



TCP Symbiosis: Congestion Control Mechanisms of TCP based on Lotka–Volterra Competition Model



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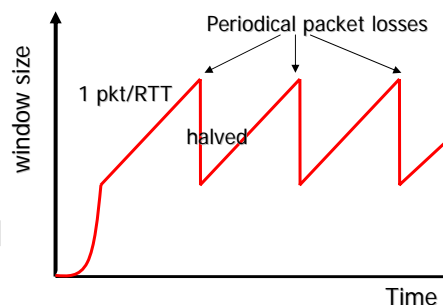
Congestion control mechanism of TCP

- **Main purpose**
 - Avoiding network congestion and utilizing fully the link bandwidth
 - Fair bandwidth usage among competing connections
- **Window-based congestion control**
 - Adjusting data transmission rate by maintaining a window size

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Window size control in TCP Reno

- **Basic Mechanisms**
 - Increase 1 packet per RTT
 - Decrease by half when packet loss is detected



- **Problems**
 - Periodical packet losses cannot be avoided
 - It cannot fully utilize the link bandwidth especially in high-speed and long-delay networks
 - It cannot distinguish a congestion-oriented packet loss and a wireless-oriented packet loss when it traverses wireless links
 - ...

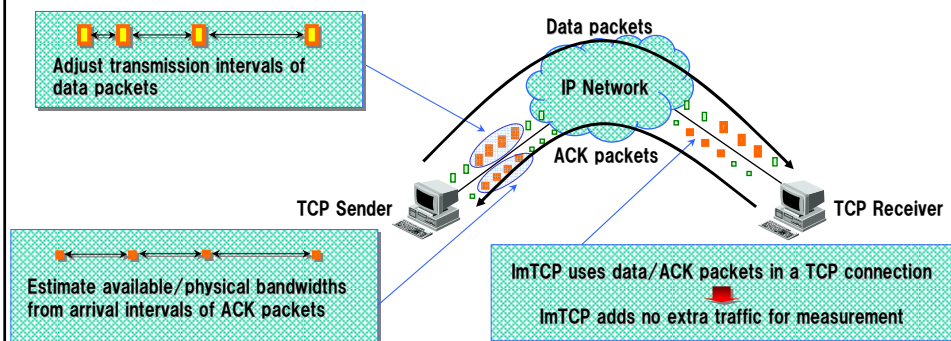
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Window Size Control in TCP Reno (2)

- **Reasons**
 - The increase speed is fixed and small and/or decrease ratio is too large, especially for long-distance and high-bandwidth networks
 - Reno cannot recognize the bandwidth information of the network path, so it continues increasing its window size until a packet loss occurs due to buffer overflow
- **Our solution: TCP Symbiosis**
 - Utilizes the bandwidth information of the network path
 - If it is possible to obtain the bandwidth information, the increase/decrease speed can be changed dynamically according to the bandwidth
 - Introduces a new algorithm in window size increase / decrease
 - Based on Lotka-Volterra competition model

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Measuring bandwidth of network path



- **Inline Measurement TCP (ImTCP) [1]**
 - Built-in measurement mechanism in TCP
 - Obtaining the information of physical capacity and available (residual) bandwidth of an end-to-end network path
 - Yielding results every 1-4 RTT

[1] Le Thanh Man Cao, Go Hasegawa and Masayuki Murata, ImTCP: TCP with an Inline Measurement Mechanism for Available Bandwidth, Computer Communications Journal, Vol.29, Issue 10, pp. 1614-1626, June 2006
<http://www.anrg.jp/imtcp/>

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Design policy of congestion control mechanism

- **Adjust the data transmission rate using the bandwidth information**
 - Increasing the rate according to the bandwidth
 - Scalability to the bottleneck link bandwidth
 - Converging the rate into a certain value
 - No packet loss occurs
- **We use an existing mathematical model**
 - Model characteristics has been revealed
 - Stability, fairness, parameter setting, ...

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Lotka-Volterra competition model

- **Describing changes in population of 2 species [2]**
 - Logistic growth with interactions between species

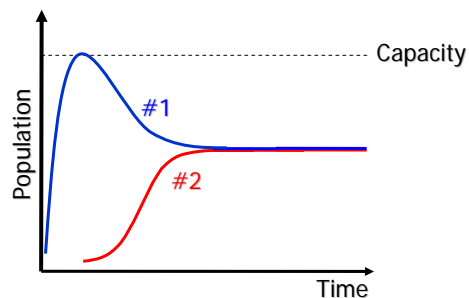
$$\frac{d}{dt} N_1(t) = \varepsilon_1 \left(1 - \frac{N_1(t) + \gamma_{12} N_2(t)}{K_1} \right) N_1(t)$$

$$\frac{d}{dt} N_2(t) = \varepsilon_2 \left(1 - \frac{N_2(t) + \gamma_{21} N_1(t)}{K_2} \right) N_2(t)$$

$N_i(t)$: Number of species # i
 K : Capacity
 ε_i : Growth rate ($\varepsilon < 2$)
 γ_{ij} : Competition coefficient
 ($0 < \gamma < 1$)

Apply to data transmission control

$N_i(t)$: Data transmission rate
 K : Physical bandwidth



[2] J. D. Murray, *Mathematical Biology I: An Introduction*. Springer Verlag Published, 2002.

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Converting the model into the congestion control algorithm

- Extend the equation for n connections

$$\frac{d}{dt} N_i(t) = \varepsilon \left(1 - \frac{N_i(t) + \gamma \sum_{i \neq j} N_j(t)}{K_i} \right) N_i(t)$$

- The amount of the bandwidth used by the other flows is estimated by:

- physical capacity K – available bandwidth A

- Both are measured by ImTCP

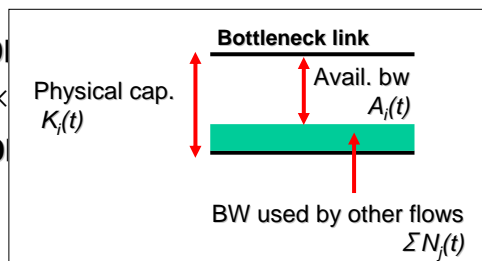
$$\sum_{i \neq j} N_j(t) \leftarrow K_i(t) - A_i(t)$$

- Convert transmission

$$w_i = N_i \times$$

- Convert the equation action

- w_i ACK packets are



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Summary of proposed mechanism

- Obtains the bandwidth information from the inline measurement mechanism

- Physical capacity and available bandwidth

- Controls the window size by using below equation:

$$\frac{d}{dAck} w_i = \varepsilon \left(1 - \frac{w_i + \gamma (K - A_i) \times RTT_{\min}}{K \times RTT_{\min}} \right) w_i$$

- Uses the same control mechanism as TCP Reno when:

- A TCP connection is in slow-start phase

- Bandwidth information is not available

- Packet losses are detected by sender TCP

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Simulation experiments

- Details

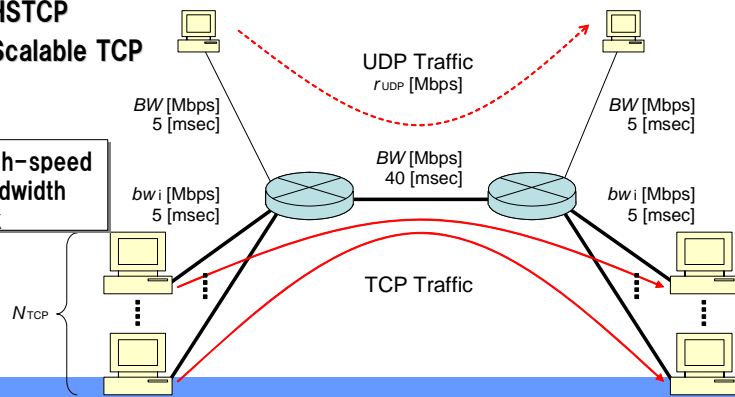
- The Network Simulator – ns-2

- $\epsilon = 1.95$, $\gamma = 0.9$

- Comparison

- TCP Reno
 - HSTCP
 - Scalable TCP

Protocols for high-speed and large bandwidth network



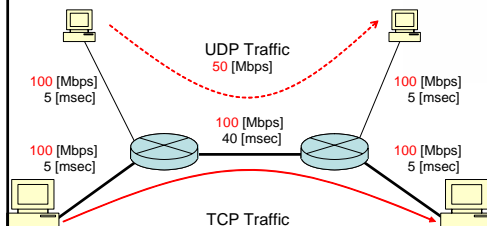
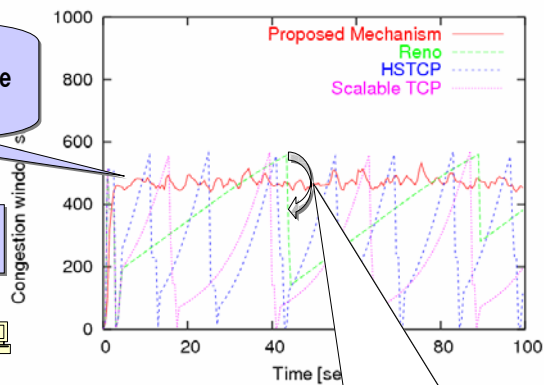
Fundamental behavior

- Change in congestion window size

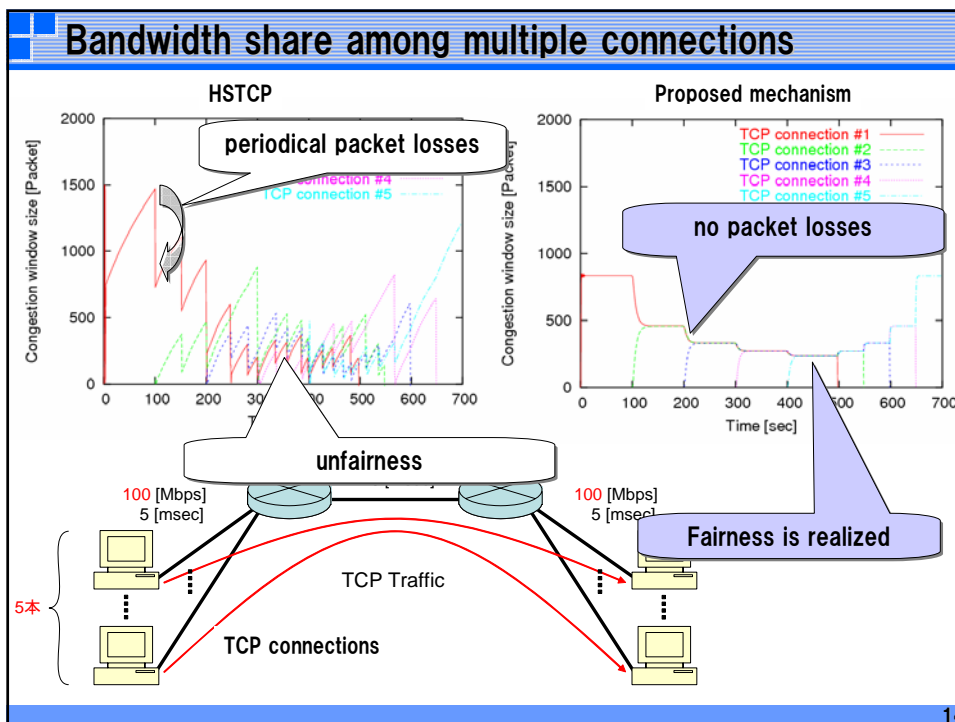
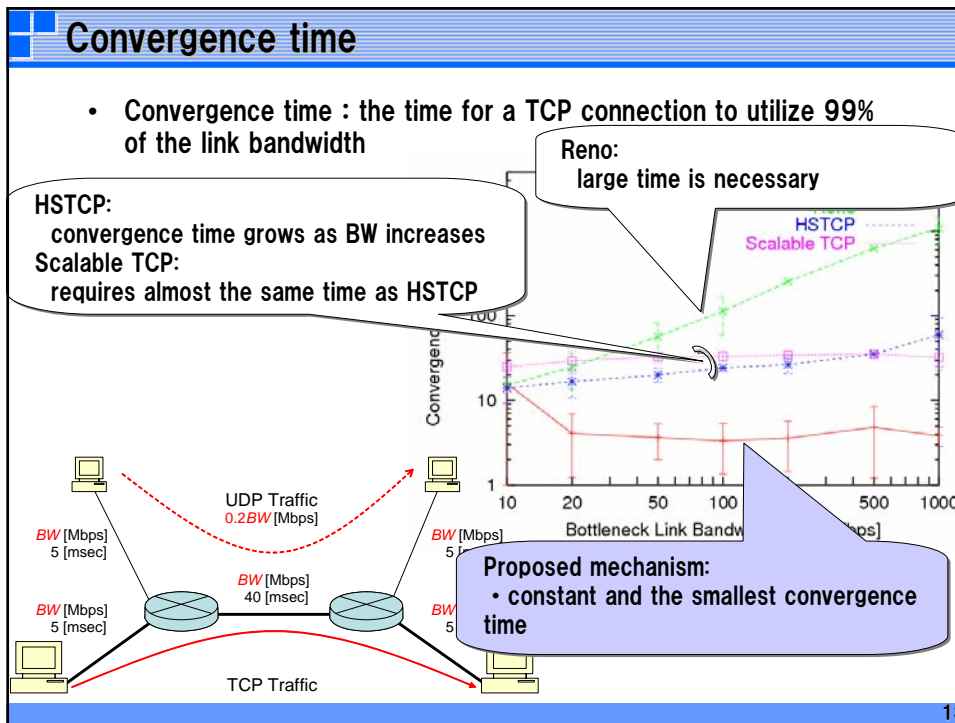
Proposed mechanism:

- converges quickly into ideal value
- experiences no packet losses

Proposed mechanism can efficiently utilize the link bandwidth



Reno, HSTCP, Scalable TCP:
• experience periodic packet losses



Conclusion

- **Congestion control mechanism of TCP based on Lotka–Volterra competition model**
 - **Features**
 - It uses the bandwidth information obtained from inline measurement (ImTCP)
 - It has the window size control algorithm based on the mathematical models from biophysics
 - **Simulation results show that the proposed mechanism can improve the performance of TCP**
- **Future work**
 - **Mathematical analysis**
 - Parameter setting with considering the effect of measurement errors
 - **Experiments in actual Internet environment**