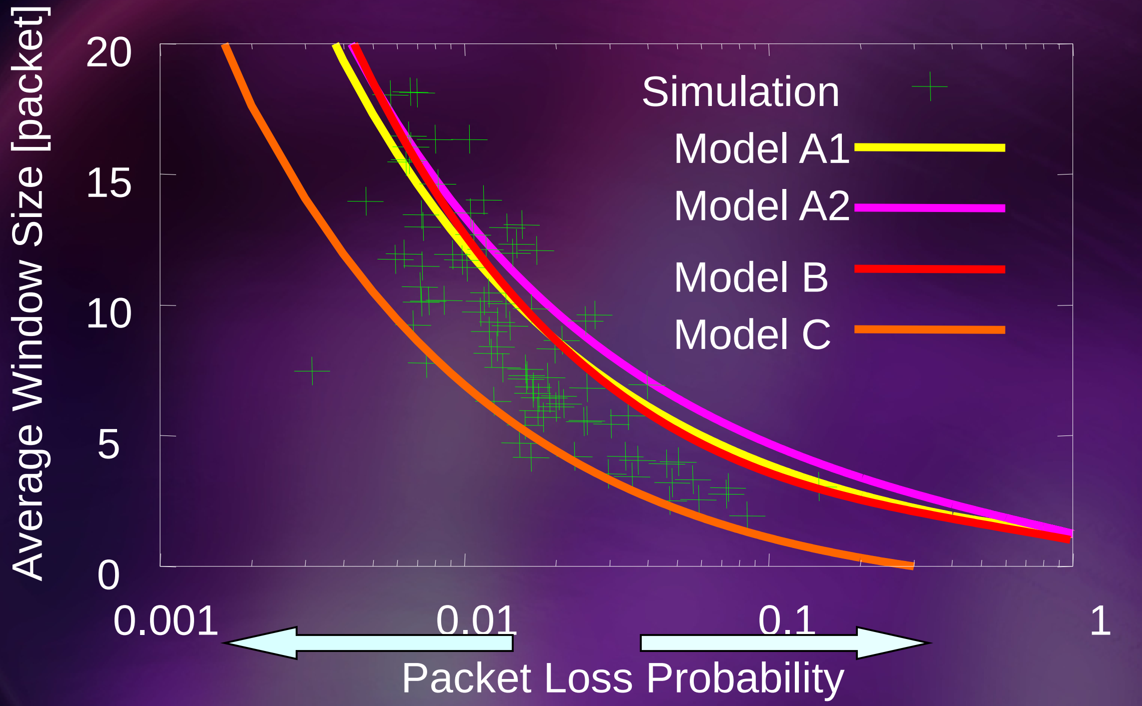
- Relation between offered traffic load and packet loss probability
  - *M/M/1/m* queuing system
  - Simulation result



M/M/1/m models dynamics of network correctly

TCP Model

- Relation between packet loss probability and window size
  - Congestion control mechanism of TCP
  - Simulation result



A1, A2, B show good agreement

B and C show good agreement

Transient Behavior

- Transient Behavior
  - Dynamics of the window size form its initial value to its equilibrium value
- Use Model B for Congestion control model of TCP

$$w \leftarrow w + (1-p)\frac{1}{w} - p(1-\hat{Q}(w))\frac{w}{2} - p\hat{Q}(w)(w-1)$$

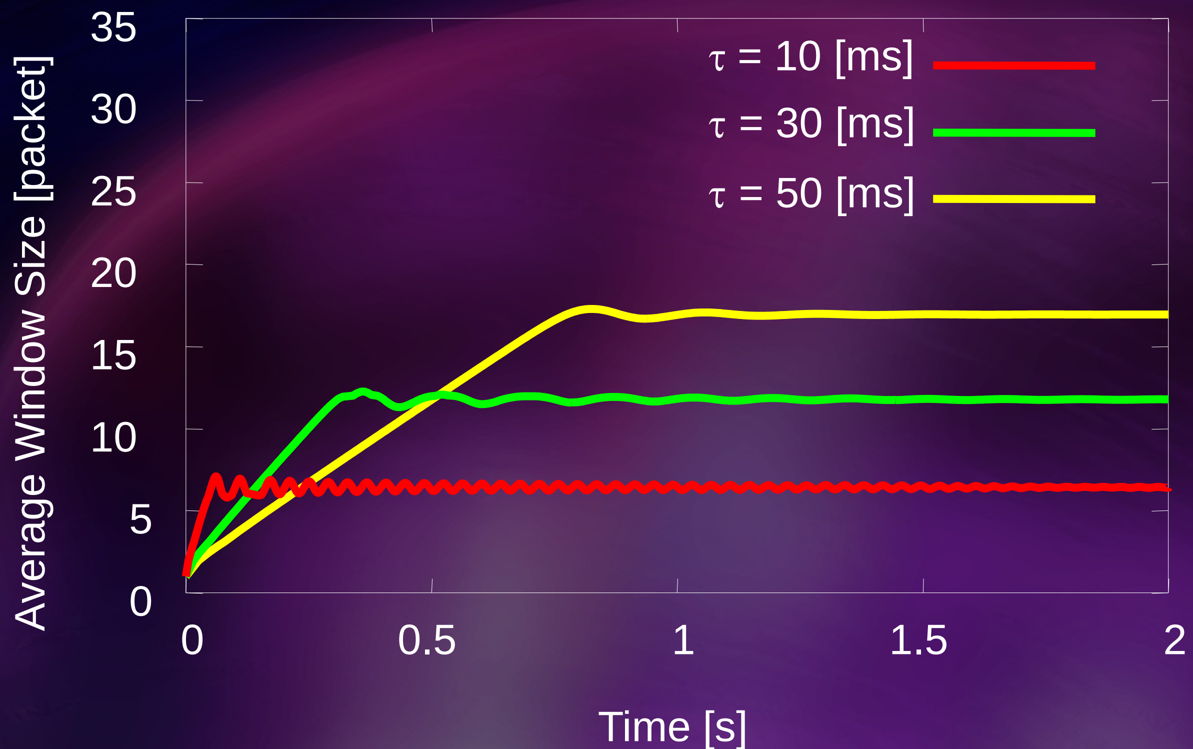
Transient Behavior Analysis

- Modeling the network as a discrete-time model
  - Time slot:duration between succeeding ACK packets received

  - Network state
    - w(k): window size of TCP connections
    - P(k): packet loss probability
- For given initial values, the evolution of the network state can be obtained

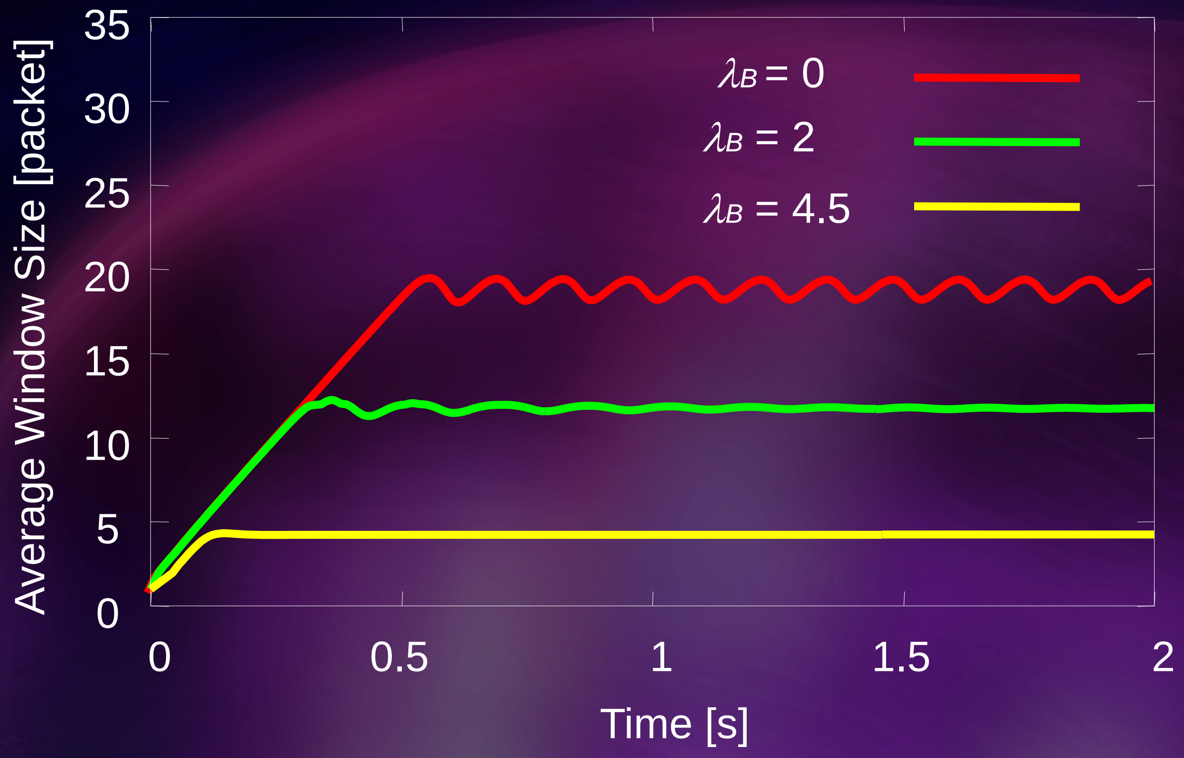
$$\begin{cases} w(k) = w(k-1) + \dfrac{1-p(k-w(k-1))}{w(k-1)} - \dfrac{p(k-w(k-1))w(k-1)}{2} \\ p(k) = \dfrac{(1-\rho(k))\rho(k)^m}{1-\rho(k)^{m+1}} \\ \rho(k) = \dfrac{1}{\mu}\left(\dfrac{w(k)}{r} + \lambda_B\right) \end{cases}$$

Numerical Example:Case of Different Propagation Delays



- When propagation delay is small
  - Ramp-up time of the window size becomes short
  - The window size oscillates for long

Numerical Example:Case of Different Amount of Background Traffic



- When the amount of the background traffic is large
  - The window size of steady state is small
  - The increase rate of the window size is independent of the amount of the background traffic

Conclusion and Future Work

- Conclusion
  - Model the dynamics of TCP
    - Feedback system consisting of two systems
  - Transient behavior Analysis of TCP
    - Propagation delay
    - The amount of the background traffic

- Future work
  - Rigorous analyses of stability and transient behavior of TCP