TCP in Wireless Mobile Networks

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TCP

- Reliable ordered delivery
- Implements congestion avoidance and control
- Reliability achieved by means of retransmissions if necessary
- End-to-end semantics
  - Acknowledgements sent to TCP sender confirm delivery of data received by TCP receiver
  - Ack for data sent only after data has reached receiver
TCP Basics

- Cumulative acknowledgements
- An acknowledgement ack’s all contiguously received data
- TCP assigns byte sequence numbers
- For simplicity, we will assign packet sequence numbers
- Also, we use slightly different syntax for acks than normal TCP syntax
  - In our notation, \( \text{ack } i \) acknowledges receipt of packets through packet \( i \)
Cumulative Acknowledgements

- A new cumulative acknowledgement is generated only on receipt of a new in-sequence packet
Delayed Acknowledgements

- An ack is delayed until
  - another packet is received, or
  - delayed ack timer expires (200 ms typical)
- Reduces ack traffic
Duplicate Acknowledgements

- A **dupack** is generated whenever an **out-of-order** segment arrives at the receiver.

- **What may cause packets to arrive OOO?**
  - Dropped segment: all the segments after the dropped segment are OOO.
  - Re-ordering the packets in the network.
  - Replication of ACK or data segments by the network.

- **TCP uses fast retransmit/fast recovery** for dupack.
Outline

- Classical TCP improvement
- Indirect TCP
- Snooping TCP
- Mobile TCP
- Fast retransmission, fast recovery
- Freezing
- Selective retransmission
Indirect-TCP

- Split a TCP connection at the foreign agent into 2 TCP connections
  - hosts in the fixed part of the network do not notice the characteristics of the wireless part
    - no changes to the TCP protocol for hosts connected to the wired Internet, millions of computers use (variants of) this protocol
  - optimized TCP protocol for mobile hosts
Indirect TCP

- The access point acts as proxy in both directions.
- AP acknowledges to both the sender and receiver.
- Re-transmission on wireless links is handled locally.
- During handover, the buffered packets, as well as the system state (packet sequence number, acknowledgements, ports, etc), must migrate the new agent.
I-TCP Socket and State Migration

socket migration and state transfer

mobile host

access point$_1$

access point$_2$

Internet
Advantages of I-TCP

- No changes in the fixed network necessary, no changes for the hosts (TCP protocol) necessary, all current optimizations to TCP still work

- Simple to control, mobile TCP is used only for one hop between, e.g., a foreign agent and mobile host
  - Transmission errors on the wireless link do not propagate into the fixed network
  - Therefore, a very fast retransmission of packets is possible, the short delay on the mobile hop is known
Advantages of I-TCP

- It is always dangerous to introduce new mechanisms in a huge network without knowing exactly how they behave.
  - New optimizations can be tested at the last hop, without jeopardizing the stability of the Internet.

- It is easy to use different protocols for wired and wireless networks.
Disadvantages of I-TCP

- Loss of end-to-end semantics
  - an acknowledgement to a sender no longer means that a receiver really has received a packet --- foreign agents might crash.

- Higher latency possible
  - due to buffering of data within the foreign agent and forwarding to a new foreign agent

- Security issue
  - The foreign agent must be a trusted entity.
Snooping TCP

- Indirect TCP
  - 2 TCP sessions.

- Snooping TCP
  - One TCP session.
  - The access point snoops into the traffic and buffers packets for fast re-transmission.
Snoop TCP

- **Transparent extension of TCP within the foreign agent**
  - Changes of TCP only within the foreign agent
  - Buffering of packets sent to the mobile host
  - Lost packets on the wireless link (both directions!) will be retransmitted immediately by the mobile host or foreign agent, respectively (so called “local” retransmission)
  - The foreign agent therefore “snoops” the packet flow and recognizes acknowledgements in both directions, it also filters ACKs
Snooping TCP

- **Data transfer to the mobile host**
  - FA buffers data until it receives ACK of the MH, FA detects packet loss via duplicated ACKs or time-out
  - Fast retransmission possible, transparent for the fixed network

- **Data transfer from the mobile host**
  - FA detects packet loss on the wireless link via sequence numbers, FA answers directly with a NACK to the MH
  - MH can now retransmit data with only a very short delay
Snooping TCP

Advantages
- End-to-end semantics is preserved.
- Handover is easy. I-TCP requires a careful handover of the system state. Here it falls back to the standard solution if no enhancements.

Problems
- snooping TCP does not isolate the wireless link as good as I-TCP
- snooping might be useless depending on encryption schemes
Mobile TCP

- What if the mobile node is disconnected?
  - I-TCP
    - more packets are buffered at AP.
  - Snooping TCP
    - no more snooping
    - Missing acknowledgement, TCP goes to slow-start.
  - Mobile TCP
    - Improve efficiency.
    - Special handling of lengthy and/or frequent disconnections.
Mobile TCP

- M-TCP splits as I-TCP does
  - unmodified TCP fixed network to supervisory host (SH)
  - optimized TCP SH to MH

- Supervisory host
  - no caching, no local retransmission
  - monitors all packets, if disconnection detected
    - set sender window size to 0
    - sender automatically goes into persistent mode
  - old or new SH reopen the window
Mobile TCP

- **Advantages:**
  - End-to-end semantics.
  - When mobile host is disconnected, it avoids useless retransmissions and slow-start.
  - No buffering, handover is easy.

- **Disadvantages:**
  - Packet loss at the wireless link propagates back to sender.
  - Not a good idea for heavy traffic.
Fast retransmit/fast recovery

- Change of foreign agent often results in packet loss
  - TCP reacts with slow-start although there is no congestion

- Forced fast retransmit
  - as soon as the mobile host has registered with a new foreign agent, the MH sends duplicated acknowledgements on purpose
  - this forces the fast retransmit mode at the communication partners
  - additionally, the TCP on the MH is forced to continue sending with the actual window size and not to go into slow-start after registration
Fast retransmit/fast recovery

- **Advantage**
  - simple changes result in significant higher performance

- **Disadvantage**
  - further mix of IP and TCP, no transparent approach
Time-out freezing

- Mobile hosts can be disconnected for a longer time
  - no packet exchange possible, e.g., in a tunnel, disconnection due to overloaded cells or mux. with higher priority traffic
  - TCP disconnects after time-out completely

- TCP freezing
  - MAC layer is often able to detect interruption in advance
  - MAC can inform TCP layer of upcoming loss of connection
  - TCP stops sending, but does now not assume a congested link
  - MAC layer signals again if reconnected
Time-out freezing

- **Advantage**
  - scheme is independent of data

- **Disadvantage**
  - TCP on mobile host has to be changed, mechanism depends on MAC layer
Selective retransmission

- TCP acknowledgements are often cumulative
  - ACK n acknowledges correct and in-sequence receipt of packets up to n
  - if single packets are missing quite often a whole packet sequence beginning at the gap has to be retransmitted (go-back-n), thus wasting bandwidth

- Selective retransmission as one solution
  - RFC2018 allows for acknowledgements of single packets, not only acknowledgements of in-sequence packet streams without gaps
  - sender can now retransmit only the missing packets
Selective retransmission

- **Advantage**
  - much higher efficiency

- **Disadvantage**
  - more complex software in a receiver, more buffer needed at the receiver
Transaction oriented TCP

- TCP phases
  - connection setup, data transmission, connection release
  - using 3-way-handshake needs 3 packets for setup and release, respectively
  - thus, even short messages need a minimum of 7 packets!

- Transaction oriented TCP
  - RFC1644, T-TCP, describes a TCP version to avoid this overhead
  - connection setup, data transfer and connection release can be combined
  - thus, only 2 or 3 packets are needed
Transaction oriented TCP

- **Advantage**
  - efficiency

- **Disadvantage**
  - requires changed TCP
  - mobility not longer transparent
  - Security issue.
## Comparison

<table>
<thead>
<tr>
<th>Approach</th>
<th>Mechanism</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Indirect TCP</td>
<td>splits TCP connection into two connections</td>
<td>isolation of wireless link, simple</td>
<td>loss of TCP semantics, higher latency at handover</td>
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<tr>
<td>Snooping TCP</td>
<td>“snoops” data and acknowledgements, local retransmission</td>
<td>transparent for end-to-end connection, MAC integration possible</td>
<td>problematic with encryption, bad isolation of wireless link</td>
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<tr>
<td>M-TCP</td>
<td>splits TCP connection, chokes sender via window size</td>
<td>Maintains end-to-end semantics, handles long term and frequent disconnections</td>
<td>Bad isolation of wireless link, processing overhead due to bandwidth management</td>
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<tr>
<td>Fast retransmit/ fast recovery</td>
<td>avoids slow-start after roaming</td>
<td>simple and efficient</td>
<td>mixed layers, not transparent</td>
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<tr>
<td>Transmission/ time-out freezing</td>
<td>freezes TCP state at disconnect, resumes after reconnection</td>
<td>independent of content or encryption, works for longer interrupts</td>
<td>changes in TCP required, MAC dependant</td>
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<tr>
<td>Selective retransmission</td>
<td>retransmit only lost data</td>
<td>very efficient</td>
<td>slightly more complex receiver software, more buffer needed</td>
</tr>
<tr>
<td>Transaction oriented TCP</td>
<td>combine connection setup/release and data transmission</td>
<td>Efficient for certain applications</td>
<td>changes in TCP required, not transparent</td>
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Summary

- Classical TCP improvement
- Indirect TCP
- Snooping TCP
- Mobile TCP
- Fast retransmission, fast recovery
- Freezing
- Selective retransmission