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

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  - Summary and problems
- TCP Symbiosis: a new congestion control mechanism
  - Uses bandwidth information of a network path by inline network measurement
  - Regulates window size based on Lotka-Volterra competition model
- Performance evaluation through simulations
- Conclusion and future work

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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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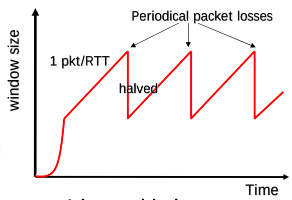
Window size control in TCP Reno

- 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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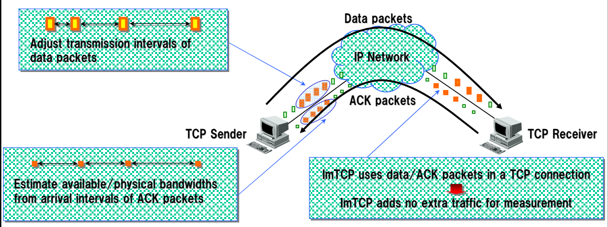
Measuring bandwidth of network path



- 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.anarg.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, …

Lotka-Volterra competition model

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

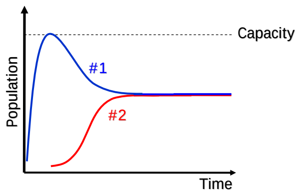
$$\frac{d}{dt}N_1(t)=\varepsilon_1\left(1-\frac{N_1(t)+\gamma_{12}N_2(t)}{K_1}\right)N_1(t)$$

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

$N_i(t)$: Number of species # i
K : Capacity
ε_i : Growth rate (ε < 2)
γ_{ij} : Competition coefficient (0 < γ < 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.

Converting the model into the congestion control algorithm

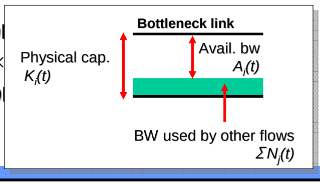
- Extend the equation for n connections

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

- 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 transmissio
  $w_i = N_i \times$
- Convert the equatio action
  - w_i ACK packets are



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:

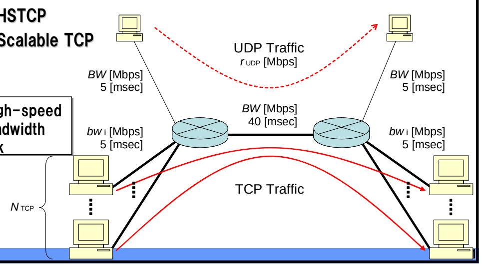
$$\frac{d}{dAck}w_i=\varepsilon\left(1-\frac{w_i+\gamma(K-A_i)\times RTT_{\min}}{K\times RTT_{\min}}\right)w_i$$

- 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

Simulation experiments

- Details
  - The Network Simulator – ns-2
  - ε = 1.95, γ = 0.9
  - Comparison
    - TCP Reno
    - HSTCP
    - Scalable TCP

Protocols for high-speed and large bandwidth network

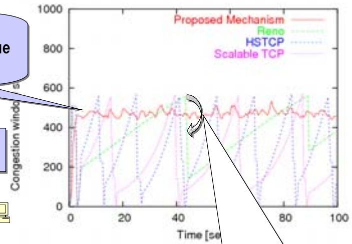


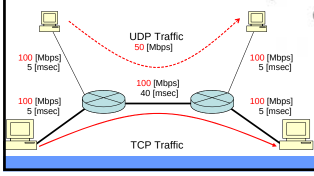
Fundamental behavior

- Change in congestion window size

Proposed mechanism:
- converges quickly into ideal value
- experiences no packet losses

Proposed mechanism can efficiently utilize the link bandwidth

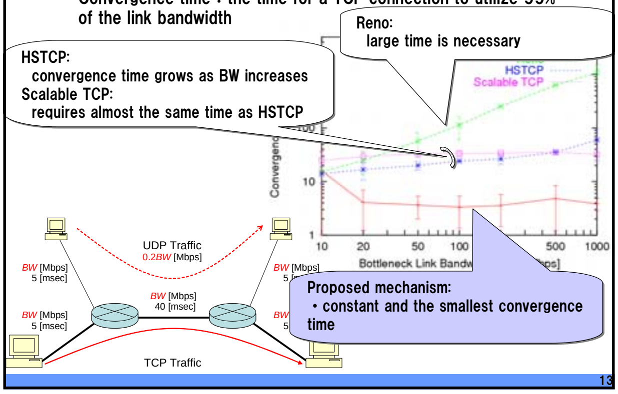




Reno, HSTCP, Scalable TCP:
- experience periodic packet losses

Convergence time

- Convergence time : the time for a TCP connection to utilize 99% of the link bandwidth



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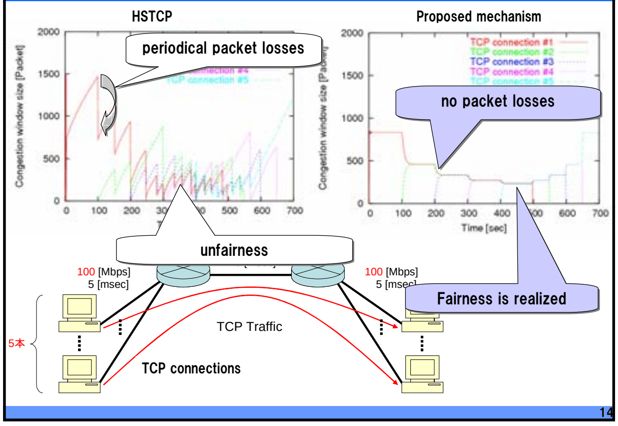
Bandwidth share among multiple connections



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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
    - Paramter setting with considering the effect of measurement errors
  - Experiments in actual Internet environment

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