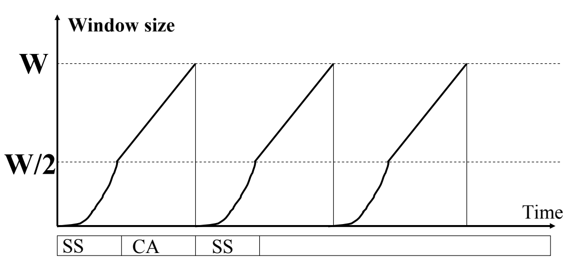
Material Covered

- Macroscopic and Microscopic performance evaluation of TCP
- Conclusion of the Reliable Transmission Part

Recall Tahoe Algorithm

- (Parameters: **cwnd**, **threshold, RTT**)
  1. Set (congestion window) **cwnd = 1**
  2. For **each** successful **ACK** increment cwnd
     cwnd = cwnd +1 (exponential growth of **cwnd)**
  3. If (**cwnd ≥ threshold) after cwnd ACK;**
     cwnd = cwnd +1 (linear growth)
  4. If there is loss (Timer expires)
     - **threshold := cwnd/2;**
     - **Go to step 1**

Macroscopic View for large file transfers



Macroscopic Description of Performance of Tahoe

- Ignore the Exponential Growth period
- Assume that **CWND** Oscillates between **W** and **W/2**
- Assume RTT is known
- Maximum Segment Size = MSS =**S**
- (Transmission Rate) Throughput varies between **W*S/RTT** and **W * S/(2*RTT)**
- Average Throughput = **0.75 W*S/RTT**

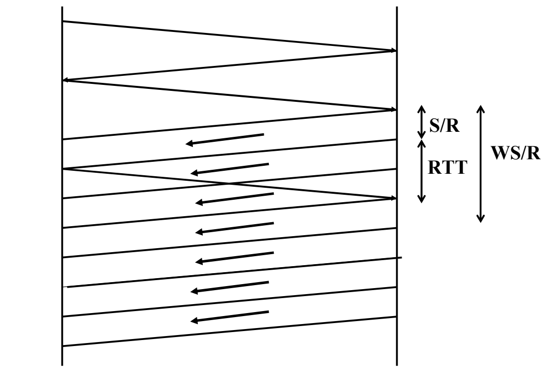
Modeling Latency in Tahoe for Small File Transfers

- If the files are small the **slow start phase** will have impact on the latency of session
- **Latency:** Time from the client initiates a Transmission connection till it receives the requested object
- Assume:
  - No packet errors of any type (**No retransmits**)
  - Sender window is bounded by **CWND** and not by receiver buffer
  - All headers have no bit overhead
  - Maximum segment size : **S**
  - File/Object size = **O**
  - Link capacity **R** bps and is allocated to the session
  - **RTT** is known (**RTT excludes the transmission time of the packet**)

Static Congestion Window Case

- Description at Sender side:
  - Transmit **W** packets back-to-back at the beginning
  - (Repeat till End Of File)Transmit **1** packet for **every ACK**
- **Cases to consider for latency**
  1. **WS/R > RTT + S/R**
  2. **WS/R < RTT + S/R**
- **If (WS/R > RTT + S/R)**
  - **ACK arrives before first window of packets are transmitted.**
  - **Note: The next ACK will arrive in an interval of S/R**
  - **Sender has no stalling**
  - **Total Latency = Connection establishment time (RTT) + {File Request time and First bit of file arrival delay }(RTT) + O/R = 2 RTT + O/R (For Tahoe)**

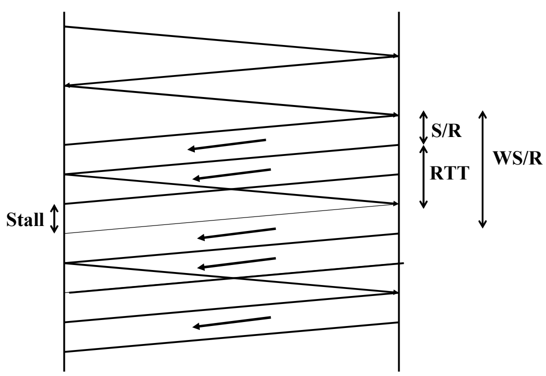
Illustration of WS/R > RTT + S/R for W=4



Static Congestion Window Case

- **If (WS/R < RTT + S/R)**
  - Sender Completes transmission of W packets before the first acknowledgement arrives
  - Sender **stalls**
  - When the first ACK arrives it transmits a new packet
  - Once the first ACK comes, **(W-1)** ACKs arrive with time spacing of **S/R.** For each ACK sender transmits one packet
  - Sender **alternates** between **transmitting W** packets **and stalling** for the **ACK**s till it completes the entire file transfer
  - The file/object size as a **multiple of CWND** is denoted as **K = O/WS (round it to the nearest integer)**
  - **Number of times sender stalls = (K-1)**
  - **Total Latency = Connection establishment time (RTT) + {File Request time and First bit of file arrival delay }(RTT) + file transfer time + (k-1) Stall times = 2 RTT + O/R + (K-1)[RTT + S/R – WS/R]**

Illustration of WS/R < RTT + S/R for W=2



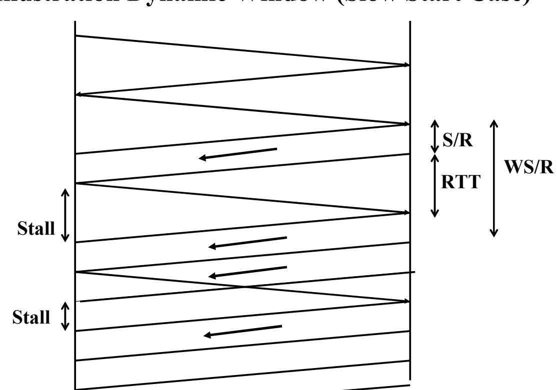
Static Congestion Window Case

- **Total Latency**
  - **2RTT + O/R + (K-1)$[RTT + S/R – WS/R]^+$**
  - **Where $[X]^+ = \max\{X, 0\}$**

Dynamic Congestion Window Case

- File size = **O**
- Number of Segments = **O/S**
- Initial **CWND = 1**
- **CWND = CWND + 1** for **each ACK**
- **i^{th} window** has **2^{i-1}** segments
- Let **K** be the number of windows covering the segment
  - **K** = min {k: 1 + 2 + 4 +…+ **2^{k-1}** ≥ **O/S**}
  - **K** = min {k: **2^k-1** ≥ **O/S**}
  - **$K = \log_2(1 + O/S)$**

Illustration Dynamic Window (Slow Start Case)



Dynamic Congestion Window Case

- Number of segments in i^{th} window = 2^{i-1}
- Transmission time for i^{th} window = $(S/R)2^{i-1}$
- Stall time for i^{th} window = $[RTT + S/R - (S/R)2^{i-1}]^+$
- Latency = $2RTT + O/R + \Sigma[RTT + S/R - (S/R)2^{i-1}]^+$
- Let **Q** = Number of times the sender will stall for $O=\infty$
  - $Q = \max\{i: RTT + S/R - (S/R)\, 2^{i-1} \geq 0\}$
  - $= \max\{ i: 2^{i-1} \leq (1 + RTT/(S/R))\}$
  - $= \log_2(1 + RTT/(S/R)) + 1$
- **Actual number of Stalls** $P = \min\{Q, K-1\}$
- **Latency** $= 2RTT + O/R + \Sigma[RTT + S/R - (S/R)2^{i-1}]$
  $= 2RTT + O/R + (2^P - 1)S/R + P[RTT + S/R]$

Example for Slow Start

Assume S = 536 bytes; RTT = 100 milliseconds;
O =100 K bytes;
Number of windows covering this files are $K = \log_2(O/S + 1) = 8$

R	O/R	P	O/R + 2RTT	Latency with slow Start
28kbps	28.6 sec	1	28.8 sec	28.9 sec
100kbps	8 sec	2	8.2 sec	8.4 sec
1Mbps	800 msec	5	1 sec	1.5 sec
10Mbps	80msec	7	0.28 sec	0.98 sec ←

Slow Start Adds high delay when the transmission rates are high