

TCP flavors for mobile and high-speed environments

Freeze-TCP, TCP-Probing and Compound TCP

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Outline

Scenario

Freeze-TCP

TCP-Probing

Compound TCP

Conclusions

Scenario

- ▶ **TCP** wasn't designed to cope with mobility issues and high-speed networks.
- ▶ Several enhancements to standard TCP have been devised:
 - mobility and power consumption is now taken into account (*I-TCP*, *M-TCP*, *Freeze-TCP*);
 - some enhancements tackle problems posed by high-speed and long-distance networks (*FAST TCP*, *Compound TCP*).

Previous approaches

- ▶ Many approaches involve base stations in flow and congestion control. Besides, they often split the connection (*I-TCP*, *M-TCP*, *Snoop* etc...).
- ▶ **Freeze-TCP** is an end-to-end scheme and doesn't require the involvement of any intermediaries for flow control.
- ▶ In order to achieve *Freeze-TCP*'s goals, changes in TCP code don't go beyond the mobile client.



Standard window management

- ▶ When the receiver advertises a zero-size window, the sender enters the **persist mode**:
 - *Zero Window Probes* are sent until the receiver's window opens up;
 - eventually, the receiver sends back a non-zero window size, and the sender will open its sending window.

Issues in mobile environments

- ▶ Even if a single packet is dropped due to a short disconnection, standard TCP wrongly thinks that the loss was caused by congestion and chokes the transmission.
- ▶ Thus, standard TCP's sender unnecessarily holds back, (slow window growth), even though the receiver often recoups quickly from a short disconnection.



Freeze-TCP approach (1)

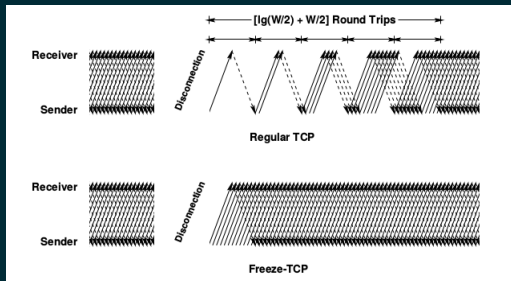
- ▶ The mobile client should signal any impending disconnection:
 - this is done via **signal strength monitoring**;
 - after detecting a disconnection:
 1. the mobile client advertises a zero window size;
 2. the sender switch to *ZWP* mode and doesn't shrink its window.

Freeze-TCP approach (2)

- ▶ How much in advance of the disconnection should the receiver advertise a window size of zero?
- ▶ There should be a *warning period* prior to disconnection.
- ▶ They figured out that a sensible choice is the *Round-Trip-Time*:
 1. if it is too long, there will be idle time prior to the disconnection;
 2. if it is too small, the sender's window could drop due to packet losses.

Freeze-TCP approach (3)

- ▶ A relevant issue: the *ZWP*s are exponentially backed off, so there could be an idle time after a reconnection.
- ▶ Trick: soon after the reconnection, the receiver sends 3 copies of the ACK for the last data segment it received before the disconnection (**TR-ACKs**).



Freeze-TCP approach (4)

It can be shown that the (approximate) number of extra packets transferred by *Freeze-TCP* is given by:

$$\frac{W^2}{8} + W \lg W - \frac{5W}{4} + 1$$

Open issues

- ▶ In order to apply this protocol, the network stack should be aware of mobility.
- ▶ Is it reasonable to restart transmission at the full rate with the old window size upon entering a new environment?
- ▶ The receiver must predict impending disconnections.



Improving energy efficiency

- ▶ Energy efficiency is becoming paramount in communication protocols (a cross-layer issue).
- ▶ The error control mechanism should be friendly both to **throughput** and **low power consumption**.
- ▶ Energy-conserving capabilities in standard TCP: after segment drops, it shrinks the window so as to save transmission effort.

Improved Error Recovery for better Energy Efficiency

- ▶ The Error Recovery mechanism is not always efficient: in fact, standard TCP thinks that packet losses always happen due to *congestion*.
- ▶ In case of *infrequent* and *transient* errors, standard TCP strategy leads to:
 1. unneeded effective throughput degradation;
 2. increase in overall connection time.
- ▶ Moreover, monitoring network conditions only by means of packet losses causes major energy wastage.

TCP-Probing approach

- ▶ In **TCP-Probing**, when a segment is dropped, the sender initiates a **probe cycle** (described later).
- ▶ The *probe cycle*'s duration is naturally extended according to the error condition.
- ▶ Random losses trigger short probe cycles.

Probe Cycle (1)

- ▶ **Immediate Recovery:**
if network conditions detected when the probe cycle is over are acceptable, the protocol simply restarts from the state before the timeout event.
- ▶ Otherwise, TCP-Probing opts for *Slow-Start* (conservative approach).

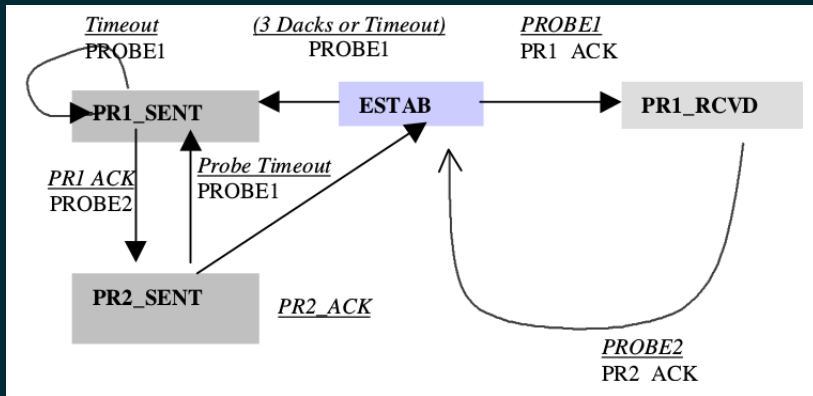
Probe Cycle (2) - Implementation

1. The sender transmits *PROBE1*, to which the receiver immediately responds with *PR1_ACK*. After receiving the latter the sender transmits *PROBE2*.
2. The receiver acknowledges this second probing with a *PR2_ACK* and returns to the *ESTAB* state.
3. A critical part of the probing mechanism is the protocol's behaviour at the end of the cycle.

Probe Cycle (3) - Implementation

- ▶ A *measurement timer* is used to measure the two RTTs from the probe cycle.
- ▶ Upon exiting the probe cycle, the two measured RTTs are compared.
 1. if both lie in the range [best RTT, last RTT], *Immediate Recovery* is applied;
 2. otherwise, the sender enters a *Slow-Start* phase.

Probing State Transition Diagram





Open issues

- ▶ Probe cycles causes more transmission effort.
- ▶ The decision-making criteria are conservative because *Immediate Recovery* is entered at the end of probing only in some cases.
- ▶ Simply stated, *TCP-Probing*'s behavior is insufficiently aggressive.

Issues in High-speed and Long Distance networks

- ▶ Standard TCP can't fully utilize the network capacity because of its conservative approach.
- ▶ In **Compound TCP**, *delay-based* and *loss-based* approaches coexist.
- ▶ In *Compound TCP*, a scalable delay-based component is plugged into the *TCP Reno* congestion avoidance algorithm, which is loss-based.



Background

- ▶ In a **high-speed** and **long delay** network, only a very large window can fully utilize the link capacity.
- ▶ In real life networks, a standard TCP sender may never open its window enough to leverage the high-speed resource.

Loss-based vs Delay-based

- ▶ **Loss-based** strategies modify the increase/decrease parameters in order to become more aggressive. Pitfalls:
 1. an aggressive behavior causes more packet losses on bottleneck links;
 2. the throughput of the regular TCP flows is pushed back.
- ▶ **Delay-based** strategies base their decisions on RTT variations (e.g. *FAST-TCP*). They have:
 1. higher utilization;
 2. less self-induced packet losses;
 3. better RTT fairness and stabilization.



The Compound TCP (1)

- ▶ Pure delay-based approaches are not competitive to loss-based approaches.
- ▶ This happens because they reduce their sending rate when bottleneck queue is built. However, this behavior will make loss-based flows increase their sending rate since they notice less packet losses.

The Compound TCP (2)

- ▶ *Compound TCP* incorporates a scalable delay-based component into the standard TCP congestion avoidance algorithm.
- ▶ Delay-based component's features:
 1. rapid window increase rule when the network is under-utilized;
 2. it reduces the sending rate once the bottleneck queue is built.

The Compound TCP (3)

- ▶ A new scalable delay-based component in the TCP congestion avoidance algorithm is added.
- ▶ A new state variable is introduced: `dwnd` (*Delay Window*), which controls this delay-based component.
- ▶ The `cwnd` remains the same, controlling the loss-based component.
- ▶ Thus, the sending window is controlled by both `cwnd` and `dwnd`.

The Compound TCP (4)

- ▶ Sending window = $\min(\text{cwnd} + \text{dwnd}, \text{awnd})$.
- ▶ The `cwnd` is updated in the same way as in regular TCP's congestion avoidance.
- ▶ The *Slow-Start* behavior of regular TCP is kept at the start-up of a new connection. In fact, *Slow-Start* is quick enough also for fast and long distance environments.
- ▶ The delay-based component comes into play in the congestion avoidance phase.



Delay-based component design (1)

- ▶ A state variable (`baseRTT`) is maintained as an estimation of the delay of a packet over the network path.
- ▶ At the start of a connection, `baseRTT` is updated to the minimal observed RTT.
- ▶ An exponentially smoothed current RTT (`sRTT`) is also maintained.



Delay-based component design (2)

The number of backlogged packets can be estimated by means of these formulas:

1. $\text{expected} = \text{win} / \text{baseRTT};$
2. $\text{actual} = \text{win} / \text{RTT};$
3. $\text{diff} = (\text{expected} - \text{actual}) * \text{baseRTT}.$

An early congestion is detected if the number of packets in the queue is larger than a fixed threshold γ ($\text{diff} > \gamma$).

Delay-based component design (3)

1. Without packet losses:

$$win(t + 1) = win(t) + \alpha * win(t)^k$$

2. With packet losses:

$$win(t + 1) = win(t) * (1 - \beta)$$

Parameters α , β and k should be tuned.

Delay-based component design (4)

The delay-based component $dwnd$ is updated following the rules below.

$$dwnd(t + 1) =$$




$$\begin{cases} dwnd(t) + (\alpha * win(t)^k - 1)^+, diff < \gamma \\ (dwnd(t) - \zeta * diff)^+, diff \geq \gamma \\ (win(t) * (1 - \beta) - cwnd/2)^+, loss \end{cases}$$



Open issues

- ▶ The γ parameter could be set adaptively.
- ▶ Early congestion should be detected by means of constant buffer requirements regardless of the number of *CTCP* flows.

Bibliography

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Thank you

Any questions?



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