

A Control Theoretical Approach to a Window-based Flow Control Mechanism with Explicit Congestion Notification

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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 Reno

- ◆ Implemented in BSD UNIX
- ◆ Widely used in the current Internet
- ◆ Use **packet loss** as feedback information
 1. Source host continuously **increases** window size
 2. Packet loss occurs at the bottleneck router
 3. Source host detects packet loss by duplicate ACK
 4. Source host **reduces** its window size to 1/2
- ◆ Packet loss is **inevitable**

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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. Source host measures RTT for a specific packet
 2. Source host estimates **severity of congestion**
 3. Source host changes window size
- ◆ Packet loss can be **prevented**

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Congestion avoidance of TCP Vegas

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

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

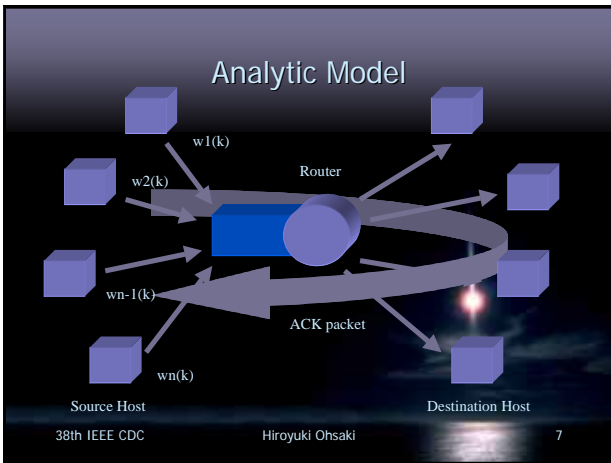
- ◆ Window size is changed based on $d(k)$

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

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System State Equations

- ◆ Window size: $w_n(k)$
 - δ : a **control parameter** that determines the amount of increase/decrease in window size
- ◆ The number of packets in the buffer: $q(k)$

$$w_n(k+1) = \max(w_n(k) + \delta(\gamma - d(k)), 0)$$

$$q(k+1) = \min(\max(Nw(k) - Bw(k), 0), L)$$

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Stability Analysis

1. Derive the **fixed point**: (w^*, q^*)
2. **Linearize** the system around the fixed point
3. Obtain conditions for the system to be **locally exponentially stable**

$$\frac{\delta}{(B + \gamma N)\tau} + 2 > 0$$

$$\frac{\delta(B - \gamma N)}{(B + \gamma N)\tau} > 0$$

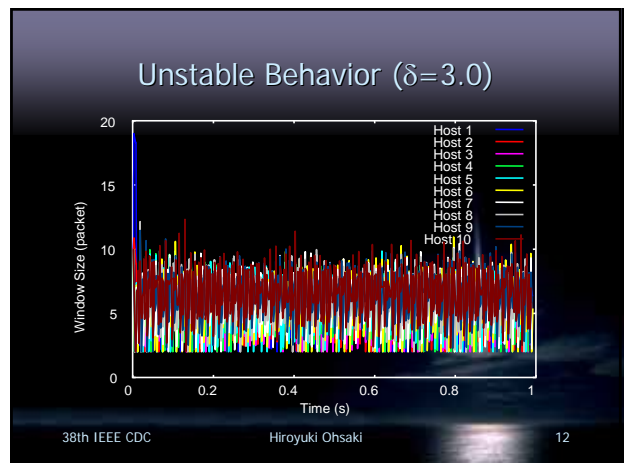
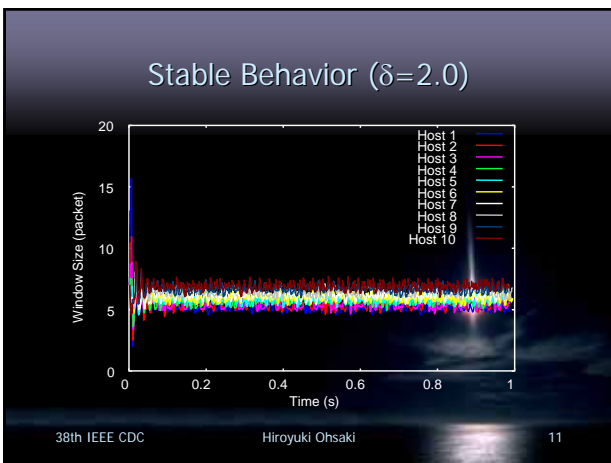
$$\frac{B\delta}{(B + \gamma N)} < 1$$

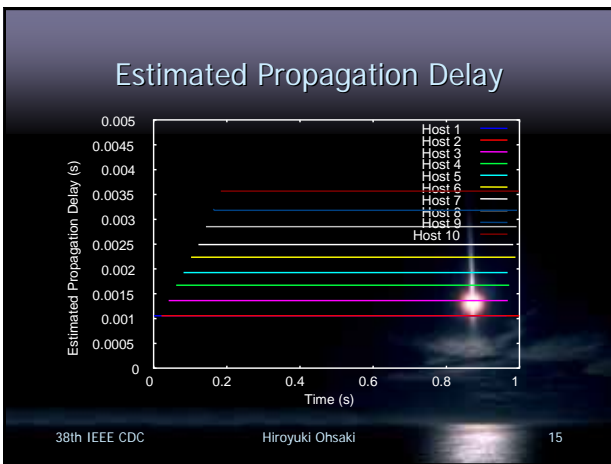
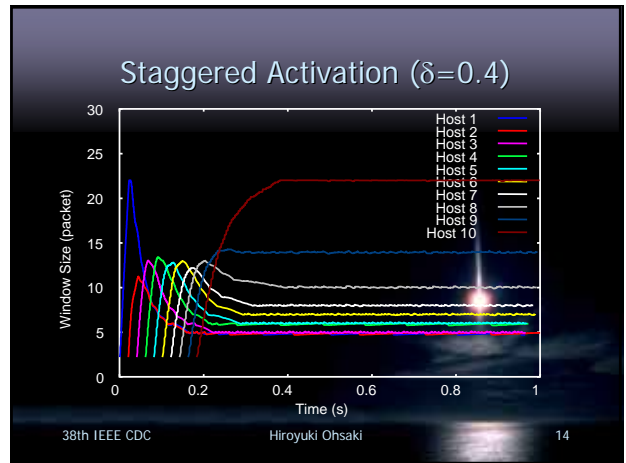
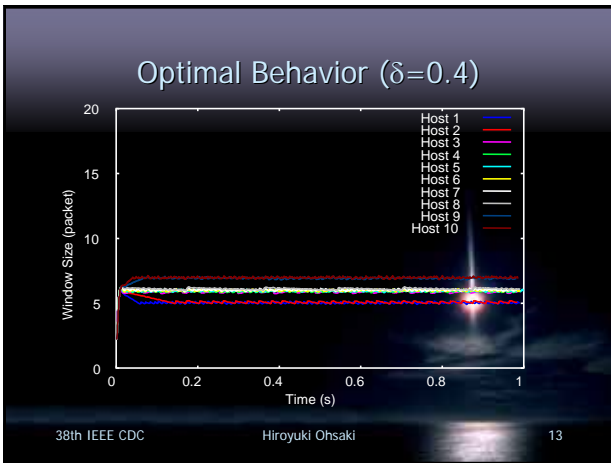
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Simulation Parameters

- ◆ Packet length 1000 byte
- ◆ Number of connections 10
- ◆ Bottleneck bandwidth 20 packet/ms
- ◆ Propagation delay 1 ms
- ◆ Control parameter γ 3 packet
 - Determine buffer occupancy per connection
- ◆ Control parameter δ 0.4, 2.0, 3.0
 - 0.4 (optimal), 2.0 (stable), 3.0 (unstable)

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Drawbacks of TCP Vegas

- ◆ **Incorrect measurement** of propagation delay
 - All routers have separate buffers for all connections
 - Offered traffic load is very low
 - Throughput becomes **proportional to the measured propagation delay**
- ◆ **No scalability** for the number of connections
 - Buffer occupancy is proportional to the number of connections

$$w^* = \tau \left(\frac{B + \gamma N}{N} \right) \quad q^* = \gamma N \tau$$

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ECN in TCP Vegas

- ◆ **ECN (Explicit Congestion Notification)**
 - Explicitly notify source hosts of congestion occurrence
- ◆ Two types of implementation
 - ICMP Source Quench packet
 - TOS (Type of Service) field in IP packet header
- ◆ When ECN message is received...
 - TCP Vegas seems not to operate correctly
 - Window size **should be decreased**

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Proposed Scheme

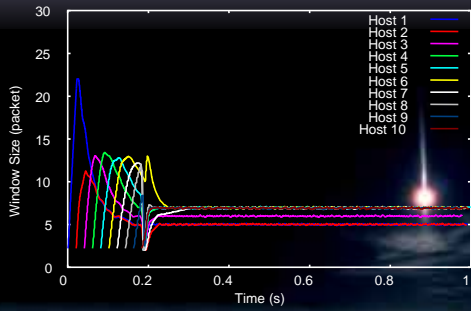
- ◆ Use TOS field of the IP packet
- ◆ Calculate the **ratio of ECN messages**

$$e(k) = \frac{N_e}{N_a}$$
- ◆ Control window size to **$e(k)$** 0
- ◆ Different from discussion in IETF

$$w_n(k+1) = \max(w_n(k) + \delta(\gamma - I(k)) - w_n(k)e(k), 0)$$

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Case of Proposed Scheme ($\delta=0.4$)



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Conclusion

- ◆ Window-based flow control mechanism based on TCP Vegas
- ◆ Stability analysis
- ◆ Simulation results
- ◆ Illustrate drawbacks of TCP Vegas
 - Incorrect measurement of the propagation delay
 - No scalability for the number of connections
- ◆ Solution using ECN mechanism
 - Fairness among connections are greatly improved

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