Analysis of a window-based flow control mechanism based on TCP Vegas in heterogeneous network environment

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TCP (Transmission Control Protocol)

- **Packet retransmission mechanism**
  - Retransmit lost packets in the network
- **Congestion avoidance mechanism**
  - A window-based flow control mechanism
- Several versions of TCP
  - TCP Tahoe
  - TCP Reno
  - TCP Vegas

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TCP Vegas

- Advantages over TCP Reno
  - A new retransmission mechanism
  - An improved **congestion avoidance mechanism**
  - A modified slow-start mechanism
- Uses **measured RTT** as feedback information
  1. Measures RTT for a specific packet
  2. Estimates **severity of congestion**
  3. Changes window size
- Packet loss can be **prevented**

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Objectives

- Analyze a window-based flow control
  - Congestion avoidance mechanism of **TCP Vegas**
  - Connections with **different propagation delays**
  - Several **bottleneck links**
  - Using a control theoretic approach
- Show numerical examples
  - **Throughput** and **fairness**
  - **Stability** and transient behavior

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Congestion avoidance of TCP Vegas

- Source host maintains the **minimum RTT**: τ
- Source host measures the **actual RTT**: *r(k)*

$$d(k) = \frac{w_n(k)}{\tau} - \frac{w_n(k)}{r(k)}$$

- Window size is changed based on ***d(k)***

$$w_n(k+1) = \begin{cases} w_n(k)+1 & \text{if } d(k) < \alpha \\ w_n(k)-1 & \text{if } \beta < d(k) \\ w_n(k) & \text{otherwise} \end{cases}$$

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Assumptions

- Network topology is **arbitrary**
- All routers employ **static routing**
- All routers have a FIFO buffer for each port
- All TCP connections are **symmetry**
- Backward path is never congested

State transition equation: window size

- **Window size** of connection *c* : w_c
  - δ_c: **control parameter** that determines the amount of increase/decrease in window size

$$w_c(k) = \begin{cases} \left[w_c(k - \frac{\tau_c}{\tau}) + \delta_c(\gamma_c - d_c(k)) \right]^+ & \text{if } k \equiv 0 \ (\text{mod } \frac{\tau_c}{\tau}) \\ w_c(k-1) & \text{otherwise} \end{cases}$$

$$d_c(k) = \left(\frac{w_c(k - \frac{\tau_c}{\tau})}{\tau_c} - \frac{w_c(k - \frac{\tau_c}{\tau})}{r_c(k)} \right) \tau_c$$

State transition equation: queue length

- **Queue length** of the buffer for link *l* : q_l
  - *b(c,l)* : the previous link of link *l* for connection *c*
  - l_c : the access link of connection *c*

$$q_l(k) = \left[q_l(k-1) + \left(\sum_{c \in C(l)} A_{c,l}(k-1) - \mu_l \right) \tau \right]^+$$

$$A_{c,l}(k) = \begin{cases} \frac{w_c(k)}{r_c(k)} & \text{if } l = l_c \\ \frac{\mu_l A_{c,b(c,l)}(k - \Delta_{b(c,l)})}{\sum_{d \in C(l)} A_{d,b(d,l)}(k - \Delta_{b(d,l)})} & \text{if } l \neq l_c \text{ and } q_l(k) > 0 \\ A_{c,b(c,l)}(k - \Delta_{b(c,l)}) & \text{if } l \neq l_c \text{ and } q_l(k) = 0 \end{cases}$$

Throughput and fairness

- Focus on equilibrium values (denoted by *)
  - $\rho_c{}^*$: **throughput** of connection *c*
  - $\theta_c{}^*$: sum of **all queuing delays** of connection *c*

$$\gamma_c = \rho_c^* \theta_c^*$$

- Can be regarded as a **Little's law**

$$N = \lambda T$$

- Fairness between TCP connections *c* and *c'*

$$\frac{\rho_c^*}{\rho_{c'}^*} = \frac{\gamma_c}{\gamma_{c'}} \times \frac{\theta_{c'}^*}{\theta_c^*}$$

Stability and transient behavior

- Obtain a **linearized** model
  - *x(t)* : state vector (current state – equilibrium state)
  - Δ_{LCM} : Lowest Common Multiple of all τ_c/τ's

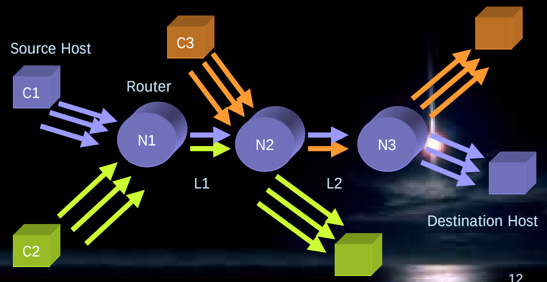
$$\mathbf{x}(k + \Delta_{LCM}) = \mathbf{A}\,\mathbf{x}(k)$$

- **Eigenvalues** of **A** determine stability and transient behavior

$$\mathbf{x}(k) \equiv \begin{bmatrix} w_{c1}(k) - w_{c1}^* \\ \vdots \\ w_{c|N|}(k) - w_{c|N|}^* \\ q_{l1}(k) - q_{l1}^* \\ \vdots \\ q_{l|L|}(k) - q_{l|L|}^* \end{bmatrix}$$

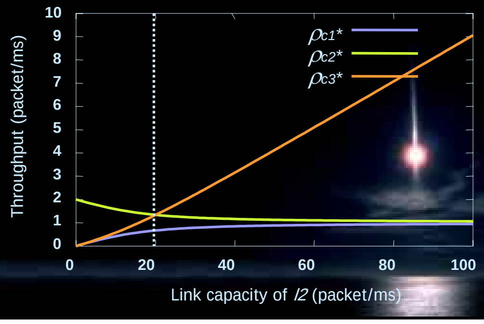
Numerical example: network model

- Two bottleneck links and 30 TCP connections



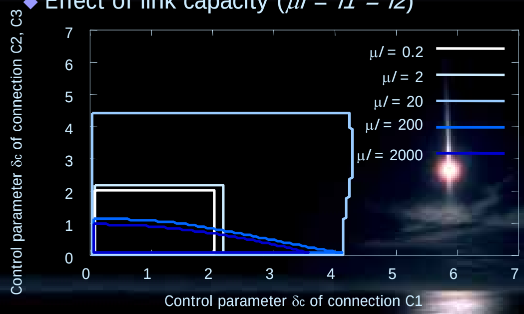
Numerical example: throughput

- Effect of difference in link capacities ($\mu/l1 = 20$)



Numerical example: stability

- Effect of link capacity ($\mu/ = l1 = l2$)



Conclusion

- Analytic model
  - Window-based flow control based on **TCP Vegas**
  - **Homogeneous network**
- Throughput and fairness
  - Can be explained by **Little's law**
  - Has a bias against **link capacity** and **# of bottleneck links**
  - Window size in steady state
    - (bandwidth) x (propagation delay) + (control parameter γc)

Conclusion (cont.)

- Stability and transient behavior
  - Determined by **eigenvalues** of state transition matrix **A**
  - Link capacity significantly affects stability
  - Investigation using **trajectories of eigenvalues**
- Future work
  - More simulation studies
  - Extension to TCP Tahoe or TCP Reno